2022 ERAD

Book of abstracts

11th European Conference on Radar in Meteorology and Hydrology

29th August - 02nd September 2022
Locarno, Switzerland

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**Dear members of the weather radar community,
You can derive the radar equation by yourself in a remote mountain cabin, but you will not be able to install a radar on a peak in the Alps on your own. You can draft the research plan for a student project on dendritic growth alone in your office, but you will not succeed to make a major scientific breakthrough in microphysics without collaborating with other research groups. You can design a radar rainfall estimation algorithm on the drawing board alone, but you will not manage to implement an operational flood alert system for Europe without having established a solid, multi-disciplinary, pan-European cooperation over the years.**

This is exactly what the European Conference on Radar in Meteorology and Hydrology, known by the abbreviation ERAD, is about. It builds a bridge between academia, industry and weather services. It has a long tradition in fostering the interaction between scientists, engineers and agencies responsible for operational radar networks around the world. Experts meet experts while newcomers have the possibility to meet senior scientists in the field, to attend training courses, to get an overview of ongoing research following the talks and poster presentations, and to present their first studies to the community. Weather services and research groups that are interested in the latest technological

developments can talk to the engineers of the radar manufacturers at their booth. The idea to establish a European radar conference was born back in 1998 at the final seminar of COST-75 in Locarno. ERAD spent an exciting childhood in Bologna, Delft, Visby, Barcelona, Helsinki, Sibiu, moved as teenager to Toulouse, Garmisch, Antalya and Ede-Wageningen, and is now, after 24 years, coming back to its birthplace in Locarno.

It is our great pleasure to present to you the collection of abstracts of the 11th edition of the European Conference on Radar in Meteorology and Hydrology! As you are all well aware of, the COVID pandemic forced us to cancel ERAD2020. We all learned from these difficult times, and scientific conferences will not be the same anymore: ERAD2022 is fully hybrid to allow people to participate even if they cannot travel to Locarno. The field evolved substantially since the 1st edition of ERAD. However, there is one thing that has not changed over the years: the importance of sharing knowledge and working together. Thank you for being a part of this journey!

Urs Germann and Alexis Berne

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NOWCASTING THUNDERSTORM HAZARDS WITH NEURAL NETWORKS FROM MULTI-SOURCE DATA

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Thunderstorms pose threats to life and property in multiple ways, including lightning, hail, heavy rainfall and strong winds. Since those hazards are all caused by strong convection and processes are closely interconnected, nowcasting them can benefit from the same set of observational data; thus, a common framework for nowcasting different hazards is beneficial. In this presentation, we introduce such a framework in the context of machine learning. We present a neural network that detects spatiotemporal patterns in the input data fields using convolutional and recurrent layers. The network can simultaneously analyze inputs from multiple sources. We apply it to data from the Swiss weather radar network, lightning observations of EUCLID, MSG/SEVIRI satellite imagery, numerical weather forecasts of the Swiss COSMO model and a digital elevation model. Our study area is Switzerland and its surroundings.The model is trained to predict lightning, hail and extreme precipitation with lead times up to 60 min at 5 min time resolution; support for longer lead times is possible. We show that the model is able to infer and predict the motion, growth and decay of thunderstorms without explicit detection and tracking of storm objects. It can also often predict the future occurrence of these hazards before their onset. The predictions are probabilistic, indicating the confidence in the occurrence of the hazard, and can be calibrated to accurately reflect the probability of occurrence. We expect that this will enable more accurate and localized warnings of thunderstorm hazards. The model is validated against Eulerian and Lagrangian persistence. We also analyze the contributions of different data sources to the skill of predicting of each hazard using explainable AI methods.

SPATIAL REFLECTIVITY-BASED HAIL STORM DETECTION USING DEEP LEARNING

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Hail storms have a substantial economic impact on businesses and populations over the world. Convective storms producing large hailstones are responsible for a huge part of climate related insured losses each year in Europe, in Australia and in the US. Radar data has been one of the main sources to identify and characterise such storms. From the computation of probability of hail to the use of dual polarisation to discriminate hydrometeors, plenty of radar techniques have been studied for local diagnostic of hail. However, the comparison of such approaches remains difficult and the performances can vary greatly depending on the methodology of validation. Recent studies suggest that hail-bearing storms have specific spatial radar signatures (Gutierrez and Kumjian, 2021). Hence, a few machine learning methods allowing the study of spatial characteristics of hailstorms using radar data have been recently introduced (Wang et al., 2018; Shi et al., 2020). These methods open a new area of investigation on the spatial characteristics of such storms. They could lead to a better understanding of hailstorm distinctive features and could reduce the false alarm rates of existing detection methods. This work aims to investigate the ability of several deep learning architectures applied to composite and three-dimensional radar reflectivities to discriminate hail storms. The radar dataset used for this study comes from the radar of Toulouse, France, for events between 2017 and 2020. The positive data labelling is done thanks to a hailpad network and collaborative hail reports while the negative data labelling uses a selection of convective and non-convective environments. Performances and results for the different architectures will be presented and compared.

USING MACHINE LEARNING TO IMPROVE MULTI-WAVELENGTH SPACEBORNE RADAR PRECIPITATION RETRIEVALS

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We employ a new physically-based machine learning retrieval approach at Ku- and Ka-band frequencies using neural networks in ice and liquid phase retrievals. The retrieval is trained and tested with inputs of observed particle size distributions from aircraft microphysical probes collected during various NASA field campaigns (OLYMPEX, GCPEX, MC3E, CAMP2EX) and state-of-the-art forward simulations of hydrometeor scattering properties at multiple frequencies. In the ice phase retrievals, attenuation is ignored, and the retrieval provides outputs of normalized number concentration, ice water content, and melted and unmelted mass-weighted mean diameter. In the liquid phase, path integrated attenuation is used to constrain the retrieval in a column-iterative approach; the number concentration, liquid water content, mass-weighted mean diameter, and Gamma particle size distribution shape parameter are retrieved. Evaluation of these retrievals is performed against a separate validation set of airborne microphysical data directly and statistically, as well as from independent data from ground-based sensors (scanning radars, ground-based in situ measurements) depending on the field campaign, and shows decreases in bias and random error from current spaceborne radar approaches. These retrievals are used evaluate operational retrievals from the NASA Global Precipitation Measurement and CloudSat missions. I will discuss using new techniques for physical understanding of the retrievals, as well as other potential machine learning approaches for spaceborne precipitation retrieval.

PRECIPITATION NOWCASTING WITH AUTOREGRESSIVE DEEP LEARNING MODELS

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Precipitation nowcasting, the high-resolution very-short-range forecasting (0–6 h ahead) of precipitation, is an essential component of severe weather and hydrological early warning systems. Timeliness and accuracy of such forecasts are essential for weather-dependent decision-making to guarantee infrastructure safety and socio-economic operations. State-of-the-art operational nowcasting methods typically advect precipitation fields with radar-derived displacement estimates, but they struggle to capture the initiation of new convective cells and the growth and decay of precipitation cells, especially in regions with complex orography. Multi-horizon temporal forecasting models can be designed to generate direct or recursive predictions. Direct models predict the N future states as a function of M past states, producing a fixed-length vector matching the desired forecast horizon. On the other hand, recursive models employ previous model predictions as input for the next model forecasts. As a first result, we present a flexible framework for the training of multi-horizon temporal forecasting deep learning (DL) models. The framework accommodates for constraining DL-model predictions with physics-based numerical weather prediction (NWP) variables (i.e. CAPE), opening also new research perspectives with respect also to the consistent blending of statistical and NWP forecasts. We then experimentally show that recursive autoregressive models improve forecast prediction accuracy compared to direct models. We will also present different designs for deterministic and probabilistic/generative models as well as specialized loss functions and possible solutions to simplify the training of such architectures.

IMPROVING NOWCASTING OF CONVECTIVE DEVELOPMENT BY INCORPORATING POLARIMETRIC RADAR VARIABLES INTO A DEEP LEARNING MODEL

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Current convective nowcasting methods are mostly developed based on single-polarized radar echo extrapolation, which suffers from both ineffectiveness of nowcasting models and insufficiency of input information. Deep-learning (DL) methods are strong tools to extract information from massive data and to make predictions. However, DL-based models are still limited in nowcasting initiation and rapid development of convective storms. As an advanced observing tool, polarimetric weather radars provide more microphysics information for convective systems. In addition, recent study has demonstrated that the patterns of polarimetric variables can disclose information about dynamical structures in storms. Therefore, a deep learning architecture, Fusion and Reassignment Networks (FURENet), specially designed for fusing and extracting information from multiple input polarimetric variables is developed. The model is based on a residual U-Net, strengthened by newly designed late-fusion branches and a squeeze and excitation (SE) block. Such a design assists the model to capture higher-level dependencies of multiple input variables as well as focusing on the crucial and informative data features. Nowcasts of two representative cases indicate that KDP and ZDR can help the DL model better forecast convective organization and initiation. Quantitative statistical evaluation shows using FURENet, KDP and ZDR synergistically improve nowcasting skills (CSI score) by 13.2% and 17.4% for the lead time of 30- and 60-minute, respectively. Further evaluation shows the microphysical information provided by the polarimetric variables can enhance the DL model in understanding the evolution of convective storms and making more trustable nowcasts.

MACHINE LEARNING FOR PREDICTION OF CONVECTIVE HAZARDS AND IMPACTS - THE TAMIR PROJECT

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Convective storms have the potential to cause heavy rainfall, hail, wind gusts and lightning that can result in significant damage to property and loss of lives. Thus, there is a critical need for accurate prediction of the future location and impact potential of such storms (i.e. in the sub-kilometer resolution for the next hour) to assist the decision making of civil protection authorities. Weather radars and machine learning-based methods provide an important tool for this purpose. Identifying storm cells and systems as separate entities from a radar images provides a natural way for associating the attributes of a storm with its potential impacts. In the TAMIR project funded by the EU Civil Protection Mechanism, this approach was implemented by combining a cell tracking method with a machine learning model. The hazard levels of storms are estimated from their distance and time delay to weather-related emergency reports obtained from the PRONTO database provided by the Finnish emergency responders. Using different meteorological attributes related to severe weather (e.g. lightning flash, hail and wind observations and indicators of convective potential), a random forest model was trained for predicting the hazard level. This was done by using a large sample of convective events between 2013-2020. A Kalman filter-based methodology was applied for probabilistic nowcasting of future storm locations, which was combined with the above model. Finally, the hazard nowcasts were combined with different exposure layers to translate them into impact nowcasts of convective storms. The added value of the hazard and impact nowcasts for decision making is demonstrated with case studies and relevant verification metrics.

TOP-DOWN HIERARCHICAL CLUSTERING OF POLARISED X-BAND DOPPLER RADAR OBSERVATIONS FOR HYDROMETEOR AND AEROECOLOGICAL CLASSIFICATION

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In last decades weather radar observations became an important source of information not only for meteorologists and hydrologists, but also for entomologists and ornithologists. A correct classification of the data is essential for all these fields. For the most part, existing classification methods approach these tasks separately and rely on preliminary assumptions about either the number of classes in the data or about hard thresholds in one or several variables. This study presents a novel data-driven technique for identifying different clusters in time series of quasi-vertical profiles (QVP) and a columnar vertical profiles (CVP), based on observations made by the NCAS X-band dual-polarization Doppler weather radar (NXPol). The technique provides a physical delineation of multivariate radar observations into classes, identified as clusters belonging to a hierarchical structure. The number of classes in the data is not predefined and the method obtains the optimal number of clusters in a recursive process. The resulting optimal clustering is then used to label the original data. This technique was first applied to the identification of hydrometeor types and their associated microphysical processes. It showed stable and accurate performance when compared to available airborne in situ measurements. Further, the same technique is applied to detection and identification of aeroecological classes (birds, insects, and subclasses of both) and then compared to ground-based observations. Although this study uses observations from the NXPol, the technique is generally applicable to similar multivariate data from other radar observations, such as the C-band data of the Met Office radar network which will improve quantitative observation and monitoring of biodiversity in the UK.

PRECIPITATION NOWCASTING BY DEEP PHYSICS-CONSTRAINED NEURAL NETWORKS

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During last year's summer storm season, we have introduced a precipitation nowcasting neural network MWNet and deployed it to operational use. The network tackles the nowcasting problem as a sequence to sequence prediction of radar echo, emphasizing high resolution and accuracy. We have conducted two quantitative experiments comparing MWNet 60 min forecasts to other available precipitation nowcasting models, using the metrics CSI and MSE. Both evaluations, over the domain of Denmark for years 2018 - 2020 and over the Czech Republic for the summer storm season of 2021, concluded in favor of our approach. However, we aim to improve MWNet capabilities further by focusing on severe weather nowcasting, the physical soundness of the predictions, and lead times longer than 60 min. Building on the advances in deep learning and its use in spatio-temporal forecasting, MWNet is based on the idea of disentangling physical dynamics from the residual factors. In this contribution, we consider modifications to the physical part of the network and its incorporation into the whole model. Mainly, we are exploring the effect of implementing non-linear partial differential equations into the physical part, with various levels of hand-engineering equation terms. We analyze the impact on the dynamics learned by each part of the network and prediction quality for each setting. MWNet v1.2, based on the proposed architecture, will be operationally used and evaluated by meteorologists in Meteopress during the summer of 2022. This work aims to contribute to bridging the gap between machine learning and physical modeling in weather forecasting, alongside improving precipitation prediction.

A NEURAL NETWORK TO DETECT WIND TURBINE CONTAMINATION USING I/Q DATA

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Wind farms are an increasingly important source of renewable energy, but wind turbines (WT) can introduce severe clutter contamination (CC) in weather radar data. Unlike stationary clutter which can be removed with a Doppler filter, WT-CC has a non-trivial Doppler spectrum due to the moving blades. Currently, the Met Office uses a database of the known locations of individual WTs to mask WT-CC, but updating this database requires lengthy manual intervention. Furthermore, a static database does not account for dynamic changes in propagation, resulting in censoring even when the weather signal is dominant. We developed a neural network (NN) to make this process automatic, so that WT-CC may be detected in real-time and censored. Censoring is avoided both in still-air conditions, when the wind-turbine clutter can be filtered as ground clutter by the existing pipeline and when the weather signal is strong enough to mask the WT signal. To train the NN, we used a data-driven approach based on 3D observed tiles of data, which we have previously shown to be useful in addressing censoring of stationary CC that is not effectively removed by the existing signal-processing pipeline. The 3D tiles, which capture the spatial (horizontal and vertical) variability of WT-CC, are created as a controlled combination of observed weather (I&Q) signals in the absence of contamination and WT-clutter signals from known wind farms measured in dry weather. The original weather signal provides a ground truth against which the neural network is trained. Initial results show that pure precipitation and pure wind-turbine tiles can be classified correctly with up to 99.7% accuracy. Preliminary results with classification of mixed tiles (precipitation and wind-turbine) will be shown at the conference.

POLARIMETRIC RETRIEVAL OF RAINDROP SIZE DISTRIBUTION PARAMETERS USING MACHINE LEARNING

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The retrieval of raindrop size distribution (DSD) parameters is essential for understanding the precipitation process. A widely accepted retrieval method is polynomial or power-law regression of DSD parameters on radar measurables (e.g., ZH and ZDR). However, the regression models often fail to capture complex nonlinearity due to the inherent limitations of linear additive models. In contrast, machine learning (ML) algorithms are promising techniques to solve these shortcomings since it appropriately handles the complex non-linear relationship between response and predictors without any distributional and modeling assumption. This study aims to construct an ML algorithm to retrieve the DSD parameters (generalized number concentration, N0', and generalized mean diameter, Dm') using polarimetric radar variables The ML algorithm was trained by simulated dual-polarization variables using DSDs from a two-dimensional video disdrometer. We used 10-year summer data collected in various locations in South Korea. The trained model was evaluated using independent observations in the summer of 2021. We will further demonstrate the capability of the retrieval algorithm in analyzing the evolution of the DSD of the storm from polarimetric radar observation. To this end, a Lagrangian cell tracking is utilized to investigate the spatial and temporal evolution of DSD by following the precipitation system. We will then apply the trained ML algorithm to polarimetric radar variables of the tracked storm. The ML algorithm developed in this study would be beneficial in understanding the DSD characteristics from polarimetric radar measurements.

APPLICATION OF CNN TO IMPROVE DETERMINISTIC OPTICAL FLOW NOWCASTING AT DWD

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Deterministic optical flow based nowcasting is a powerful technique to compute forecasts of radar reflectivity and precipitation data for small lead times up to a couple of hours. However, the method has several drawbacks. It assumes stationarity in both the data values as well as the advection information. Additionally, the computation of the optical flow information itself typically assumes no intensity changes between time-steps. Recently, machine learning techniques have shown promising results towards incorporating several data source to produce nowcasts with dynamic behavior. For longer lead times, the predictions tend to become more blurry. From a practical point of view, the loss of high intensity values makes such nowcasts ill suited for the prediction of high impact events. The goal of the current work is to explore NN techniques to improve the operational optical flow nowcasting at DWD. Several experiments are conducted to address the shortcomings of the optical flow technique, e.g., no growth and decay and constant advection. As a first step, deterministic nowcasting is considered. U-Net based feed forward CNN architectures are trained on a two year data set consisting of Radar, NWP and static information (e.g. elevation model). Experiments are conducted to understand the impact of the individual predictors and the effectivity of NN postprocessing on the individual parts of the optical flow nowcasting process. As a baseline, the new forecasts are compared to the operational nowcasting at DWD as well as a closed-loop NN approach (RainNet).

NOWCASTING OF SEVERE THUNDERSTORMS WITH ENSEMBLE DEEP LEARNING ON CAPPI IMAGES OVER LIGURIAN AREA IN NORTHERN ITALY

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Among the different methodologies for meteorological nowcasting, data-driven artificial intelligence techniques are increasingly being experimented. In this framework, we propose a deep convolutional neural network (CNN) that ingests 3-level radar reflectivity videos (CAPPI at 2000, 3000 and 5000 m a.g.l.) to feed a warning system signalling the probable occurrence of severe thunderstorms within the next hour. Here, the aim is not the exact determination of the intensity and the position of extreme events but the identification of time windows with high potential for severe convection in the reference area. We considered two different areas, one embracing the Liguria region in Northern Italy and part of the Ligurian Sea, and the other including solely the Ligurian Sea. Events are labelled as severe when precipitation exceeds 50 mm/h in the MCM (Modified Conditional Merging) field merging radar and rain gauges observations and lightning strikes are present in the surroundings. The proposed neural network is a Long-term Recurrent Convolutional Network (LRCN) that combines a CNN for frame-by-frame image analysis with a Long Short-Term Memory (LSTM) network in order to extract information in space and time. The probabilistic results of the network are finally transformed into a binary classification using an ensemble learning technique. We propose an innovative approach that takes into account the temporal distribution of alarms in order to promote forecasts correctly anticipating events by means of value-weighted skill scores (e.g. wTSS) instead of traditional ones (e.g. TSS), which do not consider time aspects of the forecast. Results show significantly better performances when wTSS is optimized rather than traditional metrics.

MELTING LAYER MONITORING WITH A MICRO RAIN RADAR USING A NEURAL NETWORK

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Reliable knowledge of the existence and height of the melting layer is useful in many applications. This includes the identification and risk assessment of icing conditions for aviation and the improvement of radar based quantitative precipitation estimation. A vertically profiling micro rain radar (MRR) is particularly fit for this task because of the favorable angle of incidence and the information about the particle fall velocity provided by the Doppler spectrum. Long-term operation of MRRs at two airports by the German Weather Service provided comprehensive data sets, which were used for evaluation of different melting layer detection algorithms. Often the melting layer detection is a trivial task. Nevertheless, it can be a challenge in case of intermittent rain or convection. A recently devised neural network approach will be evaluated with radio soundings and AMDAR data and compared with a classical fuzzy logic algorithm.

PRECIPITATION NOWCASTING BY THE COMBINATION OF GENERATIVE AND TRANSFORMER DEEP LEARNING MODELS

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This work introduces a novel deep learning method for nowcasting radar-based precipitation at a five-minute time resolution for the next 60 minutes. The proposed method is composed of a combination of two models: the first model is trained to compress and decompress the radar acquisition into and from a discrete representation, while the second model evolves the compressed representation over time. Specifically, the compression and decompression model is based on a combination of a Quantized Variational Autoencoder with a Generative Adversarial Network, while the prediction over time leverages a Generative Pretrained Transformer (GPT) architecture. This separation of concerns (information compression/decompression and time evolution) opens the possibility of exploiting the strength of each architecture: one explored example is the ability to leverage the transformer model to generate ensembles and probabilistic predictions. The combination of these two components is trained and tested on a 7-year radar dataset of reflectivity composites of the Emilia-Romagna Region. The method is then applied at two different scales: regional, over Emilia-Romagna, and national, on the entire Italian domain, showing the adaptability of the approach to multiple domains. We will present the performance of this model for deterministic nowcasting by comparing it with respect to both Lagrangian extrapolation and deep learning based on Recurrent Convolutional architecture. Favourable skills, obtained with different metrics, will be shown.

RADAR-RAIN GAUGE CUMULATED QUANTITATIVE PRECIPITATION ESTIMATION WITH DEEP CONVOLUTIONAL NEURAL NETWORK

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This work introduces a deep learning model for Quantitative Precipitation Estimation of accumulated rainfall based on the combination of radar estimate, rain gauge stations and other environmental data sources. The proposed method is based on convolutional neural network: it takes as input the estimated radar rainfall and other environmental sources and it is trained to predict the accumulated rain gauge estimate. Specifically, a fixed size square spatial window surrounding the weather station location is sourced from the radar precipitation estimates and from topographic feature maps, with the aim of predicting the precipitation accumulation at the pixel location of the rain gauge. The method is tested with different parameters and at different temporal accumulation, from 15 minutes up to 24 hours at one kilometer spatial resolution. The proposed method is applied at the regional scale in the Emilia-Romagna Region in Italy and compared with the operational baseline method based on kriging adjustment of the radar estimate, and with a regression kriging estimate based on a random forest regressor. More than 2 million records over one year of radar estimated precipitation and rain gauge data of the Emilia-Romagna Region are used for the training and testing of the presented models. We will compare the performance of the deep learning model with respect to the regression baselines by means of different verification metrics, showing favorable results.

QUANTITATIVE PRECIPITATION ESTIMATION USING WEATHER RADAR AND RAIN GAUGE DATA FUSION WITH MACHINE LEARNING

Fernanda Verdelho[1]; Cesar Beneti[1]; Leonardo Calvetti[2]; Roberto Calheiros[1]; Marco Antonio Zanata Alves[3]; Luiz Eduardo Soares de Oliveira[3]

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Improved rainfall estimates enhance the potential of weather radars for many applications such as flash flood forecasting and hydropower generation management. In less than ten years, in Brazil, we increased our radar coverage, from 23 single-polarization to 21 additional dual-polarization radars, mainly S-Band, with a concentration in the southern region, an area prone to severe weather, and where more than 35% of the national hydropower energy is generated, depending directly on precipitation distribution, and where water availability and storm events lead to flood inundations, reaching proportions of natural disasters. Precipitation estimates have been generated using different radar ZR and polarimetric relationships, both from the literature and locally adjusted, with reasonable adjustments with rain gauges and distrometers, considering data filtering, range from radar, orography, signal propagations among other factors that may affect the estimates. We have developed and used operationally a QPE multi-sensor fusion approach with the usage of weather radar, satellite and rain gauge data which does not require frequent processing to update the weights of the data sources, as in other schemes. However, we have noticed that an improvement in the radar QPE would benefit the operational algorithm, reducing the errors and numerical instabilities. In this paper we present an improvement of this multi-source QPE algorithm, using machine learning to identify a better approach for the weather radar QPE using polarimetric variables and rain gauge data with more frequent updates (5 to 15 minutes). Initially, we used random forest and gradient boosting techniques to improve the accuracy of the estimates and evaluated the impact of these algorithms on the operational environment.

WEATHER RADAR VELOCITY UNFOLDING USING CONVOLUTIONAL NEURAL NETWORKS

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Doppler weather radar is an essential tool for monitoring and warning of hazardous weathers. It is important to correct aliased Doppler velocity since it provides dynamical information of the storms. However, due to the Doppler dilemma owing to maximum unambiguous range (ra) and velocity (va) that cannot be improved at the same time. Many studies have been performed to mitigate this issue. One is to look for the aliased velocity, i.e., an abrupt change from one end of the va to another, a fold is detected when such an instance is encountered. This approach performs well when storms are spatially continuous but can suffer for the cases that isolated storms are present. Another approach employs two or more PRFs, but we will not discuss it in this paper. In this study, the convolutional neural network (CNN) is used to tackle the velocity unfolding issue. Machine learning uses a pre-determined model of weighted input combinations, then through a repetitive fit-and-adjust process, the best weights are obtained. Velocity from S-band WSR-88Ds and a variety of weather phenomena such as stratiform, squall line, gust front, and isolated storms were used as the truth in the training, while various va were applied to the same data to simulate the aliased velocity fields up to two folds from an X-band system. Similar approach was applied to test datasets to quantitatively assess the performance. The preliminary results have shown that the proposed algorithm can score on average more than 90% accuracy for all the weather events tested. The traditional method shows similar performance for spatially relatively continuous weathers. However, limited performance of much lower accuracy was observed for the other weather types that have stronger spatial discontinuity and isolation.

ESTIMATION OF SPECIFIC DIFFERENTIAL PHASE WITH A CONVOLUTIONAL AUTOENCODER

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Accurate estimation of specific differential phase (Kdp) is important in many applications of radar meteorology including rainfall estimation and understanding ice microphysical processes. However, current methods for estimating Kdp require some degree of user input for the algorithm parameters that depend on the application and characteristics of the radar. To address these shortcomings, a generalized Kdp algorithm is developed using a machine learning algorithm trained on a synthetic database of differential phase and Kdp profiles. This database is generated using randomly sampled Kdp profiles of simplified Gaussian shapes to capture a variety of natural Kdp structures that mimic different precipitation types (e.g., convective rain, stratiform snow). In addition, varying amounts of noise are added to the corresponding differential phase profiles to broaden the applicability of the algorithm to different radars and meteorological situations. Sections of the differential phase profiles in the database are also masked to force the algorithm to appropriately handle missing data. A convolutional autoencoder model is then trained to estimate Kdp from the synthetic database. This model consists of an encoding component that converts the differential phase profiles to a learned, lower-dimensional representation, and a subsequent decoding component that generates a Kdp profile from the encoding component. The resulting algorithm successfully produces Kdp estimates that are of comparable accuracy to existing methods for a wide variety of radar measurements, without the need for any parameter tuning by the user. Future improvements to the algorithm, including more realistic methods to generate the training database, are discussed.

A GUIDE TO RADAR NOWCASTING USING MACHINE LEARNING

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Deep learning is emerging as a powerful tool in radar meteorology and hydrology. For example, deep learning has proved to be effective for nowcasting through many case studies in the literature. Nevertheless, there are still some open questions in machine learning-based radar applications: how much data is sufficient to train a deep learning model? how much knowledge learned from one domain can be used in other regions? Although it is impossible to give a universal theoretical answer, it is important to carry out an empirical analysis and gain insights into these questions. To this end, we use nowcasting as an example to provide a guide to machine learning in radar meteorology. A deep learning model based on long short-term memory (LSTM) cells is devised to carry out extensive systematic experiments for precipitation nowcasting. The results show that the long-tailed distribution of radar data is the governing factor that determines the amount of data needed to train a model, i.e., 20% of the data can achieve 80% performance of a model, whereas the left 80% data is required to achieve the last 20% performance. In addition, our results show that 10,000 radar images can meet basic requirement to get an acceptable model, and 40,000 radar images can yield a reliable model. As for the number of past radar observations used for the model training, five consecutive observations are enough to obtain a reliable model. In fact, two past observations can build an acceptable model, i.e., the major storm motion feature can be represented by the most recent two consecutive observations. Another important factor affecting the model performance is the ratio of radar data samples with strong reflectivity (≥35 dBZ), which should be taken into account in extending the model applications.

CLIMATOLOGICAL STUDIES

CLIMATOLOGY OF THE VERTICAL PROFILES OF POLARIMETRIC RADAR VARIABLES AND RETRIEVED MICROPHYSICAL PARAMETERS IN CONTINENTAL / TROPICAL MCSS AND LANDFALLING HURRICANES

CHANGING PATTERNS OF HEAVY RAINFALL EVENTS ACROSS AN URBAN AREA (MILAN, ITALY)

A FIRST INSIGHT INTO THE HAIL DISTRIBUTION OVER GERMANY

USING A CATALOGUE OF RADAR-BASED HEAVY RAINFALL EVENTS (CATRARE) IN GERMANY FOR ASSESSING THE IMPACT OF CURRENT PRECIPITATION EVENTS

EXTREME RAINFALL EVENT CLASSIFICATION IN THE TROPICAL ANDES BY USING OBSERVATIONS OF AN X-BAND RADAR

DOCUMENTATION OF HEAVY RAIN EVENTS WITH AN EVENT DATA BASE

SPATIAL ANALYSIS OF THE VARIABILITY IN THE SHORT-TERM RAINFALL TIME STRUCTURE

TRENDS IN AUSTRALIAN HAIL PROBABILITY EXAMINED USING AN UPDATED HAIL PROXY AND RADAR DATA

CLASSIFICATION OF PARENT CONVECTIVE SYSTEMS OF TORNADOES BY USING RADAR REFLECTIVITY

A 20 YEARS CLIMATOLOGY OF STORM TRACKS BY JOINT ANALYSIS OF VERTICAL MAXIMUM INTENSITIES, LIGHTNING AND HAILPADS OVER NORTH-EASTERN ITALY

CLIMATOLOGY OF THE VERTICAL PROFILES OF POLARIMETRIC RADAR VARIABLES AND RETRIEVED MICROPHYSICAL PARAMETERS IN CONTINENTAL / TROPICAL MCSS AND LANDFALLING HURRICANES

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Most existing cloud models tend to overestimate the size of cloud ice particles and underestimate their concentration. This emphasizes the need to provide a reliable observational reference to optimize cloud model performance, particularly in areas of high concentration of ice at high altitudes. The dual-polarization radars give the community a unique opportunity to quantify cloud ice with a good accuracy using polarimetric radar retrievals. In this study, we utilize the network of operational WSR-88D radars to build a climatology of the vertical profiles of radar variables such as radar reflectivity Z, differential reflectivity ZDR, and specific differential phase KDP as well as the radar-retrieved vertical profiles of ice water content (IWC) above the melting layer and liquid water content (LWC) below it, mean volume diameter Dm, and total number concentration Nt of ice and liquid particles. Such climatology was created for continental / marine MCSs and tropical cyclones including hurricanes. The dataset includes 13 continental MCSs, 10 marine MCSs, and 11 tropical cyclones. Separate statistics of the "background" vertical profiles and the ones associated with high IWC aloft have been obtained in the course of this study. It is shown that continental MCSs exhibit larger size of ice in lower concentration aloft compared to the marine MCSs and especially tropical cyclones / hurricanes. A combination of high KDP and low Z aloft signifies lower Dm, higher Nt, and often substantial IWC.

CHANGING PATTERNS OF HEAVY RAINFALL EVENTS ACROSS AN URBAN AREA (MILAN, ITALY)

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There are pieces of evidence that urban areas affect the spatial structure of rainfall fields on small scales. However, since urban effects on rainfall have only been explored in a few cities, there is disagreement regarding the precise pattern of change (e.g. how the storm area is affected) and the driving dynamic and thermodynamic forces behind it. As the hydrological response in urban areas is highly sensitive to the space-time rainfall variability, it is crucial to understand how urban areas change the spatial structure of rainfall to improve our abilities to nowcast rainfall and urban floods. We used weather radar data from MeteoSwiss (5 min and 1 km resolution) to analyse the spatial structure and intensity of heavy rainfall events that cross the city of Milan (Italy). We tracked these events over 6 years using a storm-tracking algorithm (Lagrangian perspective) and investigated rainfall field properties, such as the radially averaged intensity and the spatial structure in the spectral domain. We extracted the properties of storm elements at varying distances relative to the city centre, on a storm-by-storm basis. These radial distances were defined as either upwind or downwind using the storm's average direction of motion. We then evaluated composite storm properties at these different distances. Second, we also conducted a spatial analysis of storm properties by aggregating the properties of all storm elements that cross each grid box of our study area. Then, we explored how the rainfall fields changed upwind and downwind of the city by considering fixed radar windows of 20 km by 20 km, in an Eulerian perspective. The results of the analysis from the two perspectives will be presented.

A FIRST INSIGHT INTO THE HAIL DISTRIBUTION OVER GERMANY

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Since major hail events are quite rare in Germany, there is a lack of hail size analysis and its distribution. As hailstorms are often locally very limited events, the hail distribution is hard to analyze precisely. Hail reports can only give a first intuition about the amount of hail overall. There might be a bias in the amount of reports towards too many reports in highly populated areas, which could lead to an underrepresentation of reports in rural and sparsely populated areas. Areal information from weather radar networks can overcome this issue with a high spatio-temporal resolution. The German radar network consists of 17 dual-polarimetric radar systems, which cover Germany more or less completely. First of all, a hydrometeor classification (HYMEC) is applied to the radar data to check if the occurrence of hail is reasonable. From that, a hail distribution over Germany can already be derived. For the analysis of the hail sizes, the Maximum Expected Size of Hail (MESH) and a method based on Vertical Integrated Ice (VII) are used to estimate the hail size in those regions where hail is probable. The results of MESH and VII are finally compared to the eyewitness reports sent to the ESWD and the WarnWetter-App.

USING A CATALOGUE OF RADAR-BASED HEAVY RAINFALL EVENTS (CATRARE) IN GERMANY FOR ASSESSING THE IMPACT OF CURRENT PRECIPITATION EVENTS

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One of the predicted effects of climate change in Central Europe is a growing number and increasing extremity of heavy rainfalls. Thus, it is of a great importance to investigate the structure and detailed characteristics of extreme events that have already taken place and their impact. With this objective, the German Weather Service (DWD) has developed a Catalogue of Radar-based Heavy Rainfall Events (CatRaRE), derived from 21 years of climatological radar data for the area of Germany. Using hourly data of about 1 km spatial resolution, an object-oriented analysis is performed to classify spatially and timely independent rainfall events with duration between 1 and 72 hours exceeding the official warning level for heavy precipitation for Germany. Apart from various extremity attributes, like return period or weather extremity indices, the catalogue is enriched with additional variables (e.g. weather type, antecedent precipitation index, population density, land cover, imperviousness degree, Topographic Position Index), providing the meteorological, geographical and demographic background. Combining CatRaRE with information on the impact of each event (e.g. on damage or fire brigade operations) allows an estimation of the possible impact upcoming events with comparable structure could provoke in a similar environment. We will present CatRaRE and results of a comprehensive analysis of all classified heavy precipitation events as well as first attempts to use the data set as a basis for assessing the impact of operationally detected precipitation events. This procedure could also be used for predicted precipitation from Nowcasting in the future.

EXTREME RAINFALL EVENT CLASSIFICATION IN THE TROPICAL ANDES BY USING OBSERVATIONS OF AN X-BAND RADAR

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Extreme weather events may damage ecosystems and cause economic and human losses. Extreme meteorological events like rainfall storms are difficult to analyze and forecast due the lack of reliable data particularly in remote areas of the world. Especially the lack of spatial-explicit data in high spatio-temporal are the main problem to get a better understanding of rainfall processes and dynamics. This particularly holds for the tropical Andes, where the complex topography impedes the installation and operation of a well-distributed rain gauge network. Thus, this study aims to analyze extreme rainfall events and characterize them by using a clustering approach based on spatial-explicit data. Four years of data were obtained from an X-band weather radar. The instrument was located at 4450m a.s.l in the Tropical Andes of southern Ecuador. Firstly, extreme rainfall events were identified and characterized through storm features (e.g., duration, intensity distribution, advection field, etc). Then, by using a clustering approach (e.g., k-means, hierarchical), representative extreme rainfall event classes were derived. While the statistical distinctness of classes is good, some transitions where found between classes. This novel classification allowed to improve our knowledge about the rainfall variability in this tropical mountain range and provide new insights about rainfall extreme event characteristics. Finally, the clustering approach may be used for classifying events in other locations by using the data-based approach of this study.

DOCUMENTATION OF HEAVY RAIN EVENTS WITH AN EVENT DATA BASE

Alrun Jasper-Tönnies[1]; Philipp Bühler[2]; Thomas Einfalt[1]; Katharina Lengfeld[3]; Markus Jessen[1]

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[2]Okeanos Smart Data Solutions GmbH, Germany

[3]Deutscher Wetterdienst (DWD), Germany

An event data base for the documentation of heavy rain events over Germany is presented. The event data base is accessible via a web portal which provides functionalities for finding and analysing events, linking precipitation data from radar with additional data sources such as population density or imperviousness, and allowing documentation of event-related damages and mitigation measures. It is developed on behalf of the LAWA (working group 'water' of the German federal states) and is based on two previous approaches to event data bases: an event data base for North Rhine-Westphalia by hydro & meteo GmbH and HydroLogic and the CatRaRe data base by the German Weather Service DWD. The portal is open to the public with an additional password protected internal area for expert users of the LAWA. It provides tools to find, sort, compare, classify, and analyse heavy rain events. The event analysis is based on the DWD radar climatology RADKLIM and complemented by current radar data using the adjusted product YW. Independent heavy rain events are determined in consideration of the spatial extent based on the weather extremity index. Several pre-built analysis options are provided to evaluate a selection of heavy rain events as well as to view specific details of one event. A map view is included which allows to see the event rain sum, an animation of the radar precipitation and time series at user-selected locations. Registered users also have the option to download precipitation data for further analysis. The event data base will be updated with new data by the DWD every year, providing a long-term basis for various purposes, e. g. spatio-temporal evaluation of heavy rain events or climate and trend analysis.

SPATIAL ANALYSIS OF THE VARIABILITY IN THE SHORT-TERM RAINFALL TIME STRUCTURE

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Heavy short-term rainfalls are characterized by high spatial and temporal variability of precipitation totals which should be taken into account when designing water management measures. This motivated us to analyze the spatial variability in the occurrence of typical precipitation intensity courses within a larger area of central Europe. Input dataset consists of 20-year series of precipitation intensities with the time resolution of 10 min and the spatial resolution of 1 km in the territory of Czechia. They are quantified from weather radar-derived intensities in more than 80,000 radar pixels and adjusted by 1-day precipitation totals measured in about 700 rain gauges. The analysis is based on progressive procedures of the regional frequency analysis of precipitation totals. Intensity courses typical of the studied region are approximated by 6 synthetic storm hyetographs. They are constructed by the cluster analysis of reference precipitation events using 3 similarity measures quantifying the time concentration of precipitation during a 6-h period with the highest totals. We assess the probability of the occurrence (percentage) of a given hyetograph by computing the return period of the hyetograph and by its comparison with return periods of the other hyetographs for a considered 6-h design precipitation depth. The hyetographs represent shorter-term convective events of various lengths with or without breaks in rainfalls as well as longer-lasting steady rainfalls. The spatial heterogeneity in their percentage is significantly affected by the topography and amplifies with the increasing return period of precipitation totals. In the future, we will focus on the assessment of probable antecedent totals before events of the given magnitude and course.

TRENDS IN AUSTRALIAN HAIL PROBABILITY EXAMINED USING AN UPDATED HAIL PROXY AND RADAR DATA

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Hail causes severe damage in Australia, with even single severe events costing insurers more than AUD $1b. Despite this damage potential, there remains high uncertainty about how hail may evolve under climate change, due to offsetting effects of changing environmental conditions, geographical variability in changes to hail-relevant variables, gaps in microphysical knowledge, and a lack of detailed studies over many world regions including Australia. In this study, we use an updated hail-environment proxy that uses indicators of atmospheric instability, bulk wind shear, and temperature profile information to estimate the occurrence of hail-prone days. The proxy is applied to the European Centre for Medium-range Weather Forecasts (ECMWF) reanalysis 5 (ERA5) archive (1979-2021) for Australia. Radar data are used to provide Maximum Estimated Size of Hail (MESH) estimates over major Australian cities. We calculate trends in MESH estimates to corroborate the estimates from the reanalysis-derived proxy. We examine the location and timing of hail-prone days, and trends in the monthly number of hail-prone days over the archive. With a grid spacing of ~31 km, this analysis allows us to examine the estimated occurrence of hail on a continental scale in the highest resolution to-date, and provides the first estimates of hail frequency changes over the last four decades for all of Australia. We examine the trends in detail and compare them to those from the few existing previous studies.

CLASSIFICATION OF PARENT CONVECTIVE SYSTEMS OF TORNADOES BY USING RADAR REFLECTIVITY

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Tornadoes frequently occur in Kochi Prefecture in Japan. The present study aims to classify parent convective systems of tornadoes based on the echo pattern. We analyzed the radar data obtained from our X-band radar network and JMA Muroto radar from April 2014 to December 2021. We detected the tornado and/or mesocyclone based on dipole of Doppler velocity and then evaluated the size and the shapes of the parent systems from the strong echo regions of more than 40 dBZ in reflectivity. Totally analyzed number is 34. We classified them to 6 systems; isolated cell, supercell, wavy cloud, cloud cluster, squall line and inner core of typhoon. The most detected system is isolated cell which is relatively small thunderstorm but sometimes has clear hook echo showing the tornado vortex. We observed two supercells under the environment of typhoon. The wavy clouds were observed in the far from the outer rainband of typhoon and aligned almost parallel to the radial direction from the typhoon. They are relatively shallow but they have mesocyclones. We call the system in which we cannot identify each cell, cloud cluster. Squall line is a kind of quasi-linear band of about 100 km in length rapidly moving in the right angle direction of its trend. We could not identify the parent cloud of the vortex occurred near typhoon eye and defined it the tornado in the inner core of typhoon. We found that almost vortices located in rear side of the parent system. The vortices having velocity difference of more than 15 m/s can cause damages regardless their moving velocity. But the vortices in inner core of typhoon and in squall line caused damages in spite of their relatively small velocity difference.

A 20 YEARS CLIMATOLOGY OF STORM TRACKS BY JOINT ANALYSIS OF VERTICAL MAXIMUM INTENSITIES, LIGHTNING AND HAILPADS OVER NORTH-EASTERN ITALY

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North-eastern Italy is a spot of convective events in central Europe. A new approach to the study of storms in this region has been developed by systematically analyzing Vertical Maximum Intensity (VMI) reflectivity data collected by C-band dual-polarization Doppler radar with a temporal resolution of 10 min. From these data, a system to detect each storm track has been developed, using the object oriented technique by the MODE (Method for Object-Based Diagnostic Evaluation) function from NCAR-DTC MET suite. This tool was originally developed for forecast verification: in fact it provides comparison of spatial fields with coherent spatial structures. Time sequences of VMI fields are compared using the MODE tool, which provides, as output, a set of centroids defined on certain reflectivity thresholds and a set of associated couples of centroids for each time step. Moreover, the user can define also custom criteria, as centroids distance, borders distance, storm shape, and more. Storm tracks connecting the centroids are then computed, together with some other properties, such as length, duration, VMI intensity trend, over a 20 years long period (2001-2021). The work is enriched by the analysis of associated lightning data, in order to better exploit the thunderstorm climatology, and by the analysis of hailpads, collected by 300 volunteers inside the radar domain.

CLUTTER, INTERFERENCES, INSECTS AND THE LIKE

WIND TURBINE CLUTTER DETECTION IN REAL-TIME WEATHER RADAR SIGNALS – DEVELOPMENTS FOR THE DWD C-BAND WEATHER RADAR NETWORK

ADVANCED SIGNAL PROCESSING FOR WEATHER RADARS

ANALYSIS OF INSECT CONCENTRATIONS USING WEATHER RADARS: WEATHER RADAR ECHOES CLASSIFICATION

A CONCEPT FOR POTENTIAL COHABITATION OF WIND TURBINES AND RADAR

HIGH TEMPORAL RESOLVED X-BAND WEATHER RADAR RETURNS FROM A WINDMILL SCATTERER

STUDYING THE PRESENCE OF INSECTS USING CLOUD RADAR AND VIDEO IN-SITU OBSERVATIONS

SEMAFOR PROJECT: REMOTE SENSING OF AVIFAUNA USING THE FRENCH METEOROLOGICAL RADAR NETWORK

REGRESSION GROUND CLUTTER FILTERING TO IMPROVE RADAR SIGNAL STATISTICS: APPLICATION TO EXPERIMENTAL DATA

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THE INFLUENCE OF WIND TURBINES ON WEATHER RADAR DATA IN GERMANY

MOBILE RADAR OBSERVATIONS IN WILDFIRES

ASSESSING AND MITIGATING THE RADAR - RADAR INTERFERENCE IN THE GERMAN C-BAND WEATHER RADAR NETWORK

USE OF DOPPLER RADAR TO MONITORING PRODUCTS FROM POPOCATÉPETL VOLCANO TO MEXICO CITY

ON THE INTERFERENCE OF WEATHER RADAR DATA BY WIND TURBINES: EVALUATION OF THE RESTORED METEOROLOGICAL INFORMATION

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MACHINE LEARNING ADDRESSES CHALLENGES RESULTING FROM INCREASING RADIO INTERFERENCE TO IMPROVE RADAR DATA

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RFI IN X-BAND WEATHER RADARS: A PROCEDURE TO IDENTIFY INTERFERING SOURCES DURING IN FIELD MEASUREMENTS

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ANOMALY DETECTION AND REMOVAL AT THE FMI

AN ALGORITHM FOR SUPPRESSING RADIO FREQUENCY INTERFERENCE IN WEATHER RADARS

ANALYSIS OF SPECTRAL AND POLARIMETRIC OBSERVATIONS RECORDED BY A X-BAND WEATHER RADAR FROM A WIND TURBINE SCATTERER

WIND TURBINE CLUTTER DETECTION IN REAL-TIME WEATHER RADAR SIGNALS – DEVELOPMENTS FOR THE DWD C-BAND WEATHER RADAR NETWORK

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A new Wind Turbine Clutter (WTC) detection algorithm was developed by GAMIC in cooperation with the Deutscher Wetterdienst (DWD). Wind turbines in the near surroundings of radar locations cause unwanted high reflectivity range bins which can not be detected by typical clutter algorithms. The presented approach enables to flag these bins in real-time at signal processing level. This allows to include the detection information in the post-processing algorithm chain, particularly for data quality assurance. Currently, a detailed analysis and evaluation is carried out within the DWD C-Band weather radar network. The quality of the algorithm is quantified by the probability of detection and the false alarm rate of WTC detections. In order to have a broad and meaningful evaluation for different wind turbine constellations and operating states as well as various weather situations, the algorithm is running in the operational environment on every weather radar system of the DWD network.

ADVANCED SIGNAL PROCESSING FOR WEATHER RADARS

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New advanced signal processing techniques allow you to get more meteorologically relevant data and less unwanted signals out of your weather radar hardware. Those sophisticated algorithms address strong clutter, multi-trip echoes, radio frequency interference, and wind turbine clutter.

ANALYSIS OF INSECT CONCENTRATIONS USING WEATHER RADARS: WEATHER RADAR ECHOES CLASSIFICATION

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Over the past decades, insect biodiversity and abundance are decreasing. Systematically assessing the decline requires an unintrusive observation of flying insects in the atmosphere. Radar has been known to provide quantitative estimates of flying insects. A weather radar is designed to observe meteorological targets, thus the derivation of insect echoes needs special techniques. The automation of insect retrieval methods from weather radars, for this purpose artificial intelligence approaches are well suited. In this study, level 2 data in combination with the level 3 hydrometeor classification algorithm from the KLOT S-band radar at Illinois part of the radar network of the United States of America is used. Weekly aphid counts from a suction trap in Morris, Illinois are used as in-situ data. Near-surface temperature, wind speed, and cloud cover ECMWF Reanalysis v5 data are used to assess the effects of weather on the distribution of radar variables. Decision tree, random forest and support vector machine models were generated to distinguish 10 combinations of scatterers. Low variability of differential reflectivity is found for precipitation scatterers. The differential reflectivity distributions caused by insects are broad with higher medians. Plankton and moderate insects have equivalent variability of reflectivity. Cloud cover, temperature, and wind speed heavily influence the distribution of radar variables for heavy rain, snow, and plankton respectively. The random forest algorithm produces the best accuracy to distinguish the scatterers. Across the three algorithms, the individual insects' intensity and plankton scatterers were distinguished best. This study presents the initial steps of distinguishing insect echoes and evaluating insect concentration.

A CONCEPT FOR POTENTIAL COHABITATION OF WIND TURBINES AND RADAR

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Wind turbines (WT) in the vicinity of a weather radar are known to deteriorate data quality. Permit applications for new WT have been filed to the competent authority of the region around Boostedt radar in northern Germany, a radar operated by the German Weather Service. For supporting the authority, a study was carried out highlighting the area with observed deteriorations of radar measurements and showing a way to limit these effects through appropriate measures. Based on the quantitative and statistical evaluation of radar reflectivity measurement data of one year, the area of WEA influence as seen in the measured data around a WT site was assessed. There are numerous WT already operating in the close surrounding within a radius of 15 km around the radar. The results show that there is a 600 m radius around a WT in which radar measurements are deteriorated. Among other features, the height of a WT is playing a role for its visibility in the radar data. For products like warnings, a connected area with reduced data quality should be limited in order to allow for a good automatical radar echo tracking. Based on these facts an assessment scheme has been developed with the following key elements
1. no WT is permitted within 5 km around the radar
2. the height of a WT is limited to a 10% overlap with the precipitation scan of the radar (in Germany usually the 0.8° elevation scan). An exception may be granted by the authority if the WT is automatically disabled during severe weather warnings
3. a distance of 4 km is required for two WT to be independent - else they are considered connected
4. the area of connected WT (including the 600m radius) shall be no larger than 15 km2

HIGH TEMPORAL RESOLVED X-BAND WEATHER RADAR RETURNS FROM A WINDMILL SCATTERER

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The increasing need of renewable energy fosters the expansion of windmill sites throughout Europe with manifold effects, both on the positive and negative side. The latter concerns radar observations in the proximity of windmill sites that are indispensable for aviation security and weather monitoring. With the aim of better understanding the effects of large, moving scatterers like windmills on radar returns, MeteoSwiss did a dedicated measurement campaign with a mobile X-band weather radar in March 2020. The main goal was to quantify the effects of windmills on the observed radar moments, to retrieve the Radar-Cross-section (RCS) and to investigate the conditions leading to the occurrence of the largest RCS. Fixed-antenna observations towards the windmill object allowed a data acquisition period of only 64 ms. This guaranteed the observation of any fast changes of the radar returns due to blade rotation and further underlay the thorough statistical analyses of various windmill object dependencies, like rotor speed and nacelle or blade pitch orientation. The highest measured maxima of horizontal reflectivity and RCS reached 78.5 dBZ and 44.1 dBsm, respectively. A nacelle orientation stratified statistical analysis shows no clear correlation with the received maximum returns. However, we find with help of Doppler-filtered data, that the moving parts of the windmill are of importance to understand the radar return signals. With investigating correlations we show, that the fast-changing pitch angle of the rotor blades is a key parameter, which strongly contributes to the variability in the observed data. Our results can be helpful for mitigation measures on wind turbine interference in radar systems in the future.

STUDYING THE PRESENCE OF INSECTS USING CLOUD RADAR AND VIDEO IN-SITU OBSERVATIONS

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Climate change and biodiversity loss are two of the greatest interlinked challenges of the anthropocene. In the field of aero ecology, the loss of insect populations is of particular concern. Within the frame of the interdisciplinary initiative "Breathing Nature" at Leipzig University, flying insects will be studied and characterized from two different points of view. Firstly, by using long-term observations with a zenith-pointing 94 GHz Doppler cloud radar and secondly, by a ground-based video in-situ snowflake sensor (VISSS) that is also capable of observing insects. The Cloudnet target classification as well as Doppler radar spectra-based methods will be used to distinguish insects from meteorological targets like clouds and precipitation. Number counts of insects observed with the VISSS will be related to meteorological parameters like temperature, horizontal wind speed, and precipitation occurrence among others. In the future, a closure between the VISSS and cloud radar observations for the lowest radar range gates is planned by performing scattering calculations for individual VISSS-detected insects. Observations from two different sites (Leipzig, Germany from Jan – July 2021 and Hyttiäla, Finland from Sep 2021 onward) will be used.

SEMAFOR PROJECT: REMOTE SENSING OF AVIFAUNA USING THE FRENCH METEOROLOGICAL RADAR NETWORK

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For reducing the loss of biodiversity in a globally expanding wind energy sector, the de-risking of wind farm projects is a major issue. Billions of birds fly across France every year on their way to optimal habitats depending on the season. These migratory movements are very complex to trace, even more overseas than on land. Thus, an accurate tool for bird detection is a strategic issue for project planning and the issuance of alerts of imminent passage of migratory birds. Weather radars capture any target backscattering its electromagnetic pulse: from precipitations to migrating birds. A network of weather radars therefore offers the possibility to study and quantify biomass over long periods. The ambition of the SEMAFOR project is to develop a real-time observatory of migratory birds at high resolution from the French weather radar network, and to propose a tool to forecast migratory passages. Firstly, existing algorithms for bird detection will be adapted to raw data from the weather radar network operated by Météo-France and calibrated with the ornithological radars from Biotope. Once the algorithm validated, the spatial location and temporal evolution of migratory movements will be studied on a national scale during a complete life cycle. Secondly, a predictive model for the probability of passage of migratory birds will be developed by the Swiss Ornithological Institute. The model will take into account real time measurements from weather radars, but also local meteorological and environmental parameters and orographic obstacles, as well as knowledge of the main migration routes. At ERAD 2022, we will report on preliminary calibration results of bird detection algorithms based on polarimetric quantities from S-, C- and X-band weather radars.

REGRESSION GROUND CLUTTER FILTERING TO IMPROVE RADAR SIGNAL STATISTICS: APPLICATION TO EXPERIMENTAL DATA

John Hubbert[1]; Ulrike Romatschke[1]; G. Meymaris[1]; Mike Dixon[1]

[1]*National Center for Atmospheric Research, United States*

The identification, filtering of ground clutter echoes thus separating them from weather radar echo is an ongoing area of research. Most weather radar groups employ a spectral domain technique that requires that the time series is first multiplied by a window function and then spectrum is calculated where spectral components around zero velocity are set to zero. A disadvantage of applying a window function to the time series is that it attenuates the signal and eliminates some of the information about the weather signal that may be present along with the ground clutter signal. This translates to higher measurement standard deviations for the weather signal. Another known technique for removing ground clutter signal is a regression filter. It is based on the observation that the ground clutter signal varies very slowly in time whereas weather signals generally vary substantially more. Thus, to remove the slowly varying part of the signal, a regression curve (i.e., a polynomial) is fitted to the signal and then subtracted, thus leaving the weather signal intact. The advantage of the regression filter is that no time domain window is required and thus better weather signal statistics are possible. This has been recently been investigated and shown by Hubbert et al. 2021, Using a Regression Ground Clutter Filter to Improve Weather Radar Signal Statistics: Theory and Simulations, JTECH. The paper the application of a regression ground clutter to experimental data from NEXRAD and NCAR's S-pol radar. Issues such as automated polynomial order selection.

A NEW BANDSTOP REGRESSION FILTER WITH APPLICATION TO SZ PHASE CODING

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Regression filtering is used for either eliminating the higher frequency components of a time series signal (low pass filter or "smoothing" filter) or eliminating the trend of a time series signal (highpass filter, e.g., ground clutter filtering). Thus previously, regression filtering has been limited to these applications. For example, regression filtering is not useful for bandstop (bandpass) filtering, i.e., rejecting (selecting) an arbitrary frequency or a set of frequencies. This novel filtering technique provides for regression bandstop (bandpass) filtering centered at any frequency component of the time series signal. Thus, this new "band" regression type filter can be used to eliminate (or select) arbitrary frequency components of a signal. This is accomplished without the use of a window function and it avoids filter warmup issues that plague FIR and IIR filters. SZ phase coding is a signal processing technique used by the National Weather Service for separating multiple trip echoes thereby increasing the unambiguous velocity and range for pulse transmission radars. In order to eliminate the SZ strong trip echo, a frequency domain spectral notched is used. The SZ phase coding technique also requires a time domain window function such as the von Hann. The application of this window function effectively reduces the number of independent samples available for radar variable computation which intern increases the standard measurement error of the retrieved radar variable. The band regression filter provides a way to effectively eliminate the strong trip echo without the use of a window function. The new filtering technique is illustrated with modeled data.

THE INFLUENCE OF WIND TURBINES ON WEATHER RADAR DATA IN GERMANY

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The expansion of renewable energies in Europe continues unabated. The potential areas for further expansion of wind parks are becoming scarce and are increasingly subject to conflicts of interest. One of these being the disturbance of radar data by wind turbines in the 15 km radius around weather radars. While the perturbation of raw data by wind turbines is undisputed, there is disagreement about its radius of influence and about the propagation of errors into secondary radar products. This study investigates the influence of existing wind turbines on weather radar data at different locations in Germany. We analyze the interference of wind turbines at different distances from the radar and with different overlap with the radar beam. The focus of our analysis is on the radar reflectivity in simple and polarimetrically filtered radar data provided by the German Weather Service (DWD), as well as on the German precipitation composite ("WN-product").

MOBILE RADAR OBSERVATIONS IN WILDFIRES

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Doppler On Wheels (DOW) mobile / targetable truck-borne radars have deployed to collect fine-scale observations in several wildfires, one, recently, in an urban area. DOW measurements in wildfires permit the mapping of the windfields in the fire plumes, and characterization of the near-fire environment. DOWs can collect windfield data below the observing horizon of more distant radars, and at much finer-scale resolution. Observations of three wildfires will be discussed. In 2020, two DOWs deployed in the mountains of Colorado and collected dual-Doppler vector wind data primarily in the fire environment. During another fire in 2020, the DOWs were deployed close to wildfires which destroyed many homes. Small-scale vortices and other features are resolvable due to the close proximity of the deployed radars to the wildfires. Dual-Doppler DOW analysis, the first fine-scale dual-Doppler analysis of this type, may be presented. In 2021, a DOW deployed in South Boulder, Colorado in the metropolitan Boulder wildfire / extreme wind event where winds exceeding 45 m/s enhanced fires which destroyed many homes and businesses in the south Boulder area.

ASSESSING AND MITIGATING THE RADAR - RADAR INTERFERENCE IN THE GERMAN C-BAND WEATHER RADAR NETWORK

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The German weather radar consists of 17 polarimetric radar systems at C-Band. The national German weather radar network operates in C-band between 5.6 and 5.65 GHz. In a radar network, individual transmit frequencies have to be chosen such that radar-radar induced interferences are avoided. In an unique experiment the Hohenpeissenberg research radar and five operational systems from the radar network were used to characterize radar-radar induced interferences as a function of the radar frequency. The operating frequency of the five operational radar systems cover a broad range of the C-Band (5600, 5625, 5630, 5640, 5670 MHz). We use dedicated scans where an operational radar points and transmits directly towards the research radar for about 30 seconds. The research radar performs a full sweep with typical operational settings during this period. This is done sequentially every 5 minutes for all involved radars and is followed additional sweep without explicit external interference. Interferences are determined using the signal quality index and the normalized signal power. The results allow to assess the possibility to add additional C-band radars with magnetron transmitters into the existing network. Based on the experiment, at least a 15 MHz separation of the nominal radar frequency is needed to avoid a radar-radar interference. In addition, it is shown that radar-radar interference can further be minimized by the "Radar Tango". Latter refers to the synchronized scanning of all network radar systems. Based on those results additional C-band radar systems can be added to the German weather radar network if a further improvement of the radar coverage is needed.

USE OF DOPPLER RADAR TO MONITORING PRODUCTS FROM POPOCATÉPETL VOLCANO TO MEXICO CITY

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Volcanic ash and volatile emissions are hazards considered pollutants when present in relatively low concentrations and a source of risk when yield higher concentrations that might affect population health, living stock and infrastructure (i.e. air navigation). Popocatépetl is among the largest gas emission volcanoes in the world, and Mexico City is among the largest populated areas over the planet. Therefore, it is very important to have an emissions forecasting and monitoring system, to prevent exposure and risks. This study* comprises the forecast of ash distribution from the volcano and the monitoring of ash dispersion using a doppler X-band Furuno radar installed 11 km north of the volcano at 4000 masl. This instrument is part of a larger emission monitoring system that includes gas spectrometers (DOAS and FTIR) and already installed web cameras performing surveillance. Specifically, the radar is intended to survey and calculate the mass, particle size distribution, maximum altitude, among other parameters of the ash plume and, combined with the wind vector field above the volcano, its direction of dispersion. We already developed software to visualize the data based primarily on Wradlib. Currently, we are in the process to calculate other parameters such as maximum altitude and mass concentration to feed specialized software in ash dispersion like Fall3D. Future research includes a method to distinguish between ash and water since the volcano is cloudy 7 to 8 months a year. This is progress report of the project.• Financially supported by the Secretaría de Educación, Ciencia, Tecnología e Innovación of the Mexico City government.

ON THE INTERFERENCE OF WEATHER RADAR DATA BY WIND TURBINES: EVALUATION OF THE RESTORED METEOROLOGICAL INFORMATION

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The weather radar is one of the most important components of DWD warning management. For example, in summer, small-scale thunderstorm cells with heavy precipitation may arise within a few minutes. These can only be detected and tracked area-wide and three-dimensionally using weather radar. For nowcasting, i.e. with a forecast time of up to two hours, weather radar plays a major role in assessing the type, strength and movement of precipitation areas, among other things. The quality of radar data is increasingly impaired by the expansion of wind energy, since more and increasingly larger wind turbines (often arranged in wind farms) are being built in the vicinity of weather radar systems. The meteorological radar echo can be significantly disturbed by the wind turbines such that radar-based nowcasting methods are limited in their capabilities to quantitatively diagnose and predict weather phenomena. There is currently no method available to separate (filter) the wind turbine signal from the weather signal, while promising detection algorithms have become available. Within the project RIWER, especially methods have been implemented and tested to fill in meteorological information from the surroundings into areas where wind turbines have been detected. Mathematically, the approach includes techniques from inverse problems, partial differential equation based infilling and optical flow. Subsequently, it is evaluated how meteorologically useful the correction is for different sized areas, on the one hand depending on the weather situation and on the other hand depending on the number and proximity of surrounding gaps caused by wind turbines.

THE DWD RF-INTERFERENCE MITIGATION

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[1]*Deutscher Wetterdienst (DWD), Germany*

Weather radars are regularly compromised by RF interference. Therefore, the efficient and objective detection and removal of external RF transmitters, which disturb the radar data, is an ongoing challenge. This poster elaborates on the RF interference detection C-Band weather radar network of the German Weather Service (DWD). The algorithm utilizes thresholds to determine if a specific ray is contaminated and groups such contaminated rays to identify interference sources, which lead to a severe loss of information. The operational analysis provides daily summaries across the DWD radar network. The results contain all necessary information to track down the sources of the detected interference. Identified sources of removable RF interference are reported to the national frequency protection authority. It is their duty to shut down any disturber in the protected C-Band. The poster will provide an insight into three topics. The implementation of the RF interference detection algorithm. An evaluation of the interference situation since 2017 when the German Weather Service operationally implemented the monitoring of RF interference. And last, probably most importantly, a verification procedure based on independent measurements with a WIFI-receiver that is connected into the radar receiver.

MACHINE LEARNING ADDRESSES CHALLENGES RESULTING FROM INCREASING RADIO INTERFERENCE TO IMPROVE RADAR DATA

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Weather Radars produce images of hydrometeors or other objects in the atmosphere and are one of the primary meteorological tools used by scientists, forecasters, and researchers worldwide. The recent expansion of RF communication and other technologies or even naturally occurring phenomena has resulted in interference and distortion within the radar signal. Weather radar uses reflected radio waves to locate and create images of precipitation and moisture. To be correctly interpreted operators require training, however, it is standard practice in many Hydrometeorological agencies around the world to push these images to the public for consumption. The interference on the radar produces false images that might be interpreted as precipitation making it difficult for the novice user to understand what they see. Also, many short-term weather models use radar data to predict precipitation development, and thus the highest quality data is important for these predictions. Baron has studied the problem extensively and found that using machine learning, the radar data can be "cleaned." We will demonstrate how advanced machine learning technology has improved radar imagery and discuss the benefits and importance of clarity in the generation of weather radar imagery.

POLARIMETRIC SIGNATURES OF WILDFIRE SMOKE PLUMES FROM THE 2019/2020 BLACK SUMMER IN AUSTRALIA

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Weather radars can produce significant returns from wildfire smoke plumes, in particular for intense fires emitting large amounts of debris and firebrands in the atmosphere, such as the numerous fires that burned through the 2019/2020 Black Summer in Australia. These intense fires produced 29 pyro-cumulonimbus clouds, a 50% increase in just one season of the total number of events ever observed in Australia. Because of the spatial variability in land cover where the fire front is active, various rates of spread and fire intensities, variations in vegetation moisture content, and the state of the atmosphere at the time of the event, the uplifted debris will greatly vary in size, shape, concentrations as well as electromagnetic properties. Here, we explored the spatio-temporal distributions of polarimetric signatures of wildfire smoke plumes associated to Black Summer fires, focusing on wildfire plumes within the range of capital cities S-Band dual pol radars. We compared their properties to those of polarimetric variables collected from wildfire smoke plumes with a portable dual pol X-Band weather radar during 2014-2016 and to the existing knowledge available from the scientific literature. Finally, we conducted computations of the scattering properties of idealised scatterers to determine which candidates could correspond to the observed polarimetric signatures.

RFI IN X-BAND WEATHER RADARS: A PROCEDURE TO IDENTIFY INTERFERING SOURCES DURING IN FIELD MEASUREMENTS

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One of the main challenges in weather radar data quality is electromagnetic interference. Weather radars may operate in frequency bands close to, or shared with, other telecommunication systems. This is the case of C-band radars (5.4-5.6 GHz), which share the frequency especially with HiperLAN systems. Weather radars operating around 9 GHz benefit from being the primary users in this portion of the X band, thus excluding in principle possible interferences. The RFI issue significantly affects the X-band weather radar managed by Arpa Piemonte (the environmental protection agency of Piemonte region, Italy) and, to a lesser extent, the X-band weather network of Dallas Fort Worth (USA). The X-band weather radar managed by Arpa Piemonte detects very frequent and almost ubiquitous electromagnetic interference signals, which kept increasing since their first appearance several years ago (around year 2014). Since the number of X-band radars deployed both in Europe and in the United States is constantly increasing, the identification of likely interfering sources may be useful in radar networks design and deployment.Thus, Arpa Piemonte is conducting an in-field measurement campaign to detect the sources which generate the electromagnetic interferences. Since the azimuth and power of received RFI are not constant during the day, the most frequent radial locations are identified operating specific radar scan strategies. Following this analysis, the sources identification is conducted using the Keysight N9952B FieldFox Handheld Microwave Analyzer able to detect signals up to 50 GHz and to perform real time signal analysis, and a directive antenna. In this paper, the results of the RFI detection are shown and the procedure to identify sources at X band is discussed.

PERFORMANCE ANALYSIS OF THE ARGENTINIAN METEOROLOGICAL RADAR RADIO FREQUENCY INTERFERENCE FILTER

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[1]*INVAP S.E., Argentina*

A novel Radio Frequency Interference (RFI) filter is on the features list of the processor upgrade for the Argentinian Meteorological Radar (RMA). The Argentinian network of weather radars: Sistema Nacional de Radares Meteorológicos (SINARAME) is composed by 15 C-band weather radars, of which 12 are RMA units. Almost all the SINARAME radars suffer from RFI contamination because C-band radars operate in the same frequency band as Radio Local Area Network (RLAN) and Wireless Area Network (WLAN). This research presents the work conducted as part of the validation process of the software update for the RMA processor, before the release and upgrade of the SINARAME network. Weather-only signals (I/Q time series), were collected from an RFI-free RMA site in the north of Argentina and chosen as the reference dataset. RFI-only signals were collected from some of the most heavily RFI-contaminated sites, using the RMA radars as a receive-only antenna. The RFI-only signals were numerically combined, at the I/Q level, with the weather-only signals, thus generating a new set of real-world weather data contaminated with real RFI signals. The overall impact of contamination on data quality and the suppression capabilities of the filter was tested by applying the RFI filter to the artificially contaminated dataset and comparing the results with the reference (RFI-free) dataset. Finally, a collection of several hours of I/Q data recorded from different RMA sites were processed, to study the RFI filter performance under different weather conditions and levels of contamination. The results show that after tuning the filter parameters to the scanning strategy RFI contamination is greatly reduced without eliminating hydrometeors echoes for all the study cases.

ANOMALY DETECTION AND REMOVAL AT THE FMI

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Weather radar measurements are constantly subject to quality issues originating from non-meteorological echoes and external disturbances. Since 2001, the Finnish Meteorological Institute has applied operational detection and removal of anomalies in radar data. The earliest methods, reported in ERAD 2002, applied image analysis to single-polarisation data in recognising noise, external emitters, ships, as well as birds and insects. Recent development applying dual-polarisation data has provided better separation of birds from insects and better detection of non-meteorological echoes in general. In addition, new methods for creating ground clutter maps and detecting widespread radio-frequency interference have been developed. As a design principle, detection and removal have been kept separate, allowing monitoring and combining detection results to quality fields prior to applying them in data correction. The correction process provides three alternative operations: actual removal (marking bins “no-data”), damping, and gap-filling. In addition, obtained quality information can be further applied in compositing stage. For example under signal attenuation, radar data can be corrected by using data from neighbouring, overlapping radars. In this paper, we review the methods developed this far and illustrate their usage in operational environment. We also review briefly the underlying ``quality algebra'' motivated by probabilistic modelling. In our view, radar bins should not be outright treated as “correct” and “incorrect” data but as presenting classes of various interesting phenomena: it is up to the end applications how the quality data should be finally handled. The presented methods have been implemented in open source “Rack” program.

AN ALGORITHM FOR SUPPRESSING RADIO FREQUENCY INTERFERENCE IN WEATHER RADARS

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The problems caused by radio frequency interference (RFI) in weather radars are well known, especially those produced by RLAN networks in C-band radars, as both services share a part of the frequency spectrum. Although standards foresee means to avoid them, such interferences are common. They seriously affect radar performance, and in most cases, it is not possible to enforce RLAN equipment to comply with the regulations. Some existing methods mitigate the problem by detecting segments dominated by RFI in the (I, Q) data and replacing the affected samples with estimated values obtained from adjacent pulses by interpolation or substitution. When the RFI has a high duty cycle, there is a high probability of having several contiguous pulses contaminated at the same range gates, affecting the quality of the estimated samples. The subject of this work is an algorithm for mitigating the effects of RFI that can have a high duty cycle. It detects segments of contaminated signal, but instead of replacing the bad samples excludes them from the calculations. In each gate, radar variables are computed using only the non-interfered pulses. If the clean data are not enough to allow estimation of some variable, the processor issues a "bad data" flag for that variable in the gate. The decision to use a given segment of the (I, Q) data in the calculations or discard it because it contains RFI uses a combination of criteria, processing the instantaneous signal power in fast and slow time. The algorithm uses moving averages, thresholding, order statistics, and sequential filtering. The algorithm was tested using data from several RMA, C-band polarimetric radars. The data were contaminated with high duty cycle RFI, obtaining good results in all the tests.

ANALYSIS OF SPECTRAL AND POLARIMETRIC OBSERVATIONS RECORDED BY A X-BAND WEATHER RADAR FROM A WIND TURBINE SCATTERER

Daniel Wolfensberger[1]; Marco Gabella[1]; Martin Lainer[1]; Jacopo Grazioli[2]; Jordi Figueras i Ventura[3]; Urs Germann[1]

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[3]Météo-France, France

It is well-known that windfarms can pose a severe risk to several types of crucial radar observations such as weather, air traffic monitoring or precision approach. Until now the evaluation of these impacts has focused mostly on the monitoring of the wind turbine backscattering RCS and reflectivity. Much less is known about their impact on spectral Doppler observations and polarimetric variables, which are particularly relevant for weather applications. To gain more knowledge in this topic, MeteoSwiss did a dedicated measurement campaign with a mobile polarimetric X-band weather radar in the months of March 2019 and 2020. In this study, we focus on the analysis of the Doppler spectrum records and polarimetric observations (in particular differential reflectivity and copolar correlation correlation) of wind turbines, at a high temporal resolution of only 64 ms. We relate the polarimetric signature and micro-Doppler effects to variations in the wind turbine parameters such as the rotor speed, the blade pitch angles and the nacelle orientation. In a second part, the study focuses on the evaluation of the wind turbine signature in dry and rainy conditions and assesses the shadowing effect of the wind turbine and their interference on several operational radar derived weather observations.

FREQUENCY-DIVERSITY, AIRBORNE AND SPACEBORNE

SCIENTIFIC PRODUCTS DERIVED FROM AIRBORNE W-BAND RADAR OBSERVATIONS

DEEPENING OUR UNDERSTANDING OF (SHALLOW) PRECIPITATION OBSERVATIONS RETRIEVED BY CONICAL-SCANNING RADIOMETERS

EVALUATION OF GPM DPR PRODUCTS THROUGH A COUNTRY-WIDE NETWORK OF DISDROMETERS OVER ITALY

A NEW DUAL-FREQUENCY-BASED HYDROMETEOR CLASSIFICATION APPROACH FOR THE GLOBAL PRECIPITATION MEASUREMENTS CORE-SATELLITE

VALIDATION OF THE SPACEBORNE RADAR MODULE WITHIN THE RTTOV-SCATT RADIATIVE TRANSFER MODEL

CALIBRATION OF SPACE-BORNE CONICALLY SCANNING RADARS

THE POTENTIAL OF THE W-BAND POLARIZATION DIVERSITY DOPPLER RADAR ENVISAGED FOR THE WIVERN MISSION FOR SAMPLING TROPICAL CYCLONES

IMPACT OF SECOND-TRIP ECHOES FOR SPACE-BORNE HIGH-PULSE-REPETITION-FREQUENCY NADIR-LOOKING W-BAND CLOUD RADARS

HIGHLY SUPERCOOLED RIMING AND UNUSUAL TRIPLE-FREQUENCY RADAR SIGNATURES OVER ANTARCTICA

DOPPLER VELOCITY MEASUREMENTS FROM SPACE

VERTICAL VELOCITY DERIVED FROM AIRBORNE DOPPLER RADAR MEASUREMENTS DURING IMPACTS

GRAWAC: G-BAND RADAR FOR WATER VAPOR PROFILING AND ARCTIC CLOUDS

GPM DPR HYDROMETEOR CLASSIFICATION MODULE

SCIENTIFIC PRODUCTS DERIVED FROM AIRBORNE W-BAND RADAR OBSERVATIONS

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The mission of the Earth Observing Laboratory (EOL) at the National Center for Atmospheric Research (NCAR) is to develop and deploy observing facilities and provide expertise and data services to aid the scientific community in observational field campaigns. The HIAPER Cloud Radar (HCR), a 94 GHz W-band radar, has been deployed by EOL on the NSF/NCAR Gulfstream V HIAPER aircraft in four major field campaigns, reaching from the Southern Ocean to the tropics of Central America. Based on the standard radar data products, algorithms are developed which create new derived scientific fields to increase the benefit of HCR data to scientists. Three such algorithms have been completed and the derived scientific products are available in all major HCR field campaign datasets: (a) The melting layer detection algorithm provides detected, interpolated, and estimated altitudes of the melting layer. (b) The echo type classification algorithm (ECCO-V) separates convective from stratiform clouds and provides echo type classifications that are not only resolved in the horizontal but also in the vertical dimension. It also calculates convectivity - a new quantitative measure of the convective or stratiform nature of each data point. (c) The hydrometeor particle type identification algorithm uses a fuzzy logic method to differentiate between eleven cloud and precipitation particle types of different phases and sizes. Other algorithms currently under development cover topics such as the distinction between air motion and particle fall speed, and estimation of liquid water content. Progress on these developments will be reported.

DEEPENING OUR UNDERSTANDING OF (SHALLOW) PRECIPITATION OBSERVATIONS RETRIEVED BY CONICAL-SCANNING RADIOMETERS

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Precipitation estimates retrieved from satellite observations are valuable because of their uniformly distributed and global coverage. The number of satellites with radiometers onboard is quite high, resulting in a high temporal availability. Furthermore, they cover a larger spatial area compared to space-borne radars due to their extended swath-width. Radiometers sense the radiance naturally emitted by the Earth's surface or emitted/scattered by hydrometeors, referred to as the brightness temperature (Tb). Hence, a conversion is needed to retrieve precipitation estimates. Although this conversion has been studied extensively over the past decades, persistent challenges remain. Two of these challenges are the retrieval of precipitation formed close to the Earth's surface (shallow precipitation), and low-intensity precipitation. Increased understanding of the physics behind these precipitation types will help to improve the accuracy of the conversion. This study couples observations from radiometers to both ground-based precipitation observations and reflectivity profiles from weather radars over the Netherlands. Tb observations are retrieved from conical scanning radiometers belonging to the Global Precipitation Measurement mission (GPM). First, we investigate the relationship between Tb's from different channels and precipitation intensities. Within this analysis we try to take the effect of different footprint sizes of the different channels (related to the employed radio frequencies) into account to limit the dependence of the retrieved relations on the footprint size. Second, we couple the observations of the radiometers with ground-based radar reflectivity profiles to gain insight in the vertical structure of the precipitation types and how these affect Tb.

EVALUATION OF GPM DPR PRODUCTS THROUGH A COUNTRY-WIDE NETWORK OF DISDROMETERS OVER ITALY

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The worldwide distribution of precipitation provided by satellite-borne radars is crucial for climatological applications and for understanding the hydrological balance on a global scale. However, radar-based retrievals are subjected to a variety of potential errors and need validation with ground-based measurements. To date, the Dual-frequency Precipitation Radar (DPR) aboard the Core Satellite of the Global Precipitation Measurement (GPM) mission is the only active sensor able to provide, at global scale, vertical profiles of rainfall rate, radar reflectivity, and Drop Size Distribution (DSD) parameters from space. In the literature, many studies report the comparison of the available versions of satellite precipitation products with data collected by ground-based instrumentations such as radars and rain gauges; however very few published studies used networked disdrometers data on a national scale. A cooperation among different Italian institutions has allowed using data collected by eight networked laser disdrometers dislocated along the Italian peninsula. The comparison with GPM DPR products was made in terms of rainfall and DSD parameters: rainfall rate, radar reflectivity, mass-weighted mean diameter (Dm), and normalized gamma DSD intercept (Nw). Different comparison approaches have been proposed and evaluated considering the Version V06A of the GPM algorithm. The obtained agreement with V06 products was good for rain rate, reflectivity factor, and Dm, while Nw needs improvement. The same methods will also be used for evaluating current V07A of precipitation products (available from December 2021). This study has also set the stage for the organization of the Italian Group of Disdrometry (GID; www.gid-net.it) aimed at improving the use of disdrometer data.

A NEW DUAL-FREQUENCY-BASED HYDROMETEOR CLASSIFICATION APPROACH FOR THE GLOBAL PRECIPITATION MEASUREMENTS CORE-SATELLITE

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This study introduces a new three-dimensional hydrometeor classification (HMC) based on the measurements of the dual-frequency precipitation radar (DPR) on board of the Global Precipitation Measurement (GPM) core satellite towards a more detailed satellite-based and thus area-wide classification. To establish the new dual-frequency-based HMC method, measurements from several overflights of the GPM satellite are directly compared with the dual polarisation measurements of the ground-based C-band radar network of the German Weather Service (DWD). The DPR measurements are assigned to hydrometeor classes determined via existing polarimetric HMCs applied to the ground-based measurements. For the specific hydrometeor classes, the reflectivities at Ku-band (Zku), at Ka-band (Zka) and the dual frequency ratio (DFR) are considered as three-dimensional vectors and averaged to centroids. The determined centroids are used to assign current DPR measurements to a specific hydrometeor class based on the euclidean distance between observations and centroids. Vertical distributions of hydrometeor types derived from ground-based polarimetric measurements of the X-band weather radar BoXPol operated by the University of Bonn in western Germany are used for a first evaluation of the new dual-frequency-based HMC and confirms its applicability.

VALIDATION OF THE SPACEBORNE RADAR MODULE WITHIN THE RTTOV-SCATT RADIATIVE TRANSFER MODEL

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Spaceborne radars offer a unique capability to observe vertical profiles of clouds and precipitation at a global scale, which makes them particularly appealing for Numerical Weather Prediction model validation and data assimilation. With the objective of simulating both active and passive microwave instruments within a single framework into a widely-used tool in the NWP community, a first version of the radar module has recently been released within Version 13 of the RTTOV-SCATT software by the EUMETSAT NWP SAF. This initial version supports the simulation of both the GPM/Dual frequency Precipitation Radar and the Cloudsat/Cloud Precipitation Radar. Simulations of the GPM/DPR, performed with RTTOV V13 and the ARPEGE global model running operationally at Météo-France will be shown. A revisited version of the Bauer (2001) parametrization will be employed to simulate the reflectivities in the melting region. Comparisons will be performed with observations, both on a case study as well as for a one-month period. In particular, a sensitivity of the simulations to hydrometeor radiative property specifications (particle size distributions and hydrometeor fractions) will be performed.

CALIBRATION OF SPACE-BORNE CONICALLY SCANNING RADARS

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The planned and potential introduction in the global satellite observing systems of conically scanning Ka and W band atmospheric radars [e.g. the radars in the Tomorrow.IO constellation, https://www.tomorrow.io/space/, and the WIVERN (WInd VElocity Radar Nephoscope) radar] calls for the development of methodologies for calibrating and cross-calibrating these systems. Traditional calibration techniques pointing at the sea surface at about 12o are in fact unfeasible for such fast rotating systems. We propose a cross-calibration with reference radars working on the same band and orbiting around Earth in the same period of time (e.g. the Ka-band GPM radar or W-band radars planned for future ESA and NASA missions). Ice clouds not prone to appreciable attenuation are used as natural targets. Antenna boresight positions have been propagated based on satellite orbits so that the ground-track intersections have been calculated for different intersection criteria defined by cross-overs within a certain time and a given distance. Then the climatology of the calibrating clouds has been studied using the W-band CloudSat and Ka-band GPM reflectivity dataset in order to derive the global distribution of calibrating clouds. The number and the spatial distribution of calibration points is obtained by merging the ground-track intersections and the climatology of clouds. The statistical correlation between the reflectivity distribution functions of the calibrating ice clouds for different lengths of clouds has also been studiedin order to find the optimal distance criterion which optimizes the calibration precision and minimizes the time needed to achieve a radar calibration. We will present our findings for different satellite combinations of orbits.

THE POTENTIAL OF THE W-BAND POLARIZATION DIVERSITY DOPPLER RADAR ENVISAGED FOR THE WIVERN MISSION FOR SAMPLING TROPICAL CYCLONES

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The WIVERN (WInd VElocity Radar Nephoscope) mission, soon entering in Phase-0 of the ESA Earth Explorer program, promises to complement Doppler wind lidar by globally observing, for the first time, vertical profiles of winds in cloudy areas. This work quickly presents and builds on the recently developed end to end simulator of the WIVERN conically scanning 94 GHz Doppler radar, the only payload of the mission. Specific features of the simulator are: the conically scanning geometry; the inclusion of cross-polarization effects and of the simulation of a radiometric mode; the applicability to global cloud model outputs via an orbital model; the incorporation of a mispointing model accounting for thermo-elastic distortions, microvibrations, star-trackers uncertainties, etc.; the inclusion of the surface clutter. The simulator is applied to a large dataset of tropical cyclones, simulated by various atmospheric models or observed by Cloudsat. The analysis of the results provides statistics on the potential of WIVERN for sampling tropical cyclones. Several questions are addressed: What is the frequency of good data as a function of height? What is the effect of ghost echoes produced by cross-polarization? What is the effect of noise error and how often will the radar signal be fully attenuated by rain?

IMPACT OF SECOND-TRIP ECHOES FOR SPACE-BORNE HIGH-PULSE-REPETITION-FREQUENCY NADIR-LOOKING W-BAND CLOUD RADARS

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The appearance of second-trip echoes generated by mirror images over the ocean and by multiple scattering tails in correspondence with deep convective cores has been investigated for space-borne nadir-looking W-band cloud radar observations. Examples extracted from the CloudSat radar are used to demonstrate the mechanisms of formation and to validate the modelling of such returns. A statistical analysis shows that, for CloudSat observations, second-trip echoes are rare and appear only above 20 km. CloudSat climatology is used to estimate the occurrence of second-trip echoes in the different configurations envisaged for the operations of the EarthCARE radar, which will adopt PRFs much higher than the one used by the CloudSat radar in order to improve its Doppler capabilities. Our findings predict that the presence of such echoes in EarthCARE observations cannot be neglected: in particular, over the ocean, mirror images will tend to populate the EarthCARE sampling window with a maximum frequency at its upper boundary. This will create an additional fake cloud cover in the upper troposphere (of the order of 3% at the top of the sampling window and steadily decreasing moving downwards), and, in much less frequent instances, it will cause an amplification of signals in areas where clouds are already present. Multiple scattering tails will produce second-trip echoes but with much lower frequencies: less than 1 profile out of 1000 in the tropics and practically no effects at high latitudes. At the moment, level-2 algorithms of the EarthCARE radar do not account for such occurrences. We recommend to properly remove these second-trip echoes and to correct for reflectivity enhancements. This work is relevant for the design of future space-borne Doppler Wband radar missions.

HIGHLY SUPERCOOLED RIMING AND UNUSUAL TRIPLE-FREQUENCY RADAR SIGNATURES OVER ANTARCTICA

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Riming of ice crystals by supercooled water droplets is an efficient ice growth process, but its basic properties are still poorly known. While it has been shown to contribute significantly to surface precipitation at mid-latitudes, little is known about its occurrence at high latitudes. In Antarctica, two competing effects can influence the occurrence of riming: the scarcity of supercooled liquid water clouds due to the extremely low tropospheric temperatures and the low aerosol concentration, which may lead to the formation of fewer and larger supercooled drops potentially resulting in an enhanced riming efficiency. In this work, by exploiting the deployment of an unprecedented number of multi-wavelength active and passive remote sensing systems (including triple-frequency radar measurements) in West Antarctica, during the Atmospheric Radiation Measurements West Antarctic Radiation Experiment (AWARE) field campaign, we evaluate the importance of riming incidence in Antarctica and find that riming occurs at much lower temperatures compared to the mid-latitudes. We then focus on a case study featuring a persistent layer of unexpectedly pronounced triple-frequency radar signatures but only a relatively modest amount of supercooled liquid water. In-depth analysis of the radar observations suggests that such signatures can only be explained by the combined effects of moderately rimed aggregates or similarly shaped florid polycrystals and a narrow particle size distribution (PSD). Simulations of this case study performed with a 1D bin model by introducing an additional class corresponding to rimed ice indicate that similar triple frequency radar observations can be reproduced when narrow PSDs are simulated.

DOPPLER VELOCITY MEASUREMENTS FROM SPACE

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Convective motions and hydrometeors microphysical properties are highly sought-after parameters for evaluating atmospheric numerical models. With most of the Earth's surface covered by water, space-borne Doppler radars are ideal for acquiring such measurements at a global scale. Comprehensive forward simulations enable us to assess the advantages and drawbacks of six different Doppler radar architectures currently planned or under consideration by space agencies for the study of cloud dynamics. Radar performance is examined against state-of-the-art numerical model simulations of well-characterized shallow and deep, continental, and oceanic convective cases. Mean Doppler velocity (MDV) measurements collected at multiple frequencies (13, 35 and 94 GHz) provide complementary information in deep convective cloud systems. The high penetration capability of the 13-GHz radar enables to obtain a complete, albeit horizontally under-sampled, view of deep convective storms. The smaller instantaneous field of view (IFOV) of the 35-GHz radar captures more precise information about the location and size of convective updrafts above 5-8 km height of most systems which was determined is the portion of storms where the mass flux peak is typically located. Finally, the lower mean Doppler velocity uncertainty of displaced phase center antenna (DPCA) radars makes them an ideal system for studying microphysics in shallow convection and frontal systems, as well as ice and mixed-phase clouds. It is demonstrated that a 94-GHz DCPA system can achieve retrieval errors as low as 0.05-0.15 mm for raindrop volume-weighted mean diameter and 25% for rime fraction (for a -10 dBZ echo).

VERTICAL VELOCITY DERIVED FROM AIRBORNE DOPPLER RADAR MEASUREMENTS DURING IMPACTS

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The Investigation of Microphysics and Precipitation for Atlantic Coast-Threatening Snowstorms (IMPACTS) is a 5-year NASA funded program to study Northeastern U.S. snowstorms with field campaigns during the winters of 2020, 2022, and 2023 (McMurdie et al., BAMS, 2022). IMPACTS observations are focused on the understanding of the microphysical characteristics and processes associated with the snowbands. The aircraft component included the high-altitude ER-2 (~20 km) instrumented with 3 radars (HIWRAP Ku/Ka-band, CRS W-band, EXRAD X-band) and other remote sensing instruments, and the lower altitude P-3 for in situ microphysics measurements, dropsondes, and flight level measurements. We now have two seasons of IMPACTS observations with ER-2 Doppler measurements. Vertical velocities are inherently difficult to estimate in winter storms both from direct in situ measurements and from Doppler because of their small magnitudes. Errors in vertical motion are challenging from nadir measurements because of both Doppler velocity uncertainties in addition to the need to remove particle fallspeed contributions. For the non-stabilized radar beams on the ER-2, additional errors arise in the Doppler measurements from non-uniform beam filling due to aircraft motion, and from horizontal winds when the beams are not precisely at nadir. These Doppler errors will be discussed as well as first order corrections of them. Corrections for fallspeeds as well as other adjustments to the data including an optimization scheme for assuring mass continuity in the precipitation column are described. Examples will be presented from a few of the IMPACTS flights with emphasis on elevated convection. These derived vertical air velocities will be compared with vertical air motions from the P-3 aircraft.

GRAWAC: G-BAND RADAR FOR WATER VAPOR PROFILING AND ARCTIC CLOUDS

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Arctic mixed-phase clouds play a key role in the warming Arctic climate system. Cloud life time and microphysical properties are strongly coupled to moisture availability and its vertical distribution. Yet, a continuous quantification of this interplay remains challenging with current remote sensing measurement techniques. Accurate measurements are needed to both advance process understanding and to improve the representation of mixed-phase clouds and their moisture environment in weather and climate models. The novel G-band radar system GRaWAC contributes to closing this observational gap by simultaneously profiling clouds and water vapor. GRaWAC is designed as a Doppler-capable, two-antenna FMCW dual-frequency system transmitting and receiving simultaneously between 167 and 175 GHz. Based on the dual-frequency measurements, the Differential Absorption Radar technique can be applied to retrieve water vapor profiles in cloudy conditions. High frequencies paired with a high sensitivity of -40dBZ at 1km and 1s resolution will increase the sensitivity to small hydrometeors compared to W-band radars; and will allow profiling throughout the boundary layer in case of airborne deployment. In order to study GRaWAC's potential for a ground-based and airborne deployment in the Arctic around Svalbard, we use synthetic measurements generated by the radiative transfer model PAMTRA based on ICON-LEM simulations from recent Arctic airborne field campaigns. We investigate the expected reflectivity and Doppler velocity signals, analyze sensitivities to water vapor conditions, and outline the added value of GRaWAC when deployed in synergy with Ka- and W-band radars as well as passive microwave radiometry between 22 – 340GHz.

GPM DPR HYDROMETEOR CLASSIFICATION MODULE

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A vertical description of the profiles of precipitation is a long-term goal of atmospheric research and precipitation science (Skofronick-Jackson et al. 2017). As the next step of the dual-frequency classification module in GPM DPR, we have developed a vertical profile of hydrometeors, adding the third dimension to the dual-frequency classification module. Although GPM DPR has fine vertical resolutions in dual-frequency observations, most of the algorithms or products developed are 2 dimensional with either a "flag" or "type" (or etc.) on a 2-dimentional surface. By extending this to vertical dimension, a vertical profile of hydrometeor type will be available for DPR resolution in full swath if precipitation is present. In the initial phase, five hydrometeor types will be introduced. They are dry snow/ice crystal (DS/ICE) wet snow (WS), graupel (GPL), hail (Hail) and rain (Rain). These products include precipitation type, melting layer top, melting layer bottom, melting layer quality, hail flag, surface snowfall flag and graupel hail flag. Different hydrometeor portfolios are made for stratiform and convective rain types. Mixed phase hydrometeors are judged with melting layer top and bottom information together with the 0° isotherm. Flag of surface snowfall is used to identify snow only profile, while flags for detecting graupel and hail help identify range bins with those hydrometeors.

HAIL AND SEVERE CONVECTION

SUPERCELLS VS. HAILSTORMS AND RAINSTORMS – A RADAR-BASED COMPARISON OF SEVERE THUNDER-STORMS IN THE ALPINE REGION

T- AND M-DATING – DETECTION AND TRACKING OF THUNDERSTORMS AND MESOCYCLONES

AN ARGUABLE INFLUENCE OF TERRAIN ON INTENSITY OF SUPERCELLS BASED ON TWO-DIMENSIONAL RADAR REFLECTIVITY DATA

RELATIONSHIPS BETWEEN CHANGES IN TORNADO WIND FIELD AND TORNADIC DEBRIS SIGNATURE STRUCTURE WITH VARIATIONS IN TERRAIN AND LAND COVER

DUAL-WAVELENGTH POLARIMETRIC ANALYSIS OF A SEVERE HAILSTORM IN VIENNA, AUSTRIA

POLARIMETRIC SCATTERING COEFFICIENT LIBRARY OF ROUGH HAILSTONES OBTAINED WITH A COMMERCIAL ELECTROMAGNETIC SOLVER

RAPID-SCAN, POLARIMETRIC DOPPLER-RADAR OBSERVATIONS OF THE LIFE CYCLE OF AN ANTICYCLONIC TORNADO IN A CYCLONICALLY-ROTATING SUPERCELL

DRONE-BASED HAIL SIZE ESTIMATION WITHIN A HAIL SWATH OF A LARGE SUPERCELL IN SWITZERLAND

OBSERVATION SYSTEM SIMULATION EXPERIMENTS FOR MICROBURST DEMONSTRATION TEST USING WISSDOM-AIR

THE SUMMER 2021 SWITZERLAND HAILSTORMS: NEW CLIMATOLOGICAL EXTREMES

A NOVEL MULTI-SENSOR TECHNIQUE FOR THE OPTIMAL DETECTION OF HAILSTORMS

RADAR DEPLOYMENTS IN THE PERILS (PROPAGATION, EVOLUTION AND ROTATION IN LINEAR STORMS) SOUTHEASTERN TORNADO STUDY

FINE-SCALE DOW RADAR OBSERVATIONS OF HURRICANE BOUNDARY LAYERS

SEVERE CONVECTIVE STORMS ANALYSED BY COMBINED MEASUREMENTS OF KA-BAND CLOUD PROFILER AND X-BAND WEATHER RADAR

A HAIL BEARING SUPERCELL RADAR ANALYSIS IN THE MEDITERRANEAN BASIN

PRELIMINARY RESULTS FROM THE PRECIP 2022 FIELD CAMPAIGN

AUSTRALIA'S NEW OPERATIONAL HAIL ANALYSIS SYSTEM: HAILCORE

AUTOMATIC HAIL REPORTING IN METAR MESSAGES FOR AIRCRAFT SAFETY

ZDR-COLUMN DETECTION AND THE VERTICAL STRUCTURE OF POLARIMETRIC VARIABLES IN RELATION TO HAIL PROBABILITY AND SIZE IN SWITZERLAND

CITIZEN WEATHER REPORTS AT RMIB AND THEIR USE FOR RADAR-BASED HAIL DETECTION VERIFICATION

FORECASTING THE WEATHER TO ASSIST ATC AND ATM OPERATIONS

RADAR CHARACTERISTICS OF DERECHO PRODUCING MESOSCALE CONVECTIVE SYSTEMS IN THE CZECH REPUBLIC

TWO PARADIGMS FOR RADAR-BASED HAIL-SIZE ESTIMA-TION: PROBLEMS AND POSSIBILITIES

OFF-SHORE AND IN-LAND HAIL DETECTION THROUGH RADAR AND SATELLITE

EXPLORING TORNADO DEBRIS SIGNATURE HYPOTHESES USING RADAR SIMULATIONS AND LARGE-EDDY SIMULA-TIONS

SPACE-TIME VARIATION OF LARGE HAIL-PRODUCING MESOSCALE CONVECTIVE SYSTEMS OVER A COMPLEX TERRAIN OF THE INDIAN SUBCONTINENT AS REVEALED BY THE INTEGRATED TRMM AND GPM OBSERVATIONS

SUPERCELLS VS. HAILSTORMS AND RAINSTORMS – A RADAR-BASED COMPARISON OF SEVERE THUNDERSTORMS IN THE ALPINE REGION

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With six years of radar-based thunderstorm track data, we establish a thunderstorm catalogue of ordinary thunderstorms, intense or severe rain storms, hail or severe hail storms and supercells. Particularly supercells show a large overlap with the other hazardous categories, as they frequently bring multiple severe weather hazards with them. Subsequently we examine the intensity lifecycles of the storm types. This analysis allows us to identify predictors of intensification within severe storm life cycles. One such predictor is the formation of a mesocyclone in a supercell thunderstorm, which is usually followed by an intensification of the storm and the occurrence of hail. We then subdivide the radar area into regions of varying topographical complexity, ranging from the Po Valley, the Southern Pre-Alps, the main Alpine ridge, the Northern Pre-Alps, and the Swiss Plateau to the Jura. An examination of the intensity distribution of the storms in the individual regions shows a clear decrease in intensity over the main Alpine ridge, intermediate values over the moderately complex Pre-Alps and peak values for the flat Po Valley and the Swiss Plateau. In contrast, the peak in convective activity for all thunderstorm classes lies over the Prealpine areas, particularly in the South. These analyses compare multiple categories of hazardous thunderstorms and examine the impact of increasingly complex terrain on different types of strong convection from an observational perspective.

T- AND M-DATING – DETECTION AND TRACKING OF THUNDERSTORMS AND MESOCYCLONES

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The thunderstorm-tracking algorithm T-DATING is a python-based open-source algorithm integrated in the pysteps package. Utilizing a multi-threshold object detection technique, advection with optical flow and tracking via object overlap, it provides detection and tracking of thunderstorms similar to the operational thunderstorm radar tracking algorithm TRT at MeteoSwiss. Within the contours of identified thunderstorms, the mesocyclone detection algorithm, that detects the rotating updraft of supercell thunderstorms, is employed. Utilizing the Doppler velocity data of all available radars, the azimuthal derivative computed, which corresponds to the vertical component of rotation. The detection of cyclonic and anticyclonic anomalies allows building a vertically consistent rotation object. To meet the definition of a supercellular mesocyclone, range-dependent vorticity, rotational velocity and vertical extent criteria need to be met and maintained for several consecutive timesteps. Both algorithms together allow for a systematic detection of supercell thunderstorms. With supercells representing particularly severe thunderstorms, this monitoring is beneficial for forecasters that issue real-time thunderstorm warnings. In addition, analysis of past cases and the creation of a supercell archive can help understanding the spatio-temporal distribution of supercells.

AN ARGUABLE INFLUENCE OF TERRAIN ON INTENSITY OF SUPERCELLS BASED ON TWO-DIMENSIONAL RADAR REFLECTIVITY DATA

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The understanding of potential effects of terrain on spatiotemporal behavior of supercells and their inner dynamics remained rather limited until radar-based observational techniques have advanced. Still, the evolution of supercell environments, subsequent pre-storm processes, and supercells themselves, have been predominantly studied via numerical experiments. Those have delivered somewhat ambiguous results how supercells may react to terrain-related environmental inhomogeneities in actual conditions. The presented work aims to uncover this nebulous topic through the first real-world application of its kind. Due to severe weather reports and follow-up remote investigation, the occurrence and intensity of supercells over the Western Carpathians in Central Europe is examined. The intensity of the storms is statistically quantified by the distribution of hydrometeors within the proximity (5, 10, 15-km radius) of detected mesocyclones in 5-min radar scans. Two-dimensional reflectivity composite imagery of CAPPI at 2–6 km MSL and CMAX are employed, compared with each other, and finally assigned to underlying morphometric attributes, even with a time shift up to 30 min. The poster highlights several interesting findings of supercells' characteristics over complex terrain. Although the intensity does not generally indicate a significant response to the terrain asymmetry, there are other aspects of storms' activity that are clearly affected. The storms are also categorized into three groups by their propagation speed and the results show that they can behave differently according to their motion (velocity). Supercells are certainly a violent consequence of unstable atmosphere and because of associated hazards should be studied world-wide in as many cases as possible.

RELATIONSHIPS BETWEEN CHANGES IN TORNADO WIND FIELD AND TORNADIC DEBRIS SIGNATURE STRUCTURE WITH VARIATIONS IN TERRAIN AND LAND COVER

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There is an increasing body of knowledge that terrain and perhaps even changes in surface roughness affect tornado structure and intensity. In this study, rapid-scan, polarimetric, Doppler radar (RaXPol, University of Oklahoma) observations of 10 tornadic supercells that occurred in the Central Plains states of the U.S. are used to investigate the role that such changes in the underlying physical ground have on tornadoes of varying intensity. Specifically, the temporal evolution of the vortex structure as evident through Doppler velocities (e.g. single vs multiple vortices at varying heights/elevation angles) and the structure and distribution of tornadic debris around the vortex as manifest by the tornadic debris signature (TDS) in the correlation coefficient field will be analyzed. The radar observations are put into context with the underlying ground characteristics by overlaying the tornadic vortex signature location on top of digital elevation model data and the United States national land cover database to determine if correlations can be extracted relating qualitative and quantitative changes to the tornado with variations in the underlying elevation or surface roughness characteristics. The physical changes in the tornado's velocity and TDS structure will then be compared statistically to changes in intensity, quantified by the maximum velocity differential across the tornadic couplet as well as pseudo vorticity in order to relate the changes in structure to changes in intensity.

DUAL-WAVELENGTH POLARIMETRIC ANALYSIS OF A SEVERE HAILSTORM IN VIENNA, AUSTRIA

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Large hail has a significant damage potential in Austria, where the northern and eastern parts of the country are among Europe's most active hail regions. While overall progress in our observational and forecasting capabilities has been made during recent years, there is still need for adequate short-term forecasting and warning techniques, requiring a more detailed process understanding of hail formation and thunderstorm microphysics. With the introduction of dual-polarized weather radars and increasing spatial and temporal resolutions of these systems in recent years, different polarimetric features have been linked to hail development in various studies, most of them based on observational data from North America. Since 2020, the University of Natural Resources and Life Sciences in Vienna operates a dual-pol X-band weather radar. Providing a radial resolution of 50 m and an update time of 1 minute for volumetric scans with up to 8 elevation angles, it allows detailed insights into storm characteristics. This data is supplemented by a nearby dual-pol C-band radar of Austro Control. Based on the differing scattering properties at C- and X-band, additional information about hail size can be inferred, and the three-dimensional wind field can be retrieved by a dual-Doppler analysis. We present these detailed data in a mesoscale study of a severe hailstorm over Vienna on 26 June 2020, producing hailstones of up to 4 cm diameter. Our analysis shows that the hail was preceded by an intense ZDR column development and other distinct polarimetric features. Multiple pulses of hail could be observed by both radars. In addition, the dual-Doppler retrieval highlights the updraft intensification and hydrometeor trajectories within the thunderstorm cell.

POLARIMETRIC SCATTERING COEFFICIENT LIBRARY OF ROUGH HAILSTONES OBTAINED WITH A COMMERCIAL ELECTROMAGNETIC SOLVER

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Traditionally, polarimetric variables from hail were calculated using spheroidal scattering models, forward operators and the “backscattering rule”. The “backscattering rule” is violated if hydrometeors are canted by more than >10o. At such large canting angles the forward operator fails to replicate low correlation coefficient often associated with giant hail. Recently advances into modeling of realistic hailstone shapes were made. These typically use some available Computational Electromagnetic (CEM) codes and 3D scanned models of hailstones observed in nature. Yet due to limitations in model sizes and shapes only limited number of particular hailstones were used in previous studies. Herein we present a library of polarimetric scattering coefficients obtained from a spheroidal hail models with surface roughness. We consider a range of hail sizes typically observed on the ground with various axis ratios reported in literature and ground observations. Furthermore, we model various levels of surface roughness and define it using percentage of hailstones equatorial diameter. This enables us to mathematically quantify hailstones’ roughness and create two different surface roughness distributions. We present implication form this study to operational applications.

RAPID-SCAN, POLARIMETRIC DOPPLER-RADAR OBSERVATIONS OF THE LIFE CYCLE OF AN ANTICYCLONIC TORNADO IN A CYCLONICALLY-ROTATING SUPERCELL

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A mobile, rapid-scan, X-band, polarimetric, Doppler radar (RaXPol) from the Advanced Radar Research Center (ARRC) at the University of Oklahoma (OU), Norman, collected volume scans in a cyclonically-rotating supercell that produced several tornadoes in northwest Kansas, on 24 May 2021. The temporal resolution was high enough to resolve the evolution of the vortex intensity as a function of height, in the lower and mid-levels of the troposphere. The time period of data collection covered the entire life cycle of a major cyclonic tornado and also, unexpectedly, of a weak anticyclonic tornado that formed near the southern end of the rear-flank gust front that curved back into the cyclonic tornado. The anticyclonic tornado passed directly over the radar while it was collecting data, continuing until the vortex moved away and weakened. In addition, extensive video and photographic documentation was obtained. This presentation will focus on the anticyclonic tornado, owing to its rarity. The anticyclonic tornado was marked by a well-defined anticyclonic Doppler shear signature and a debris signature characterized by low co-polar cross-correlation coefficient. Since the vortex passed directly over the radar, this dataset is a unique opportunity to examine the fine-scale wind structure near the surface. The nature of the wind field in a tornado near the ground is of great scientific importance. An estimate the sizes, orientations, and density of debris from a close-up photograph of airborne vegetation at the radar site while the vortex passed by will be compared with the polarimetric radar data.

DRONE-BASED HAIL SIZE ESTIMATION WITHIN A HAIL SWATH OF A LARGE SUPERCELL IN SWITZERLAND

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Hail is a major threat connected to thunderstorms and an estimation of the hail size is important to issue warnings for the public. Radar products exists that estimate the size of the expected hail. For the verification of such products, ground based observations are necessary. Automatic hail sensors can provide information about the hail size observed on the ground but due to the small size of these sensors (0.2 m^2) estimation of the hail size distribution can have large uncertainties. To overcome this issue we analyze aerial drone footage using a machine-learning based technique to detect hail stones on the ground and to estimate the size distribution and provide comparisons with nearby automatic hail sensors. A large right moving supercell crossed the midlands of Switzerland from south west in the afternoon of 20th June 2021. The hail swath of the supercell was intercepted near Entlebuch and aerial images of the hail on the ground were taken by a drone. The drone was equipped with a 50 megapixels full frame camera. The average ground sampling distance (GSD) was 1.5 mm per pixel, which is set by the mounted camera objective with a focal length of 35 mm and a flight altitude of 12 m above ground. A 2D orthomosaic model of the survey area is created based on 116 captured images during the drone mapping flight. The total covered area in this case is 850 m^2 and it is used to detect hail by applying a Convolutional Neural Network (Mask R-CNN) model. First, we characterize the hail sizes based on the individual hail segmentation masks resulting from the CNN model detection. From this dataset, we compute the distribution and compare it with nearby automatic hail sensors and weather radar based hail products like MESHS (Maximum Expected Severe Hail Size).

OBSERVATION SYSTEM SIMULATION EXPERIMENTS FOR MICROBURST DEMONSTRATION TEST USING WISSDOM-AIR

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Local severe weather phenomena such as a gust front, wind shear, and microburst near the airport threaten to aviation operations. The airport wind information system in high spatiotemporal resolution is necessary for early monitoring of the hazardous weather phenomena. We proposed a fine-scale wind information system(WISSDOM-AiR) for aviation meteorological service based on WISSDOM. The WISSDOM-AiR provides 3-D wind vectors(u, v, w), vorticity, and divergence with a horizontal resolution of 0.2 km and vertical resolution varying from 0.02 to 0.5km over the domain of 50kmx50km. In this study, we conducted a reliability demonstration test of a microburst(or wind shear) of WISSDOM-AiR using the Observing System Simulation Experiment(OSSE) based on simulated ideal microburst by WRF model. The wind field of the simulated microburst was converted to the radial velocity of four weather radars as an input data of the OSSE test. We evaluated the reliability of the microburst demonstration of WISSDOM-AiR by comparing the horizontal and vertical wind speed, the location, and the size of the microburst of WISSDOM-AiR and WRF model. While overall pattern(wind direction, the position of a microburst, and its size) of the wind field from WISSDOM-AiR showed good agreement with the simulated wind fields, its wind speeds underestimated by 45% and 35% in vertical and horizontal, respectively. We concluded that the WISSDOM-AiR could be useful for the early monitoring of small-scale hazardous weather phenomena such as microbursts. This study can lead to enhance our ability to support the aviation meteorological service.

THE SUMMER 2021 SWITZERLAND HAILSTORMS: NEW CLIMATOLOGICAL EXTREMES

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From June 18 to July 31, 2021, a series of exceptional hailstorms occurred over Switzerland, causing major damages to buildings, cars, and crops. Available estimates from insurance companies suggest that these events were among the most expensive of the last decades. The recently released radar-based Swiss hail climatology (www.hailclimatology.ch) allows us to assess the 2021 summer hail events in a historical context. It is based on the two radar-based operational hail products probability of hail (POH) and maximum expected severe hailstone size (MESHS). We found that the events of 2021 were extreme both in terms of hail stone size return periods and in their spatial extent. We observed that the hail season 2021 recorded 15 days MESHS>=4cm, which clearly exceeds the expected annual number of hail days with MESHS>=4cm of 10.95 days (+/- 4.0). On June 28, Switzerland recorded its second-largest hail-affected area (POH>80%), and the largest areas ever recorded for severe (MESHS>=4cm) and extreme hail (MESHS>=6cm). Besides the historical records, an environmentally constrained stochastic resampling approach with 3000 synthetic hail years is used to assess local return periods of MESHS. The daily maximum MESHS values reached 9.2cm on June 28, corresponding to local return periods exceeding 50-100 years. Aware of the limitations of POH and MESHS, we used data of 80 automatic hail sensors, crowdsourcing hail reports and dual-polarisation hydrometeor identification to verify them. The 2021 events demonstrate the possibilities of the radar-based hail climatology for both scientific questions and practical applications.

A NOVEL MULTI-SENSOR TECHNIQUE FOR THE OPTIMAL DETECTION OF HAILSTORMS

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The Multi-sensor Approach for Satellite Hail Advection (MASHA) is a new satellite hybrid technique conceived for the real-time detection and advection of hail clouds. MASHA is based on a machine-learning algorithm to identify hail clouds and predict the evolution of hail-bearing systems. Operationally, MASHA combines the strengths of the MWCC-H method to detect hail through the whole GPM constellation (Laviola et al., 2020a-b) with the high temporal rate of the Meteosat Rapid Scan Service (MSG-RSS). Thus, the quasi-real-time additional use of the lightning mapping array strongly improves the capability of detection and tracking of the original computational scheme. Recent experiments have also demonstrated the potential of the MASHA scheme when supported by radar indices for identifying hail clouds: the Probability Of Hail (Waldvogel, 1979) and VIL density (Amburn S. A. and P.L. Wolf, 1997) provide key information to optimally detect and advect hail clouds. The latter prototype version of the MASHA technique will be used during an experimental campaign aimed to reconstruct the hail events in the Emilia-Romagna region during 2022. During the experimentation, hail events will be simultaneously observed from satellite and ground radar and the observations are combined in order to produce an optimal and robust hail map. Our outcomes will be the first proxy of next future applications where ground radar composite will be combined with the EUMETSAT new-generation satellite missions Meteosat Third Generation (FCI+LI) and EPS-SG (MWS, MWI).

RADAR DEPLOYMENTS IN THE PERILS (PROPAGATION, EVOLUTION AND ROTATION IN LINEAR STORMS) SOUTHEASTERN TORNADO STUDY

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Quasi-linear convective systems (QLCSs) cause about 1/4 of tornado events in the U.S. The majority of QLCS tornadoes occur in the Southeastern U.S. and the percentage of tornadoes associated with QLCSs is higher in this region than in the remainder of the U.S. Common forecast skill metrics (such as warning lead time and false alarm rate) are significantly worse in QLCS tornado events than in supercell tornado events. This is due, in part, to our lack of understanding regarding QLCS tornadogenesis processes and is compounded by short temporal and small spatial scales for QLCS tornadogenesis, which are not often captured by the conventional operational radar network. Coarse data and forecast analyses suggest a large area along a QLCS may be favorable for tornadogenesis, but tornadoes tend to occur within a small fraction of that area. Field campaigns have focused on collecting data to better understand supercell tornadogenesis, but no campaigns have focused specifically on QLCS tornadogenesis. PERiLS (Propagation, Evolution, and Rotation in Linear Storms) is the first such project, combining a dense, adaptable X- and C-band research radar array, including substantial instrumentation from the Flexible Array of Radars and Mesonets (FARM) including the new quickly-assembled C-band On Wheels (COW), two Doppler On Wheels (DOW) a multitude of quickly-deployable surface instruments (PODNET), the UI deployable wind profiler, Mobile Mesonets, and several upper air sounding systems, to provide the sampling necessary to address environmental factors and storm processes that lead to QLCS tornadogenesis. We will discuss the Spring 2022 PERiLS project and present preliminary results.

FINE-SCALE DOW RADAR OBSERVATIONS OF HURRICANE BOUNDARY LAYERS

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In order to characterize the hurricane boundary layer structures over a range of hurricane intensities, the Doppler on Wheels radars (DOWs) deployed in several hurricanes during the 2020 season, obtaining both dual-Doppler and rapid single-Doppler observations in the boundary layer of landfalling hurricanes. Results will be presented from three hurricanes: Hurricane Laura, Hurricane Sally, and Hurricane Delta. These results will be discussed in the context of standard hurricane wind models. Two DOWs targeted landfalling Category 4 Hurricane Laura. The DOWs deployed in southwestern Louisiana during landfall. As is usual, the DOW radars uniquely operated in the most intense wind regions of the hurricane, collecting the only fine-scale, near-surface data in the eyewall near landfall. The dual-DOW baseline was ~6.3 km, providing ~60 m spatial resolution in the center of the dual-Doppler lobes. Anemometer data at 1 Hz were collected from DOW masts ~8-10 m above radar level (ARL). Laura is the 1st ever fine-scale dual-Doppler deployment sampling the HBL and eyewall in a Category 4 hurricane at landfall. Single-Doppler radar data were collected in Hurricanes Sally and Delta. This allowed for the two-dimensional quantification rapidly evolving of boundary layer structures. An array of surface based instruments, including a prototype, “POLENET”, which attaches existing infrastructure, allowing for a customizable observation level, were deployed in Hurricane Delta in order to correlate observations at radar level with surface observations. Using corrections based on turbulence statistics and roughness lengths, a reduction factor was derived for the radar winds, allowing for comparison between radar level winds and winds observed at 1, 2, and 10 m.

SEVERE CONVECTIVE STORMS ANALYSED BY COMBINED MEASUREMENTS OF KA-BAND CLOUD PROFILER AND X-BAND WEATHER RADAR

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Ka-band Doppler polarimetric cloud profiler METEK 35 (35 GHz) and X-band Doppler polarimetric radar FURUNO are installed at the Milešovka meteorological observatory which is situated in the northern part of Czechia at the top of the Milešovka mountain at 834 m a.s.l. Both radars have been measuring simultaneously since 2021. Research activities at the Milešovka observatory are focused on studying clouds and storms which pass across or close to the station and are associated with electrical discharges. The research is also enriched by data of ceilometer, distrometer and standard meteorological instruments placed at the station. At the conference, we will present results that we obtained for two storms registered in 2021 and also for storms which are likely to occur this summer.

A HAIL BEARING SUPERCELL RADAR ANALYSIS IN THE MEDITERRANEAN BASIN

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In recent years, the Mediterranean area has been affected by a continuous and significant increase in the intensity of violent weather events resulting in floods, hailstorms and tornadoes and an increasing impact on human activities, infrastructure and agricultural production. Among these extreme events, a particularly intense phenomenon occurred on July 10, 2019 affecting much of the central Adriatic coast. In particular, the Pescara area was affected by a supercell that produced heavy rainfall and an exceptional hailstorm, with hailstones even larger than 10 cm in diameter, causing extensive damage. This contribution documents the dynamics, morphology and main characteristics of the Pescara supercell which was simultaneously observed, for the first time in Italy, by two C-band meteorological radars of the national Department of Civil Protection (DPC). The results obtained highlight the irreplaceable role of dual-polarization Doppler weather radars in monitoring the evolution of hail, identifying the mesocyclone initiation and the related updraft and downdraft zones as well as their vertical extension, and highlighting the current limitations in determining the size of hail particles from radar measurements. Numerical simulations with the WRF model, using the HAILCAST module to simulate the evolution of hail, were carried out in order to evaluate the capabilities of an operational model in the simulation of such a particular event. In the context of the intensification of extreme events, this work is also a food for thought on the main aspects to be addressed in the near future to improve the chain of alerting and modelling of extreme events for prevention and civil protection.

PRELIMINARY RESULTS FROM THE PRECIP 2022 FIELD CAMPAIGN

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Extreme rainfall is a high impact weather phenomenon that profoundly affects people around the world, but our fundamental understanding and quantitative forecast skill for these events remains limited. To address these important scientific and forecast challenges, the Prediction of Rainfall Extremes Campaign In the Pacific (PRECIP) was funded by the U.S. National Science Foundation to make observations of the East Asian monsoon to improve our understanding of the multi-scale dynamic, thermodynamic, and microphysical processes that produce extreme precipitation. The campaign is designed to maximize the chances of observing a variety of heavy rainfall events in the moisture-rich natural laboratory of the western North Pacific in order to find the commonalities across different weather phenomena. Due to the global pandemic, PRECIP was delayed and will now be conducted in spring/summer 2022 in partnership with scientists in Taiwan, Japan, and Korea. The campaign will collect observations with the Colorado State University SEA-POL radar, radiosondes, disdrometers, and the National Center for Atmospheric Research S-PolKa radar and MicroPulse DIAL. Preliminary results from PRECIP 2022 will be presented, highlighting new radar observations that will improve our understanding of heavy rainfall.

AUSTRALIA'S NEW OPERATIONAL HAIL ANALYSIS SYSTEM: HAILCORE

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Hail has a significant impact on the Australian community and economy, with insured losses over the last fifty years greater than those from bush-fire and flood events. For capital city regions, the Bureau of Meteorology provides cell-based warnings to mitigate the impact of hailstorms. These warnings incorporate an estimate of hail size using information from weather radar and basic nowcasting using cell tracking algorithms. The conventional hail size estimate (MESH) is a reflectivity-based retrievals that has changed little in the past twenty years. The recent expansion of the polarimetric radar network in Australia and new real-time monitoring of the absolute reflectivity calibration provides exciting new opportunities to increase the robustness of conventional retrievals and utilitse modern polarimetric information. This talk will introduce these new capabilities as part of the HailCORE system. This includes: (1) the impact of reflectivity calibration on conventional hail size estimates for hardware-diverse radar networks (2) challenges of transitioning to polarimetric-based hail size estimates (3) Validation of retrievals. Commercial applications for products generated by HailCORE will also be demonstrated through a collaboration with PERILS AG.

AUTOMATIC HAIL REPORTING IN METAR MESSAGES FOR AIRCRAFT SAFETY

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The reporting of hail at aerodromes is an important task for aircraft safety. Hail can damage aeroplanes and severely impact the operation of airports. At Swiss International Airports, hail reports for METAR messages are produced manually by certified aeronautical observers during the airport operational hours (05:50-23:20 LT). Currently, MeteoSwiss is working on the complete automation of METAR messages (AutoMETAR) within the AMAROC (AutoMETAR / AutoReport rOund the Clock) program, starting with Geneva airport. Part of this program is the development of an automatic hail detection algorithm for operational use. Here we present the resulting algorithm and its performance, which is verified against crowd-sourcing reports collected with the MeteoSwiss smartphone App. The algorithm consists of a decision tree that takes advantage of several operational hail products (Probability of Hail, Maximum Expected Severe Hail Size and a hydrometeor classification product) derived from measurements of the dual polarization Swiss C-band radar network in combination with hail sensors. In order to fulfill operational needs, the algorithm was tuned to offer the highest possible probability of detection for hail while keeping the number of false alarms low. The algorithm is currently being implemented for operational use.

ZDR-COLUMN DETECTION AND THE VERTICAL STRUCTURE OF POLARIMETRIC VARIABLES IN RELATION TO HAIL PROBABILITY AND SIZE IN SWITZERLAND

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The northern and southern boundaries of the Alps are two regions where convective storms are particularly frequent in Europe. Consequently, storm-related damages, especially the impacts of hail, are of particular concern in Switzerland. Here we investigate the vertical structure of polarimetric radar variables in relation to hail with a special focus on differential reflectivity columns (ZDR-columns). ZDR-columns have been shown to occur in thunderstorm updraft regions and to provide information about storm evolution and updraft intensity. They further have the potential to improve the nowcasting of hail size and hail mass. Despite this potential, ZDR-Columns have yet to be investigated in the complex topography of Switzerland. In this work, data from the Swiss C-band Doppler radar network is used to detect the vertical structure of polarimetric variables and to describe their characteristics in storms of the convective season of 2021. The evaluation of radar data in the alpine region provides challenges regarding visibility and data quality. Effects such as ground clutter and the shielding of the radar beam by mountains need to be considered. The Swiss radar network offers a wealth of data due to its 5 radars of which two are located at an altitude of 3000 m with good visibility in the Alps. In a first step, established ZDR-column detection algorithms designed for S-band radars are tested and adapted for the Swiss C-band radar Network. Afterwards, ZDR-columns in combination with further polarimetric signatures are investigated in regards to their correlation to hail probability and size at the ground using crowdsourced hail reports from the MeteoSwiss Smartphone App.

CITIZEN WEATHER REPORTS AT RMIB AND THEIR USE FOR RADAR-BASED HAIL DETECTION VERIFICATION

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The detection and prediction of very local weather effects, like wind gusts, fog or hail storms, remains a challenging issue in meteorology. Moreover, the verification of the forecasts of these phenomena is hampered by the lack of ground truth data: in many cases only fragmentary information is available, e.g., through a climatological network or through (social or conventional) media. In particular, there is a lack of ground observations of precipitation type and related quantities like hailstone dimensions and snow depth. A promising approach to obtain in-situ meteorological information is the collection of citizen weather reports through smartphones. In August 2019, the Royal Meteorological Institute of Belgium (RMIB) added such a reporting feature in its smartphone app. Currently the database of citizen reports holds more than two million records. In this contribution, we describe the general concept of the app feature and how the quality control is organised. Then, we give some general statistics of the aggregated dataset. The collected data have already been exploited in several use cases at RMIB, such as the verification of the official warnings for severe weather and the forecasts on communal level. Here, we focus on the use of rain and hail reports for evaluating the performance of a radar-based hail detection product. Comparisons between radar-derived information and hail reports allow estimating the probability of detection, while rain reports can be used to obtain a rough estimate of the probability of false detection. Additionally, precipitation type related reports are currently also exploited in the development and validation of a new hydrometeor classification scheme based on dual-pol data. Some preliminary results of this work will be shown too.

FORECASTING THE WEATHER TO ASSIST ATC AND ATM OPERATIONS

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In EUROCONTROLS's recent summary report on Climate Changes Risks for European Aviation, several weather-related impacts were highlighted. There is a strong relation between highly impacting weather events and disruptions to the aviation network resulting in additional fuel consumption and CO_2 emissions. In Europe, severe weather is responsible for up to 7.5% of the total en-route delays. In this respect, the H2020 Satellite-borne and IN-situ Observations to Predict The Initiation of Convection for ATM (SINOPTICA) project aims to demonstrate that very high-resolution and very short-range numerical weather forecasts, benefiting from the assimilation of radar data, in-situ weather stations, GNSS and lightning data, can improve the prediction of extreme weather events to the benefit of Air Traffic Management (ATM) and Air Traffic Control (ATC) operations. The assimilation of radar, GNSS, and lightning data shows a positive impact on the forecast of the convective cells for the four selected severe weather events. Moreover, two radar-based nowcasting strategies, PhaSt and RaNDeVIL, are tested to predict storm structures. Both methods are able to follow the more intense cells (VIL > 10 kg/m2) in all the case studies, as shown by the MODE results and the eye-ball verification The forecasts are used in an arrival management system (AMAN) to compute 4D trajectories around convective areas, integrate the affected aircraft into the arrival sequence, and assist air traffic controllers in implementing the approaches through just in time advisories and dynamic weather displays. With the help of real traffic scenarios and different weather models, diverse approach planning strategies are evaluated.

RADAR CHARACTERISTICS OF DERECHO PRODUCING MESOSCALE CONVECTIVE SYSTEMS IN THE CZECH REPUBLIC

David Rýva[1]

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The Czech weather radar network (CZRAD) consists of two radar sites, both the sites have been dual-pol C-band radars since 2015. This fact allows us to use polarimetric radar measurements for many purposes, including a better correction for attenuation which can provide us better data of precipitation estimations, better erasing of ground clutters and WLAN interference. Use of polarimetric data also allows us to identificate of updrafts of convective storm cells based on detection of so called ZDR-columns. This study uses radar data, including polarimetric and Doppler ones, to focus on derecho producing convective systems (MCS) and their behaviour from the view of the radars. Our research focuses on organization of MCS's and behaviour of their updrafts based on ZDR-columns detection algorithm. We also study rear inflow jet presence and variations of lightning activity. We have used data from warm season derecho cases since year 2000 for general part of the study and data since 2015 for the most detailed analyses with the use of polarimetric data. We studied the ability of data from ZDR-column detection (its area, vertical development, integrated spatial volume and also their temporal variations) to predict intensity changes of the convective system and its accompanied phenomena for the next tens of minutes. We also tried to find weak points of this type of product and possible ways how to reduce them as much as possible.

TWO PARADIGMS FOR RADAR-BASED HAIL-SIZE ESTIMATION: PROBLEMS AND POSSIBILITIES

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There is an essential need for remote sensing in determining the location of damaging hailfall and in characterizing the degree of the hail threat. Radar provides the best tool for mapping hail-bearing storms, which is useful for operational warnings and nowcasting, as well as post-storm hail swath analyses. Despite this critical need, however, radar-based hail size estimation has been a long-standing challenge. Traditionally, there have been two main paradigms for radar-based hail size estimation: (1) direct size estimation from hailstones' backscattering properties, and (2) indirect estimation based on storm structural features and/or proxies for storm strength. In this presentation, we will review the traditional approaches to radar-based hail-size estimation, as well as the limitations of these approaches informed by recent hail research. As an example of the first paradigm, algorithms based on hailstone backscattering properties often employ simplified assumptions about hailstone shapes (e.g., spheres, spheroids). We will show results from state-of-the-art, three-dimensional hailstone scanning that now allows for direct calculation of the hailstones' electromagnetic scattering properties, and how these differ from simpler shape assumptions. As an example of the second paradigm, there is widespread use of vertically integrated reflectivity metrics (e.g., MESH and MESHS) to estimate hail size, which implicitly assumes that taller, stronger storms produce larger hail. We will show recent hailstorm simulations that demonstrate this assumption is flawed, and how these metrics are uncorrelated to simulated hail production. Finally, possible avenues to improved radar-based hail-size estimation for both paradigms will be presented, informed by recent research results.

OFF-SHORE AND IN-LAND HAIL DETECTION THROUGH RADAR AND SATELLITE

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The estimation of hail probability based on satellite and radar observations opens up interesting perspectives for nowcasting methods. Most ground instruments are based on impact sensors that can classify hailstones in terms of DSD and intensity; the weather radar systems (in particular the polarimetric ones) can observe microphysical processes of within-cloud atmospheric levels and weather satellites collect information from medium-high levels of precipitating systems. In this work a comparison between radar and satellite-based products is proposed for hail detection. S- and X-band single polarization radar data have been selected from the high Tyrrhenian Sea network. The Probability Of Hail (POH) has been estimated using two different approaches, based on the VIL (Vertical Integrated Liquid)-Density parameter and on the Waldvogel (1979) method, respectively. Satellite hail product is based on the MicroWave Cloud Classification-Hail (MWCC-H) method developed by Laviola et al. (2020a-b). This method exploits the whole suite of microwave high-frequency radiometers of the Global Precipitation Measurement Constellation (GPM-C) for detecting hail clouds and classifying the intensity degree of hail clusters: Hail Potential, Hail Initiation, Hail, and Super Hail. The hailstorms case studies have been selected by using raincap sensors (i.e., piezoelectric impact sensors measuring hail occurrence and intensity) mounted onboard of a ship-based GNSS-meteo observation network. The hail events where matched in time and space with the available satellite- and radar-based hail data. The comparison between the different POH products shows an encouraging cross consistency in the core and shape localization of the severe systems and in the quantification of the hail probability.

EXPLORING TORNADO DEBRIS SIGNATURE HYPOTHESES USING RADAR SIMULATIONS AND LARGE-EDDY SIMULATIONS

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Tornadoes can loft various types and sizes of debris, sometimes resulting in a polarimetric radar signature called the TDS (Tornado Debris Signature). The presence of a TDS in on radar can help confirm the presence of a tornado, and provide information about the amount of damage occurring, making it a useful feature for operational forecasters. Past observational studies have suggested how the TDS evolves during a tornado's lifecycle, but few studies have related the polarimetric characteristics of a TDS to the tornado's wind field owing to the difficulty in obtaining three-dimensional wind data in tornadoes. This study aims to not only investigate the relationships between polarimetric weather radar variables in TDSs and the three-dimensional winds of tornadoes, but to also breakdown the relationship of the TDS by debris size, type, and concentration. A simulation-based framework is adopted since the tornado debris and wind characteristics are known, and thus these relationships proposed from observations can be explored in a more controlled manner. To observe relationships between polarimetric variables and debris size, type, and concentrations, simulations were performed using a dual-polarimetric, radar simulator (SimRadar) and a single-volume emulator. SimRadar is coupled with Large-Eddy Simulations of a dynamic, tornado-like vortex to allow for the analysis of the evolution of polarimetric variables over time. Results from these simulations show how wind characteristics of the simulated tornadoes, such as updraft and the magnitude of horizontal wind speeds, are related to the polarimetric characteristics of the TDS. These findings can aid operational forecasters in tornado detection and potentially the categorization of damage severity using radar data.

SPACE-TIME VARIATION OF LARGE HAIL-PRODUCING MESOSCALE CONVECTIVE SYSTEMS OVER A COMPLEX TERRAIN OF THE INDIAN SUBCONTINENT AS REVEALED THE INTEGRATED TRMM AND GPM OBSERVATIONS

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Space-time variation of large hail-producing mesoscale convective systems (MCSs) is investigated over the eastern and north eastern part of the Indian subcontinent during the premonsoon (March-April-May) season by using long-term (1998-2020) intregated observations of Precipitation Radar and Microwave Imager onboard the TRMM and GPM satellites. At the outset, the 37.0-GHz polarization corrected temperature ≤ 176 K, is utilized as a hail proxy and is evaluated with the available ground truth hailstorms reporting. The large hail-producing MCSs are most frequently observed over plains, whereas, such MCSs are not found over mountains. The MCSs in April have the highest probability to contain hail though the hail-producing MCSs are more common in May. The average morphological and microphysical properties are distinctly different for the MCSs with and without hail. Compared to the active convective cores of MCSs without hail, the hail cores of MCSs (i) extend higher vertically and borderer horizontally, (ii) are associated with much larger area (~ 1000 km2 vs. 100 km2) occupied by radar reflectivity larger than 40 dBZ in the mixed-phase region (~ 7 km), and (iii) are associated with larger values of cloud ice water content (CIWC; 395 mg.m-3 vs. 153 mg. m-3) in the mixed-phase region. The results from the high-resolution ERA5 reanalysis data show that the hail-producing MCSs are more sensitive to synoptic forcing than the MCSs without hail. Very strong mean sea level pressure anomalies over the whole northern part of India along the Himalayan foothills to the Bay of Bengal occur for the MCSs with hail days. The findings of this study will support the forecasting of these hailstorms and mitigation of their damage within this region.

HARDWARE, CALIBRATION AND MONITORING

ESTIMATION OF TRANSMITTED DIFFERENTIAL PHASE ON DUAL POLARIZATION RADARS

MONITORING OF RADAR REFLECTIVITY ON NATIONWIDE S-BAND WEATHER RADAR NETWORK USING GROUND CLUTTER, SELF-CONSISTENCY, AND INTERCOMPARISON

CALIBRATION OF DIFFERENTIAL REFLECTIVITY USING DRY AGGREGATED SNOW

DEVELOPMENT OF INTEGRATED RADAR MONITORING SYSTEM FOR EASY VIEWING OF RADAR SYSTEM CONDITION

RECONCILING THE DIFFERENCES BETWEEN RADAR AND RAIN GAUGES, BOTH ARE CORRECT, BUT RADAR IS USUALLY MORE REPRESENTATIVE

TESTING THE “DRY SNOW” TECHNIQUE TO CALIBRATE ZDR OBSERVATIONS OF SUPERCELLS FROM DISPARATE X-BAND RADARS

MONITORING OF RADAR DATA QUALITY IN THE CZECH WEATHER RADAR NETWORK

CALIBRATION OF THE RADAR DIFFERENTIAL REFLECTIVITY USING QUASI-VERTICAL PROFILES

THE INTERACTION OF DATA QUALITY MONITORING AND OPERATIONAL SURVEILLANCE OF WEATHER RADAR NETWORKS

COMPARISON OF RADAR REFLECTIVITY FROM DISDROMETERS AND WEATHER RADARS OF HUNGARIAN MEASURING NETWORK

QUANTIFYING THE PEDESTAL LEVELLING ERROR WITH THE SOLAR MONITORING METHOD

LINEAR AND CIRCULAR POLARIZATION USING PHASE SHIFTER AT THE DWD HOHENPEIßENBERG RESEARCH RADAR

STUDY OF HISTORICAL “MONITORING SIGNALS” TO SUPPORT MAINTENANCE

A SYSTEMATIC APPROACH TO UNTANGLING C-BAND RADAR ERRORS UTILIZING A NETWORK OF DUAL FREQUENCY VERTICALLY PROFILING RADARS

MONITORING THE QUALITY OF QUALITY-CONTROLLED RADAR MOMENTS

QUALITY APPROVAL FOR MOBILE X-BAND RADAR MEASUREMENTS

SHORT JOURNEY INTO THE BEST PRACTICES OF MONITORING AND CALIBRATION OF THE WEATHER RADAR RECEIVER AT METEOSWISS DURING THE LAST 25 YEARS

EXPERIENCES OF ONE-MONTH SYNCHRONOUS MEASUREMENTS WITH TWO DIFFERENT CLOUD RADARS

COMPARISON OF SOLID STATE VS MAGNETRON C-BAND WEATHER RADAR

ADVANCED TARGET GENERATION APPLICATIONS: FROM POINT TARGETS TO COMPLEX TIME-VARYING DOPPLER-RCS PATTERNS

ESTIMATING WET ANTENNA LOSSES WITH HELP OF SOLAR SCANS MADE AT ALL WEATHER CONDITIONS WITH A KA-BAND CLOUD RADAR

MONITORING BRIGHT GROUND CLUTTER TARGETS IN THE CANADIAN WEATHER RADAR NETWORK

ESTIMATION OF TRANSMITTED DIFFERENTIAL PHASE ON DUAL POLARIZATION RADARS

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A measurement procedure to determine the transmitted differential phase between the horizontally and vertically polarized radiation of a dual-polarization radar is presented. It uses solely weather data with no instrument intrusions whatsoever. The procedure applies to polarimetric radars operating in the simultaneous transmission and reception of linear orthogonal electromagnetic waves. Description of data collection and processing are presented. Data were collected at vertical incidence while the antenna rotates in azimuth. The large number of collected samples reduces statistical errors in estimates. The theory supporting computation of the transmitted differential phase is presented. It requires measurement in the melting layer and rain below. These measurements and relations between the various elements of the backscattering matrix are used to derive a set of nonlinear equations whereby the differential phase on transmission is one of the unknowns. The method for solving these equations is presented. Demonstration of the results on actual data follows. Attempts to estimate the differential phase from external signals are described as well as its potential uses.

MONITORING OF RADAR REFLECTIVITY ON NATIONWIDE S-BAND WEATHER RADAR NETWORK USING GROUND CLUTTER, SELF-CONSISTENCY, AND INTERCOMPARISON

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Radar calibration is an essential prerequisite to ensure the data quality and to improve the performance of operational applications, such as quantitative precipitation estimation (QPE) and hydrometeor classification algorithm (HCA). The main issue of the radar calibration is the malfunction and miscalibration of radar system components after the routine inspection. In this study, we developed the technique to monitor reflectivity (ZH) using ground clutter (GC), self-consistency (SC), and intercomparison in real-time. The procedures for GC monitoring was divided into three steps: 1) construction of ground clutter map (GCM), 2) determination of the baseline from the statistics of ZH at ground clutter and, 3) calculation of the relative calibration adjustment (RCA). The GCM was constructed by counting the frequency of occurrence of ZH over the given threshold. And then, the RCA was calculated from the difference between the baseline and the statistics of ZH at ground clutter. The SC method can calculate the absolute calibration bias from the relationship between ZH and specific differential phase. Unfortunately, it is impossible to monitor the change in the absolute calibration bias during the non-precipitation period. With the GC monitoring method, it is possible to estimate the calibration bias even when the calibration bias changes regardless of weather conditions. In terms of radar network, the homogeneity of ZH can be examined by calculating the mean bias between adjacent radars. In conclusion, this technique makes it possible to use the radar measurements, which are immune to the calibration bias. In addition, monitoring of the calibration bias in real-time is valuable in that radar engineers can figure out the status of the radar system as soon as possible.

CALIBRATION OF DIFFERENTIAL REFLECTIVITY USING DRY AGGREGATED SNOW

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Accurate calibration of differential reflectivity ZDR on polarimetric weather radars remains a challenge. In addition to the system internal calibration, various techniques based on the analysis of radar data are being used in research and operations. These include “bird bathing” with vertically pointing antenna and the use of “natural calibrators” with known intrinsic ZDR such as light rain, dry aggregated snow, Bragg scattering echoes, and ground clutter. “Bird bathing” may not be available for many operational polarimetric radars (like WSR-88D), Bragg scattering signal with intrinsic ZDR equals to 0 dB may not be available all year round for the most radar locations, ZDR of ground clutter varies between different radar locations, and the light rain methodology may not ensure a required accuracy of 0.1 – 0.2 dB. In this study, we focus on the use of dry aggregated snow (DAS) routinely observed just above the melting layer (ML) in stratiform precipitation assuming that the intrinsic value of ZDR in DAS varies between 0 and 0.2 dB depending on the intensity of snow and its degree of aggregation. We utilize quasi-vertical profiles (QVP) of polarimetric radar variables providing accurate measurements of ZDR above the ML. The critical part of the calibration methodology is to identify DAS as opposed to other snow types with wider distribution of ZDR. Criteria for DAS identification include the value of Z within the ML and above it, vertical gradient of Z in snow, minimal value of the cross-correlation coefficient in the ML, and the depth of the cold part of the cloud above the ML. This calibration technique was tested for a large number of storms of different types and it was demonstrated that the achieved accuracy of the suggested ZDR calibration is within 0.1 dB.

DEVELOPMENT OF INTEGRATED RADAR MONITORING SYSTEM FOR EASY VIEWING OF RADAR SYSTEM CONDITION

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The Weather Radar Center (WRC) of the Korea Meteorological Administration has installed three Solid State Power Amplifier (SSPA) X-Band dual polarization radars to monitor low-altitude hazardous weather over the metropolitan area with high temporal and spatial resolution. These radars are located in the military zone and operated unmanned remotely. Even though skilled operators are performing relatively efficient monitoring but a more robust monitoring system is needed for tight radar operation. WRC has developed an integrated monitoring system that can monitor the radar network on one screen. The main purpose of this monitoring system is to more effectively manage the inspection points without missing. The integrated remote monitoring system developed by WRC consists of four parts. The Part 1 is monitoring radar data acquisition including data transmission, access rights, and quality control processes. The 2nd and 3rd parts are checking server availability including network infrastructure and environmental sensors (temperature, humidity, UPS power level, and etc.), respectively. The last part is monitoring of radar HW state using IRIS BITE variables and radar parameters' (differential reflectivity and reflectivity) system offset level using WRC in-house developed program. In order to respond more quickly to the radar network operation failure signals we plan to improve this system continuously through testing and adding other check points and plugging the better graphical output information.

RECONCILING THE DIFFERENCES BETWEEN RADAR AND RAIN GAUGES, BOTH ARE CORRECT, BUT RADAR IS USUALLY MORE REPRESENTATIVE

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Traditionally rainfall rates inferred from radar have been validated or adjusted using rain gauges, but these two instruments have very different sampling characteristics. a) the temporal sampling mismatch between the 5-minute radar snapshots and the finite time for the gauge to record a "tip" of 0.2mm, b) the spatial sampling mismatch of the radar pulse volume (~ 0.1 km3 at 30km range) and the gauge which is a factor of ~106 smaller. These sampling issues are then combined with difficulties in calibrating both the gauges and the radar and the uncertainty in the Z-R relationship. In this study we have used three unique ground-based drop counting gauges that respond to each 0.003mm of rain that falls, collocated with a conventional tipping bucket gauge (0.2mm) that has about 60-times lower resolution. The high-resolution gauges are then used to a) calibrate the neighbouring disdrometer for any exposure bias (~0.5dB) and to derive the random error of about 1dB introduced by the 5-minute sample of the radar. The values of Z from the Dean Hill operational UK C-band radar at 20km range, is compared to the disdrometer value using the pixel some 450m above the disdrometer. To ensure that only rain is being sampled the value of pho_hv must be above 0.99. For individual scans, the error is ~3dB, but by averaging over several hundred 200 scans, which can take a few months, this is reduced to ~ 0.5dB. This stability is validated by monitoring stable clutter targets within 30km of the radar. Finally, the absolute calibration value is independently confirmed using the redundancy of the polarisation parameters. Further tests are needed, but the suggestion is that it is reliable and would provide adequate calibration without the need for gauges or disdrometers.

TESTING THE "DRY SNOW" TECHNIQUE TO CALIBRATE ZDR OBSERVATIONS OF SUPERCELLS FROM DISPARATE X-BAND RADARS

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As part of an ongoing effort to characterize polarimetric features in X-band radar observations of supercells, it is necessary to harmonize the observations from a heterogeneous array of X-band polarimetric radars with varying hardware, volume coverage patterns, and calibration characteristics. Collecting vertically-pointing scans in light rain is a standard ZDR calibration technique, but many observations of supercells by X-band mobile radars lack such accompanying vertical "birdbath" scans. In this presentation, we report our preliminary efforts to calibrate ZDR observations from disparate X-band radars and cases using the "dry snow" technique posited previously in the literature. This technique is predicated upon the assumption that ZDR in dry snow at X-band should be narrowly Gaussian-distributed around a value of 0.15 dB in continental convective environments. An established hydrometeor classification algorithm is used to delineate regions of dry snow. Following the calibration, hydrometeor classification is applied again in order to ensure that the calibration did not drastically alter the classification. Results are validated for those radar deployments where birdbath, solar, or other calibration scans are available. It is found that this method works well for those polarimetric radars employing a mechanically scanning dish antenna, but less well for a novel polarimetric phased array radar.

MONITORING OF RADAR DATA QUALITY IN THE CZECH WEATHER RADAR NETWORK

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The Czech Hydrometeorological Institute (CHMI) operates weather radar network CZRAD which consists of two Doppler C-band dual-pol radars Vaisala WRM 200 which were installed during summer 2015 replacing older single-pol weather radars. Data output of CZRAD network is widely used by forecasters in meteorology and hydrology, air traffic control and other users. Radar measurements in horizontal and vertical polarization enable improvement of quality of standard horizontal radar reflectivity and radial velocity data (better filtering of non-meteorological targets and attenuation correction) and provide also fully new radar products that extend ways of their utilization (e.g. hydrometeor classification, detection of strong storm updrafts using ZDR column product). However increasing quantitative use of these radar data has also increasing demands on radar data quality. Therefore to ensure better quality of dual-pol data extended effort has to be focused on radar data calibration and monitoring. Several procedures are currently being developed in the CHMI. These procedures monitor various radar moments like ZDR , PhiDP , ZH , ZV and TH , TV including their dependency on distance, azimuth and their changes in time in order to detect possible internal changes in radar system and external factors such as RLAN interferences. The contribution gives an overview of the procedures implemented in the CHMI used for monitoring of various radar data parameters.

CALIBRATION OF THE RADAR DIFFERENTIAL REFLECTIVITY USING QUASI-VERTICAL PROFILES

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The differential reflectivity (Z_{DR}) is a crucial radar measurement to produce accurate quantitative precipitation estimates (QPEs) using polarimetric weather radars. However, a system bias between the horizontal and the vertical radar channels produces an offset in Z_{DR}. Such offset must be corrected if Z_{DR} is used for radar rainfall estimation. In this work, we present and evaluate a novel method for correcting and monitoring the Z_{DR} offset using quasi-vertical profiles of polarimetric variables built from scans collected at 9° elevations. The method relies on a computed intrinsic value of Z_{DR} of light rain derived from disdrometer measurements. The proposed routine is then applied to radar data collected through one year of precipitation events by two operational C-band polarimetric weather radars located in the UK. We found a relative error of 0.1 dB when evaluating the proposed methodology against the traditional approach based on Z_{DR} measurements collected at 90° elevations. Additionally, the method was independently assessed using disdrometers located near the radar sites. The results showed a reasonable agreement between disdrometer-derived and radar-calibrated Z_{DR} measurements.

THE INTERACTION OF DATA QUALITY MONITORING AND OPERATIONAL SURVEILLANCE OF WEATHER RADAR NETWORKS

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Modern technologies provide a lot of potential to derive performance and quality measures without interfering the radar operation partially even independent from different weather radar system hardware or system manufacturer. Many of these inherently given capabilities do not only base on hardware monitoring, but also on data capture, integration, visualization and analytics of atmospheric measurements. Therefore, for improved data quality performance management capabilities, LEONARDO has decided to enable the commercial software for easy integration of available open source radar data processing and analytics packages such as BALTRAD, wradlib, Py-ART or pyrad. Using the new feature "COSMOS" = Commercial Software Meets Open Source, existing algorithms can be extended by customized analytics in order to improve the overall asset performance management and to implement new skills based on data mining and machine learning methods. In connection to the general strategy improving the monitoring and surveillance of weather radar networks, the anticipated solution concept is currently refined. Conducted surveys result in a flexible, coherent three-tier concept approach incorporating inter alia real time capabilities as well:
- Tier 1: General, operational monitoring and surveillance level, web page and dashboard driven (based on a synergy of commercial and non-commercial software).
- Tier 2: For specific meteorological or hardware related issues, beyond the web application, a dedicated set of different applications will be used.
- Tier 3: For a comprehensive study, other software are dedicated for deep case studies, historical analysis and trend search. A user group of experts may be consulted if needed.

COMPARISON OF RADAR REFLECTIVITY FROM DISDROMETERS AND WEATHER RADARS OF HUNGARIAN MEASURING NETWORK

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Hungarian weather radar network consists of five dual-polarized C band radars measuring up to 240 km distance, covering the whole area of the country. The disdrometer network consists of 30 instruments mixed of LPMs (Laser Precipitation Monitor) from THIES and OTT Parsivel². Laser weather sensors were installed scattered nearby radars. Selected disdrometers that are at optimal distance from radars gave the opportunity to investigate the radar reflectivity from the two different instruments. Reflectivity from radars is scanned in operativ manner in every 5 minutes on 10 different elevation angles. Disdrometers calculates reflectivity in every minutes. Due to time delay - because of the different measuring methods – the most matching minute data from the laser weather sensors were choosen to the reflectivity from radar PPI-s from low altitudes above the sensors. It was found that reflectivity calculated by disdrometers is significantly higher than reflectivity measured by radars.

QUANTIFYING THE PEDESTAL LEVELLING ERROR WITH THE SOLAR MONITORING METHOD

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During the last decade, continuous monitoring of the antenna pointing error through the solar monitoring method developed by Huuskonen and Holleman (2007)[1] has become widespread, as an easy-to-implement, portable and accurate procedure that does not interfere with the continuous and real-time operation of the radar. For an adequate georeferencing of weather radar data, an accuracy within 0.01° in the weather radar antenna alignment is generally required. To reach such an accuracy all over the area covered by the radar, it may be relevant to determine the position dependence of the pointing error and link it to different sources, such as the pedestal levelling or other electromechanical aspects of the system. In the present work, we explore the feasibility of characterizing the antenna pedestal levelling error by means of a year-long analysis of the pointing error derived from the solar monitoring method, given that the online solar signatures carry information on the azimuthal dependence of the error [2]. The methodology requires reanalysis of solar signature data, but has the potential for continuous application. To assess the performance (accuracy and stability) of the methodology, we analyze its results over several years and for different radars and compare them with the pedestal levelling errors estimated through independent methods, such as dedicated offline solar scans, sun tracking and/or in-situ plumb-line measurements.

[1] Huuskonen, A., & Holleman, I. (2007). Determining weather radar antenna pointing using signals detected from the sun at low antenna elevations. JTECH, 24(3), 476-483.
[2] Altube, P., et al. (2016). Intercomparison and potential synergies of three methods for weather radar antenna pointing assessment. JTECH, 33(2), 331-343.

LINEAR AND CIRCULAR POLARIZATION USING PHASE SHIFTER AT THE DWD HOHENPEIßENBERG RESEARCH RADAR

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The dualpol systems operated by DWD are specified to transmit in linear polarization with 0° phase difference upon transmission. There is no means to adjust for the transmit phase in the original design. Dualpol data quality are affected depending on the actual transmit phase. In order to investigate aspects to this, we installed a phase shifter installed at the research radar Hohenpeißenberg. In this contribution we will report on the on-site installation of the phase shifter and describe its adjustment. This includes a transmit phase measurement at the antenna feed horn using a gain horn and a transmit phase measurement in the far-field of the antenna. The far-field measurement was taken at a site 8.4 km away from the radar. Some examples with meteorological measurements will be shown as well.

STUDY OF HISTORICAL “MONITORING SIGNALS” TO SUPPORT MAINTENANCE

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The daily routine of monitoring the weather radar is a useful systematic task for detection of malfunction of the system. In addition, old systems require advance-monitoring tasks to maintain the best quality of data that it is possible to register. The unusual, incoherent or strange signals are always a source of interest because they respond to some uncontrolled target or some changes in the operation of the system. In general, the quality of the final products is associated in many studies to a well list of sources of errors and this is an indicator of the quality and representative of the data registered in a particular meteorological phenomenon, in space and time. There are new sources of errors that start to appear with the age of the radar, what happens then with old systems and the subtle imbalance in hardware? The role of the monitoring signals in a good operation of the radar, their studies as a reference signal and experiences of the past, give a good approximation of the deviations in the present situation. The study shows how useful it is to study trends of these monitoring signals in real time to find deviations in the operation. These changes of a reference signal could have an impact in the final products and sometimes require an immediate maintenance action that could reduce, solve the present trend. Tracking characteristic patterns of monitoring signals help find these variations over time. This work shows some of the monitoring experiences, which caused a maintenance intervention.

A SYSTEMATIC APPROACH TO UNTANGLING C-BAND RADAR ERRORS UTILIZING A NETWORK OF DUAL FREQUENCY VERTICALLY PROFILING RADARS

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Rainfall retrievals from C-band radar form an important component of operational quantitative precipitation estimation systems, including in the Auckland region of New Zealand. The quality of radar retrievals depends on careful data processing to resolve well known sources of uncertainty: calibration, ground clutter, attenuation, vertical reflectivity profile variations and raindrop size distributions. However, in most operational settings the only in-situ observations available for comparison with radar are tipping bucket rain gauges; data from which are not inherently well suited for investigating radar errors. We have developed a network of dual-frequency profiling radar sites to provide long-term observational data of relevant rainfall parameters at appropriate time and space scales for interrogation of individual sources of error that are present in the C-band single polarization weather radar observations. At each site, observations are provided by a K-band (24GHz) FMCW radar (MRR-PRO, Metek GmbH) and an X-band (9.4GHz) 25kW pulsed magnetron radar incorporating Doppler spectral processing of our own design. Dual frequency measurements allow independent estimation of vertical velocity and drop size, while the X-band profiler ensures that data can be collected even during heavy rainfall. The network is exercised initially to provide calibration of the C-band radar; end-to-end calibration is established to within 0.1dB and found to be stable between maintenance visits and of order 4dB. A real-time correction for radome attenuation has also been developed. Future applications of the network will include validation of path integrated attenuation, vertical profile corrections, and investigation of Z-R relationships in the Auckland climatological setting.

MONITORING THE QUALITY OF QUALITY-CONTROLLED RADAR MOMENTS

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Radar data are input to many subsequent procedures, such as hydrometeor classification, quantitative precipitation estimation and data assimilation for numerical weather prediction. To ensure the optimal performance of these downstream applications, the radar moments first have to be quality controlled (Werner et al. WXRCalMon 2017). Continuous longterm monitoring of these quality control procedures for the entire radar network provides valuable insight into the performance of the quality control system, and thus uncovers weak spots and fosters improvements. The performance of individual quality control algorithms can be surveilled, long-term trends in the data can be detected, and changes caused by updates to the data processing system can be quantified based on realtime information. In this workshop contribution, a system monitoring the German radar network will be presented. The quality of the quality-controlled radar moments is assessed individually for each radar, compared for areas with overlapping radar coverage and analyzed over different periods of time. The presented Grafana dashboards provide easy ways to compute custom metrics, choose from a wide variety of visualizations, and enable to interactively and flexibly analyze the data.

QUALITY APPROVAL FOR MOBILE X-BAND RADAR MEASUREMENTS

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Quality control for mobile radars is more challenging and in greater demand than for operational fix installed radars. Strain during transport may impact the performance of the radar (e.g., calibration). Furthermore, the changing setting introduces varying sources of errors like ground clutter, beam blockage, foreign sources of radiation, occurrence and intensity of clear air echoes, and so on. Finally, the meteorological conditions may vary showing new features not observed with that instrument elsewhere. Our mobile X-band radar was used in several measuring campaigns. The quality assurance procedure is slowly becoming stable. Showing our progress, we want to exchange our experience with others. The recent measuring campaign took place in Neckar Valley in south-west Germany in the framework of the Swabian MOSES campaign (2021). Based on these radar measurements we demonstrate our quality control routine. It performs a scatterer classification based on membership functions for reflectivity, differential reflectivity, co-polar cross-correlation coefficient (RhoHV) and the textures of differential reflectivity, differential phase and RhoHV which classifies scatterer as meteorological echoes, ground clutter or clear air echoes. Spike signals are removed based on their differential phase and signal quality index. The effects of attenuation are reduced by applying the ZPHI algorithm. A single calibration for the campaign is based on rain gauge measurements of the German Weather Service. Radome attenuation is addressed by assuming a linear dependency between attenuation (in dB) and rain intensity, measured close to the radar. Our results show that our corrections achieve large improvements in the representation of precipitation with radar data.

SHORT JOURNEY INTO THE BEST PRACTICES OF MONITORING AND CALIBRATION OF THE WEATHER RADAR RECEIVER AT METEOSWISS DURING THE LAST 25 YEARS

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The paper presents the radar receiver monitoring and calibration strategies of MeteoSwiss over the last 25 years. This includes the systems of the 3rd and 4th Swiss weather radar generation. Different methods for monitoring andcalibrating the receiver are presented, from the delivered solution requested in the Call for Tender and implemented during the installation phase, to the best practices developed over the years and regularly discussed in the international community (EUMETNET OPERA). The worthiness, both financially and technically, of each solution is evaluated over the long run of 20 years of operational quantitative use of weather radars. Fancy solutions may work well in the lab environment, but often show drawbacks when installed on a remote mountain site with limited access and harsh weather conditions. Already the 3rd generation of the Swiss weather radars included automatic monitoring and calibration of the receiver, a visionary approach considering the fact that the design of the 3rd generation was defined in the 80ies of the last century. A comprehensive automated monitoring system is the basis for an early detection of malfunction or aging of components. The transition to digital receiver technology resulted in substantially improved stability and sensitivity. The amount of performance indicators that are available to the engineers and scientists increased drastically with the installation of the 4th generation. Thanks to this the monitoring and calibration procedures of the receiver path can continuously be reviewed and refined. The knowledge accumulated over the past years leads to several new ideas for the next generation MeteoSwiss radar network.

EXPERIENCES OF ONE-MONTH SYNCHRONOUS MEASUREMENTS WITH TWO DIFFERENT CLOUD RADARS

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The integrated atmospheric observation system KITcube includes a pulsed 35 GHz cloud radar that has been in operation since 2005. As an extension a new FMCW dual frequency (35 GHz/94 GHz), dual-polarization cloud radar was integrated into KITcube in 2021. Both systems will be used independently of each other. The technical differences between the two radars may lead to different measurement results, even with the common measurement frequency of 35 GHz. We have to avoid that such differences are assigned to the weather situation. Therefore, we operated both radars collocated with similar operation parameters for roughly one month. Among the insights from this experiment, we should mention the very high correlation of the radar reflectivity measurements. The different measurement principles introduce some easily identified features. Nevertheless, there are effects that we do not yet understand, e.g., a reduction of certain deviations with measurement height. We want to emphasize that we do not want to compare the two radars, e.g. in terms of quality. The completely different prices, features, and age do not allow a fair comparison.

COMPARISON OF SOLID STATE VS MAGNETRON C-BAND WEATHER RADAR

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Solid-state weather radars still do not have the trust of the meteorological offices. Meteopress has built a fully solid-state C-band radar from commercial-of-the-shelf components (COTS). It is based on software-defined radio and solid-state power amplifier modules. In our presentation, we will showcase examples and comparisons of the performance of the high end magnetron C-band radar compared on the same area with a solid-state C-band weather radar. One of the most important choices proved to be the design of the waveform the radar is transmitting, as the approaches available in existing literature, utilized for point targets, such as airplanes, do not necessarily generalize to distributed scatterers, i.e., clouds. As our solid-state radar has the entire signal processing implemented in software on a standard computer, it allows us to generate arbitrary waveforms and change them in real time to investigate their impact on signal quality.

ADVANCED TARGET GENERATION APPLICATIONS: FROM POINT TARGETS TO COMPLEX TIME-VARYING DOPPLER-RCS PATTERNS

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A full polarimetric radar transponder system has been developed which is capable to calibrate radar reflectivity, differential reflectivity, Doppler velocity, antenna pointing and range accuracy. The system provides a calibration chain that allows to trace back radar reflectivity measurements to SI units. Since its invention the system underwent significant improvements and extensions of its application range. The technology was applied to numerous X- and C-band radars that cover various technologies (i.e., magnetron, pulse compression and multi-static systems). An insight into the calibration accuracy of the different systems will be given, emphasizing linearity considerations as well as previously unknown relations between the differential phase and the differential reflectivity accuracy. It will also be shown how Zdr offsets can be related to polarimetric inhomogenities in the antenna patterns. The capability of Palindrome's target simulator was enhanced such that not only point targets but also complex time-varying Doppler-RCS patterns can be generated. In this manner the system is now able to simulate realistic radar reflectivities of wind turbines. Such reflectivities are a long standing problem in many radar applications. With this new technology, artificial wind turbines with arbitrary parameters can be set-up within the field-of-view of a weather radar. It can hence be tested if a wind turbine is disturbing the radar under test and if signal-processing based mitigation techniques are capable to clean contaminated radar pixels. C-band applications of this technology will be shown as well as comparisons between real and simulated wind turbine signatures.

ESTIMATING WET ANTENNA LOSSES WITH HELP OF SOLAR SCANS MADE AT ALL WEATHER CONDITIONS WITH A KA-BAND CLOUD RADAR

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Hourly solar scans were made with a Mira-35 cloud radars near Bucharest since 2021. It turns out that sun scan can not only be used for testing the pointing accuracy. They can also be used to determine the attenuations of the radar signal due to atmosphere, rain and wet antenna. During sun scans a parallelogram shaped region in the direction where the sun is expected is sampled. When the radar beam hits the sun the thermal radiation of the sun is detected like radiometric noise. It increases the noise floor in all range gates by a few dBs which reduces the sensitivity for clouds a bit. The thermal sun noise is attenuated by the atmospheric gases, by clouds, rain, and wet antenna. From the sun scans made during different weather and at different elevations the different contributions to the attenuation can be determined separately. After fitting the antennuation the sun noise can be used to validate the receiver calibration. The cloud radar also receives radiometric noise from the from rain and clouds though it is not as sensitive as a radiometer. During the sun scans both sorts of radiometric noise are measured, sun noise and sky noise. During rain the sky noise is increased as the droplets emit thermal radiation. At the same time the sun noise becomes weaker due to attenuation. Both effects are related to each other by Kirchhoff's law of thermodynamics. A simple modle was made from Kirchhoff's law which relates the sun noise attenuation and sky noise. This modle was validated and fitted by the sun scan data. In case of normal cloud radar operation only the sky noise is abailable. With help of the Kirchhof modle it is possible to estimate the attenuation caused by rain and wet antenna. This can be used to improve the accuracy of reflectivity measurements.

MONITORING BRIGHT GROUND CLUTTER TARGETS IN THE CANADIAN WEATHER RADAR NETWORK

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Strong ground clutter targets can provide signals related to radar performance. Rinehart (1978) is probably the most cited early proponent of using such targets to monitor changes in radar calibration. A number of studies, such as Silberstein (2008) and Wolff et al (2015), have proposed increasing sophisticated methods for monitoring calibration with ground clutter, often referred to as relative calibration adjustment (RCA). Typically, results have been presented for only a few radars. Here a slightly less sophisticated tool, spun off a pre-existing statistical study, looks at bright clutter targets across the Canadian Weather Radar operational network. The returns from clutter in a specific radar sample area should remain constant provided four things do not change over time: the target(s), the illumination of the target(s), the radar electronics, and the radar processing. If any three are constant, one can monitor changes in the fourth. In this study, monthly statistics of echoes around a radar were used to find relatively steady strong targets around a radar and then the mean properties of this collection were monitored over several years. One main difference from most of the previous studies was that larger distances were used, because many radars had too few targets within 10-15km. The study shows that diurnal and seasonal variations in illumination were a significant source of variability in the target collections used, with the variability itself changing between climate regimes. The results suggest that operational implementation of clutter monitoring across a continental scale radar network can be problematic.

HYDROLOGICAL APPLICATIONS

IMPROVING RADAR RAINFALL ESTIMATION FOR FLOOD RISK USING MONTE CARLO ENSEMBLE SIMULATION

HYDROMETEOROLOGICAL ANALYSIS AND FORECASTING OF A 3 D FLASH-FLOOD-TRIGGERING DESERT RAINSTORM

TOWARDS NATIONWIDE POST-PROCESSING OF ENSEMBLE NOWCASTS TO SUPPORT FLOOD WARNINGS IN SMALL CATCHMENTS

SYNERGISTIC PRECIPITATION OBSERVATIONS IN AN URBAN ENVIRONMENT

RADAR-BASED ENSEMBLE RAINFALL FORECASTS TO ENHANCE FLOOD FORECASTS AND WARNINGS IN AUSTRALIA

MODELLING SOIL EROSION UNDER EXTREME RAINFALL USING A RADAR-RUNOFF-NOWCASTING-SYSTEM

POLARIMETRIC SIGNATURE OF EXTREME RAIN EVENTS IN HIGH SPATIAL RESOLUTION RADAR DATA IN SWITZERLAND

SWABIAN MOSES 2021: A HYDRO-METEOROLOGICAL MEASUREMENT CAMPAIGN

BRAIN AND ITS HYDROLOGICAL APPLICATION

A FLASH FLOOD WARNING SYSTEM FOR UNGAUGED BASINS IN THE TROPICAL CONTEXT OF LA REUNION ISLAND

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ON THE BENEFIT OF USING RADAR-BASED QPE FOR LANDSLIDE EARLY WARNING AT REGIONAL SCALE

ACCOUNTING FOR SUBBASIN PRECIPITATION VARIABI-LITY IN FLOOD CHARACTERIZATION

RADAR NOWCASTING IN AUCKLAND, NEW ZEALAND: A CATCHMENT FOCUSED STUDY

SEAMLESS PREDICTION USING RADAR DATA, NOWCA-STING AND NUMERICAL WEATHER PREDICTION MODELS, TO ENHANCE HYDROLOGICAL OPERATIONAL FORECA-STING

IMPROVING RADAR RAINFALL ESTIMATION FOR FLOOD RISK USING MONTE CARLO ENSEMBLE SIMULATION

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Weather radar is a crucial tool in rainfall estimation, for flood forecasting and urban drainage design. While rain gauges give sparsely distributed ground observations over time, a weather radar provides a picture of the spatial distribution of rainfall, with area-averaged pixels. In June 2012, the city of Newcastle suffered extensive flooding due to a high-intensity rainfall event, during which a month's worth of rainfall fell in just two hours. This event caused traffic chaos and millions of pounds worth of damage. Radar rainfall images showed areas of unexpectedly low rainfall amounts with ground-based estimates telling a different story, caused by attenuation due to intervening high-intensity rainfall. This occurred to such an extent that volumes of rainfall were missing, referred to as rainfall 'shadows', which cannot be accurately estimated from attenuated reflectivity measurements. To investigate the error structure in radar rainfall estimation, a flexible stochastic model for simulating spatio-temporal rainfall event fields is designed and implemented. Simulated fields satisfy key aspects of a spatial rainfall field, namely the spatial correlation structure, anisotropy, marginal distribution and advection. Standard radar processing methods are inverted, with uncertainties imposed through a combination of a stochastic drop-size distribution field, random errors and path-integrated attenuation effects, resulting in an ensemble of radar images. This provides realistic weather radar images, of which we know the true rainfall field, and the corrected 'best guess' rainfall field (equivalent to the real-world case), resulting in an increased understanding of the spatial behaviour of radar rainfall errors, allowing for the improved design of correction strategies.

HYDROMETEOROLOGICAL ANALYSIS AND FORECASTING OF A 3 D FLASH-FLOOD-TRIGGERING DESERT RAINSTORM

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Flash floods are among the most devastating natural hazards. In 2018, three flash-flood episodes resulted in 46 casualties in the deserts of Israel and Jordan alone. Here we present the hydrometeorological analysis and forecasting of a substantial storm (April 2018) that hit an arid desert basin (Zin, ~1400km2, southern Israel) claiming 12 human lives. This paper aims to (a) spatially assess the severity of the storm, (b) quantify the timescale of the hydrological response, and (c) evaluate the available operational precipitation forecasting. Return periods of the storm's maximal rain intensities were derived locally at 1 km2 resolution using weather radar data and a novel statistical methodology. A high-resolution grid-based hydrological model was used to study the intra-basin flood magnitudes which were consistent with direct information from witnesses. The model was further used to examine the hydrological response to different forecast scenarios. A small portion of the basin (1–20%) experienced extreme precipitation intensities (75-100-year return period), resulting in a local hydrological response of a high magnitude (10-50-year return period). Hillslope runoff, initiated minutes after the intense rainfall, reached the streams and resulted in peak discharge within tens of minutes. Available deterministic operational precipitation forecasts poorly predicted the hydrological response mostly due to location inaccuracy. Therefore, we suggest using deterministic forecasts with caution as it might lead to fatal decision-making. To cope with such errors, a novel cost-effective methodology is applied by spatially shifting the forecasted precipitation fields. In this way, flash-flood occurrences were captured in most of the subbasins, resulting in few false alarms.

TOWARDS NATIONWIDE POST-PROCESSING OF ENSEMBLE NOWCASTS TO SUPPORT FLOOD WARNINGS IN SMALL CATCHMENTS

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Convective heavy rainfall events present a major challenge in flood forecasting. The small spatial extent of such events primarily affect smaller catchments. In addition to considerable uncertainties in meteorological predictions, flood forecasts in small catchments are challenging due to short response times, a lack of stream gauges and limitations of operationally used hydrological models at small spatial scales– prompting efforts to explore alternative prediction and warning strategies. Radar-based nowcasting data, updated every 5 min, offer valuable predictions in highly dynamic convective situations, but are often not used quantitatively in forecast models due to large data amounts and short forecast times. We aim at developing a post-processing approach tailored to the detection of potential flood hazards in small catchments. We aim at using the Nowcasting-NWP ensemble combination developed in the DWD-SINFONY project, encompassing a forecast time of 12h. Areal precipitation is calculated for all catchments between 5 km² and 500 km² from observations and QPFs at different durations from 1h to 12h. In order to assess the severity of catchment-based rainfall events, areal rainfall statistics are derived. In order to obtain catchment-specific estimates of return periods, we plan to use a 20a radar climatology combined with rain gauge extreme value statistics (KOSTRA). The final data product is supposed to help flood forecasters identify catchments likely affected by strong rainfall in the next hours. In cooperation with regional flood forecasters, it is designed to support their workflow based on hydrological modeling. First efforts on combining radar climatology and rain gauge statistics show that this part is crucial for a realistic assessment of event extremity.

SYNERGISTIC PRECIPITATION OBSERVATIONS IN AN URBAN ENVIRONMENT

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Knowledge of small-scale rainfall variability is needed for several meteorological and hydrological applications, particularly in urban environments due to its water-related sensitivity. In 2021 the University of Hamburg extended its networked precipitation observations by one X-band weather radar and three micro rain radars (MRR). From now on two low-cost, operational, single-polarized X-band radars provide measurements with high temporal (30 s), range (60 m), and sampling (1°) resolution within the 20 km scan radius. The radars are 22 km apart resulting in an overlapping area with dual information on reflectivity. Five vertically profiling K-band radars measure Doppler spectra of hydrometeors at time resolution of 10 s and range resolution of 35 m using 31 or 128 height levels. These MRRs are from 250 m up to 13 km apart from the X-band radars. Within common volumes of the X-band radar and MRR, it provides drop size distributions. Additionally, the domain is covered by the German nationwide C-band radars. Rain gauges provide the local ground truth. A similar network proofed its performance in an rural area in the past. Firstly, the new urban precipitation measurement network enables studies on urban hydrology and small-scale or vertical rainfall variability as required within the project Sustainable Adaption Scenarios for Urban Areas – Water from Four Sides of Climate Climatic Change, and Society (CliCCS). Secondly, the synergy of radar measurements facilitates the calibration of the X-band radars, investigations of measurement uncertainties with distance and increasing beam width, estimates of the Z-R relation, and studies on attenuation. We show first measurements and results of a selected rain event using the synergistic precipitation observations in Hamburg.

RADAR-BASED ENSEMBLE RAINFALL FORECASTS TO ENHANCE FLOOD FORECASTS AND WARNINGS IN AUSTRALIA

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Operational flood forecasting and warning service in the Australian Bureau of Meteorology is currently supported by a large network of rain and river gauges and gridded forecast rainfall from multiple Numerical Weather Predictions (NWP) models. The use of gridded rainfall fields from radars as input for the hydrological modelling system, and radar-based ensemble nowcasting rainfall products as complement of the NWP forecasts has been trailed to identify practices to improve this operational service. The Short-Term Ensemble Prediction System (STEPS) was used to generate ensembles of rainfall forecasts (up to 32 members) that are updated every 10 minutes with a very short latency. These ensemble rainfall forecasts, based initially on radar rainfall observations that gradually are blended with a downscaled NWP model rainfall forecast to extend the rainfall predictions up to 12 hours in the future, allow initially the generation of ensemble hydrological forecast in real-time and then impact-based probabilistic flood warnings. Selected historical flood events in one large catchment in the southeast of Australia were used as case studies to assess the performance of the ensemble rainfall forecast and ensemble hydrological forecasts to produce suitable and accurate flood estimations. A radar-based nowcasting system has the key advantage of providing updated ensemble of rainfall forecasts to flood forecasters every few minutes, rather than once every few hours as per NWP models. However, further investigation is needed to identify and implement adequate operational practices that allow the efficient use of these very-frequent updates in an operational environment that nowadays is closely based on updating rainfall and hydrological forecasts only few times per day.

MODELLING SOIL EROSION UNDER EXTREME RAINFALL USING A RADAR-RUNOFF-NOWCASTING-SYSTEM

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Soil erosion by water is one of the most widespread forms of soil degradation in Europe responsible for relevant agricultural productivity losses. Under climate change, soil erosion is expected to increase for the most part because of a rising of the frequency of extreme, localised events. In critical hydrological phenomena, such as intense surface runoff, flooding, and soil erosion, the spatiotemporal extent significantly affects the impact and the evolution of the phenomena, especially during extreme events. Therefore, an approach directed to refine the knowledge of these dynamics is recommended. Here, we present the SED-RUN project, focusing on quantifying extreme rainfall effects on soil erosion by means of ground-based weather-radar observations and hydrological modelling at regional scale (namely in Tuscany, central Italy). Using an approach based on a statistical analysis and modelling, the project aims to: 1) Quantifying on historical data the spatiotemporal distribution of extreme rainfalls / runoff and soil erosion over the last decade, 2) Building a platform to model runoff and soil erosion in extreme events, 3) Simulating in real-time runoff and soil erosion integrating the current regional-warning-system for extreme weather events. Rainfall data will be provided by the national and regional institutions such as LaMMA Consortium, disposing of ground-radar data from year 2015 at 1-km spatial and 15-mins time resolutions, and the "Italian Civil Protection", whose radar dataset of the national network (DPCN) covers the 2010–2020 period, with a spatial resolution of 1km in a 10-mins time-step.
The project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie, Grant Agreement n.101033236.

POLARIMETRIC SIGNATURE OF EXTREME RAIN EVENTS IN HIGH SPATIAL RESOLUTION RADAR DATA IN SWITZERLAND

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Localized intense rain events can cause significant societal and economic damages. Weather radars collect space-time observations that provide useful information for the analysis and forecasting of such events. In Switzerland, five operational polarimetric C-band radars are scanning the atmosphere above the whole territory up to a height of 18 km, with 20 interleaved sweeps that are updated every 5 minutes, and provide data at a native radial resolution of 83 m. This information is then aggregated at 500 m combining all clutter-free 83-meter gates and quality-checked before being used in subsequent product chains. While rainfall peaks at the scales of a few hectares that are potentially relevant for such localized events could be identified in the native data at 83 m resolution, they are likely smoothed out during the integration process. So far, no polarimetric signature at the 500 m radial resolution allows the distinction for intense rain events that result in effective damages, and the information from high-resolution data might become very valuable in this context. In this study, we select several documented localized intense rain events in Switzerland based among others on the damages caused, the data availability, the catchment area properties, and the hydrological response. From this list of events, we investigate the associated radar polarimetric variables and assess if their polarimetric signature at the high-resolution is distinctive or not from less extreme rain events. The insights obtained by such analysis will then be exploited to better detect localized intense rain events.

SWABIAN MOSES 2021: A HYDRO-METEO-ROLOGICAL MEASUREMENT CAMPAIGN

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MOSES (Modular Observation Solutions for Earth Systems) is a novel research infrastructure of the Helmholtz Association, developed by the Helmholtz Centres. It comprises highly flexible and mobile observation modules which are specifically designed to investigate the interactions of short-term events and long-term trends across Earth compartments. MOSES focusses on four event chains. Two of them, called “Hydrological Extremes” and “Heat Waves” joined to conduct a hydro-meteorological measurement campaign in the area of Neckar valley and Swabian Jura in southwestern Germany from May to September 2021. Besides several Helmholtz institutions further partners from local Universities, and the German Weather Service (DWD) participated. The campaign concluded the implementation phase of MOSES and begins a 10-year application phase. The primary research goal is to capture and explore interdisciplinary the entire chain of events: From the initiation and development of deep convection and associated transport of trace gases over the formation of (heavy) precipitation and hail, to the influence on soil moisture distribution, surface runoff and associated pollutant transport, to flooding. We will present an overview on the cooperation structure and coordination within the “Hydrological Extremes” working group as well as first results, especially from a supercell that crossed the investigation area on June, 23rd, 2021.

BRAIN AND ITS HYDROLOGICAL APPLICATION

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Tropical cyclonic disturbances such as cyclones and typhoons cause severe damage and losses in low/middle latitudes of the globe. To monitor such large-scale tropical disturbances, it is necessary to build an international 'borderless' network of more than hundred of weather radars existing in the countries of the South and Southeast Asian region. Although these radars have been operated individually by each national hydro-meteorological service in the region, sharing (or exchanging) the information of radar observations the 'borderless' network of the radars can be built substantially. To materialize the network, the Borderless Radar Information Networking over South and Southeast Asia (BRAIN) project was launched in April 2018. The BRAIN project also contributes to the Asian Precipitation Experiment (AsiaPEX) project as highlighted in GEWEX News (Vol. 29, No. 3, 2019). Building the BRAIN radar network may not be a perfect solution, that is, it may not be a 'correct' solution to make a stand against the tropical disturbances. However it can be materialized using existing local technologies (the existing radar facilities) and common knowledge (to utilize the radars most effectively), and thus it is a 'viable' solution in the region. There is 'no border' in the atmosphere. Thus the 'borderless' network to monitor the tropical disturbances in the atmosphere should be built as a common tool in the region.

A FLASH FLOOD WARNING SYSTEM FOR UNGAUGED BASINS IN THE TROPICAL CONTEXT OF LA REUNION ISLAND

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Early detection of flash floods, which are typically triggered by severe rainfall events, is still challenging due to large meteorological and hydrologic uncertainties at the spatial and temporal scales of interest. This is particularly true in tropical climate, where extreme precipitation events can be devastating. To better anticipate such events on the French island of La Reunion (Indian Ocean) and help mitigate flood damages, the French environmental agency of la Reunion (DEAL Reunion) is currently developing a flash flood warning system for small-to-medium ungauged basins (with a catchment area from 8 to 220 km^2). The system is based on a conceptual distributed model called SMASH (Spatially-distributed Modelling and ASsimilation for Hydrology, Jay-Allemand et al, 2020), run at a 250-m spatial resolution and a 15-min time step. The flow simulations are estimated in real-time by ingesting high-resolution radar-gauge rainfall grids produced by Meteo-France (product called ANTILOPE). The comparison of these discharges with reference flood quantiles (defined for different return periods) leads to identify real time maps of potential flooding. This communication aims to present the methodology developed to set up the warning system, and the first results obtained in real time during the 2021-2022 tornado season. Interests and limits of the current warning system will be discussed, as well as future planned operational enhancements.

Jay-Allemand et al.: On the potential of variational calibration for a fully distributed hydrological model: application on a Mediterranean catchment, Hydrol. Earth Syst. Sci., 24, 5519–5538, https://doi.org/10.5194/hess-24-5519-2020, 2020.

INCREASING THE RESILIENCE OF GREATER PARIS TO SPACE-TIME VARIABILITY OF HEAVY RAINFALLS: A CLOUD-BASED PLATFORM FOR THE ENPC X-BAND RADAR

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To deepen our understanding of local heavy rainfalls which under the threat of climate change will hit our cites even harder, an advanced urban hydro-meteorological observatory, the Fresnel platform of the ENPC Co-Innovation Lab, has been set-up. The mission of the Fresnel platform is to facilitate synergies between research and innovation in the pursuit of upstream research and the development of innovative downstream applications. The X-band radar has been the first major research facility for environmental observation, covering the greater Paris region at a pixel scale of about 100 m. Contrary to non-polarimetric radars, its polarimetric capacity enables to avoid any rain gauge calibration or adjustment. Its Doppler capacity yields estimates of the wind field, which could be helpful for hydrological and non-hydrological applications, e.g., hydrological and air quality nowcasts. As data accessibility, speed and reliability of infrastructure were major challenges, the platform was built as a cloud-based solution. The platform provides access, including by mobile phone, to graphical representations of various radar data in real time on https://radx.enpc.fr, whether for the general public or for professionals. The components that make up this platform are designed to be configurable for specific case studies using an adjustable visual interface. Depending on a case study, specific georeferenced components can be integrated other visual tools and forecasting systems. With profiled access for specialized services, it provides the necessary high resolution measurements, associated statistics and alerts in real and delayed time , which easily yield Big Data.

ON THE BENEFIT OF USING RADAR-BASED QPE FOR LANDSLIDE EARLY WARNING AT REGIONAL SCALE

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The challenge of landslide warning at regional scale consists of mapping the locations and timing of potential landslides with limited in situ observations over a large domain. In many cases, landslide warning systems rely on precipitation observations from rain gauge networks. However, at regional scale, the average density of rain gauge networks is many times insufficient and results in underestimated rainfall intensities in locations where landslides are actually triggered, thus resulting in underestimated landslide hazard and missed events. In this work we analyse the added value provided by QPE using radar rainfall estimates and compare it with alternative QPE products more frequently used in the field of landslide warning. The study focuses on the performance of the regional landslide early warning being developed in Catalonia (NE Spain) during year 2021 and some recent regional events that resulted in multiple landslides.

ACCOUNTING FOR SUBBASIN PRECIPITATION VARIABILITY IN FLOOD CHARACTERIZATION

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In the hydrological sciences, the outstanding challenge of regional modeling requires to capture common and event-specific hydrologic behaviors driven by rainfall and catchment physiography. The overall objective is to develop a robust understanding and predictive capability of how rainfall spatial variability influences flood peak, timing and duration across scales. Disentangling the interactions between precipitation forcing and hydrological processes is a challenge because of the lack of consistent and diverse observation datasets. We propose an analysis based on a database comprised of morphological, climatological, bioclimatic, streamflow, and precipitation data from over 21,000 flood-related rainfall events that occurred over 900+ basins over the Conterminous U.S. during 2002-2011. Our objective is to develop a robust understanding of how rainfall spatial variability impacts flash flood severity and to quantify its contribution relative to basin physiography. Event-based rainfall spatial moments representing sub-basin scale rainfall spatial variability are derived from a Multi-Radar/Multi-Sensor (MRMS) decadal archive of radar precipitation rates. The database has been subjected to rigorous quality controls, e.g. by accounting for radar beam height and percentage snow in basins. We specifically focus on the impact of rainfall variability on basin lag time and peak discharge. Data-driven supervised machine learning approaches and variable importance analysis enable to determine relevant hydrometeorological processes. Precipitation moments demonstrate significant explanatory power relating to lag time and peak value characterization. A large-scale approach is expected to provide a deeper insight into how sub-basin scale precipitation variability affects flooding.

RADAR NOWCASTING IN AUCKLAND, NEW ZEALAND: A CATCHMENT FOCUSED STUDY

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Short-duration, high-intensity rainfall events can pose a significant flood risk to communities located in small catchments with rapid hydrological response times. Alongside physical engineering works and managed retreat strategies, radar based nowcasting has been investigated as a tool for managing flooding hazards in support of warnings and evacuations. The Piha Stream catchment in Auckland, New Zealand has been adopted as a case study. The steep and naturally forested catchment is of 2x3km extent, and rises from the coast to about 300m altitude. Records from a permanent rain gauge, located near sea level, indicate that depth/durations of 23 mm in one hour have a recurrence interval of approximately 1.5 years. Hydrological modeling suggests that a catchment averaged accumulations of over 20mm in an hour can cause overtopping of the stream banks, resulting in flooding hazards to the community. A radar derived Quantitative Precipitation Estimation archive was exercised to provide initial conditions to pySTEPS in order to generate a 10-year record of hindcasts of catchment averaged accumulations. These hindcasts were then interrogated to investigate the suitability of nowcasting for a conceptual Piha Stream hazard forecasting system. While the nowcasts (after bias correction) were found to be formally reliable, it was difficult to find an acceptable compromise between probability of detection and false alarms at accumulation thresholds relevant to the hazard forecasting system beyond 30-min leadtime. For the Piha Stream catchment, peak water level lags rainfall by up to one hour. Results suggest warning leadtimes can be extended by coupling 30-min nowcasts to catchment models, but nowcasting for longer leadtimes risks degrading public confidence in the warning system.

SEAMLESS PREDICTION USING RADAR DATA, NOWCASTING AND NUMERICAL WEATHER PREDICTION MODELS, TO ENHANCE HYDROLOGICAL OPERATIONAL FORECASTING

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The prediction of rainfall is one of the key inputs for the forecast of potentially critical events related to hydrogeological hazard. The on-time forecast is essential for civil protection and early warning purposes because of the small spatial and temporal scales characterizing most of the events in the Mediterranean area, prone to the risk of flash floods and recurrently interested by them in the last years. To deal with this issue is setting up a hydro-meteorological modeling chain used to forecast rainfall and discharge which can be updated with high frequency. The work explores the possibility of using such a system at Italian National scale based on the following elements: a nowcasting a spectral-based nowcasting procedure, the Numerical Weather Prediction model WRF corrected with data assimilation with 3DVAR technique and Continuum, a continuous distributed hydrological model. The combination of the rainfall fields forecasted is performed testing different approach of blending, aimed at linearly combining the rainfall fields according to a reliability function which depends on different factors: the lead time, the quality of the starting radar data and the performances of the models assessed in real time. Beside that, in this study the information retrieved from the NWPS is exploited both to improve the Nowcasting Technique and to carry out the linear combination between Nowcasting and NWPS rainfall fields. The hydro-meteorological chain was tested on a period of 10 days of October 2019, during which relevant hydrological events occurred in some areas of Northern Italy.

INTERNATIONAL COOPERATION

EURADCLIM: THE EUROPEAN CLIMATOLOGICAL HIGH-RESOLUTION GAUGE-ADJUSTED RADAR RAINFALL DATASET

COHERENT RFI MONITORING IN THE EUMETNET OPERA RADAR NETWORK

OPERA5 – NEWS FROM THE RENEWAL OF THE PRODUCTION LINES

WMO OPERATIONAL WEATHER RADAR BEST PRACTICES GUIDE PREPARATIONS AND STATUS

EUROPEAN-WIDE HISTORIC PRECIPITATION ACCUMULATIONS BASED ON THE OPERA RAINFALL RATE COMPOSITES COLLECTED DURING 2013-2022

IMPACT BASED FORECASTING USING RADAR NETWORKS: THE HIGH ADDED VALUE OF OPERA NETWORK FOR EMERGENCY MANAGEMENT IN TIMES OF CLIMATE CHANGE ADAPTATION

EURADCLIM: THE EUROPEAN CLIMATOLOGICAL HIGH-RESOLUTION GAUGE-ADJUSTED RADAR RAINFALL DATASET

Aart Overeem[1]; Hidde Leijnse[1]; Else van den Besselaar[1]; Gerard van der Schrier[1]; Emiel van der Plas[1]; Jan Fokke Meirink[1]; Hylke de Vries[1]; Geert Lenderink[1]; Lotte de Vos[1]

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Project EURADCLIM, funded by KNMI's multi-annual strategic research programme, addresses the need for an accurate (sub-)daily rainfall product covering Europe. A climatological dataset of 1-h and 24-h rainfall depths at a 2-km grid is derived, which covers a large part of Europe for the period 2013 through 2019. The starting point is the OPERA gridded radar dataset of 15-min rainfall intensities, which is based on data from approximately 100-150 radars. EURADCLIM first applies methods to further remove non-meteorological echoes from these images by applying statistical methods and a satellite-based cloud type mask. Subsequently, the radar composites are merged with a pan-European dataset from more than 7000 rain gauges (ECA&D, data kindly provided by the European NMHSs) in order to substantially improve its quality. The methodology and datasets behind EURADCLIM are presented. The quality of precipitation estimates are evaluated against rain gauge data. EURADCLIM may serve as a reference for validation of weather prediction models and satellite precipitation products, which allows for improving them. EURADCLIM may also allow for better monitoring of rainfall extremes. A couple of showcases are presented highlighting the potential of EURADCLIM, e.g. for validation of a geostationary and the GPM IMERG satellite precipitation product.

COHERENT RFI MONITORING IN THE EUMETNET OPERA RADAR NETWORK

Vera Katharina Meyer[1]; Lukas Tüchler[1]; Annakaisa von Lerber[2]

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Radar frequency interferences (RFI) caused by wireless technology, which operates at same frequencies, such as RLAN devices and surveillance cameras, severely affect C-band radar measurements and can strongly impede operational weather monitoring scans up to several degrees in elevation. Affected radar beams lose important information and usually have to be dismissed. Radar operators deploy different RFI detection and monitoring tools tailored to their needs. Within the EUMETNET OPERA5 program a RFI detection and monitoring tool has been set up in autumn 2020 with the aim of establishing a comprehensive and centralized monitoring of RFI signatures within the OPERA radar network. The RFI signature detection algorithm analyzes data patterns in the unfiltered reflectivity along and across the rays following the approach developed by Osroda, K., Szturc, J., & Jurczyk, A. (2014). Monthly analyses for each radar site and the OPERA network are available for OPERA members. Since the algorithm is based solely on unfiltered reflectivity, the thresholds are set to rather underestimate the current situation. National monitoring algorithms, which use other parameters like signal quality or dual-pol parameters may provide more detailed analyses. After more than one year of continuous RLAN monitoring, it will be shown how RLAN devices affect the radar measurements within the OPERA network. The approach will be discussed with its benefits and limitations and the current situation with the trend as assessed by the algorithm will be presented. Ośródka, Katarzyna, Jan Szturc, and Anna Jurczyk. "Chain of data quality algorithms for 3-D single-polarization radar reflectivity (RADVOL-QC system)." Meteorological Applications 21.2 (2014): 256-270.

OPERA5 – NEWS FROM THE RENEWAL OF THE PRODUCTION LINES

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The Operational Program on the Exchange of Weather Radar Information (OPERA) has coordinated radar co-operation among national weather services in Europe for more than 20 years (www.eumetnet.eu/opera, Saltikoff et al. 2019). Since 2011, the OPERA data center (ODC) has created Pan-European radar composites every 15 min. The ODC produces three composites with a resolution of 2 km — maximum reflectivity, rain rate, and hourly accumulation. It also provides quality-controlled radar data for the numerical weather prediction (NWP) consortia for assimilation. The applications using OPERA data vary from nowcasting to flood warnings, and some users require advanced quality control and production of products, while others need the data as soon as possible. In the current OPERA phase 5 (2019-2023), the main focus is to replace the ODC with three new production lines that will be able to serve better the various needs of different user groups; i) the CUMULUS/STRATUS line is responsible for gathering the incoming radar data and forwarding this data to the other production lines. In future, this line can also provide the data for the independent processing outside OPERA, ii) the CIRRUS line is aimed to generate a maximum reflectivity composite (every 5-minute with 1 km horizontal resolution), and iii) the NIMBUS line will produce precipitation composites and the quality-controlled volume radar data for the purpose of the NWP assimilation. In addition, OPERA centrally monitors the network performance e.g. with solar monitoring method (Huuskonen and Holleman, 2007) and the level of RFI (Radio Frequency Interference) (separate presentation by V. Meyer et al.). At the conference, we will present the implemented steps of the renewed production lines as well as future plans.

WMO OPERATIONAL WEATHER RADAR BEST PRACTICES GUIDE PREPARATIONS AND STATUS

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The Joint Expert Team on Operational Weather Radar (JET-OWR) of the World Meteorological Organization (WMO) is preparing an eight-part Operational Weather Radar Best Practices Guide (BPG). The scope addresses the end-to-end of a complete weather radar system starting with the planning and sustainable resourcing of a national weather radar programme, and ending with a radar-based quantitative precipitation estimate (QPE). The respective BPG parts are guides to weather radar

A. Network Design
B. Technology
C. Procurement
D. Siting, Configuration and Scan Strategies
E. Calibration, Monitoring and Maintenance
F. Data Processing
G. Data Representation and International Exchange
H. Operational Weather Radar Glossary of Terminology

The BPG identifies typical challenges associated with each of these topics, and offers solutions for each, including essential literature references. Target audiences are managers (decision-makers) of weather radar networks and practitioners like engineers and software developers, of WMO's Members that are National Meteorological and Hydrological Services, both those embarking on the establishment of a national weather radar network and those that already have. The first complete version of the BPG is expected to be ready for vetting by the WMO's Infrastructure Commission later in 2022. While the exact publication form is yet undecided, the BPG is expected to complement existing material such as the chapter on weather radar in the WMO Guide on Instruments and Methods of Observation (GIMO), the International Standards Organization's "Meteorology — Weather radar — Part 1: System performance and operation" (ISO 19926-1:2019), and WMO Integrated Global Observing System (WIGOS) Manual and Guide.

EUROPEAN-WIDE HISTORIC PRECIPITATION ACCUMULATIONS BASED ON THE OPERA RAINFALL RATE COMPOSITES COLLECTED DURING 2013-2022

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Precipitation is one of the essential climate variables. There has been a constant need of a reliable sub-daily pan-European QPE dataset, in particular for hydrological applications and climate studies. Within the EU projects ERICHA, ANYWHERE and TAMIR, the radar-based precipitation rate composites produced by the EUMETNET-OPERA project have been used to produce the European-wide gauge-adjusted hourly precipitation accumulations since 2013, which have been used in the context of developing flash flood assessment and warning. From an end-user perspective of the OPERA data, despite some quality issues monitored for the past years, the present work analyses the added value of the gauge-adjusted radar precipitation historic dataset of 1-h accumulations (2 km grid, 2013-2022). These include i) the retrieved gridded Intensity-Duration thresholds and its application for European-wide flood hazard assessment within the OPERA coverage with the ERICHA system, ii) its application to produce a historic flash flood hazard dataset over Europe (2013-2022), and iii) preliminary analysis of the potential use of these results for climate impact assessment with the climate indicators from Copernicus C3S.

IMPACT BASED FORECASTING USING RADAR NETWORKS: THE HIGH ADDED VALUE OF OPERA NETWORK FOR EMERGENCY MANAGEMENT IN TIMES OF CLIMATE CHANGE ADAPTATION

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Impact-based forecasting is a key piece of the most advanced Early Warning Systems (EWS), and a crucial step ahead towards implementing the Multi Risk-Impact based EWS (MR-IEWS) required to confront the increase in frequencies and intensity we will see due to climate change worldwide in the next years. In the EU we have a considerable delay in achieving the inclusion of these Impact forecasting in the current weather forecasts, especially when we compare our reference warning systems (e.g. Meteoalarm) with the type of warnings already available in countries such as Japan, Australia, or China. In the last years, several EU projects (such as ERICHA, ANYWHERE, or TAMIR) have demonstrated methodologies to incorporate impact-based forecasting in Weather EWS. Particularly ANYWHERE (www.anywhere-h2020.eu) has operationally demonstrated the added value of the use of radar QPE and QPF to transform high-resolution evolution of heavy rainfall into impact-based EWS, especially during flash flood events, able to trigger early response and local self-protection plans to reduce vulnerabilities, damages, and deaths. As the recent events in central Europe during July 2021 have shown, climate change is not just increasing the frequency and intensity of these events, but also affecting places where they have not been previously observed. And the ERICHA (available through EFAS) and ANYWHERE operational products have shown how the OPERA radar network products can be converted into a crucial high added value, actionable information for the next generation of MR-IEWS required in the climate change adaptation process. An illustration of the OPERA added value based on several events, including the one in July 2021, will be shown and discussed.

MICROPHYSICS

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UTILITY OF GROUND BASED CLOUD RADAR TO OBSERVE TURBULENCE ON CLOUD DROPLETS TO RAINDROP TRANSITION

MIXED-PHASE CLOUD CHARACTERISTICS OVER A TROPICAL SITE USING CLOUD RADAR

CLOUD RADAR PERSPECTIVE ON TROPICAL CUMULUS CONGESTS CLOUD AND ITS ROLE ON THE RAINFALL

DISDRODB: A GLOBAL DATA BASE OF RAINDROP SIZE DISTRIBUTION OBSERVATIONS

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The raindrop size distribution (DSDs) describes the number and size distributions of raindrops in a volume of air. It is key to model the propagation of microwave signals through the atmosphere (crucial for telecommunication and remote sensing), to improve microphysical schemes in numerical weather prediction models, and to understand rain-related land surface processes (rainfall interception, soil erosion). Despite its importance, the spatial and temporal variability of the DSD remains poorly understood. This has motivated scientists all around the globe to deploy DSD recording instruments known as disdrometers, in order to collect DSD observations in various climatic regions. However, only a small fraction of this data is easily accessible. Data are stored in disparate formats with poor documentation, making them difficult to share, analyze, compare and re-use. Additionally, very limited software is currently publicly available for DSD processing. We recently undertook an initial effort to index, collect and homogenize DSD data sets across the globe, as well as to establish a global standard for DSD observation sharing. The envisioned publicly-available global database of well-maintained and homogenized disdrometer data (DISDRODB) aims to accelerate and advance precipitation research by promoting the mobilization of data archives currently scattered across various institutions. An open-source python package aims to enclose all algorithms for DISDRODB product generation and will provide an API to facilitate data preprocessing, analysis and visualization of disdrometer data. This contribution will present DISDRODB and its tools, based on a preliminary set of DSD observations from various regions in Europe.

CHARACTERISTICS OF RAINDROP SIZE DISTRIBUTION OBSERVED IN SOUTHERN CHINA IN DIFFERENT WEATHER SCENARIOS USING 2-D VIDEO DISDROMETER

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The characteristics of raindrop size distribution (DSD) in different weather scenarios have been studied using measurements from two-dimensional video disdrometer (2DVD) installed at Chek Lap Kok (CLK) in Hong Kong. Based on the precipitation classification by Wen et al. (2016), stratiform and convection precipitation types in each of the weather scenarios were identified, including cold surge, tropical cyclones' (TC) rainbands and monsoon trough, etc. Comparison was made with the DSD data collected from 2 sets of 2DVD installed respectively at Enping (EP) and Yangchuan (YC) in Guangdong to analyse any spatial variations in DSD over southern China. Preliminary analysis showed that the mass-weighted mean diameter (Dm) for stratiform precipitation fell largely in the range of 0.5 – 2 mm for rainfall intensity (R) below 15 mm/hr. For convective precipitation, Dm varied mostly from 1 to 3 mm. Based on the scatterplot of Dm and R, for convective precipitation with high R values (> 50 mm/hr), Dm seemed to have plateaued in around 2 mm. Further increase of R was mainly due to the increase in concentration of raindrops. The results were consistent with the findings of Wen et al. (2016) for DSD observed in East China. Using DSD data at CLK, EP and YC, the composite raindrop spectra (CRS) associated with the outer rainbands of TC Wipha in 2019 at the above three locations were found to be similar. Such similarity was also observed when comparing those CRSs associated with the rainbands of TCs Lionrock and Kompsau in 2021. Among all the analysed CRSs related to TC's rainbands, the maximum raindrop size was around 4 to 5 mm which was slightly higher than those observed by Tokay et al. (2008) in analysing the CRSs of TCs over the Atlantic ocean.

A PICASSO CASE-STUDY: CAN WE REPRODUCE ACCURATE OBSERVATIONS USING IN-SITU MEASURED PSDS AND SCATTERING FROM PARTICLE MODELS IN THE ARTS DATABASE?

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A combination of in-situ and remote sensing measurements of ice clouds is necessary to provide a deeper understanding of how different particles scatter radiation. To address this, a novel dataset has been obtained as part of the PICASSO campaign. The campaign involved combining in-situ observations (from a suite of instruments on board the FAAM BAe-146 aircraft) with co-located ground-based radar measurements at Chilbolton observatory in the UK. The ground-based radars at Chilbolton operated at three different frequencies of 3, 35 and 94GHz. Compared to using a single frequency, multi-frequency measurements allow for more accurate estimation of particle properties such as size (and consequently cloud ice water content (IWC)), shape/structure, and density. Here we show examples of data collected during the campaign, and examine whether particle models from the ARTS scattering database (Eriksson et al., 2018) are capable of reproducing accurate observations of radar reflectivity and multi-frequency radar parameters. Accurate co-location of observations from the aircraft and scanning radar were obtained using a unique tracking system. This allows us to directly compare measured radar reflectivity to forward modelled Z using in-situ PSDs and scattering data of particle models in the ARTS database. At times when all radars pointed vertically during aircraft overpasses, we forward model the dual wavelength ratios for 3-35-94 GHz and compare to observed profiles. We also forward model the Doppler spectra and compare to observations, allowing us to probe the realism in different parts of the size spectrum.

SUPERCOOLED LIQUID WATER AND SECONDARY ICE PRODUCTION IN KELVIN–HELMHOLTZ INSTABILITY AS REVEALED BY RADAR DOPPLER SPECTRA OBSERVATIONS

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In this study, supercooled liquid water and newly formed ice needles in a stratiform precipitation system are revealed by radar Doppler spectral analysis. We show, in detail, that the onset of drizzle and the presence of multiple populations of ice needles are associated with the Kelvin-Helmholtz (K-H) instability. The spectral width of supercooled liquid water mode in radar Doppler spectrum is used to identify a layer of increased turbulence. This layer collocates with a region of large liquid droplets that are characterized by reflectivity values exceeding -20 dBZ. The modelling study estimates that the concentration of these ice crystals is 3 ~ 8 L-1, which is at least one order of magnitude higher than that of primary ice nucleating particles. Therefore it is anticipated that K-H instability provides conditions favorable for enhanced droplet growth and formation of secondary ice particles. We have further recorded two events of SIP, in which we argue that one is rime-splintering and the other is freezing fragmentation, within 0.2 km.

IMPROVING RADAR-BASED PRECIPITATION TYPE CLASSIFICATIONS AT THE UK MET OFFICE

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A radar-based, in-situ hydrometeor classification algorithm (HCA) has been operational at the UK Met Office for a few years. The algorithm is based on a Fuzzy Logic framework – which includes membership functions developed at Meteo France – and has consistently been found to produce visually realistic-looking classifications – which are particularly useful for the identification of hail in convective situations. However, a requirement has been identified amongst the forecasting community for greater provision of probabilistic information – such that any classification may be associated with a corresponding degree of uncertainty. Related recent work at the Met Office has focused on the development of a melting layer detection algorithm (MLDA), which has been shown to provide reliable identification of the melting region using vertically-pointing scan data. It is proposed that this MLDA, which may be adapted to run with different types of input scan geometry, can be used to construct an improved, probabilistic classification scheme – one based on a Bayesian framework. In this sense, the real-time melting layer detection, if available, will provide the 'a priori' probability of frozen, melting, or liquid precipitation at a given point along the radar measurement beam, whereas the 'conditional' probability may be estimated using climatological datasets generated from historical melting layer identifications. This report describes the use of the MLDA output within a re-imagined in-situ HCA, and demonstrates how the MLDA may also be used to provide more information relating to the confidence of precipitation classifications at the surface – which is most often where the effects of high-impact weather types are felt.

NOVEL VIEW ON THE DENDRITIC GROWTH ZONE BY COMBINING TRIPLE-FREQUENCY RADAR AND SPECTRAL POLARIMETRY

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The dendritic growth zone (DGZ) centered around -15°C plays a key role in the formation of precipitable ice and snow particles. Particle growth by vapour deposition and subsequent aggregation are strongly enhanced in the DGZ. As a result, multiple radar observables display distinct features in the DGZ related to the plate-like particle shapes as well as rapid formation of aggregates. Numerous observational studies described these signatures in the past but a number of questions are still under debate. In this contribution we present a unique combined view on processes in the DGZ including zenith triple-frequency (X, Ka, W band) spectra and slat-viewing W band spectral polarimetry collected at a site close to Cologne, Germany. The post-processed dataset allows us to derive statistics of the obtained radar profiles for a wide range of winter clouds. After categorising all profiles by their maximum aggregate size in the DGZ using dual-wavelength ratios, we are able to connect aggregation with small particle characteristics revealed by polarimetric observables. While a number of previously published signatures can be confirmed with our measurements, we also found interesting new insights: One is related to the frequently observable mean Doppler velocity reduction in the DGZ which we are able to explain by a combination of new ice particle formation and updraft. Using spectral ZDR, we are also able to study the vertical evolution of the most asymmetric crystals independent of the presence of aggregates. Together with KDP, we find that small particle concentration remains enhanced also below the DGZ down to the -4°C level despite the ongoing aggregation visible in the multi-frequency observations. Possible responsible processes including secondary ice will be discussed.

EVALUATION OF STATE-OF-THE-ART POLARIMETRY-BASED ICE MICROPHYSICAL RETRIEVALS USING GROUND-BASED RADAR AND IN-SITU AIRBORNE MEASUREMENTS

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Polarimetric microphysical retrievals reveal a great potential for the evaluation of numerical models and data assimilation. However, the accuracy of ice microphysical retrievals is still poorly explored. To evaluate these retrievals and assess their accuracy, polarimetric radar measurements are spatially and temporally collocated with in-situ aircraft measurements obtained during the OLYMPEX campaign. Retrievals of IWC, Nt, and Dm of ice particles are assessed exploiting both an in-situ dataset obtained by the Citation aircraft and X-band Doppler on Wheels measurements. Sector averaged RHI scans are used to derive vertical profiles of microphysical retrievals. Comparison of these estimates with in-situ data provides insights into strengths, weaknesses, and accuracy of the retrievals, and quantifies the improvements of polarimetry-informed retrievals compared to conventional, non-polarimetric ones. In particular, the recently introduced hybrid IWC retrieval exploiting reflectivity ZH, differential reflectivity ZDR and specific differential phase KDP outperforms other retrievals based on either (ZH, ZDR) or (ZH, KDP) or non-polarimetric retrievals in terms of correlations with in-situ measurements and the root mean square error. Only IWC retrievals based on optimal fitting parameters from Cayenne campaign data using either KDP or ZDR and KDP achieve comparable correlations, but exhibit a higher root mean square error. ZH-based retrievals for Dm partly exhibit significant deviations from airborne in-situ measurements, while polarimetric retrievals show a good agreement. Based on our evaluation study, the most accurate ice microphysical retrievals are now used to evaluate the ICON model to reveal potential biases and deficiencies as a first step towards model improvements.

TOWARDS A DATABASE OF SCATTERING PROPERTIES OF ENSEMBLE RATHER THAN INDIVIDUAL ICE AND SNOW PARTICLES

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Scattering properties of ice and snow particles are essential components but are also one of the biggest challenges for radar forward operators. Large progress has been made during recent years in developing databases of scattering properties for individual particles including an increasing number of more and more realistic particle habits. However, by assuming that the scattering properties of hydrometeors are represented by single particles, we strongly idealize the fact that any sensor observes scattering from an ensemble of particles rather than one specific habit. Recently, the so-called Self-similar Rayleigh Gans Approximation (SSRGA) has been presented as a new way to tackle this problem. SSRGA leverages the self-similarity of snow aggregates to derive their ensemble scattering properties with the Rayleigh-Gans approximation. After deriving a number of coefficients for the particle structures, all non-polarimetric scattering properties can be derived for a wide frequency range with analytic formulas. Those analytic formulas could be easily parametrized according to any property of the ensemble such as rime mass fraction, aspect ratio, or monomer type, making SSRGA easy to combine with advanced numerical microphysics schemes. In this contribution, we will present the performance of the SSRGA derived for over 100k various aggregates and compare their physical and scattering properties with well-established scattering databases. We will also show evaluations of the new SSRGA to scattering signatures observed by multi-frequency radar observations. Finally, a python tool will be introduced which allows the scientific community to easily infer scattering and particle properties similar to well-established single-scattering scattering databases.

DUAL-FREQUENCY SPECTRAL RADAR RETRIEVAL OF SNOWFALL MICROPHYSICS: A DEEP-LEARNING BASED APPROACH

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Better understanding and modeling of snowfall microphysical properties and processes is a key challenge in atmospheric science: it is crucial for snowfall quantification, remote sensing, and weather prediction in general. The use of meteorological radars for this purpose has become quite popular, in particular through two techniques: multi-frequency radar measurements or radar Doppler spectra. We propose a novel approach that makes the most of both techniques while relaxing some assumptions on beam matching and non-turbulent atmosphere. The approach relies on a two-step deep-learning framework inspired from data compression techniques: an encoder maps a high-dimensional signal to a lower-dimensional "latent" space, while the decoder reconstructs the original signal from this latent space. Here, dual-frequency Doppler spectrograms constitute the high-dimensional input, while the dimensions of the latent space are constrained to represent the snowfall properties which we seek to retrieve. First, a decoder neural network is trained to generate Doppler spectra from a set of microphysical variables, using simulations from the radiative transfer model PAMTRA as training data. In a second step, the encoder network learns the inverse mapping, from dual-frequency spectrograms to the microphysical latent space; this training is performed directly on real data. The method was implemented on X- and W-band data from the ICE GENESIS campaign that took place in the Swiss Jura in January 2021. An in-depth assessment of the retrieval's accuracy was performed through comparisons with aircraft in-situ measurements collected during 3 precipitation events. The agreement is good and opens up possibilities for acute characterization of snowfall microphysics on larger datasets.

NEW INSIGHTS ON THE PREVALENCE OF DRIZZLE IN MARINE STRATOCUMULUS CLOUDS OBSERVED FROM MILLIMETER-WAVELENGTH RADAR

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An accurate description of drizzle existence in warm marine clouds is a foundation for understanding the roles of drizzle in cloud microphysical and dynamical processes. Radar reflectivity observed from millimeter-wavelength radar is commonly used for drizzle detection, but is unable to identify weak drizzle signals. Conversely, Doppler skewness is a measure of Doppler spectral symmetry and has proven to be a more sensitive quantity for the detection of drizzle embryos. In this study, a machine-learning-based technique that uses radar reflectivity and skewness for detecting small drizzle particles is presented using millimeter-wavelength radars operated by the Atmospheric Radiation Measurement (ARM) program. The drizzle detection algorithm is applied to three ARM observational campaigns to investigate the drizzle occurrence in marine boundary layer clouds. It is found that drizzle is far more ubiquitous than previously thought, the traditional radar reflectivity-based approach significantly underestimates the drizzle occurrence, especially in thin clouds with liquid water path lower than 50 gm^(-2). The drizzle occurrence in marine boundary layer clouds differs among the three ARM campaigns, indicating that drizzle formation which is controlled by the microphysical process is regime-dependent. To further investigate the drizzle formation process, observations collected from a 94-GHz cloud profiling radar system (ROGER) will be shown to indicate its potential application in warm cloud research. The ultra fine-resolution measurements provided by ROGER can resolve more detailed dynamical structures and improve our understanding of the drizzle formation mechanism in the cloud process.

INFLUENCE OF KELVIN-HELMHOLTZ WAVE ON ICE MICROPHYSICAL PROCESSES AS REVEALED BY POLARIMETRIC RADARS AND VERTICALLY POINTING RADARS

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Kelvin-Helmholtz (KH) wave occurs in the environment of strong wind shear and low static stability. In recent decades, several studies provided observational evidence from radar and airborne instruments as the KH wave impacts the microphysical processes within the wave and affects quantitative surface precipitation. Despite the research efforts, microphysical processes within the in-cloud KH wave have not yet been fully understood due to the limited number of measurements. The in-cloud KH and its impact on ice microphysical processes were characterized by the aid of comprehensive in-situ and remote-sensing measurements collected during the ICE-POP 2018 (International Collaborative Experiments for Pyeongchang 2018 Olympic and Paralympic winter games) field campaign. In this study, several KH wave events were identified in a strong shear environment and well captured by the collocated microphysical instruments. Vertical velocity fluctuations within the KH wave modulated radar moments (e.g., Z, ZDR, and ρHV) and Doppler spectrum characteristics within and beneath the KH wave. The increase of spectral skewness at vertically pointing radar suggests that the microphysical behavior associated with the KH wave leads to the pronounced production of smaller particles. The resultant particle size distribution at the surface also implies that the KH wave contributes to the increase in the number of small particles. This study provides possible microphysical mechanisms to explain the observed characteristics associated with the KH waves observed at several different events.

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INVESTIGATING MICRO-PHYSICAL PROCESSES IN ARCTIC MIXED-PHASE CLOUDS USING CLOUD RADAR DOPPLER SPECTRUM SKEWNESS

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Low-level mixed-phase clouds occur frequently in the Arctic. They are known to be important for the surface energy balance but are not well represented in climate models. Our work aims to gain understanding of how features of the cloud radar Doppler spectra can be used to evaluate micro-physical processes in shallow mixed-phase clouds (MPC). The study utilized 94 GHz vertically pointing cloud radar observations, which were carried out at the Arctic Research Base AWIPEV in Ny-Ålesund, Svalbard. Higher moments of the cloud radar Doppler spectra have rarely been utilized for Arctic MPCs. Similar to the case study in Kalesse et al. (2016; https://doi.org/10.1175/MWR-D-16-0155.1), we found features in the skewness profiles that relate to changes in the partitioning between liquid and ice. An algorithm to detect the positive-turning-negative skewness profile, describing the change from liquid- to ice-dominated radar signal when moving downwards from cloud top, was developed. The feature was found in 60% of the persistent low-level MPCs identified in the 2.5-year data set. We further evaluated the occurrence and variation of the skewness feature in combination with other radar parameters, the liquid water path, and cloud top temperature. Our investigation suggests that close to cloud top, ice depositional growth is likely impacting skewness. We conclude that skewness can provide insights into the early stages of precipitation formation. The work presented contributes to the understanding of how the moments of the Doppler spectra, especially skewness, can be used for interpreting micro-physical properties and processes in MPCs. Furthermore, by using a radar forward operator we will be able to evaluate model simulations of MPCs directly in the observational space.

FALL VELOCITY OF MELTING SNOW PARTICLES EXAMINED IN ENSEMBLES

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The current parameterizations of melting particles e.g. changes in fall velocity or shape as a function of melted mass fraction, are based on, although detailed, but just a few studies. For example, one often used parameterization for the changes in fall velocity as a function of melting is based on the study of 45 falling snowflakes (Mitra et al. 1990). They showed that the fall velocity transition is not linear as a function of melting fraction, but there is a slow linear increase for small fractions and a rapid increase for fractions larger than 0.7. Here, we would like to present the preliminary results of the properties of melting particles investigated with Precipitation Imaging Package (PIP), a video disdrometer. We have a dataset of seven years with more than a hundred melting snow events. We have analysed the changes in the melting particle properties (shape, fall velocity) and linked these with the environmental conditions. The particle properties are also studied as a function of estimated melted mass fraction with a simple 1D – melting layer model, and the goal is to parametrize the particle properties influenced by the melting. While this method cannot observe the progress of melting for individual particles, the melting process can be resolved statistically by sampling particles in different stages of melting. Our preliminary analysis using 5-minute averages show that we can observe the rapid transition in the fall speeds from a melting snow particle to a rain drop, however in the conference we would like to present more detailed analysis performed particle by particle basis to capture the threshold of melted mass fraction where this change occurs and show its dependence on the particle habit.

THE DYNAMICS AND MICROPHYSICS OF HIGH-LATITUDE CLOUDS DURING THE COMBLE FIELD EXPERIMENT

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The Cold-Air Outbreaks (CAOs) in the Marine Boundary Layer Experiment (COMBLE) was conducted successfully between December 1st, 2019 and May 31st, 2020 around the Norwegian Sea. The main objective of COMBLE is to quantify the properties of shallow convective clouds that develop as part of an air-mass transformation process when cold air blows over open water. Specifically, the experiment aims to describe the mesoscale organization of clouds and precipitation during CAOs and to investigate the dynamics, cloud properties and precipitation in boundary layer convection. COMBLE deployed the ARM Mobile Facility (AMF) #1 along the coast of northern Scandinavia, at an Arctic latitude (70°N), and an array of additional instruments on Bear Island (75°N) in the Norwegian Sea. The instruments deployed at these two sites collected a large array of in-situ and remote sensing observations of atmospheric conditions, clouds, precipitation, and aerosol. This study focused on 13 CAO days during the 6-month observational period. The Ka-band Zenith-pointing Radar (KAZR) observations are used to provide the complete characterization of the vertical air motion and eddy dissipation rate above and below the cloud base. Updraft cores are isolated, and distributions of updraft characteristics (width, depth, and magnitude) are provided. We show distributions of updraft magnitude as a function of depth, and we compute the same updraft characteristics at different estimated horizontal resolutions. Finally, the KAZR and disdrometer observations are combined to delineate the type of precipitation reaching the surface.

AGGREGATION IN ARCTIC SHALLOW MIXED-PHASE CLOUDS IS ENHANCED BY DENDRITIC GROWTH AND ABSENT CLOSE TO THE MELTING LEVEL: EVIDENCE FROM LONG-TERM REMOTE SENSING OBSERVATIONS IN NY-ÅLESUND

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Shallow mixed-phase clouds (SMPCs) are ubiquitous in the Arctic, and are known to significantly impact the surface energy budget. However, our incomplete understanding of how they develop precipitation is likely to affect our ability to accurately simulate them. The significance of different precipitation formation processes for Arctic SMPCs has been in fact widely overlooked. We statistically assess the significance of aggregation for the formation of precipitation in Arctic SMPCs, employing a 3-year dataset of ground-based remote sensing observations taken in Ny-Ålesund, Svalbard. Dual-wavelength ratio (DWR) is obtained from two vertically-pointing Doppler radar systems, a K-band precipitation radar, the MRR-2, and a W-band cloud radar. DWR is used as a proxy for the characteristic size of the particle population, and matched with Doppler velocity and temperature retrievals to identify situations when the ice growth is dominated by aggregation. High DWR signals are predominantly observed when temperatures compatible with dendritic growth, especially in the -15 to -10°C range, are found above the liquid base of the cloud. Low fall speeds strongly suggests that these high-DWR particles are due to aggregation of dendritic particles. The occurrence of high DWR signatures is observed in limited regions in the cloud deck, suggesting that dynamical processes might be needed to fully explain these signatures. Surprisingly, we find no evidence of enhanced aggregation at temperatures above -5°C in Arctic SMPCs. This is typically observed in mid-latitude clouds, and in deeper cloud systems in Ny-Ålesund as well. We hypothesize that ice particles sedimenting from higher levels might be an essential component needed to trigger enhanced aggregation above -5°C.

EVALUATION OF MELTING LAYERS DETECTED VIA DWD'S C-BAND RADAR AND MRR

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The melting layer describes the height in the atmosphere in which frozen precipitation is thawing. Knowing its depth and location is important for nowcasting applications especially in spring and autumn. Often, model-predicted temperature profiles are used by hydrometeor classification schemes or quantitative precipitation estimation to determine the location of the melting layer. It is well known that the melting layer can be seen as a substantial increase in reflectivity in weather radar data and its signature is also distinctly visible in dual pol radar moments. We present the evaluation of the melting layer detection using DWD's C-Band research radar Hohenpeißenberg. The height and extent of the melting layer was calculated over several months from 90°-elevation BirdBath scans using the gradients in a pseudo-variable constructed from the reflectivity and the cross-correlation coefficient, closely following Wolfensberger et al. (2016). The usability of other radar moments is explored as well. The high vertical (25m) and temporal (5-min) resolution of the birdbath data enables a detailed view of the evolution of the melting layer height and depth over time. Results are evaluated against the melting layer heights determined by a collocated micro rain radar (MRR) and radiosonde measurements. We also explore a sector-wise melting layer detection via quasi-vertical profiles from radar sweeps at 25° elevation in order to identify further data points for the location of the melting layer at a horizontal distance of the radar.

MICROPHYSICAL FEATURES OF TYPHOON AND NON-TYPHOON RAINFALL OBSERVED IN TAIWAN, AN ISLAND IN THE NORTHWESTERN PACIFIC

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Information about the raindrop size distribution (RSD) is vital for comprehending the precipitation microphysics, improving the rainfall estimation algorithms, and appraising the rainfall erosivity. Previous research has revealed that the RSD exhibits diversity with geographical location and weather type, which leads to the assessment of the region and weather-specific RSDs. Based on long-term (2004 to 2016) disdrometer measurements in northern Taiwan, this study attempts to demonstrate the RSD aspects of summer seasons that were bifurcated into two weather conditions, namely typhoon (TY) and non-typhoon (NTY) rainfall. The results show a higher concentration of small drops and a lower concentration of large-sized drops in TY compared to NTY rainfall, and this behavior persisted even after characterizing the RSDs into different rainfall rate classes. RSDs expressed in gamma parameters show higher mass-weighted mean diameter (Dm) and lower normalized intercept parameter (Nw) values in NTY than TY rainfall. Moreover, sorting these two weather conditions (TY and NTY rainfall) into stratiform and convective regimes revealed a larger Dm in NTY than in TY rainfall. The RSD empirical relations used in the valuation of rainfall rate (Z–R, Dm–R, and Nw–R) and rainfall kinetic energy (KE–R and KE–Dm) were enumerated for TY and NTY rainfall, and they exhibited profound diversity between these two weather conditions. Attributions of RSD variability between the TY and NTY rainfall to the thermodynamical and microphysical processes are elucidated with the aid of reanalysis, remote sensing, and ground-based data sets.

ANALYSIS OF CHARGE STRUCTURE IN A TYPICAL DEEP CONVECTION USING C-BAND POLARIMETRIC RADAR AND LF-BAND THREE-DIMENSIONAL LIGHTNING MAPPER

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A tripole charge structure in typical deep convection is explained by the ice crystal–graupel collision charging mechanism as follows: wet graupels with more than −10°C are charged in positive (lower positive charge: LP); dry graupels less than −10°C are charged in the negative (main negative charge: MN); and ice crystals charged in positive are lofted above the MN (main positive charge: MP). Thus, the charge distribution and precipitation particles are closely related, and the charge distribution may be estimated from precipitation particles. The three-dimensional distribution of precipitation particles can be obtained from the hydrometeor classification algorithm (HCA) using a C-band dual-polarization radar. In addition, the three-dimensional charge distribution can be obtained from three-dimensional lightning mapper data. In this study, we compared the three-dimensional HCA results and the three-dimensional charge distribution in order to clarify the relationship between the charge structure and the precipitation distribution structure during the developing period of typical deep convection. As a result of the comparison, the MN has a very good correspondence with graupels, consistent with the ice crystal–graupel collision charging mechanism. Meanwhile, the precipitation particles observed in the LP region were composed of raindrops and/or mixing with raindrops, rather than graupels with below −10°C altitudes. In addition, the positively-charged rain-related particles are located in the core of convective cells with above 0°C altitudes and are corresponding to column structure of differential reflectivity and specific differential phase. These results show that rain-related particles with updrafts possibly contribute generation of the LP.

THE LINK BETWEEN RAIN AND ICE MICROPHYSICS ACROSS THE MELTING LAYER

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By exploiting measurements from vertically pointing multi-frequency Doppler radars this study investigates to what degree the information about the rain can help in understanding the microphysics of the ice cloud above. The analysis is limited to stratiform precipitation where melting signatures are easy to detect. Our results confirm the widely accepted expectation that the mass flux through the melting zone is well preserved when averaging on long-time scales. For the 6-hour case study period, the total accumulation of rain (2.65mm) and the melted equivalent accumulation of snow (2.60mm) show only a 2% difference. Nevertheless, during some periods large discrepancies between precipitation rates are reported. For instance, when large aggregated snowflakes occur above the freezing level the snowfall rate is approximately 33% larger than the corresponding rainfall rate below. In turn, the mass flux in rain was usually greater than in ice when dense snowflakes are detected. We hypothesise that these discrepancies are associated to the relative humidity changes within the melting layer, with the regions dominated by rimed snow more likely to be supersaturated. Moreover, it is shown that, not only the mass flux but also the mean (mass weighted) size of particles below and above the melting zone are strongly linked. On average, the melted equivalent diameter of ice is 21% larger than the diameter of rain underneath, with low uncertainty on this parameter (~0.12 mm only). This prediction leads to slight underestimation of the ice size during aggregation, potentially due to the breakup of melting snowflakes, and to overestimation for dense ice particles. These results are based only on the 6-h case study and it is advisable to confirm them on long-term observations.

STUDYING DIFFERENCES IN SNOWFALL MICROPHYSICS WITH SURFACE OBSERVATIONS AT GPM GROUND VALIDATION SITES

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While monitoring snowfall on a global scale, such as in Global Precipitation Measurement (GPM) mission, a question arises about the similarity of snowfall characteristics and constraints utilized in the retrievals. Certain microphysical processes appear more frequently in some parts of the world than in others and therefore, statistically, the snowfall characteristics depend on the location. As part of the GPM ground validation program, similar instrumentation suites are deployed to different parts of the world. This provides an opportunity to study snowfall microphysics using the same methodology. The main instrument deployed at all sites is a video disdrometer, the Precipitation Imaging Package (PIP) and the mass retrieval of the falling particles is performed as described in von Lerber et al., 2017. In this study, we compare snowfall microphysics between three GPM ground validation sites: Hyytiälä (HYY, Finland), CARE (Canada), and Marquette (MQT, USA). HYY is an inland site, thus lake effect snow (LES) seldom reaches the site, whereas the vicinity of the Great Lakes produces LES snow blizzards, typically associated with winter cyclones to MQT and CARE. We show here the differences in the measured Particle Size Distributions (PSDs) and retrieved masses of snow particles. For example, the higher values of intercept parameter N0 and the slope parameter, lambda, are associated with synoptic cases (high number of small particles) and the lower values of the lambda are more frequent with LES events (smaller numbers of larger particles). Statistically speaking, in HYY the climatology seems to favour riming growth aloft as the snow particles are approximately three times heavier than the particles observed at the CARE or MQT sites.

CLOUDS BLOWING IN THE WIND: MOMENTUM TRANSPORT IN CLOUDY BOUNDARY LAYERS OBSERVED FROM COLLOCATED WIND LIDAR AND CLOUD RADARS AND SIMULATED WITH DALES.

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Convective clouds may be associated with substantial transport of momentum. Much of what we know about convective momentum transport stems from high-resolution simulations because high-resolution measurements of the wind profile are rare. This study exploits ground-based remote sensing techniques to visualize wind below and within clouds and their surroundings, to assess momentum transport. The Tracing Convective Momentum Transport in Complex Cloudy Atmospheres experiment (CMTRACE) took place at the experimental Cabauw site (The Netherlands) between 13.09.2021 and 03.10.2021. The goal of CMTRACE was to provide continuous profiles of horizontal and vertical wind with a temporal resolution of ~1 minute and vertical resolution of ~50 m within the cloud and sub-cloud layers to improve our understanding of the role of momentum transport from cloud- to mesoscales. A scanning wind lidar provided the observations in the sub-cloud layer, while in the cloud layer, one scanning and one vertically pointing cloud radar provided observations. During CMTRACE, we sampled various cloud regimes including non-precipitating shallow cumulus clouds, deep convective clouds and stratiform clouds. In this study, we illustrate some of the most interesting CMTRACE observations that reveal the circulations (winds) near clouds and present statistical analyses as a function of different cloud regimes. Specifically, we calculate profiles of wind fluctuations and their cross-correlations to address the momentum flux carried on cloud- and mesoscale scales. The observations from different cloud regimes (e.g. clear sky, shallow convection and frontal passage) are compared to momentum fluxes and wind variability in the Dutch Large-Eddy Simulations nested on the experimental site for the selected days.

COMPARISON OF WINDPROFILER AND A MICRO-RAIN RADAR PRECIPITATION OBSERVATIONS

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The Cerdanya-2017 field campaign was a collaborative international effort to study several mountain meteorology phenomena such as cold pools, mountain waves and orographic precipitation effects. It took place from October 2016 to April 2017 in the eastern Pyrenees mountain massif, near the border between Andorra, France and Spain (Udina et al 2020). This study focuses on the comparison of various parameters between two remote sensing instruments: a UHF windprofiler (Degreane PCL 1300) and a K-band micro-rain radar (Metek MRR2). The instruments were located 2.4 km apart and provided detailed time series of precipitation profiles, each one with their specific sampling characteristics (wavelength, and temporal and spatial resolution) so some differences are expected between the two resulting datasets. Data examined included precipitation vertical speed, radar reflectivity and hydrometeor type estimates. We considered the recent processing of Micro Rain Radar proposed by Garcia-Benadí et al (2020) and also specific processing to wind profiler developed for this study. Results include a discussion about the information provided by each instrument type and its compatibility. This research was partly funded by projects CGL2015-65627-C3-2-R (MINECO/FEDER), CGL2016-81828-REDT (AEI) and RTI2018-098693-B643-C32 (AEI).

VARIABILITY OF MESOSCALE CLOUD AND PRECIPITATION STRUCTURES DURING NEAR-FREEZING SURFACE CONDITIONS USING GROUND-BASED RADAR OBSERVATIONS FROM WINTRE-MIX

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While near-freezing precipitation events have large impacts on human and natural systems, fundamental challenges remain in our ability to adequately observe, diagnose, simulate, and predict these events. The Winter Precipitation Type Research Multiscale Experiment (WINTRE-MIX) was designed to study the multiscale processes influencing the variability and predictability of p-type (rain, drizzle, freezing rain, freezing drizzle, wet snow, ice pellets, and snow) and the amount under near-freezing surface conditions. The experiment was conducted in February-March 2022 in the vicinity of Montreal. The field campaign utilized operational networks (New York State Mesonet, Canada Foundation of Innovation Climate Sentinels) and research instruments like the NRC Convair-580 research aircraft with a suite of in-situ and remote sensors, one C-band on Wheels (COW), and two X-band Doppler on Wheels (DOWs) radars, four mobile sounding systems, and four manual p-type observation stations. We will analyze the variability of mesoscale cloud and precipitation structures and mesoscale flow during near-freezing conditions using ground-based radars. Small-scale vertical motions within clouds (convective generating cells, coherent wave motions, and shear-driven turbulence) are shown to enhance the formation of ice in supercooled clouds, leading to the enhancement of surface snow or rain. Mesoscale precipitation bands, produced by either convergence of mesoscale terrain-channeled flows or by embedded disturbances within synoptic storms, locally enhance vertical motion, increase cloud depth, and intensify precipitation rates.

DERIVING THE FULL 4-PI STERADIAN SINGLE SCATTERING PROPERTIES FROM QUADRATURE NODES FOR COMPLEX HYDROMETEORS

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As multiple studies have shown, polarization signals from microwave radiometers indicate that solid precipitation hydrometeors are likely preferentially oriented rather than uniformly randomly oriented. In order to improve the quantitative retrieval of precipitation, we must take into consideration the hydrometeor's preferential orientation distribution, which is likely to vary depending on the size, shape, and density of the hydrometeor in a given atmospheric condition. Since the information is not available a priori, we must thus obtain scattering solutions for all possible orientations of a hydrometeor in the full 4*pi steradian to be able to derive the orientation-averaged single-scattering properties for any orientation distribution to use in quantitative retrievals and sensitivity studies. Because solving for the scattering of realistic solid hydrometeors is quite computationally intensive, it is more economical to save the solution once it has been obtained to avoid solving the same problem repeatedly. However, it also takes considerable storage space to save the scattering solution even for one single orientation. Thus, storage cost increases when the solutions for more orientations need to be saved. Economy again motivates us to minimize the number of orientations needed by using a high-order quadrature. We report the effectiveness of using MIDAS, short for MoM Integral-equation Decomposition for Arbitrarily shaped Scatterers, solutions at the quadrature nodes (corresponding to hydrometeor orientations) of a high-order quadrature scheme to recover the solution at any orientation in the 4-pi steradian. In addition, we highlight the advantage of using MIDAS for this purpose over using the popular discrete dipole approaches.

SENSITIVITY ANALYSIS OF μ-Λ RELATIONSHIP IN STRATIFORM RAIN

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Raindrop size distributions (DSD) considered to be the key source of uncertainty in quantitative precipitation estimations from ground based radars and/or satellites. Thanks to dual-polarization capabilities, crucial information about the DSD in a given volume of air can be retrieved. A widely accepted mathematical model to approximate naturally occurring DSDs is the gamma distribution. However, in order to reduce the number of free parameters a common DSD retrieval method requires an additional constrain between the shape (μ) and slope (Λ) parameters which are linked by a deterministic relationship. In the literature, μ-Λ relationships are often taken for granted and applied without much critical discussion. In this study, we take another look at this important issue by conducting a detailed analysis of μ-Λ relations. Crucial aspects of our research include the sensitivity of μ-Λ relations to the temporal aggregation scale, drop concentration, inter-event variability and adequacy of the gamma distribution model. All these issues were investigated using DSD data collected by a Parsivel optical disdrometer during several episodes of light to moderate stratiform rain in the Netherlands. Our results show that μ-Λ relationships in stratiform rain proved quite robust to the choice of the temporal sampling resolution, validity of the gamma model hypothesis, sample size and event by event variability. This can be explained by the fact that the DSD data in this study were comprised of rather similar stratiform rain events with no convective rain periods.

MICROPHYSICAL PROCESSES IN EMBEDDED CONVECTIVE CELLS IN LANDFALLING TROPICAL CYCLONE NIVAR USING X-BAND DUAL POLARIZATION RADAR

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Dual-polarization radar for observing precipitation at X-band (DROP-X) has been used to track embedded convective cells within the NIVAR cyclone to understand the microphysical processes in their growth and decay. A total of 4 cells have been considered in this study, in which 2 cells (Cell-I and Cell-II)are observed in the inner rainband, and the other 2 (cell-III, and a wide convective cell)are in the outer rainband. Observations reveal that the microphysical processes associated with convective cells embedded in various regions of a TC are different. Size sorting associated with the developing phase of Cell-I results in decrease ofreflectivity factor at horizontal polarization (ZH) and ρHV and enhancement in differential reflectivity (ZDR) below 4 km, while above 4 km predominance of riming is observed. Below 4 km raindrop growth and decay processes are in equilibrium in the mature stage, while collision-coalescence process is dominant in the decay phase. Contour frequency by altitude diagrams for polarimetric parameters at different stages show that the distributions are wider for mature stage. The core of Cell-II depicts the predominance of depositional growth of ice crystals during the developing and mature stages above 4 km and raindrops growth by the collision-coalescence process below the melting layer. The size of the raindrops is found to be smaller in the decay phase (~ 1.6 mm) than in the developing and mature phases (~ 2 mm) of Cell-II. Cell-III and wide convective regions in the outer rainband show the collisional breakup of raindrops below 3 km and dominant riming above 5 km. These results are compared and contrasted with those obtained at other locations and also with those inferred from other instruments, like disdrometer.

ANALYSIS OF DYNAMIC AND MICROPHYSICAL CHARACTERISTICS OF DIFFERENT PRECIPITATION TYPES DERIVED FROM VOLUMETRIC DUAL-POLARIMETRIC RADAR OBSERVATIONS

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The regions of stratiform and convective clouds are formed by different developing mechanisms. These different regions can be identified by an algorithm of precipitation types and their characteristics can be investigated by dual-polarimetric observations. We first constructed the optimized categorization algorithm for the various precipitation types in Korea and then investigate their physical and microphysical properties using dual-polarization variables and dynamical attributes (e.g., vertical velocity, and divergence). The classification method is developed using the SL3D (Storm Labeling in Three Dimensions) and feature parameters (e.g., vertical integrated liquid water contents and mean reflectivity). The precipitation types are discriminated into 8 categories such as precipitation and non-precipitation stratiform, convection, updraft, deep system, shallow system, anvil (or high cloud), and low (or mid) cloud. We studied the vertical structure of dynamical characteristics for precipitation types. The generalized microphysical parameters (N0' and Dm) are also derived and their vertical distribution is investigated. The bright band appeared at 4.5~5.5 km altitude in stratiform and deep system as shown in the vertical profiles of ZH and ZDR. The convergence (divergence) patterns of convection and updraft regions are distinctive in lower (higher) atmospheric layers. The Dm in rain regions was almost constant value (0.99 mm) in stratiform and was slightly higher (about 1.2 mm) in convection and updraft regions. We will further explore the microphysical and dynamic characteristics to understand the formation mechanism of precipitation types and their implication.

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EVALUATION OF VERTICAL VARIABILITY OF PRECIPITATION THROUGH MICRO RAIN RADAR MEASUREMENTS IN ROME

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The accurate knowledge of the vertical variability of precipitation if useful in different research fields such as for a deeper understanding of the physical processes involved in the evolution of the precipitation systems, for the characterization of the precipitation type, for the developing of accurate numerical prediction models for quantitative precipitation forecasts and for the improvement of the quantitative precipitation estimation from remote sensing devices. Space-borne and ground-based weather radars can provide some information regarding the vertical structure of precipitation however the use of a Micro Rain Radar (MRR) allows to have data with much higher vertical resolution and much closer to the ground. This study investigates the vertical variability of precipitation through the analysis of high temporal and spatial resolution data collected by an MRR PRO installed on the roof of the Institute of Atmospheric Sciences and Climate (ISAC) of National Research Council of Italy (CNR) in Rome. The MRR PRO is vertically pointing K-band radar that measures power spectra from which vertical profile of Drop Size Distribution (DSD) from the ground level up to few kilometers can be retrieved. The MRR PRO at ISAC-CNR has been installed on December 2021 with 138 range gates, an averaging time of 10 sec and a range resolution of 35 m providing data from the ground up to 4500 m above the ground level. The vertical variability of precipitation has been evaluated using a three-parameter exponential function to determine the correlation distance of DSD and integral rainfall (namely rain rate and radar reflectivity) parameters within the MRR bins. Furthermore, an ad-hoc preprocessing of the MRR raw data have been performed to reduce uncertainty on MRR profiles estimates.

PERFORMANCE IMPROVEMENT OF SPECTRAL BIN MODEL THROUGH OPTIMIZATION OF MICROPHYSICS SCHEME IN PYEONGCHANG REGION

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The Spectral Bin Model (SBM) is a bin microphysics model used for predicting precipitation types. The performance of SBM was examined by using ICE-POP 2018 data in Pyeongchang region for three precipitation types (rain [RA], snow [SN], RASN). The overall skill scores of the SBM are relatively higher as compared with the statistical methods. However, the SBM have low accuracy for RA events. The results imply that the SBM simulation tends to relatively slow melting with "small melting fraction" in Pyeongchang region. "The small melting fraction" issue of the SBM simulation in Pyeongchang region is further explored. The mispredicted RA events are divided as three groups following vertical structures of environment: single deep melting layer (SDML) group, single shallow ML (SSML) group, double ML (DML) group. The microphysics scheme of SBM is optimized by reflecting microphysical characteristics in Pyeongchang region and the optimized SBM is evaluated for three groups. The optimized SBM shows perfect accuracy about SDML group whereas still slightly less melting fraction at SSML group. The SSML group have low-level strong southerly implying existence of horizontal warm advection that is not considered at the SBM simulation. Precipitation types at DML group was well predicted in case of exact cloud top height that was used in the optimized SBM.

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DYNAMICAL AND MICROPHYSICAL PROCESS IN THE LAYER AROUND -15˚C

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Microphysical and dynamical processes are intertwined, in particular, in diabatic feedback into atmospheric stability and supersaturation by upward motion. The layer around -15˚C to -17˚C has a maximum excess vapor density over ice in the atmosphere saturated with respect to plane water. Thus, a lateral growth such as dendritic growth is dominant. In the literature, this layer showed distinctive signature of ZDR maximum and KDP maximum below. Many researchers explained this signature as dendritic growth but rapid growth of smaller pristine or planar crystal was need to explain rapid increase of KDP maximum below. The existence of smaller ice particle was proved by bi-modal Doppler power spectra from vertical pointing cloud radar measurement. This research shows similar bi-modal spectra, and ZDR and KDP feature around this layer. In addition, we found mesoscale ascent below the layer from vertical pointing radar data in climatological sense. Thus, we speculate that new ice nucleation in increased supersaturation condition is most feasible explanation. This supersaturation can be explained by the combined effect of mesoscale ascent below and diabatic heating due to excess vaper density.

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ON COMPARING 94 GHZ SATELLITE MEASUREMENTS WITH A MICRO RAIN RADAR AND DISDROMETER OBSERVATIONS IN AN ANTARCTIC SITE

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Ground-based snowfall observations over Antarctica are rare and sparse due to the harsh environment and high costs of logistic, equipment maintenances and operations. Satellite measurements are crucial to provide a continent-wide precipitation estimates and this highlights the importance of validating the satellite estimates with measurements collected by the ground-based Antarctica stations. The CloudSat satellite, launched in 2006, is equipped with the W-band (94 GHz) Cloud Profiling Radar that provides measurements of reflectivity profiles of precipitation events, whereas the incoming ESA/JAXA EarthCARE mission will add Doppler capability to a 94 GHz radar. This work explores how the synergy between two instruments available at most Antarctica Stations, namely a Micro Rain Radar (MRR, 24 GHz) and a laser disdrometer can validate satellite borne W-band radar measurements, including Doppler estimates. Measurements collected at the Italian PNRA station "Mario Zucchelli" (Victoria Land, East Antarctica) were used. To this end, firstly, the consistency of MRR and disdrometer observations was evaluated in terms of the vertical velocity of falling particles by comparing MRR Doppler velocity with the characteristic velocity of precipitation calculated from disdrometer measurements. Then, MRR Doppler spectra were used to obtain profiles radar reflectivity and Doppler velocity at W-band using DDA backscattering cross-sections and velocity-diameter relationships derived from disdrometer. The good correspondence found in terms of W-band reflectivity profile between coincident Cloudsat overpass and ground-based observations reassures us for using this approach for validating satellite measurements and confirms the soundness of the matching strategy employed in this study.

WHERE ARE RAINFALL DROPS MEASURED BY A RADAR FALLING IN A MULTIFRACTAL TURBULENT WIND FIELD?

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Hydro-meteorologists are looking for rainfall at ground level, but radars measure it in altitude. The advection of drops by wind during their fall, can create biases in the location of measured fields. The governing equation for rain drop motion, which relates acceleration, gravity, buoyancy and drag is known. Standard relations are used for the latter which depends non-linearly on the instantaneous relative velocity between the drop and the local wind. This leads to complex behaviour. A correction to account for drop oblateness with a shape model more accurate than a simple ellipsoid is suggested and then validated through computation of "terminal fall velocity" (i.e. without wind) and comparison with known values. Then, an explicit numerical scheme is implemented to solve this equation for 3+1D turbulent wind field, and obtain the velocities and trajectories of drops during their fall. First simulated Universal Multifractals (UM, which are widely used to characterize and simulate geophysical fields extremely variable) fields are used as input to understand better their behaviour. It appears that UM features of the input are simply transferred to drop velocity with an additional fractional integration whose level depends on drop size, and a slight time shift. Finally consequences on radar measurement are explored. For this, initial steps towards the simulation of realistic wind fields over large areas from actual 100 Hz 3D sonic anemometer data and a scale invariant approach are presented. This enables to discuss the ground dispersion of drop of various size all initially located within a radar gate during few minutes. Authors acknowledge the RW-Turb project (ANR-19-CE05-0022), for partial financial support.

RAINDROP SIZE DISTRIBUTIONS OF NORTH INDIAN OCEAN TROPICAL CYCLONES OBSERVED AT THE COASTAL AND INLAND STATIONS IN SOUTH INDIA

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The current study summarizes the raindrop size distributions (RSDs) characteristic of the North Indian Ocean (NIO) tropical cyclones (TCs) measured with ground-based disdrometers installed at the coastal (Thiruvananthapuram, 8.5335°N, 76.9047°E) and inland (Kadapa, 14.4742°N, 78.7098°E) stations in south India. The NIO TCs observed at the coastal station showed more mid- and large-size drops (>1 mm) than the inland station. On the other hand, for both inland and coastal stations, small and mid-size drops (<3 mm) primarily contributed to the total number concentration and rainfall rate. The RSDs of the NIO TCs segregated into precipitation types (stratiform and convective) demonstrated the presence of more mid- and large-size drops at the coastal station. The RSD relations of the NIO TCs, which are used in rain retrieval algorithms of remote sensing (global precipitation measurement) radars, exhibited contrasts between the coastal and inland station. Further, the NIO TCs' rainfall kinetic energy relations, which are crucial in rainfall erosivity studies, estimated for the coastal station revealed dissimilar characteristics to that of the inland station. The conceivable thermo-dynamical and microphysical processes that are accountable for the disparities in the NIO TCs RSDs measured at the coastal and inland stations are also elucidated in this work.

MELTING OF GRAUPEL AND HAIL: A VERTICAL WIND TUNNEL STUDY

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The melting process of graupel and hail is still poorly understood although it plays a crucial role in now- and forecasting of surface precipitation. Besides the most important physical parameters of hydrometeors, such as shape, density, fall speed, meltwater content, and total melting time, the size distribution of the drops which shed off from the surface of the melting ice particles is of great importance for radar applications. We conducted experiments in the Mainz vertical wind tunnel to characterize the temporal evolution of these microphysical quantities by freely floating the ice particles in a vertical air stream at their terminal fall velocities. Our setup provided detailed investigation of individual graupel and hail particles throughout their melting process from the fully glaciated to the completely molten state. The shape variation was observed by means of a video camera, while the drop size distribution of the shed droplets was measured by an in-house built digital holographic instrument. The melting experiments were carried out on ice spheres from 4 to 20 mm in diameter as proxy for graupel and hail, and on ice particles with natural shape. By using a specially designed mounting, it was possible to keep the hydrometeors at the center position of the wind tunnel for the total period of the melting process. In this way the heat transfer, and thus melting rates were simulated in a realistic manner. The experiments were performed applying dry and moist adiabatic temperature gradient and at different relative humidities from about 0% to 80%. Our results provide insight into the shape variation during melting, and the formation mechanism of a bimodal size distribution of droplets shedding off the hail particles.

RAINDROP SIZE DISTRIBUTION AND MICROPHYSICS CHARACTERISTICS OF PRECIPITATION IN DIFFERENT SEASONS IN TAIWAN

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In the present work, long-term (10 years) raindrop size distribution (RSD) measurements from Joss-Waldvogel Disdrometer (JWD) installed at National Central University (NCU, 24°58'6''N 121°11'27''E), Taiwan and vertical profile of radar reflectivity were used to analyze the variations in gamma parameters of six seasons (winter, spring, mei-yu, summer, typhoon, and autumn) and types of precipitation. The normalized gamma distribution of RSD revealed that the highest mean Dm (Mass-weighted average diameter) values occurred in summer, whereas the highest mean log10Nw (normalized intercept parameter) values were found in winter. Furthermore, most of the rainfall rate falling at less than 20 mm h-1 occurs in Northern Taiwan. In this study, we used radar reflectivity to differentiate between convective and stratiform systems. It was revealed that the mean Dm values are higher in convective systems, whereas the mean log10Nw values are higher in stratiform systems. The structure of RSD in stratiform systems remains constant in all seasons; however, convection is similar to maritime type. The microphysical characteristics that are responsible for different RSD features in different seasons and types of precipitation are illustrated with the help of contoured frequency by altitude diagrams of radar reflectivity.

RETRIEVAL OF ICE MICROPHYSICS USING POLARIMETRIC AND DUAL-WAVELENGTH RADAR OBSERVATIONS – A SENSITIVITY STUDY

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Multi-frequency radar techniques have become very popular the last decades. The combination of different frequency radars can provide size information about the detected atmospheric hydrometeors exploiting the different scattering properties of them in Rayleigh and Mie regime. Such techniques are commonly applied to vertically pointing radars, usually located at the same place, lacking to provide sufficient hydrometeors shape information obtained by polarimetric measurements. Within Ice-PolCKa project, we investigated the synergy of two spatially-separated radars; the C-band POLDIRAD and the Ka-band MIRA-35. Located 23 km apart, the radars performed coordinated RHI scans monitoring snowfall over Munich, acquiring an innovative combination of radar measurements: dual-wavelength and polarimetric variables, i.e., differential reflectivity. The dual-wavelength observations provided size information, while the differential reflectivity observations from the C-band radar provided shape information about the ice particles. The measurements were compared to T-matrix ice simulations aiming to constrain size, shape and mass of ice particles detected within the radars cross-section. In this study, we represented ice particles with soft spheroids and tested different relations between mass and particle size as well as different particle size distributions. We present a couple of sensitivity studies to investigate how our assumptions on the mass-size relation, particle size distribution, shape or orientation can affect the ice retrievals. We advocate that our approach could constrain uncertainties in current numerical weather prediction models connected with ice microphysical processes using the available cloud radar sites combined with operational weather radars.

INVESTIGATION OF MICROPHYSICS AND PRECIPITATION FOR ATLANTIC COAST-THREATENING SNOWSTORMS (IMPACTS): REMOTE SENSING AND MICROPHYSICS RESULTS FROM RECENT DEPLOYMENTS

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The Investigation of Microphysics and Precipitation for Atlantic Coast-Threatening Snowstorms (IMPACTS) is a NASA-supported field campaign to study snowstorms particularly over the northeastern United States. Snowfall within these storms is often organized in banded structures that can vary on multiple scales. The goals of IMPACTS are to characterize the structures of snowbands and their spatial and temporal scales; understand the dynamical, thermodynamical and microphysical processes that produce the observed structures; and apply this understanding to remote sensing and modeling of snowfall. IMPACTS takes place over three winter seasons, 2020, 2022 and 2023. In order to sample storms over a broad geographical expanse from the Midwest to northeastern United States, aircraft are the primary platforms for obtaining observations. The high-altitude NASA ER-2 carries a suite of remote sensing instruments including cloud and precipitation radars, lidar, and passive microwave instruments to simulate satellite-borne instrumentation, and the in-situ NASA P-3 samples environmental and microphysical quantities using a turbulent air motion measurement system, microphysics probes, and a dropsonde system to sample vertical profiles of temperature, humidity and winds. These airborne measurements are supplemented with stationary and mobile radar facilities, mobile sounding teams, and a dense network of specialized surface meteorological observations. Initial results highlighting the differences in radar characteristics and microphysical properties within and outside of snowband structures from the 2020 deployment and the recent 2022 deployment will be presented.

CLOUDBOSS: A BAYESIAN WARM RAIN MICROPHYSICS SCHEME DESIGNED FOR OBSERVATIONAL CONSTRAINT AND UNCERTAINTY QUANTIFICATION

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We present research on CloudBOSS, a version of the BOSS microphysics parameterization scheme that includes cloud and rain processes. The approach is to eschew the hard assumptions and structural approximations of most bulk microphysics schemes in favor of a structurally flexible model that allows for any choice and combination of prognostic drop size distribution (DSD) moments, does not assume a particular shape for the DSD, and uses a flexible power-law basis set for process rate calculations. We demonstrate how CloudBOSS can be fit to bulk and bin schemes with different levels of structural mismatch, and discuss how radar and satellite observations can be used as constraint. Our findings demonstrate clear shortcomings to the traditional bulk two-category (cloud and precipitation) approach to modeling warm microphysical processes. We draw parallels to recent work demonstrating constraint of BOSS rain microphysics with simulated polarimetric radar data.

TRACKING ISOLATED THUNDERSTORMS IN HOUSTON TX WITH POLARIMETRIC RADAR AND THE LIGHTING MAPPING ARRAY

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This 2021-2022 DOE Tracking Aerosol Convection Interactions Experiment (TRACER) is aimed at providing insights into convective microphysics across a region with highly variable anthropogenic aerosol concentrations. We present combined polarimetric radar and lightning flash analysis of tracked thunderstorms in the Houston region, both a historical study using National Weather Service NEXRAD polarimetric radars, as well as preliminary data from TRACER and a related NSF field campaign, ESCAPE. We compare these to cells tracked in a version of the NASA-Unified Weather and Forecasting Model (NU-WRF) with prognostic lighting parameterization. In the case of NU-WRF, convective updraft thermals occurring within the cells are also tracked in 3D, providing an additional level of detail to analysis of deep convection microphysics.

X-BAND RADAR TECHNOLOGY AND NEW MULTIFRACTAL DROP SIZE DISTRIBUTION MODEL

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A century of cascades and three decades of multifractals have built up a truly interdisciplinary framework that has enabled a new approach and understanding of nonlinear phenomena, in particular in geophysics. Nevertheless, there seems to be a profound gap between the potentials of multifractals and their actual use. This presentation proposes a new multifractal drop size distribution model. We will demonstrate that not only the drop size distribution could be easily defined by the multifractality of the radar reflectivity fields, but also it could be concretely determined with the help of semi-analytical estimates of the codimension that can depend on a very limited number of parameters. Universal Multifractals (UM) are an interesting, generic case because they correspond to a broad multiplicative generalisation of the additive central limit theorem. Their statistics are fully determined the help of the mean codimension C_1 and the multifractality index $\alpha \in [0,2]$, which measures how the fractality changes with the activity of the field is increased, i.e. by considering statistical moments of order $q > 1$ or equivalently singularities $\gamma > C_1$. Finally, we will discuss why the proposed approach to drop size distributions could revolutionize radar technology. Indeed, the proposed theoretical results are not limited to improving a real time quantitative estimation of rain rates but could also improve and simplify the nowcasts.

PRECIPITATION TYPE ANALYSIS USING A HYDROMETEOR CLASSIFICATION OF HIGH-RESOLUTION RADAR DATA – DETAILS ON THE ALGORITHM DEVELOPED AND USED AT DEUTSCHER WETTERDIENST

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In recent years the scope of operational weather radar assisted precipitation analysis was broadened from precipitation rate by the type of precipitation. To address this topic, the Deutscher Wetterdienst (DWD) utilizes a C-Band dual-polarimetric weather radar network in combination with synoptic measurements from ground-based stations and output from numerical weather prediction (NWP). The resulting algorithm consist of a hydrometeor classification at radar beam height (algorithm HYMEC) using dual-polarimetric radar data and snowline data from NWP (ICON-D2). The vertical extrapolation of hydrometeor types throughout the lower troposphere to ground level includes the potential transition from solid to mixed to liquid precipitation phase (algorithm NASMA). Phase transitions are estimated from empirical thresholds of vertical integrals of wetbulb temperature exceeding 0°C between radar beam height and ground. The wetbulb temperature is derived from vertical profiles of ICON-D2. Additionally, temperature and humidity measurements from ground-based stations are applied to optimize the ICON-D2 profiles within the boundary layer. The described procedure is performed for analysis time, but also up to a forecast horizon of two hours applying optical-flow technique and using MOS point forecasts. The ongoing in-house evaluation is realized by colleagues from the weather forecasting department at DWD. Details on the evaluation in winter season 2021/2022 are presented in the contribution of Böhme and Schultze. This contribution will give an overview on the algorithm discussing up to date cases studies. Also, recent improvements and prevailing challenges will be discussed.

SIMULTANEOUS OBSERVATION OF VERTICALLY POINTING KA BAND RADAR AND HORIZONTALLY LOOKING X BAND RADAR IN SAIL

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The Surface Atmosphere Integrated Field Laboratory (SAIL) is a two year deployment of Advanced Atmospheric Laboratory, operated by the U.S. Department of Energy's Atmospheric Radiation Measurement (ARM) Facility. SAIL has a suite of 34 atmospheric observational instruments that characterize precipitation, aerosols, clouds, winds, radiation, temperature, and humidity at a wide range of spatial and temporal scales. In this research, we focus on the precipitation observing instruments, namely the Ka-band Zenith pointing Radar (KAZR) and X band Polarimetric weather radar (XBPWR) as well as ground-based disdrometer. The KAZR is a vertically pointing radar and the XBPWR is a horizontally pointing X band radar. These two radars make complementary observations where the KAZR measures vertical profile at a fine scale in a given location, the XBPWR measures the spatial variability of precipitation in three dimensions by performing PPI and RHI scans. The combined effects of difference in operation frequency, spatial resolution, and viewing geometry between the two radar make this type of analysis challenging. To this end, the radar observations will be matched in volume and time in order to minimize error. In this paper, simultaneous radar observations of the vertical profile of precipitation from both winter and summer time precipitation will be studied and contrasted. In addition, microphysical analysis will be performed using dual-frequency observations.

UTILITY OF GROUND BASED CLOUD RADAR TO OBSERVE TURBULENCE ON CLOUD DROPLETS TO RAINDROP TRANSITION

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High-resolution ground-based 35-GHz cloud radar measurements are instrumental in investigating the process responsible for the onset of rain. Since cloud radar is sensitive to cloud droplets, cloud radar observation is the one potential component to capture cloud droplets' growth to bigger droplets and then into raindrops. Therefore, high-resolution vertical-looking measurements of cloud radar deployed over the Indian Western Ghats are utilized to understand the processes of the onset of rain. Since the equivalent reflectivity factor contains the information of drop diameter and its number concentration and vertical velocity is related to the drop size, the combination of these two radar parameters has been used to understand the size evolution pertinent to cloud droplets into a raindrop. The measurement of the vertical spectral width, less affected by the large-scale broadening factor, is used to explore the condition responsible for the growth of cloud droplets. For the non-precipitating clouds, the spectrum width measurement describes the velocity variance (distribution of hydrometeor size) within the resolution volume. Turbulence produces random relative radial motion of scatterers, which causes the broadening of the spectrum. Hence spectral width can be considered an indicator of turbulence within the cloud. Cloud radar observation shows that an abrupt enhancement in turbulence near the cloud base has a positive impact on gradually increasing the size of the cloud droplets. This study stands as observational evidence of small-scale features associated with the cloud droplet to raindrop transition and the possible factor responsible for rain initiation.

MIXED-PHASE CLOUD CHARACTERISTICS OVER A TROPICAL SITE USING CLOUD RADAR

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Mid-level mixed-phase cloud is sandwiched cloud height region beneath the cold cloud and aloft warm cloud that exhibits diverse nature of supercooled liquid and ice phase crystals. These clouds affect the Earth's climate system by influencing radiation budget and thermodynamic structure. Millimeter wavelength radars are the best tool to study cloud properties. Ka-band is being used to explore the physical and dynamical characteristics of the monsoon cloud systems in this study. Ka-band radar can make vertical-looking mode observations with a high time-height resolution and dual-polarization ability. Mid-level humidification occurs through favorable low-level convection or 'descending cirrus' clouds. Low-level convection aided by updrafts and turbulence processes enters the mixed-phase region, resulting in the formation of ice and supercooled droplets. Descending cirrus is predominantly seen during ISM active phase, whose base descends having higher reflectivity values. These observations can help understand mixed-phase ice processes, mainly ice multiplication and secondary ice production. Sufficient vertical motions are required, particularly in mixed-phase clouds, for liquid water condensation at a supercooled temperature in the presence of cloud ice. In a mixed-phase cloud, the substantial disparities in size distributions and fall regimes between liquid droplets and ice crystals cause these two phases to descend at distinct speeds, resulting in a bimodal spectral signature. Analysis of these vertical motions and spectral mode information provides more knowledge of dynamic processes involved in the growth and development of the cloud. The radar observations provide a wealth of information to explore the mixed-phase cloud characteristics.

CLOUD RADAR PERSPECTIVE ON TROPICAL CUMULUS CONGESTS CLOUD AND ITS ROLE ON THE RAINFALL

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Cumulus congestus clouds often extend through or are completely above the freezing level and often contain a mixture of liquid and ice. Cumulus congestus clouds are ubiquitous globally and make substantial contributions to precipitation and latent heat fluxes in the tropics. Cumulus congestus clouds occur globally and account for a significant amount of precipitation in the tropics. Despite their importance, some aspects of these clouds are not fully understood. Therefore, the role of congestus clouds in geographic rainfall is investigated using ground-based Ka-band radar (KaSPR) measurements over an orthographic location of Western Ghat, India. The quality-controlled data of KaSPR from June-September, 2016 serves the purpose. Because of their higher sensitivity, such ground-based cloud radars are instrumental for characterizing mid-level congestus clouds. An indigenous algorithm helps to identify congestus clouds. Besides radar observations, co-located, surface-based and space-based measurements are used to bring more robust conclusions. The important role of congestus in preconditioning the environment for deeper convection is also shown. CFAD diagram of equivalent reflectivity factor and micro rain radar profile prominence sustained heavy drizzling condition with its predominant value of 10 dBZe. Result also shows rain caused by congestus is dominated by raindrops of size 1.11 µm. Generally, the rain rate is below 0.1 mm hr-1 indicating drizzling conditions. The maximum rain rate can exceed 20 mm hr-1 with a maximum reflectivity value of 20 dBZe. Congestus cloud contributes greatly to the total rainfall than low-level warm clouds because of their precipitating characteristics. Analysis of such type and more shall be further elucidated in the upcoming ERAD conference.

NOWCASTING OF CONVECTION AND THUNDERSTORM

3D CONVECTIVE/STRATIFORM ECHO TYPE CLASSIFICATION AND CONVECTIVITY FROM RADAR REFLECTIVITY

OBJECT-BASED NOWCASTING AT DWD USING KONRAD3D, HYMEC, AND LIGHTNING DATA

CONVECTION DETECTION FOR AUTOMATIC METAR REPORTS BASED ON RADAR, LIGHTNING AND MODEL DATA

RECENT IMPROVEMENTS OF KONRAD3D, DWD'S SCHEME FOR DETECTION, TRACKING, AND NOWCASTING OF CONVECTIVE CELLS

EXPLORING THE POLARIMETRIC CAPABILITIES OF THE S-BAND MWANZA RADAR IN TANZANIA, AFRICA: TOWARDS AN EARLY WARNING SYSTEM IN LAKE VICTORIA BASIN

METEOROLOGICAL ALGORITHM REQUIREMENTS FOR DISASTER EARLY WARNING AND DECISION SUPPORT

COMBINATION OF OBJECT-BASED PROBABILISTIC NOWCASTING AND NWP ENSEMBLE OF CONVECTIVE CELLS FROM KONRAD3D

A SYNERGETIC APPROACH TO STUDY DIFFERENTIAL REFLECTIVITY (ZDR) COLUMNS FOR PRECIPITATION

LIGHTNING-JUMPS, ZDR-COLUMNS AND AN IMPROVED CELL SEVERITY RANKING FOR AUTOMATIC THUNDERSTORM WARNINGS IN THE ALPINE AREA

SWIRL: THE AUSTRALIAN OPERATIONAL 3D WIND ANALYSIS AND NOWCASTING SERVICE AND ITS VALIDATION

USING DUAL-POLARIZATION RADARS TO NOWCAST SEVERE WEATHER EVENTS

IMPROVING AUTOMATIC THUNDERSTORM WARNINGS AT DWD

AUTOMATIC REPORTING OF CONVECTION IN METAR MESSAGES FOR AIRCRAFT SAFETY

DETECTION OF HAIL PRE-SIGNAL USING THE 3-DIMENSIONAL RADAR AND TEMPERATURE DATA

IMPROVEMENTS TO SEVERE STORM NOWCASTING IN THE CZECH HYDROMETEOROLOGICAL INSTITUTE

APPLYING RANDEVIL TO SEVERE WEATHER NOWCASTING TO ASSIST AIR TRAFFIC CONTROLLERS

THE RELATIONSHIP BETWEEN ZDR ARCS AND STORM-RELATIVE HELICITY IN SIMULATED TORNADIC AND NON-TORNADIC THUNDERSTORMS

HOW HAIL FALLOUT AFFECTS THE ACCURACY OF AUTOMATED ZDR ARC IDENTIFICATION: PRELIMINARY RESULTS

SEVERE CONVECTIVE STORM ENVIRONMENTS OF NORTHWESTERN ITALY: DIFFERENCES BETWEEN COASTAL AND INLAND AREAS

C-BAND WEATHER RADAR COMPARISON OF THE 24TH JUNE 2021 TORNADO EVENT SEEN BY AUSTRIAN, CZECH AND SLOVAKIAN RADAR NETWORK

DEFINE AND VALIDATE ADVERSE WEATHER AREAS FOR AIR TRAFFIC MANAGEMENT BASED ON WEATHER RADAR DATA

PATTERN RECOGNITION USING COMPLEX NUMBERS TO ACCOUNT FOR DATA QUALITY AND PATTERN IMPORTANCE: SEVERE WEATHER DETECTION APPLICATIONS

RESULTS FROM A CLIMATOLOGY OF POLARIMETRIC RADAR FEATURES IN SUPERCELLS

THUNDERSTORMS CHARACTERIZATION IMPROVEMENTS COMBINING NWCSAF-RDT ESTIMATED PARAMETERS WITH MEASUREMENTS FROM WEATHER RADAR

MESOCYCLONE DETECTION AT MÉTÉO-FRANCE

LAKE VICTORIA THUNDERSTORMS: RADAR-OBSERVED INITIATION AND STORM EVOLUTION MODES

3D CONVECTIVE/STRATIFORM ECHO TYPE CLASSIFICATION AND CONVECTIVITY FROM RADAR REFLECTIVITY

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Even though different physical and microphysical processes are observed in convective vs. stratiform clouds and precipitation, on a fundamental level these terms refer to the vertical vs. horizontal structure of clouds. To separate convective from stratiform radar echoes, investigating the homogeneity of clouds and precipitation on the horizontal axis has proven especially useful. Building on the concept of radar echo homogeneity, we developed the ECCO (Echo Classification from COnvectivity) algorithm which calculates the horizontal texture of reflectivity for all grid points in a 3D grid, which is then mapped onto a newly introduced convectivity field. Convectivity is a 3D unitless field that indicates the probability that a region is convective in nature as opposed to stratiform. It ranges from 0 to 1 and provides a numerical measure as opposed to only a qualitative classification. A qualitative convective/stratiform echo type classification is also created by thresholding the convecivity field appropriately. The 3D nature of this classification field allows further subdivision based on the horizontal and vertical extent of the echo regions into e.g. deep and shallow convective echo or high and low stratiform echo. We initially developed the method on the MRMS radar mosaic from the PECAN field campaign (US Great Plains, 2015), validating the accuracy against lightning rate data. We have since tested the algorithm on the full MRMS US grid, data sets from Australia and the UAE, compared the results against the spaceborne Global Precipitation Measurement (GPM) algorithm, and adapted it for the 2D European OPERA radar grid, and ground based, airborne, and space-borne vertically pointing radars.

OBJECT-BASED NOWCASTING AT DWD USING KONRAD3D, HYMEC, AND LIGHTNING DATA

Lukas Josipovic[1]; Manuel Werner[1]; Ulrich Blahak[1]

[1]*Deutscher Wetterdienst (DWD), Germany*

In recent years, a new nowcasting algorithm has been developed at DWD (Deutscher Wetterdienst), called KONRAD3D. It aims to automatically detect, track, and nowcast convective cells in order to support DWD's warning decisions. The deterministic core of KONRAD3D consists of state of the art techniques, e.g. adaptive thresholding for the cell detection and Kalman filtering of cell centroids and velocities during the tracking step. Originally, KONRAD3D made use of 3D radar reflectivity data only. Currently, work is in progress to include lightning data and information on hydrometeor types that is based on polarimetric radar data. In this context, we will introduce a new polarimetric hail flag—a parameter that assesses a cell's threat of hail—that should roughly estimate the expectable near-ground hail size. Studies about relationships of lightning and the hail amount of KONRAD3D cells showed strong correlations. A lightning jump detection within KONRAD3D turned out to be a promising approach for hail nowcasting. Statistics on 800 hailstorms over Germany between April and September 2019 revealed that lightning jumps occur 15 to 20 minutes before the maximum near-ground hail intensity on average. One part of DWD's project SINFONY (Seamless INtegrated FOrecastiNg sYstem) focuses on extending KONRAD3D towards an object-based ensemble nowcasting algorithm called KONRAD3D-EPS. It enables a suitable way of including cell life-cycle models to better predict intensification and weakening tendencies. We give an overview of KONRAD3D, present statistics of cell attributes, and we demonstrate the concept of our probabilistic nowcasting system. We also illustrate the basic functionalities of our algorithms for prominent example cases with focus on hail threat assessment.

CONVECTION DETECTION FOR AUTOMATIC METAR REPORTS BASED ON RADAR, LIGHTNING AND MODEL DATA

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The project AutoMETAR at Deutscher Wetterdienst (DWD) has been initiated in 2014 for the automation of the flight weather observations (METAR). It is currently in the process of replacing the manned weather stations at all 15 international German airports. METARs contain data about the weather condition at and in the vicinity of the airport, e.g., wind, visibility, present weather, cloud cover, temperature and pressure. As showers and thunderstorms pose a thread to aviation, convective weather and clouds need to be encoded in the METAR. The subproject autoKON utilizes radar, lightning and model data to detect thunderstorms (TS), showers (SH), towering cumulus (TCU) and cumulonimbus (CB). Remote sensing data is in particular suited for the detection of convection, but it also complements in-situ measurements at the airport. The multi-sensor approach ensures a high reliability and robustness of the resulting weather report. We will outline the design and setup of autoKON: Lightning data and DWD's new cell detection scheme KONRAD3D are used to detect thunderstorms and stronger showers. Weaker showers are detected by a convective-stratiform separation based on a bandpass filter in Fourier space of radar data. All data is combined on a pixel basis also considering convective available potential energy (CAPE) taken from the ICON-EU model to suppress false detections of convection. The present weather and clouds for each airport are determined with the precipitation type derived from DWD's hydrometeor classification algorithm HYMEC.

RECENT IMPROVEMENTS OF KONRAD3D, DWD'S SCHEME FOR DETECTION, TRACKING, AND NOWCASTING OF CONVECTIVE CELLS

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KONRAD3D is a tool for detection, tracking and nowcasting of convective cells developed at Deutscher Wetterdienst (DWD). Its main goal is to further improve the performance of DWD's automated warning decision support system and to equip external customers with improved information on thunderstorm development and severe weather risks. The scheme is designed as a multi-sensor application, but, at its core, relies on three-dimensional radar reflectivity data. During the convective seasons 2020 and 2021, KONRAD3D has been intensively evaluated by forecasters at DWD as well as in the ESSL (European Severe Storms Laboratory) Testbed with many valuable comments and suggestions on how to modify, improve or better tune the method. Inspired by these findings, various extensions have been implemented, sub-algorithms have been revised, and tuning parameters have been adapted. Additional data sources have been included recently. Lightning data is used to derive cell-related lightning densities, and an algorithm to determine lightning jumps has been implemented. Furthermore, hail information from hydrometeor classification data derived from DWD's dual-polarization radars is used to asses hail risk. This work gives an overview on the current status of KONRAD3D's design and setup. We will illustrate the impact of the latest extensions of the scheme, present the current status of its visualization in DWD's meteorological workstation NinJo and give an insight into the ongoing work of integrating KONRAD3D in follow-up applications and end customer interfaces.

EXPLORING THE POLARIMETRIC CAPABILITIES OF THE S-BAND MWANZA RADAR IN TANZANIA, AFRICA: TOWARDS AN EARLY WARNING SYSTEM IN LAKE VICTORIA BASIN

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East African countries benefit from the largest freshwater lake in Africa: Lake Victoria. Around 30 million people live on its coastline and ~5.4 million people subsist on its fishing industry. However, more than 1,000 fishermen die yearly due to high waves produced by severe convective wind phenomena, which makes this lake one of the deadliest spots in the world. The World Meteorological Organization launched the 3-year "High impact weather lake System" (HIGHWAY) project, with the main objective to reduce the loss of lives and goods in LVB and to improve resilience for the local communities. The project included a field campaign running from March to December 2019, to provide forecasters with high-resolution observations and to study the storm life cycle on the lake basin. A notable advance of the EOP was the utilization of S- and C-band dual-polarization radars in the surrounding countries. Previous research using the S-band radar in Mwanza, Tanzania, has demonstrated a marked diurnal cycle on Lake Victoria with a clear northeast to southwest occurrence and evolution from midnight to early in the morning. Storms typically intensify and organize in linear fast-moving systems, sometimes into upscale growth convection and posing a major risk to the fisherman operating on the lake. After this initial analysis, the goal is to investigate the role of the land-lake breeze and the mesoscale configuration over the lake and how these relate to the organization of these systems. Using the TA4 UK convective-permitting model in addition to Mwanza ZDR and radial velocity observations, we examine two severe wind cases that took place on the lake during the campaign period, with the goal of obtaining key parameters to provide nowcasting guidance.

METEOROLOGICAL ALGORITHM REQUIREMENTS FOR DISASTER EARLY WARNING AND DECISION SUPPORT

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In this paper, meteorological algorithm requirements currently under development for Disaster Early Warning and Decision Support are detailed in the concept of METRAD polarimetric X-Band radar system. METRAD System provides the user with raw moments of meteorology regime such as reflectivity and velocity which are produced from digital I/Q data produced by Signal Processing Unit from the received x-band radar signal reflections. Meteorological regime products to be used in emergency hazard detection and prevention are produced from these raw moments. Detection of the smoke plumes caused by grass fire, brush fire, and forest fire to locate the flame center of emergency fires is key to fire hazard early detection. Detection of dense clouds and calculating flood risk of clouds from a medium distance is also of utmost importance for flood warning systems. Artificial intelligence raises alerts for fire/flood events, and tries to give decision support to emergency teams about the regions where the disaster can spread with the radar's wind vision. Decision support helps emergency teams with firefighting location suggestions and new flood events in the area to protect the teams from dangers of following flash floods or fire spread. One of the main objectives of this work is to ensure that meteorology engineers directly participate in algorithm design and development activities. For this purpose, a wide range of university-industry cooperation and remote access capabilities are planned for data recording and playback including scenario studies on laboratory hardware prototype. Our work also includes the Turkish General Directorate of Meteorology (MGM) and the Turkish Disaster and Emergency Management Directorate (AFAD) suggestions on the current system developments.

COMBINATION OF OBJECT-BASED PROBABILISTIC NOWCASTING AND NWP ENSEMBLE OF CONVECTIVE CELLS FROM KONRAD3D

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Convective events can be hard to predict and are therefore in the focus of the project SINFONY at DWD. SINFONY has the goal to improve forecasts of such events in the short range up to 12 hours by enhancing both nowcasting and NWP separately and developing more reliable combined products. Within this work, we want to provide an object-based ensemble forecast based on the combination of convective cells detected in propabilistic nowcasting and NWP. The detection of these cells is carried out with KONRAD3D, a method developed at DWD to detect and track convective cells based on radar reflectivity. This method can also be used to detect cells simulated by NWP since the model forward operator EMVORADO is able to provide simulated radar data with the same structure and time resolution as the actual radar observations. First, the simulated cells are clustered spatially using the DBSCAN method. Once grouped, they are compared with each observation and those simulated objects whose cluster is closest to the observation are selected. The properties of the simulated cells are compared with those of observed radar cells by using a score called total interest. Only cells which exceed a certain threshold of the total interest and thus are the most similar to the observations will be seleceted for combination. Finally, these simulated cells are spatially relocated to make their centroid position equal to the position of the closest observed cell. This method is applied to objects of SINFONY-RUC simulations during summer 2021, which comprises the ICON-D2-EPS employing the 2-moment microphysics scheme. It is foreseen to include the nowcasting ensemble KONRAD3D-EPS as soon as possible. This way, we are able to generate a seamless object-based forecast ensemble.

A SYNERGETIC APPROACH TO STUDY DIFFERENTIAL REFLECTIVITY (ZDR) COLUMNS FOR PRECIPITATION

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ZDR columns consist of rain dominated by large drops that are being lofted above the freezing level. They have been recognized as a proxy for the location of updrafts and for the nowcasting of precipitation. An algorithm that identifies and tracks ZDR columns is applied to a convective event observed by C and X-band radars. Derived 3D wind fields are used to verify the relation between ZDR columns with updrafts. Since ZDR columns are a manifestation of an updraft, various ZDR columns properties (height, volume, area) are expected to be related to updraft intensity. These connections are verified in our results at the individual cell level, however when all cells are considered the correlations are lower. In turn intensification of updrafts, as indicated by ZDR columns properties, should be translated into an intensification of observed precipitation at the surface. For each cell, the properties of ZDR columns are correlated with rain rate values. For the nowcasting of precipitation, an extrapolation algorithm based on spatial and temporal properties of rain was used. Results have shown that higher precipitation rates are generally associated with ZDR columns. In addition, ZDR column height and volume show a positive correlation with precipitation intensity. The time lag between the intensification of the ZDR column and the associated increase in precipitation varies mostly between 5 to 15 minutes. Regarding nowcasting, it was found that the difference between the observed and predicted precipitation fields is spatially correlated with the height of ZDR columns. It is foreseen that early identification of ZDR columns, associated with precipitation, could benefit the skill of the nowcasting of localized convective rain cells, which often are smoothed during extrapolation.

LIGHTNING-JUMPS, ZDR-COLUMNS AND AN IMPROVED CELL SEVERITY RANKING FOR AUTOMATIC THUNDERSTORM WARNINGS IN THE ALPINE AREA

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Latest improvements of the operational MeteoSwiss thunderstorms nowcasting and warning system TRT (Thunderstorms Radar Tracking) are presented and discussed. They include an automatic, operational lightning jump detection for each identified storm cell with a time resolution of 2.5 minutes. Lightning jumps are defined as an abrupt increase in lightning frequency and often occur in intense thunderstorms from few minutes to some tenth of minutes before the onset of severe convection. ZDR-columns, co-located in the updraft regions of thunderstorms, also have the potential to improve nowcasting of severe convection. As of this year, the separately computed, grid-based ZDR-column height is included into the cell properties as an additional severe weather information for the forecasters. Further, an improved cell severity ranking computation gives now higher weight to the radar-based, operational hail parameters POH (Probability Of Hail) and MESHS (Maximum Expected Severe Hail Size). The specific warning for heavy precipitation is newly computed with an independent severity ranking parameter. It combines the precipitation accumulation in the perimeter of the cell in the last 30 minutes, as measured by the volumetric radar network, with the 60 minutes forecast for the same cell computed by the operational nowcasting systems NowPAL/NowPrecip, and allows an early warning of the heavy precipitation risk. The emitted warning is then triggered by the highest of the two warning levels. The improved TRT algorithm will be integrated with the other convection nowcasting and warning systems already in use at MeteoSwiss (such as NowPAL, NowPrecip, COALITION and INCA) and it provides the basis for the fully automatic thunderstorm warning chain in Switzerland.

SWIRL: THE AUSTRALIAN OPERATIONAL 3D WIND ANALYSIS AND NOWCASTING SERVICE AND ITS VALIDATION

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The Bureau of Meteorology is currently transitioning to operations a new radar-based wind analysis and nowcasting technique based on its existing research-grade single-Doppler and multi-Doppler 3D wind retrieval techniques. This new service is called SWIRL (Synthetic Winds from Radar or Lidar). Radar signal noise characteristics, limited radar sampling of the 3D volumes (typically 14 elevation angles, 5-minute temporal resolution), conversion from polar to Cartesian (grid) coordinates, and fundamental assumptions in 3D wind retrievals (simplified conservation equations, boundary conditions, smoothness constraints) all conspire to produce relatively unknown and technique-dependent errors on the retrieved 3D wind components. Quantifying these errors is important for several applications, such as radar data assimilation, and use of this information by the energy and resources sector. In this work, three references are used to assess the individual impact of these different sources of errors :1) automatic weather station data, 2) wind profiler data, and 3) radar simulations using a high-resolution (50m) numerical simulation of the 8 May 2003 Oklahoma supercell case study from the University of Oklahoma's Advanced Regional Prediction System. We will also present results from the evaluation of single-Doppler wind retrievals against dual-Doppler retrievals as a reference in the Sydney region.

USING DUAL-POLARIZATION RADARS TO NOWCAST SEVERE WEATHER EVENTS

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Dual-polarization (dual-pol) radar data provide additional information to forecasters that is beneficial for assessing storm-scale processes and issuing severe weather alerts. Additionally, as radar update times decrease with new scanning strategies and technologies such as phased array radar systems, more information is available for the nowcasting process. To examine the potential benefits of dual-pol radar data, scientists at the National Severe Storms Laboratory have been using data from the National Weather Service's operational radar network in addition to data collected by a research radar located in central Oklahoma. This research radar has been used to collect rapid-update (i.e., volumetric update times of 2 min or less) data of storms with varying modes and intensities. These datasets provide an opportunity to study dual-pol signatures and determine the impact of radar update time on observing such signatures. Two potentially important dual-pol signatures are the ZDR column and KDP core, which can provide information about the character and microphysics of a storm's updraft and downdraft, respectively. As such, these signatures may be helpful for short-term prediction of hail, downbursts, and mesovortices within quasi-linear convective systems (QLCS). Results from a series of studies indicate that ZDR columns are useful in distinguishing between severe and nonsevere storms. At the same time, KDP cores provide a reliable indicator for downburst development, while also providing information about QLCS mesovortex development. Rapid-update data may also be important to adequately resolve signature evolution and is therefore needed to take full advantage of a signature's predictive capability. The lead author will present results from this ongoing work.

IMPROVING AUTOMATIC THUNDERSTORM WARNINGS AT DWD

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Short-term warnings for severe thunderstorms are produced at the German Weather Service (DWD) with the support of NowCastMIX, which automatically creates warning areas for the next 60 minutes. In short, NowCastMIX processes meteorological fields from various sources such as NWP, radar, surface station reports and lightning detections. Based on the available data the potentials for heavy rain, hail and severe gusts are calculated every 5 minutes by a hierarchy of fuzzy logic sets. From these potentials, categorical thunderstorm warnings are issued for detected cells. By condensing the information into clusters, regions are then identified which require warnings. One system that NowCastMIX currently uses as input is KONRAD. KONRAD is a method for automatic detection, tracking and prediction of thunderstorm cells based on two-dimensional weather radar data. In recent years, a new scheme, KONRAD3D, has been developed, which provides three-dimensional objects of detected cells with the help of 3D radar volume scans. KONRAD3D also provides new state-of-the-art approaches to capture features such as the storm track more smoothly and consistently over time. In order to let NowCastMIX benefit from this new development, KONRAD3D will be tested as a replacement for KONRAD. Subsequently, reanalyses with the new KONRAD3D module will be calculated in a number of case studies. A comparison of both data sets will show in which areas NowCastMIX benefits from the three-dimensional objects provided by KONRAD3D. As a long-term goal, the deterministic module KONRAD3D will eventually be replaced by a probabilistic KONRAD3D-EPS and subsequently integrated into NowCastMIX.

AUTOMATIC REPORTING OF CONVECTION IN METAR MESSAGES FOR AIRCRAFT SAFETY

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AMAROC (AutoMETAR / AutoReport rOund the Clock) is a MeteoSwiss program aiming at producing new meteorological services for the aviation sector. The main goal is to automatically produce and deliver meteorological observations at Swiss civil airports (AutoMETAR) that are compliant with international regulations. A new Python application (autometpy) is being developed to meet these objectives and is expected to become operational at Geneva airport during 2024. In this article, we present the last version of autometpy's convection module, which has been developed to report thunderstorms (TS), showers (SH), and convective clouds, i.e., towering cumuli (TCU) and cumulonimbi (CB). This algorithm relies on two different data sources, namely lightning and radar data, and is composed of three submodules. The lightning submodule detects TS and CB from the presence of lightning alone. Second, the radar3D submodule detects TCU, CB and SH looking at the vertical structure of reflectivity, by employing different thresholds at different height levels and for each cloud type (algorithm adapted from Austro Control). Finally, the bandpass submodule applies a Fourier decomposition with a Butterworth frequency filter on the 2D maximum reflectivity grid, in order to isolate small and intense cells on the horizontal plane (algorithm adapted from DWD). This submodule is currently used to report TCU and SH, but not CB, and aims especially at capturing TCU in their growth phase, when they have not yet reached a sufficient vertical extension to be spotted by the radar3D submodule. The individual results of the three submodules are then combined to produce the METAR message. The convection algorithm is verified against METAR's produced by human observers at Geneva airport during 2021.

DETECTION OF HAIL PRE-SIGNAL USING THE 3-DIMENSIONAL RADAR AND TEMPERATURE DATA

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Hail is mainly generated within strong convective cells and is frequently observed on the ground in spring (March to May) and autumn (October to December) over the Korean Peninsula. In particular, hail from strong convective cells that develop rapidly can occur within 30 minutes. Pre-signal detection of developing hail will contribute to predicting hail and reducing damage. Therefore, Weather Radar Center of KMA (Korea Meteorological Administration) developed an algorithm to detect hail pre-signal. In this study, 3-dimensional gridded radar reflectivity data utilizing a dense radar observation network on the Korean Peninsula and 3-dimensional temperature data were used to detect hail pre-signals. The pre-signals represent the area where hail can develop before hail exists in the upper atmosphere. There are 2 categories of signals: "hail possible" and "hail warning". Within "hail possible" areas, the areas with a possibility of hail size of 2 cm or larger were classified as "hail warning" areas. For signal classification, 3-dimensional data based VIL (Vertically Integrated Liquid), UVIL (Upper-level VIL, -10℃~-40℃), 35 dBZ Echo top, freezing level height, and hail observation information such as hail size, observed time and location were used. Hail ground observation cases for 4 years (2018~2021) were analyzed to select thresholds for signal classification variables and verify this algorithm. As a result of analyzing hail cases observed on 61 days, at 174 sites through this algorithm, all cases but 4 days were detected (ACC=0.81, POFD=0.21), and the hail signals were detected in advance of an average of about 40 minutes. And all 13 cases in which hail with a size of 2 cm or larger was observed were detected as "hail warning" signals.

IMPROVEMENTS TO SEVERE STORM NOWCASTING IN THE CZECH HYDROMETE-OROLOGICAL INSTITUTE

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An updated application JSMeteoView2 for displaying and analyzing of radar and other remote sensing data over various geographical layers has been developed. It is used operationally in CHMI forecast offices as a primary application for displaying of radar and other remote sensing data. Part of this application is also a new implementation of CELLTRACK, a set of utilities for identification of convective storms from radar data, calculation of their characteristics based on radar and lightning data and tracking their development. We have implemented several storm cell characteristics based on radar reflectivity and hail detection algorithms. Since the evaluation using grid fields has its limitations, we alternatively tried to use object-oriented approach based on CELLTRACK identified storm cells. In case of hail detection algorithms we used hail records from European Severe Weather Database and also 24/7 observations from Czech professional meteorological stations in order to try to evaluate also the false alarms of hail detection. The contribution will present implementation of storm cell characteristics into CELLTRACK, results of their evaluation and introduce JSMeteoView2 application with main focus on displaying storm cell characteristics from the updated CELLTRACK tool.

APPLYING RANDEVIL TO SEVERE WEATHER NOWCASTING TO ASSIST AIR TRAFFIC CONTROLLERS

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The SINOPTICA project (EU H2020 SESAR, 2020 – 2022) intends to exploit and combine different forecasting techniques to better predict severe weather events affecting Air Traffic Management (ATM) operations. One of the final goals is to integrate compact nowcast information into an Arrival Manager software to support Air Traffic Controllers in severe convective weather. The results here presented, involve the development of a new nowcasting technique based on the radar magnitude Density of the Vertical Integrated Liquid (DVIL). The DVIL combines the information of the VIL and Echo Top of 20 dBZ, providing volumetric information of storms in a single 2D radar product. The proposed Radar Nowcasting strategy, using the Density of VIL (RaNDeVIL) is a three steps nowcasting algorithm. In the first stage, using a DVIL threshold identifies the existence of convective activity and potentially severe storms. Then it stores relevant information of the storms, calculates the centre of mass and retrieves past position information. Finally, the nowcasting is performed for each storm cell identified at least twice in the radar images (meaning they have a life cycle above 10 minutes) considering all the storm tracks. Along with the prediction of the future storm positions for the next 5 to 30 minutes, an estimation of the affected area is also provided. RaNDEVIL has been applied to the three study cases of SINOPTICA (occurred in 2019 over Italy) where severe weather had compromised the normal operation of at least one airport. The nowcasted outputs have been compared with the radar observed areas obtaining a very good overlapping. Also, the statistics from MODE analysis tool (from The Model Evaluation Tools, by the Developmental Testbed Center, NCAR) are promising.

THE RELATIONSHIP BETWEEN ZDR ARCS AND STORM-RELATIVE HELICITY IN SIMULATED TORNADIC AND NON-TORNADIC THUNDERSTORMS

Allison LaFleur[1]; Robin Tanamachi[1]

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SRH is frequently used to differentiate tornadic thunderstorm from non-tornadic thunderstorm environments. However, it is typically assessed from radiosondes, which are not operationally available from near-thunderstorm environments in real time. It is hypothesized that ZDR arc area will change with SRH and can be used as a real-time proxy to estimate SRH. To test this hypothesis, output from the Cloud Model 1 (CM1), processed with a polarimetric emulator, is used to simulate ZDR arcs in 9 tornadic and 9 non-tornadic supercells. For each of these 18 simulations, a random forest algorithm is used to automatically identify the ZDR arcs, and inflow sector SRH is calculated at times when ZDR arcs are identified. This research uses a stochastically generated model ensemble and simulated radar data, which is distinct from previous research on ZDR arc-SRH relationships. We conclude that using ZDR arc area is just as effective as using SRH values to differentiate simulated tornadic versus non-tornadic thunderstorms.

HOW HAIL FALLOUT AFFECTS THE ACCURACY OF AUTOMATED ZDR ARC IDENTIFICATION: PRELIMINARY RESULTS

Allison LaFleur[1]; Robin Tanamachi[1]

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It has been suggested that ZDR arc metrics can be useful for forecasting tornadogenesis in supercells. It has also been observed that hail fallout complicates the automatic identification of ZDR arcs. In this study, two ensembles of simulated ZDR arcs are produced from CM1 numerical model output, one using all categories of hydrometeors, and the other excluding the contribution to ZDR from the hail hydrometeor category. A random forest algorithm is used to automatically identify the ZDR arcs in both ensembles. The size and intensity of these ZDR arcs, with and without hail, will be compared, and implications for operations discussed.

SEVERE CONVECTIVE STORM ENVIRONMENTS OF NORTHWESTERN ITALY: DIFFERENCES BETWEEN COASTAL AND INLAND AREAS

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Northern Italy represents one of the most prone regions of Europe for severe convective storms. More specifically, the Po Valley is often affected by large hail, severe convective wind gusts as well as tornadoes. On the other hand, coastal regions with complex terrain such as Liguria are mostly characterized by flash flooding. This study takes in consideration the north-western portion of Italy (including Liguria, Piedmont, and Lombardy) to analyze differences in storm environments and hazards between coastal and inland regions. Thunderstorm objects were obtained for the period 2019-2022 using a radar-based Rapid Developing Thunderstorm (RDT) algorithm. Storms were filtered based on their intensity using rain gauge measurements, as well as impact reports from the European Severe Storms Database (ESWD). Storms associated with an impact report, or a rain gauge threshold exceedance were considered severe, with the remaining being classified as ordinary. To identify environmental conditions associated with severe convective storms, a subset of parameters from the ECMWF model and High-Resolution Non-Hydrostatic Limited Area Model MOLOCH have been investigated in temporal-spatial proximity of the severe event. Results highlight a different environmental setup in terms of instability and wind profile between coastal and continental areas. In particular, skinny CAPE and strong low-level wind shear prevail around coastal areas. Conversely, in Piedmont and Lombardy, severe storms are more often associated with high CAPE and high DLS. Such a CAPE-shear overlap is supportive for the formation of supercells which have a higher likelihood of producing large hail, severe wind gusts and even tornadoes rather than flash flooding.

C-BAND WEATHER RADAR COMPARISON OF THE 24TH JUNE 2021 TORNADO EVENT SEEN BY AUSTRIAN, CZECH AND SLOVAKIAN RADAR NETWORK

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On 24th June 2021 a devastating F4 tornado along the Austrian – Czech and Slovakian border occurred in prefrontal highly unstable westerly flow accompanied by high low level shear (convective available energy around 2500 J/kg and modified storm relative helicity 0-3km approx. 250 m^2/s^2). The event was captured by three operational C-band weather radars of different manufacturer using different scan strategies including discrepancies in the low level coverage. Additional, the storm was seen from a variety of distances and perspectives, which influences the appearance of the storm seen by the three dual polarized Doppler weather radars. The pronounced Doppler radar signatures of supercell storms like the hook echo, bounded weak echo region and the mesocyclone was compared in terms of attenuation, shielding effects and applied data correction schemes as well as derived weather radar related products. By the other hand, the supercell storm revealed cloud microphysical structures in polarized radar data like the hydro meteor classification, large hail, debris, size-sorting and up/downdraft signatures. The presentation compares these polarized radar signature appearances seen by the three radar sites. Additional, a comparison to other tornado producing supercell storms in this area will be shown.

DEFINE AND VALIDATE ADVERSE WEATHER AREAS FOR AIR TRAFFIC MANAGEMENT BASED ON WEATHER RADAR DATA

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An optimized air traffic management (ATM) network must be robust and resilient to meteorological events such as frontal and convective events. The use of weather radar data for nowcasting makes ATM operation more predictable during deep convection and reduces the complexity of flow management. The advantage in using weather radar data for this purpose is the high spatial and temporal resolution and resolving mesoscale - and microphysical cloud processes in all three dimensions. The focus of this work is to optimize the threshold of weather radar reflectivity contour, which leads to avoidance maneuver from aircrafts in convective precipitation systems due to the risk of severe icing / turbulence, lightning strike or hail damage. Typical, less than 2 % of airplanes enter reflectivity values larger than 38 dBZ during deep convection. Analyses show dependency of altitude, respectively the impact of flight phase, traffic density, dimension, orientation and severity of thunderstorms and the relevance of exact timing considering antenna pointing and aircraft positioning within the timeframe of seconds. Additional, improvements in echo top products are taken into account.

PATTERN RECOGNITION USING COMPLEX NUMBERS TO ACCOUNT FOR DATA QUALITY AND PATTERN IMPORTANCE: SEVERE WEATHER DETECTION

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Matching storm-scale patterns of reflectivity for the purpose of detecting severe weather signatures is impeded by the fact that not all elements of a pattern have equal importance and data quality is spatially variable. For example, to detect a severe tornadic supercell, one would like to put more emphasis on the presence of a (small) hook echo and less on that of a (large) overhang. In parallel, data with lower quality should be deemphasized compared to higher quality data. However, efficient ways of computing correlations do not allow for weighting either the wanted pattern or the field observed without deforming the pattern sought or the data, resulting in an artificial loss of correlation. We instead attempted to correlate two complex fields: For the pattern to match, we use the interest weight I as the modulo and the reflectivity of the pattern to match remapped between 0 and π as the argument; for the data, we use data quality Q as the modulo and the reflectivity data, also remapped. The resulting complex correlation has a modulo corresponding to match quality while the argument provides information whether the echo was stronger or weaker overall than the sought pattern, and that correlation naturally accounts for the interest field I and the data quality Q, reducing the weight of the correlation where I*Q is low and increasing it where I*Q is high. The proposed approach is contrasted with a real-number correlation in the context of detecting threatening supercells. Using I*Q to better detect patterns is simply intelligent! ;) (and no, it has nothing to do with in-phase and in quadrature radar signals).

RESULTS FROM A CLIMATOLOGY OF POLARIMETRIC RADAR FEATURES IN SUPERCELLS

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Results from four studies examining polarimetric radar features in several hundred supercells from the WSR-88D network in the U.S. from 2013 onward are presented. The data were used to examine hook echo bulk DSDs, ZDR columns, ZDR arcs, and ZDR-KDP separation vectors in both tornadic and non-tornadic supercells. The focus of study is on differences in radar features between tornadic and non-tornadic supercell cases, the evolution of radar features leading up to tornadogenesis and tornado dissipation, and relationships between radar features and peak tornado intensity. Bulk DSDs are found to be largely similar in tornadic and non-tornadic supercells, but ZDR column areas are far more variable in tornadic than non-tornadic supercells as the latter tend to be relatively small. Both ZDR arc magnitude and ZDR-KDP separation angle decrease prior to tornado dissipation, while hook echo KDP tends to increase. Multiple dissipation “behaviors” are also more likely as tornado dissipation approaches, but operational use may not be as effective compared to monitoring tornadic vortex signature behavior. ZDR column areas both just prior to and at the time of tornadogenesis are found to have a large predictive relationship with peak tornado intensity as estimated using EF scale ratings. Finally, given the potential importance of ZDR columns in nowcasting tornado evolution and other severe weather hazards, we examine the tradeoffs of receiving fewer midlevel WSR-88D scans with additional low-level scans through the use of Supplemental Adaptive Intra-Volume Low-Level Scan (SAILS) strategies. Several thousand storm reports and severe weather warnings are used to determine SAILS impacts on warning skill and lead time, and guidance is provided as to the cost of such a tradeoff.

THUNDERSTORMS CHARACTERIZATION IMPROVEMENTS COMBINING NWCSAF-RDT ESTIMATED PARAMETERS WITH MEASUREMENTS FROM WEATHER RADAR

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Many algorithms based on weather radar data are available to identify, track and characterize thunderstorms. According to the available measurements, important information about the cell structure and content can be inferred, useful to evaluate which phenomena are associated with thunderstorms and their severity. In this study we investigate the possibility of improving knowledge on thunderstorms by associating radar data with parameters obtained from satellite measurements. In particular we considered two case study days with numerous and intense thunderstorms over Italy: 01/08/2020 and 23/08/2020. We analyzed data provided by the HRD algorithm, developed by the Italian National Civil Protection Department, identifying thunderstorms based on radar data, and by NWC-SAF-RDT algorithm, developed by Meteo-France, providing information about convective clouds based on MSG satellite data. Aim of the study is a better comprehension of the severity and phase of life of thunderstorms identified by HRD, analyzing some of the clouds parameters (i.e. Phase Life, Cooling rate, Brightness Temperature, Severity Intensity) provided by RDT.

MESOCYCLONE DETECTION AT MÉTÉO-FRANCE

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Supercells are particularly long-lived thunderstorms known for their capacity to produce damaging weather phenomena such as large hail, heavy rain, severe wind gusts or tornadoes. They are characterized by the presence of a deep and persistent rotating updraft called mesocyclone, whose diameter usually ranges from 2 to 10 km. The rotation can be seen as a symetric dipole of inbound/outbound velocities in the radial storm-relative velocity field of Doppler weather radars. Several mesocyclone algorithms have been developed in the past for operational nowcasting (e.g. Zrnic 1985, Stumpf et al. 1998, Hengstebeck et al. 2018). In recent years, Meteo France has undertaken the development of its own algorithm based largely on this work. The first results show a good detection capacity but also an important difficulty to distinguish mesocyclones of low intensity from false alarms generated by a bad quality of Doppler data or the presence of strong horizontal wind gradient. A few case studies will be shown to illustrate the performance of this new version of the algorithm.

LAKE VICTORIA THUNDERSTORMS: RADAR-OBSERVED INITIATION AND STORM EVOLUTION MODES

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The enhanced observation period during the HIGHWAY field campaign in East Africa provided the opportunity to obtain continuous ground-based radar observations over the Lake Victoria Basin . This provided insight into thunderstorm initiation processes and thunderstorm evolution. This insight is significant for it can lead to nowcasting thunderstorms over Lake Victoria which is particularly important because of the > 200,000 fishers using the lake daily and the extremely high number of drownings resulting from capsized boats caused by large waves and high winds from thunderstorms. Radar data from the south shoreline of Lake Victoria made it possible to observe thunderstorm activity over the entire lake. Unexpectedly the radar returns from high concentration of insects over the lake made it possible for the radar to observe boundary layer convergence lines. With this information a radar trained forecaster could provide nowcasts of severe storm locations and by using extrapolation techniques provide nowcasts of their future location. In addition, rules for forecasting the timing and extent of nighttime thunderstorm activity over the lake based on radar monitoring of earlier activity along the northeast land/lake region are provided. While there are many obstacles to be overcome it is hoped that in the near future this possible life saving information can be provided to Lake Victoria boaters.

NOWCASTING OF PRECIPITATION

LAGRANGIAN CONVOLUTIONAL NEURAL NETWORK FOR RADAR-BASED PRECIPITATION NOWCASTING

THE OPERATIONAL FINNISH METEOROLOGICAL INSTITUTE PROBABILISTIC PRECIPITATION NOWCASTING SYSTEM

COMBINING OBJECT-BASED CELL TRACKING AND OPTICAL FLOW TO IMPROVE NOWCASTING OF QUASI-STATIONARY RAINFALL

INTENSE -- THE NEW SEAMLESSLY COMBINED PRECIPITATION ENSEMBLE FORECASTING SYSTEM AT DWD

NOWPRECIP: LOCALIZED PRECIPITATION NOWCASTING IN THE COMPLEX TOPOGRAPHY OF SWITZERLAND

A STUDY ON THE MOTION VECTOR CALCULATION OF RADAR IMAGES USING OPTICAL FLOW AND RADIAL BASIS FUNCTION (RBF)

ADVANCING NOWCASTING SCIENCE AND OPERATIONS WITH FREE AND OPEN-SOURCE SOFTWARE: THE PYSTEPS SUCCESS STORY

EXTENDING SKILLFUL LEAD TIMES WITH A SCALE-DEPENDENT BLENDING OF ENSEMBLE RAINFALL NOWCASTS AND NWP IN PYSTEPS

PREDICTING PRECIPITATION GROWTH AND DECAY WITH WEATHER RADAR RAINFALL MEASUREMENTS

EVALUATION OF A DEEP LEARNING ALGORITHM IN RADAR-BASED PRECIPITATION NOWCASTING

STEPS AS A SERVICE - A NEW GENERATION OF OPERAITONAL NOWCASTING FOR THE AUSTRALIAN CONTINENT

STUDY OF OPTICAL-FLOW TECHNIQUES FOR PRECIPITATION NOWCASTING BASED ON RADAR DATA IN BASQUE COUNTRY

CALIBRATION AND TEMPORAL FORECAST CONSISTENCY IN AN ADAPTIVE BLENDING OF PROBABILISTIC PRECIPITATION FORECASTS

WIND FIELD RETRIEVAL AND QUANTITATIVE EVALUATION FROM THE ITALIAN RADAR MOSAIC

BLENDING OF PRECIPITATION PROBABILITY FORECASTS: WEATHER RADAR ADVECTION AND NWP MODELS

A PRECIPITATION PHASE NOWCASTING SYSTEM: WEATHER RADAR DATA, NWP FORECASTS AND METEOROLOGICAL OBSERVATIONS

BLENDING RAINFALL NOWCASTING WITH RADAR DATA AND HIGH-RESOLUTION NUMERICAL WEATHER PREDICTION MODEL OVER ITALY

PROJECT IMA: BELGIUM'S SEAMLESS PREDICTION SYSTEM

METAMODELING USING GOES-R SATELLITE DATA FOR SHORT-TERM FORECASTING OF PRECIPITATION THROUGH CONVLSTM MODEL

DEVELOPMENT OF RADAR-BASED NOWCASTING FOR INTENSE PRECIPITATION IN THE TROPICS

LAGRANGIAN CONVOLUTIONAL NEURAL NETWORK FOR RADAR-BASED PRECIPITATION NOWCASTING

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Several applications, such as flash flood prediction and flood warnings, require short-term forecasting (i.e. nowcasting) of rainfall that is both spatially and temporally accurate (e.g. in the scale of 1 km^2 and temporal resolution of 5 minutes). However, the current nowcasting methods that combine extrapolation of radar echoes with time series models still have a limited ability to predict the growth and decay of convective rainfall beyond the first 30 minutes. While new applications of deep learning have recently shown improvement compared to extrapolation-based methods, they still have difficulties forecasting small-scale intense convective rainfall. To address this issue, we present a new method called L-CNN that implements a physics-informed neural network. In the proposed method, a RainNet-based convolutional neural network (CNN) is applied to rainfall fields that have been transformed to the Lagrangian coordinates using the advection equation. Such a transform allows us to separate the growth and decay of rainfall from horizontal advection, resulting in a better representation of the temporal evolution of rainfall in the deep learning model. The final forecast is then obtained by transforming the output of the CNN back to the Eulerian coordinates. The proposed model is trained using a multi-scale structural similarity index measure (MS-SSIM) loss function that has been shown to improve nowcasts of small-scale and high-intensity rainfall. The method is benchmarked against the existing extrapolation- and deep learning-based nowcasting methods using rain rate composites from the Finnish radar network.

THE OPERATIONAL FINNISH METEOROLOGICAL INSTITUTE PROBABILISTIC PRECIPITATION NOWCASTING SYSTEM

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Finnish Meteorological Institute Probabilistic Precipitation Nowcasting System (FMI-PPN) is used for operational radar-based nowcasting in FMI. It is a user interface for Python framework for short-term ensemble prediction systems (pySteps). We present an overview of the current operational FMI-PPN production chain. A series of consecutive radar composite images is first used to calculate a motion vector field using Lucas Kanade optical flow method. The STEPS method is then used to extrapolate the most recent radar composite image and perturbed images to produce deterministic and ensemble nowcasts. These extrapolated images are then postprocessed and distributed to different in-house users. In addition to accumulated precipitation rate nowcasts produced by FMI-PPN being used as such by weather forecasters, they are also blended with NWP model data to produce short-range precipitation forecasts.

COMBINING OBJECT-BASED CELL TRACKING AND OPTICAL FLOW TO IMPROVE NOWCASTING OF QUASI-STATIONARY RAINFALL

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Many nowcasting techniques for gridded rainfall data are derived from a simple concept: The current displacement of rainfall fields is quantified by motion vectors and extrapolated to generate short-term predictions. However, motion vector fields need to be smooth and local movement of single convective cells cannot be reproduced. Quasi-stationary rainfall structures, which are quite important due to their potential to cause flash floods, are often shifted along the larger-scale mean flow, i.e. their displacement is overestimated by optical flow. We aim at overcoming this limitation by considering information derived from object-based cell tracking (KONRAD3D). Once a quasi-stationary cell is detected by KONRAD3D, a forecast about its longevity is needed to perform a local adjustment of the motion vector field used for grid-based nowcasting. We recomputed KONRAD3D for a 5-year time period, where we integrated several other data sources in order to compute specific cell attributes. For instance, NWP model data is used to characterize the convective environment. Cells we did not identify as quasi-stationary are discarded and a large subset of cell attributes is selected for training machine learning models to predict duration of stationary. We compared artificial neural networks, random forest and gradient boosting by k-Fold cross validation and found that prediction of quasi-stationarity is challenging. No method is yet able to achieve a skillful prediction using the available KONRAD3D cell attributes, but random forest seems to be useful for generating ensembles of possible lifetimes. An integration into grid-based nowcasting methods might help to improve forecasted rainfall amounts and corresponding uncertainties for some events caused by quasi-stationary structures.

INTENSE -- THE NEW SEAMLESSLY COMBINED PRECIPITATION ENSEMBLE FORECASTING SYSTEM AT DWD

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Reliable and accurate forecasts in the very-short-term range are essential for precise warnings that help to increase the lead time for decision makers in hydrological and emergency services. Nowcasting techniques and numerical weather prediction (NWP) are commonly used as the basis of these warnings in current operational weather forecasting. Both approaches can provide valuable warning guidance, however, for different forecast lead times. The ongoing DWD project SINFONY (Seamless INtegrated FOrecastiNg sYstem) developes an integrated ensemble forecasting systems on the convective scale within the short-term range. Towards combining nowcasting and NWP, both have been further enhanced. To replace the purely advective precipitation nowcasting, STEPS-DWD was introduced, providing ensemble forecasts every 5 min. It represents an adaption of the well-known STEPS (e.g. Seed 2003). The new ICON-D2-RUC provides hourly initialized ensemble forecasts running 8 h ahead with a horizontal resolution of 2.2x2.2 km^2. Precipitation variables are given every 5 min. In order to reduce that amount of data and to condense information by preserving the best forecast quality at all lead times, the combined ensemble forecasting system INTENSE (Integration of NWP Ensembles and Extrapolations) is introduced. INTENSE adapts the Bayesian combination approach according to Nerini et al., 2019 by utilizing the ensemble Kalman filter in a dimension-reduced space. It provides combined forecasts up to 6 h ahead with a spatial and temporal resolution of 5 min and 1x1 km^2. The adaption of the combination approach will be presented and additional modifications will be discussed. A verification study for various precipitation variables will be shown for a case study period in summer 2021.

NOWPRECIP: LOCALIZED PRECIPITATION NOWCASTING IN THE COMPLEX TOPOGRAPHY OF SWITZERLAND

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NowPrecip is the areal precipitation nowcasting system of MeteoSwiss. It is based on the following pillars: (a) It is stochastic in design, able to generate multi-member ensembles of precipitation nowcasts. (b) It supports the paradigm of seamless forecasting: the evolution of the nowcasts starts from the most recent radar observation and evolves smoothly, through merging, towards the ensemble members of the numerical weather prediction (NWP). (c) Its optical flow relies on a geostatistical algorithm, coined as ``NowTrack,'' capable of capturing accurately even complex situations like a fine-scale rotation. (d) It has a localized architecture motivated by the need to deal with scenarios where distinct rainfall patterns characterize different parts of the domain. This is particularly pertinent to complex topographies like the in Switzerland, but it is also useful for areal nowcasting operating on extensive regions. (e) It comes with techniques to estimate and incorporate localized growth and decay into the nowcast. This is very useful for the Alpine terrain, where a systematic growth and decay is often associated with orographic features. The growth and decay factors rely on analysis of the available NWP product, allowing for a more efficient coupling between a nowcast and the corresponding numerical model output. A verification of NowPrecip was performed for several representative cases. The main outcomes were: (a) the optical flow scheme (NowTrack) is characterized by small errors, (b) the growth and decay mechanism improves the outcome over orography, and (c) the skill of the output is better than that of the numerical model output for four hours in average.

A STUDY ON THE MOTION VECTOR CALCULATION OF RADAR IMAGES USING OPTICAL FLOW AND RADIAL BASIS FUNCTION (RBF)

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Weather radar is an essential meteorological equipment that monitors the location and intensity of precipitation through the intensity and reception time of the electromagnetic wave signal that is reflected from precipitation particles by radiating electromagnetic waves into the atmosphere. Moreover, weather radar images can be used in a variety of ways because of their high visibility in terms of visuals. In other words, it has the advantage of being able to grasp the flow of weather phenomena using not only the raw data of the weather radar, but also the change characteristics between consecutive images. In particular, image processing techniques are gradually expanding in the field of meteorological research, and in the case of image data having high resolution such as weather radar images, it is expected to produce useful information through a new approach called image processing techniques. If the optical flow is calculated with very high-resolution, the possibility of errors can be increased. In this study, to minimize motion vector errors generated from very high-resolution images, two-step calculations were performed. The 1st step is generating a rough motion vector using the optical flow and then a high-resolution motion vector was calculated using mesh grid interpolation and Radial Basis Function (RBF) extrapolation as the 2nd step. The calculated moving direction and the motion vector are evaluated in typhoon cases.

ADVANCING NOWCASTING SCIENCE AND OPERATIONS WITH FREE AND OPEN-SOURCE SOFTWARE: THE PYSTEPS SUCCESS STORY

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Born in 2018 with the ERAD nowcasting short course, pysteps has since then grown into a mature software suitable for a range of applications, from research to real-time production, with applications well beyond its original educational scope. Along this journey, the aim to provide a free and open-source software (FOSS) has been a defining factor, while the focus on user experience has promoted a rapid adoption by the community. As a result, the pysteps project has gone as far as to disrupt the nowcasting scene, and it is now the de-facto standard for new developments in the field, including sophisticated AI-based approaches. Thanks to its open-source community, simple design, and high level of portability, pysteps has been adopted for production by agencies seeking to reduce the risk, time, and cost of an in-house development. This talk will look at the past four years to highlight and describe the factors that have been the most important to this journey. We will review successes and challenges of this experience and how, within its small community, pysteps has become a platform for scientific collaboration and personal development. In the light of this experience, we will argue once again that open-source software has proven its value as a scientific software development model not only within academia, but for the whole radar community. Finally, we will put our experience in perspective by considering emerging technologies, and try to draft a roadmap for the pysteps nowcasting community for the years to come. Namely, we envisage the adoption of a new data model based on labelled multidimensional arrays (i.e., xarray), the support of nowcasting methods based on machine learning, and the development of seamless techniques to combine multiple forecasting sources.

EXTENDING SKILLFUL LEAD TIMES WITH A SCALE-DEPENDENT BLENDING OF ENSEMBLE RAINFALL NOWCASTS AND NWP IN PYSTEPS

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Capturing the timing and location of rainfall is crucial for e.g. (flash) flood warnings. This local scale is at present not sufficiently well captured by rainfall forecasts of numerical weather prediction (NWP) models and, therefore, rainfall nowcasting techniques are increasingly used to provide skillful forecasts for short ranges of up to 6 hours. Pysteps is a free and open-source nowcasting software, which provides a Python implementation of the probabilistic nowcasting scheme STEPS. It generates rainfall forecast ensembles by perturbing a deterministic extrapolation nowcast with spatially and temporally correlated, scale-dependent stochastic noise. This approach ensures an appropriate representation of uncertainty associated with growth and dissipation of rainfall. Despite this representation, a radar-only nowcasting approach quickly loses skill after 2 hours, or even less for convective rainfall. To extend the skillful lead time to 6 hours or more, a blending with NWP is necessary. We present the implementation of an adaptive scale-dependent blending approach in pysteps based on earlier work in the STEPS scheme. This implementation blends the radar rainfall nowcast, NWP rainfall forecasts and noise components at different spatial scales using varying blending weights per cascade level. The scale-dependent blending weights are computed from the recent skill of the forecast components and converge to a climatological value, which is computed from a multi-day rolling window. To constrain the (dis) appearance of rain in the forecasts to regions around rainy areas, we introduce a Lagrangian blended probability matching scheme and incremental masking strategy. We validate the blending approach in a hydrometeorological testbed using the Belgian radar and NWP products.

PREDICTING PRECIPITATION GROWTH AND DECAY WITH WEATHER RADAR RAINFALL MEASUREMENTS

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Forecasting precipitation in the very short range (0–6 h) commonly relies on extrapolation-based nowcasting tools that exploit the persistence of the most recent weather radar observations. In this time range, many critical decisions are taken to ensure people's safety. To obtain the best possible prediction skill in the 0–6-h range, one cannot solely rely on numerical weather prediction (NWP) but must also use the available observations in a more direct way. Weather radars are instruments capable to provide rainfall measurements with suitable spatial and temporal resolutions. The potential benefit of using radar rainfall in hydrology is huge, but practical hydrological applications of radar have been limited by the inherent uncertainties and errors in radar rainfall estimates. The unknown future evolution of precipitation intensity comprises its initiation, growth, decay, and termination. Machine learning algorithms can be trained with weather radar data to identify regions of precipitation growth and decay based on historical observations. Artificial neural networks (ANN) can be employed to learn the complex nonlinear dependence relating the growth and decay to the input predictors, which are geographical location, motion vectors, freezing level height, and time of the day as proposed by Foresti et al (2019). The motion field can be calculated by using the optical flow method implemented in the open-source python library 'pysteps', which is driven by weather radar data. This paper will present some preliminary analysis of predicting precipitation growth and decay in different places in the UK.

EVALUATION OF A DEEP LEARNING ALGORITHM IN RADAR-BASED PRECIPITATION NOWCASTING

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Extreme precipitation events can cause catastrophic natural disasters such as severe floods and landslides, putting people's lives, property, and economies at risk. Accurate precipitation nowcasting is a key element in the risk management of weather-related disasters. Traditional methods used in very short-term rainfall forecasting are numerical weather prediction (NWP) and radar extrapolation. NWP produces poor rainfall nowcasts due to the long time it takes to spin up and their coarse time scales for early warnings. Radar extrapolation is the principal approach in rainfall nowcasting however, these methods have limitations such as being unable to cope with complex weather conditions. Recently, deep learning-based (DL) methods for adaptively learning the wide range of rainfall variations from massive previous radar sequences have been proposed. These methods are still in their early stages and their full potential in rainfall nowcasting requires further investigation. This study presents a preliminary analysis of the performance of a deep convolutional neural network (called RainNet) in a comparison with three optical flow algorithms (called Rainymotion Sparse, Rainymotion Dense and Rainymotion DenseRotation) and the baseline method, Eulerian Persistence, to assess their predictive skills in rainfall nowcasting. Synthetic precipitation scenarios have been created with different motion fields (linear and rotational motions), velocities, intensities, and sizes. The models have been evaluated to forecast different precipitation processes that contribute mainly to model errors such as constant and accelerated linear and rotational motions, growth, and decay in both size and intensity. The predictive performance has been evaluated using different verification metrics.

STEPS AS A SERVICE - A NEW GENERATION OF OPERATIONAL NOWCASTING FOR THE AUSTRALIAN CONTINENT

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A new generation of STEPS, the Short-Term Ensemble Prediction System, has recently entered operation at the Bureau of Meteorology, providing a significant uplift of precipitation nowcasting services for the Australian public. STEPS-3 is a completely new implementation that provides low cost, high performance, reliable nowcasting services for large scale radar networks. This presentation outlines the scientific and engineering enhancements involved, including deployment of STEPS as a cloud-based service. Scientific improvements have been made in several areas: Redesigned decomposition filters increase spectral isolation of cascade levels and reduce ringing artefacts, an alternative optical flow technique improves tracking in low texture areas, and the process parameters of the AR models that drive stochastic evolution are now spatially varying. This change ensures that localized scaling characteristics are retained during the life of the nowcast rather than becoming statistically homogenous. Verification shows significant improvement in nowcast quality compared to earlier generations. The engineering priorities for STEPS-3 are performance, reliability and suitability for operational deployment. A highly parallelized code base allows generation of large ensembles with very low latency. In the Bureau of Meteorology's operational configuration STEPS-3 generates a 32-member ensemble in less than 30 seconds, compared to over 5 minutes for the equivalent configurations using STEPS-1 and pySTEPS. The deployment of STEPS-3 as a cloud-based application allows it to scale dynamically based on weather conditions, without impacting internal IT resources. It also opens the possibility to offer customized "nowcasting as a service" to a broad range of users.

STUDY OF OPTICAL-FLOW TECHNIQUES FOR PRECIPITATION NOWCASTING BASED ON RADAR DATA IN BASQUE COUNTRY

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Nowcasting plays an increasing role in crisis management and risk prevention. Its operational realization is a highly complex and integrated task, where many different approaches are possible, varying from the monitoring of available observational data based on humans, to fully automatic complex systems with different algorithms and computational techniques. Weather radar systems, where available, are one of the most used instruments for nowcasting purposes, particularly in the field of precipitation nowcasting. In order to consider the rapid information update and integration needed for automatization, extrapolation methods, where optical-flow techniques are a key component, are a plausible approximation. In order to determine in which terms those optical-flow techniques could be used in the Basque Country in an operational context, different experiments has been done based on Euskalmet radar data available in the study area. In this work we present some results from those tests, where radar reflectivity fields are estimated for very-short term (up to 2 hours) using different optical-flow techniques for some representative rainfall scenarios in the Basque Country area. Selected techniques includes different optical flow models available from some Python packages and libraries (Rainymotion, Pystep,…). We include a comparative study between selected techniques applied to Euskalmet Radar data for different precipitation events. Selected events represent typical local weather where some kind of impact due to precipitation characteristics (intensity and/or persistence) are plausible. A number of verification metrics is used in order to analyze the general characteristics of the nowcasts experiments in terms of consistency and goodness.

CALIBRATION AND TEMPORAL FORECAST CONSISTENCY IN AN ADAPTIVE BLENDING OF PROBABILISTIC PRECIPITATION FORECASTS

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There might be several forecasting models at the same time for the prediction of the same weather event. In an operational setting this leads to the question of how to utilize several models, especially when these models make contradicting predictions. While some models perform better than others, each forecast contains valuable information. Therefore it is desirable to combine all available forecasts into a new forecast with improved skill. Here, we present the extension of an ANN-based combination model, which has been proposed in Schaumann et al., 2021, for the seamless combination of two precipitation ensemble forecasts. The basic forecast models are 1) STEPS-DWD, a nowcasting technique and 2) an experimental setting of the operational NWP model ICON-D2, which have a much higher spatial resolution than the models that have been used to optimize the combination model. While STEPS-DWD achieves very good validation scores for short lead times, its performance declines faster compared to ICON-D2. The result of the combination model are hourly exceedance probabilities for a chosen set of thresholds. To evaluate the spatial consistency of each model, several validation scores are considered, not only in aggregate but also spatially resolved. The temporal consistency has been evaluated with the help of the flip-flop score. To test the models robustness, a new dataset has been used with a finer grid, additional winter months and different initial forecast models. Validation results show that the combined forecast outperforms both basic forecasts and improves spatial and temporal consistency. The proposed extensions make the combination model more useful in operational scenarios and further improve its forecast quality.

WIND FIELD RETRIEVAL AND QUANTITATIVE EVALUATION FROM THE ITALIAN RADAR MOSAIC

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Radar nowcasting of precipitation is one of the main challenges in radar meteorology. Early studies exploited the correlation of sequences of radar reflectivity maps to extrapolate the prevailing motion of precipitation field and to project it ahead. More refined approaches uses the explicit solution of the optical flow equation, which represents a special case of mass conservation law under the assumption of no source-sink terms and incompressible fluid. Recently, artificial intelligence is getting momentum with the explosion of a plethora of neural network configurations for radar nowcasting. This work focuses on wind field estimation from sequences of radar images and its quantitative error evaluation. Such effort has been undervalued so far, because, often, only the overall error is estimated, being it evaluated comparing the nowcasted maps with the actual ones. Specific error sources e.g, those related to precipitation source-sink terms or to the specific nowcasting method are entangled together and it is difficult to point out the error due to a specific source. We built a robust dataset (103 rainy days, i.e. 14479 frames, from 09-Mar-2021 to 27-Feb-2022) of the Italian radars in terms of reflectivity and Doppler mosaics and applied to it a wind-field retrieval using the Lucas and Kanade (LK) solution in two- (2D) and three-dimensional (3D) framework. The Doppler information is then used to constrain the LK solutions as well as reference for evaluating the wind field estimation error. Results show that LK-2D solution is robust although improvements are found when constraining it with Doppler. An RMSE of ~4-5 m s^-1 was found. In the 3D case a deterioration of 10% is registered even though a considerable uncertainty on the vertical wind component remains.

BLENDING OF PRECIPITATION PROBABILITY FORECASTS: WEATHER RADAR ADVECTION AND NWP MODELS

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The Meteorological Service of Catalonia has been working on obtaining a seamless forecast with a lead time of up to 10 days for different meteorological variables. This study focuses on the first six hours of forecast to obtain a probabilistic precipitation product. It is known that the best forecast for the first one to two hours of lead time is usually achieved by the extrapolation of weather radar data, being then surpassed by NWP forecasts. Therefore, a blending between these two kinds of forecasts is required. An operational chain to build a blending product was set up following a modular approach. Modules are classified between sources, those providing forecasts, and tools, those which process data. The formers include a weather radar data extrapolation ensemble, obtained with pySTEPS (Pulkkinen et al., 2019), and a NWP model time-lagged ensemble. Regarding the available tools, some of them provided by IMPROVER (Ayliffe and Roberts, 2019), include different probability calculation methodologies, smoothing filters, blending weights, and reliability calibration methodologies among others. Results are obtained from the spatial verification of fourteen precipitation events. They show that the performance of the blending product surpasses that of weather radar extrapolation and NWP if individually considered. Verification results also show that is advisable to use different probability calculation methodologies depending on the precipitation threshold considered.

REFERENCES

Ayliffe B, and N Roberts 2019: IMPROVER: A probabilistic, multi-model post-processing system for meteorological forecasts. GRA. Vol. 21.

Pulkkinen S et al. 2019: Pysteps: an open-source Python library for probabilistic precipitation nowcasting (v1.0). GMD 12.10: 4185-4219

A PRECIPITATION PHASE NOWCASTING SYSTEM: WEATHER RADAR DATA, NWP FORECASTS AND METEOROLOGICAL OBSERVATIONS

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Mediterranean areas are not used to heavy snowfall events so they may cause major road safety problems, and disturbance of every-day activities. For this reason, nowcasting of snowfall is a key point for forecasters and decision-makers. This involves two aspects: the precipitation field and the precipitation type. The latter can be derived from NWP forecasts and surface meteorological observations, accounting for vertical temperature profiles and surface temperature conditions. In this study, the nowcasting (0-3h) of both the precipitation field and the precipitation phase at low altitude events in a NW Mediterranean region are addressed. Different precipitation phase classification algorithms and the radar extrapolation methodology STEPS, provided by pySTEPS, are combined to create a precipitation phase nowcasting system. Results are evaluated with categorical skill scores using SYNOP, METAR and official meteorological observation datasets. Results indicate that a combination of precipitation phase algorithms is advisable, specially in situations with temperatures close to the freezing point. In addition, precipitation phase transitions are analysed and, on average, they can be correctly forecast with 2h of lead time. The proposed nowcasting system is operationally running at the Meteorological Service of Catalonia. More details available at Casellas et al (2021a,b). This research was supported by grants DI-053/2017 and RTI2018-098693-B-C32 (MINECO).

REFERENCES

Casellas E et al. 2021a: Nowcasting the precipitation phase combining weather radar data, surface observations, and NWP model forecasts. QJRMS 147.739 3135-3153

Casellas E et al. 2021b: Surface precipitation phase discrimination in complex terrain. J Hydrol 592 (2021b): 125780

BLENDING RAINFALL NOWCASTING WITH RADAR DATA AND HIGH-RESOLUTION NUMERICAL WEATHER PREDICTION MODEL OVER ITALY

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The continuous improvement of numerical weather prediction (NWP) models has led to increased resolution and the use of assimilation systems that provide atmospheric conditions closer to the true state of the atmosphere as the initial forecast state. With the implementation of more frequent forecast cycles, it is now possible to use numerical models for very short-term forecasting applications. In order to limit the still present spin-up problems of numerical models, blending of fields extrapolated from radar observations with NWP model output can be used to produce a short-term forecast in the 0-6 hour time frame. This technique allows to obtain a continuous transition in the critical period around 1-3 hours, when the accuracy of the forecast with extrapolative methods is typically outperformed by the use of numerical modeling, which allows the generation of new precipitation structures, overcoming one of the limitations of the radar-based nowcasting techniques. Arpa Piemonte and Arpae Emilia-Romagna have implemented a blending method to seamlessly combine radar data and NWP model output over Italy. The radar-based nowcasting relies on the processing of the Italian rainfall estimation composite products with the SPROG (Spectral PROgnosis) method, which is available in the open-source library Py-STEPS. The model output is provided by the deterministic forecasts of the high resolution COSMO model, with assimilation of radar observations, updated with a frequency of one hour. The implemented method and the verification of the results obtained will be presented, showing the strengths and weaknesses of the system.

PROJECT IMA: BELGIUM'S SEAMLESS PREDICTION SYSTEM

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Data assimilation (DA) in numerical weather prediction (NWP) models cannot make use of the full spatiotemporal resolution of contemporary observation systems, nor can it beat the speed of an extrapolation-based nowcast, or match its accuracy at short lead times. A logical move is therefore to implement seamless prediction systems, which make optimal use of today's rapidly available high-resolution observations, nowcasting algorithms and state-of-the-art convection-permitting NWP models. This approach aims to provide a single, frequently updating, deterministic or probabilistic forecast for lead times from minutes to days. We present the probabilistic seamless ensemble prediction system (EPS) of the Royal Meteorological Institute of Belgium, called Project IMA (Japanese for "now" or "soon"). The precipitation nowcasting component is based on pySTEPS' scale-dependent blending with NWP (presented by R. Imhoff), and is combined with INCA-BE nowcasts for other variables. The short-range NWP component is a multimodel lagged mini-EPS of two convection-permitting configurations of the ACCORD system: AROME and ALARO, running at 1.3km resolution. It features a 3-hourly DA cycle and provides high-frequency precipitation output to facilitate the blending of precipitation nowcasts and forecasts. The system runs robustly using our NodeRunner tool, based on ECMWF's EcFlow. We will present the development (past and future), lessons learned, and what lies ahead for Project IMA, especially in the realm of artificial intelligence.

METAMODELING USING GOES-R SATELLITE DATA FOR SHORT-TERM FORECASTING OF PRECIPITATION THROUGH CONVLSTM MODEL

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Heavy rains can have a destructive impact in urban centers and socially vulnerable regions. Considering this context, a meta-modeling scheme base in Convolutional Structures in Long Short Term Memory Model (CONVLSTM) is a common type of neural network for spatio-temporal prediction capable of producing short-term forecasts (2h), which probability output for precipitation rate above 1 mm/h and 15 mm/h. Initially, the study was tested in Brazil, but can be generalized to the entire domain of the GOES-R satellite. The input data are constituted by the infrared channels of the GOES satellite, orographic features from MODIS and the Geostationary Lightning Mapper (GLM), combined with the Deep Residual Convolutional model for estimate reflectivity and property of the hydrometeors (CABII, 2019) to increasing the input features and information with the same sensor. Global Precipitation Measurement (GPM final run) for all GOES-R domains training data. The test data is considered a network of rain gauges of National Center for Monitoring and Natural Disaster Alerts (CEMADEN)in 580 rain gauges for validation, selecting two events which caused destruction in parts of the Southern of Brazil (2019). The results of the Probability of Detection (POD) show that the first case with a precipitation rate > 1 mm/h is 0.93. The False Alarm Rate (FAR) results at 0.23 and the Area Under the Curve (AUC) is 0.88. For the second case, precipitation rate is a > 15 mm/h, the POD=0.77, FAR=0.61 and AUC=0.83. The proposal for future works with continuous time should improve the tests, increasing the significance of the results over longer periods of time, the ability to use the model to improve the safety of regions vulnerable to high precipitation.

DEVELOPMENT OF RADAR-BASED NOWCASTING FOR INTENSE PRECIPITATION IN THE TROPICS

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The tropical climate of Singapore produces year-round convective thunderstorms that are typically localized in nature and are characterized with rapid growth and decay as well as weak environment winds (particularly during inter-monsoon seasons) that often result in back-building to occur. As a result, these characteristics can go well beyond the limits of a radar-based nowcasting system that relies exclusively on extrapolation methods. For the Centre for Climate Research Singapore (CCRS), the focus over the last couple of years has shifted towards identifying and then nowcasting thunderstorms producing intense precipitation that may result in flooding. This study attempts to establish a base-line performance for nowcasting these intense precipitation events. Various open source nowcasting tools such as TITAN, pySTEPS and SwirlsPy have been implemented. A 5-year dataset (2017-2021) consisting of radar and 5-minute rain gauge data is available for this study. Nowcasts with 90-minute lead-time using extrapolation and STEPS ensemble methods, among others, are evaluated using appropriate verification metrics. A total number of 629 events were found to exceed the more than 35 mm in 30 minutes definition as set out by Meteorological Service Singapore (MSS) during the 5-year study period. These events had a maximum frequency of occurrence in April and November, which corresponds to Singapore's inter-monsoon rainfall season. Most of the events occurred between 2pm and 7pm, indicating that the intense precipitation events are due to heat-driven thunderstorms. These events will be analysed in more detail and the performance of the various nowcasting tools will be presented. Plans on development towards improvements using Machine Learning based approaches will also be presented.

OROGRAPHIC PRECIPITATION

THE ANALYSIS OF AN OROGRAPHICALLY STRONG WIND CASE UNDER CLEAR-AIR CONDITION DURING ICE-POP 2018

STUDYING OROGRAPHY-INFLUENCED RIMING AND SECONDARY ICE PRODUCTION AND THEIR EFFECTS ON PRECIPITATION RATES USING RADAR POLARIMETRY AND RADAR DOPPLER SPECTRA

LACY X BAND METEOROLOGICAL RADAR 2022 OBSERVATIONS OF CYCLONIC RAINS IN LA RÉUNION

THE ROLE OF THE ARGENTINE MOUNTAINS ON THE DISCRETE PROPAGATION OF A MESOSCALE CONVECTIVE SYSTEM

SURFACE RAINFALL ESTIMATES IN MOUNTAINOUS AREAS INFERRED FROM RADAR VOLUME SCANS AND NWP PRECIPITATION PROFILES

THE ALTITUDINAL EFFECT OF THE RADAR-GAUGE ERRORS OVER SWITZERLAND

SUPERCELLS IN COMPLEX TERRITORY: A COMPARISON WITH SIMILAR CASES IN OTHER GEOGRAPHIC ENVIRONMENTS

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THREE-DIMENSIONAL VARIATIONAL MULTI-DOPPLER WIND RETRIEVAL OVER COMPLEX TERRAIN

ANALYSIS OF X-BAND DUAL POLARIZATION RADAR OBSERVATIONS OVER MULTIPLE COMPLEX TERRAIN REGIONS

THE ANALYSIS OF AN OROGRAPHICALLY STRONG WIND CASE UNDER CLEAR-AIR CONDITION DURING ICE-POP 2018

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This study try to understand the possible mechanisms of localized strong winds across a high mountainous area and on the leeside associated with a low-pressure system (LPS). A strong wind event under clear-air conditions during the 2018 Winter Olympic and Paralympic games in Pyeongchang, Korea, was examined using high spatiotemporal resolution wind information was obtained by Doppler lidars, AWS, wind profilers, soundings, reanalysis datasets under the International Collaborative Experiments for Pyeongchang 2018 Olympic and Paralympic winter games (ICEPOP2018). The evolution of surface winds shows quite different patterns, exhibiting intensification of strong winds in the leeside and persistent strong winds in upstream mountainous areas with the approaching LPS. The surface wind speed was intensified from ~3 to ~12 m s-1 (gusts were stronger than 20 m s-1) at a surface station in the leeside. A budget analysis of the horizontal momentum equation suggested that the pressure gradient force (PGF) contributed from adiabatic warming and the passage of LPS was the main factor in the acceleration of the surface wind in the leeward side of the mountains. The detailed 3D winds revealed that the PGF also dominated at the mountainous station, which caused persistent strong winds (~10 m s-1) related to the channeling effect. The evidence showed that under the same synoptic condition of a LPS, different mechanisms are important for strong winds in determining the strength and persistence of orographic-induced strong winds under clear-air conditions, it would be good reference for the initiations of orographic precipitation.

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STUDYING OROGRAPHY-INFLUENCED RIMING AND SECONDARY ICE PRODUCTION AND THEIR EFFECTS ON PRECIPITATION RATES USING RADAR POLARIMETRY AND RADAR DOPPLER SPECTRA

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In mid-latitudes, most precipitation is generated through the ice phase in mixed-phase clouds, but the exact pathways through which ice, liquid water, cloud dynamics, orographic forcing, and aerosol particles are interacting precipitation formation are not well understood. This is particularly true for riming and secondary ice production (SIP) processes that are likely related to the largest uncertainties with respect to quantitative snowfall formation. Filling the gaps in our understanding of SIP and riming is especially crucial for mountainous regions that are particularly vulnerable to changes in the ratio between rain and snowfall. Here, we give an overview of our research project dedicated to understanding riming and SIP processes in complex terrain. We will operate an innovative simultaneous-transmission-simultaneous-reception (STSR) scanning W-band cloud radar together with a novel in situ snowfall camera for the winter 2022-2023 in the Colorado Rocky Mountains. Our observations will be enhancing the extensive measurements of the Atmospheric Radiation Measurement (ARM) Surface Atmosphere Integrated Field Laboratory (SAIL) campaign where a Ka-band and a X-band radar will be deployed. Combining spectral polarimetric and multi-frequency Doppler radar observations with empirical and Bayesian machine learning retrieval techniques, we will identify riming and SIP events and quantify their impact on snowfall rates. This goal requires extending the Passive and Active Microwave radiative TRAnsfer model (PAMTRA) with additional polarimetric variables and state of the art scattering capabilities. Using the extensive collocated measurements of SAIL will allow us to relate the observed process rates to environmental conditions.

LACY X BAND METEOROLOGICAL RADAR 2022 OBSERVATIONS OF CYCLONIC RAINS IN LA RÉUNION

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The Southwest Indian Ocean islands are characterized by strong orographic gradients, generating risks of intense rainfall. The study of precipitations over mountainous tropical islands is essential to get a better understanding of tropical rainfalls formation mechanisms, spatial and temporal variability, and statistical properties at local scales. As part of the INTERREG V programs in the Réunion region, the ESPOIRS project (Study of Precipitation Systems in the Indian Ocean by Radar and Satellites) focuses on the study of the internal (dynamic, microphysical) and external (interactions with the relief) processes driving the formation and life cycle of extreme meteorological rain events in the South West Indian Ocean basin. Within this project, the Atmosphere and Cyclone Laboratory (LACy) has acquired a transportable dual-polarization Doppler X-band radar. This radar was installed in Saint Joseph, in the south of La Reunion late September 2021. During its first months of use, it was thus possible to observe the passage of two cyclones near the island: Batsirai, 3 February 2022 at ~ 200 km for over 24h, and Emnati, 20 February 2022 at 360 km. In this contribution, we will first briefly present the characteristics, operability and installation of the radar in Saint Joseph. We will then discuss its missions within the ESPOIRS project. Finally, we will present the first results of the analysis of the passage of the various cyclones and more particularly of the interactions between the generated rains and the marked reliefs of the island and their corresponding hydrological impacts.

THE ROLE OF THE ARGENTINE MOUNTAINS ON THE DISCRETE PROPAGATION OF A MESOSCALE CONVECTIVE SYSTEM

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During the early morning hours of 5 November 2018, a mature mesoscale convective system (MCS) propagated discretely over the second-most populous province of Argentina, Córdoba Province, during the RELAMPAGO-CACTI joint field campaigns. Storm behavior was modified by the Sierras de Córdoba, a north-south oriented regional mountain chain located in the western side of the province. We present observational evidence from C- and X-band Doppler radars, surface stations, and radiosondes of the discrete propagation event and the impact of the mountains on the associated physical processes. As the mature MCS moved northeastward and approached the windward side of the mountains, isolated convective cells developed downstream in the mountain lee, 20-50 km ahead of the main convective line. Cells were initiated by an undular bore, which formed as the MCS cold pool moved over the mountain ridge and perturbed the lee-side nocturnal, low-level stable layer. The undular bore was identified in radar observations, including a novel perturbation radial velocity analysis that revealed the wavelike structure. The field of isolated cells organized into a new MCS, which continued to move northeastward, while the parent storm decayed as it traversed the mountains. Only the southern portion of the storm propagated discretely, due to variability in mountain height along the chain. In the north, taller mountain peaks prevented the MCS cold pool from moving over the terrain and perturbing the stable layer. Consequently, no bore was generated, and no discrete propagation occurred in this region. To the south, the MCS cold pool was able to traverse the lower-relief mountains, and the discrete propagation was successful.

SURFACE RAINFALL ESTIMATES IN MOUNTAINOUS AREAS INFERRED FROM RADAR VOLUME SCANS AND NWP PRECIPITATION PROFILES

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The use of weather radar data to produce Quantitative Precipitation Estimations (QPE) is often complicated by the height of the measurement. This is particularly true in mountainous areas where the beam is generally very far from the ground. The method conventionally used in operational systems (and in particular at Météo-France) to extrapolate reflectivities to ground level, does not allow to consider some processes too complex to be modeled easily, such as evaporation or strengthening of precipitation under the radar beam. In addition, the spatial variability of the precipitation profiles is not taken into account, limiting considerably the performance of the rainfall estimation. To adress these issues an innovative approach has been recently developed (Le Bastard et al., 2019). It relies on the use of vertical precipitation profiles predicted by the Météo-France's high-resolution nowcasting model (AROME-PI) to estimate the most probable one according to the available observations of reflectivity, and then to use it to infer the ground rain rate. An evaluation over several stratiform and convective situations has been conducted by comparing the performances of both the new and the current Météo-France operational methods. For this purpose, in addition to the traditional rain gauge accumulations, the SAFRAN reanalysis (a model producing analysis and forecast of meteorological quantities adapted for the mountain) has been used to evaluate the radar QPEs at the massif scale and their variations depending on the altitude. In particular, the method developed shows a remarkable ability to reproduce the precipitation gradient as a function of the altitude of the terrain.

THE ALTITUDINAL EFFECT OF THE RADAR-GAUGE ERRORS OVER SWITZERLAND

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The change in altitude plays an essential role in the spatial distribution of precipitation, especially in mountainous areas. Due to the rapid changes in precipitation characteristics in such regions, gauge measurements are highly affected by the representativeness error. On the other hand, typical sources of error in radar estimates are expected to increase in mountainous areas. Over the last decades, different approaches have been implemented to merge gauges and radar estimates to reduce these errors and increase the reliability of precipitation estimates in the Alpine region, and yet the relationship between radar-gauge errors and terrain altitude is difficult to apply in practice, calling for more research on the subject. This study analyzes the relationship between log-transformed radar-gauge errors (bias and scatter) and altitude over Switzerland using 16 years of hourly precipitation data. We use two radar products (radar-only and cross-validated-merged-with-gauge product) along with the gauges over Switzerland. We implement a linear regression model to show the relation between the gauge elevation and the error metrics. The data from the old and the new radar networks in this relationship are analyzed. The results show an increase in radar underestimation at higher altitudes in old and new networks for both products. The weakest trend happened in winter when most precipitation events in higher altitudes are in snow-form. In terms of precipitation intensity, the results show that the radar products tend to have different trends in higher and lower intensities, i.e. the underestimation in radar products increased with altitude in low intensities up to -49%. In contrast, these products have a weak overestimation trend with increasing altitude in high intensities.

SUPERCELLS IN COMPLEX TERRITORY: A COMPARISON WITH SIMILAR CASES IN OTHER GEOGRAPHIC ENVIRONMENTS

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This research analyses two long-lived supercell thunderstorms formed on 11th May 2017 afternoon in a complex topographic area in northern Catalonia (NE Iberian Peninsula). The objectives of the analysis are (i) to document a case study that affected a mountainous region in the southern side of the Pyrenees, (ii) to describe thermodynamic and dynamic environmental conditions, (iii) to study how the topography affects the life cycle of both storm cells and (iv) to demonstrate the high correlation between Lightning Jump and radar parameters in complex terrain. ERA5 reanalysis was used to assess the synoptic framework and environmental storm conditions, whereas remote-sensing data (Doppler radar, satellite, and lightning observations) and terrain characteristics were considered to study the evolution of both cells. Reanalysis data revealed some differences between preconvective environments for both thunderstorms, showing more favourable conditions for supporting supercells (i.e. stronger deep-layer shear) for the first thunderstorm than for the second one. The analysis suggests substantial interaction between topography and storm cells, influencing their internal dynamics and the development of mesocyclones. The presentation will examine differences with other thunderstorm events of similar duration but over different orography areas (lower mountains, flat terrain and coastal zones) focusing on the discussion of weather radar variables evolution along the storm life cycle.

DEVELOPMENT OF MULTI-RADAR MULTI-SENSOR (MRMS) MACHINE LEARNING QPE FOR COMPLEX TERRAIN

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The Multi-Radar Multi-Sensor (MRMS) suite of hydrometeorological products are essential for applications such as flash flood warning operations and water resource management. The radar-based quantitative precipitation estimation (QPE) product has been updated recently to use dual pol variables and is highly accurate in areas of adequate radar coverage. The accuracy generally decreases in higher terrain areas such as the western US and Hawaii where radar coverage is substantially reduced and low level orographic enhancement of precipitation commonly goes unobserved. The multi-sensor QPE product is able to fill in gaps in radar coverage with precipitation information from additional sources such as model QPF, rain gauges, and climatological fields, but it comes with much higher latency and requires manual tuning of the weighting parameters. To address the limitations of the physically-based QPE approaches, a convolutional neural network (CNN) model has been developed in this work. The model is given input images from a variety of radar, model, and terrain-related variables and uses that information to generate a precipitation amount at the corresponding central grid point. The CNN model 24 hour accumulated QPE field shows improved statistical performance compared to the radar-based QPE for several atmospheric river events affecting California. The improvement is most evident in areas of poor low-level radar coverage. Model interpretation results show seamless hybrid scan reflectivity (SHSR) is the most important radar variable for the model prediction, with other NWP model moisture variables also showing strong importance. A long term statistical analysis of the CNN QPE performance will be presented along with further model optimization efforts.

OROGRAPHIC FLOW INFLUENCE ON PRECIPITATION DURING AN ATMOSPHERIC RIVER EVENT AT DAVIS, ANTARCTICA

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Snowfall in Antarctica is the main input to ice sheet mass balance, which is heavily influenced by maritime moisture intrusions from lower latitudes. The most intense moisture incursions often occur as narrow corridors of enhanced vapor transport, called atmospheric rivers (ARs). However, the fate of ARs depends on the state of the coastal boundary layer. For instance, katabatic or foehn winds can lead to a subsaturated boundary layer, resulting in total snowfall sublimation. In this study, we used recent data collected during the PLATO campaign to investigate how the synoptic evolution and the orography influenced snowfall sublimation during an AR event (08 – 10 January 2019) at Davis, Antarctica. The dataset includes scanning polarimetric and vertically pointing Doppler radars, radiosounding, and Raman lidar measurements. We also use simulations from the WRF model. Our analysis revealed that orographic gravity waves (OGWs), generated by a north-easterly flow impinging on the ridge upstream of Davis, were responsible for snowfall sublimation through a foehn effect. Despite the strong meridional moisture advection associated with the AR, almost no precipitation reached the ground at Davis. We found that the direction of the flow with respect to the orography determined the intensity of OGWs, which in turn influenced the snowfall microphysics. We hypothesize that turbulence induced by the OGWs likely enhanced the aggregation process, as identified by dual-polarization and dual-frequency radar observations. This study suggests that despite the intense AR, the snowfall distribution was determined by local processes tied to the orography. It also stresses the importance of studying local effects when interpreting the impact of ARs on the Antarctic surface masse balance.

PRECIPITATION MICROPHYSICS ANALYSIS DURING WINTER STORMS IN A INNER VALLEY OF THE PYRENEES USING A K-BAND DOPPLER RADAR AND DISDROMETER DATA

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While leeside and windward precipitation processes have been widely studied, inner mountain valleys have received less attention. The study of precipitation processes in these regions is challenging because traditional ground-based weather radars are often blocked, and space borne radars are affected by ground clutter by the surrounding mountains. To fill this gap we present microphysical observations measured during the campaign Cerdanya-2017 located at the Eastern Pyrenees using a Parsivel disdrometer, a K-band Doppler radar (MRR-2), an UHF wind profiler and a microwave radiometer. Using data from these instruments, several events were examined to characterize the precipitation processes in this region finding that valley air is often decoupled from the free atmosphere by a wind shear layer (Gonzalez et al 2021). One particular case study illustrates that microphysical processes under the shear layer became also decoupled showing the complexity of extrapolating ground precipitation using space borne reflectivity in mountain areas. The Cerdanya-2017 field campaign was a research effort organised by the University of the Balearic Islands, the University of Barcelona, METEO-FRANCE and the Meteorological Service of Catalonia funded by the Spanish projects CGL2015-65627-C3-1-R, CGL2015-65627-C3-2-R (MINECO/FEDER), CGL2016-81828-REDT and RTI2018-098693-B-C32 (AEI/FEDER).

REFERENCES

González S, Bech J, Garcia-Benadí A, Udina M, Codina B, Trapero L, Paci A, & Georgis JF, 2021: Vertical structure and microphysical observations of winter precipitation in an inner valley during the Cerdanya-2017 field campaign. Atmospheric Research, 264, 105826.

THREE-DIMENSIONAL VARIATIONAL MULTI-DOPPLER WIND RETRIEVAL OVER COMPLEX TERRAIN

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Airflow interactions with complex terrain can greatly enhance the potential for extreme precipitation events and alter the structure and intensity of the precipitating cloud systems, but these events are difficult to understand and forecast, partly due to limited direct in-situ measurements to sample wind and thermodynamic fields. SAMURAI software uses a three-dimensional variational (3DVAR) technique to retrieve kinematic and thermodynamic fields by ingesting radar and other meteorological data sources. The analysis has high fidelity to observations when retrieving flows over a flat surface, but the capability of imposing topography as a boundary constraint is not previously implemented in the software. Here we implement the impermeability condition at the ground and ingest the high-resolution ASTER-DEM terrain map to SAMURAI. The new implementations are first compared with an idealized two-dimensional WRF simulation with the bell-shaped mountain as perfect input observations, followed by simulated radar observations from a mesoscale Weather Research and Forecasting (WRF) simulation to quantify the uncertainties, and finally an example of dual-Doppler radar observations when Typhoon Chanthu (2021) was over Taiwan. The new implementations broaden SAMURAI applications and will be beneficial to improving our understanding of the evolution of convective weather systems over complex terrain.

ANALYSIS OF X-BAND DUAL POLARIZATION RADAR OBSERVATIONS OVER MULTIPLE COMPLEX TERRAIN REGIONS

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Precipitation over mountainous areas remains a major challenge for hydrometeorological science and applications. Short-range dual polarization X-band radars provide key observations near the surface with multiparameter measurements that allow to estimate the drop size distribution (DSD) and rainfall rates. Unique radar observations have been collected in Europe (Northeast Italian Alps, Cyprus, and Greece), the North America (North Carolina, Olympic Mountain, Southern tip of Vancouver Island, Colorado) and the South America (Argentina), and are consistently processed with the SCOP-ME algorithm. It uses optimal parameterization, specific attenuation coefficients and the backscattering differential phase shift to derive high-quality and high-resolution precipitation and microphysical estimates. SCOP-ME self-consistency and accuracy of the radar signal attenuation correction are evaluated against in situ observations, and uncertainty estimates are derived from error characterization. Algorithm is evaluated based on both radar parameters calculated from disdrometer data and rainfall rates measured by rain gauges. In addition, the SCOP-ME retrievals of median volume diameter (D0) and normalized intercept parameter (Nw) are evaluated against in-situ disdrometer spectra observations. Finally, the rain-path attenuation horizontal and differential attenuation reflectivity ray-paths are evaluated based on disdrometers located at different radar-ranges. High-quality precipitation retrievals lay the groundwork to document the properties of precipitation in complex terrain and for applications such as hydrologic modeling and validation of satellite precipitation estimates.

PHASED-ARRAY AND EMERGING TECHNOLOGIES

PULSE COMPRESSION FOR SOLID STATE WEATHER RADARS

USE OF X-BAND DUAL POLARISATION PHASED ARRAY WEATHER RADAR FOR DETECTION OF INCLEMENT WEATHER IN HONG KONG

OBSERVATIONS OF SEVERE CONVECTION WITH A PASSIVE MULTISTATIC RADAR NETWORK

A CALIBRATION METHOD OF PHASED ARRAY RADAR USING METAL BALL MOUNTED ON UNMANNED AERIAL VEHICLE

NOVEL MEASUREMENTS OF G-BAND DOPPLER SPECTRA IN CLOUD ICE

DESIGN CRITERIA FOR PRECIPITATION MEASUREMENT SYSTEMS BASED ON SATELLITE DOWNLINK MONITORING

PRECIPITATION OBSERVATIONS BY MULTI-PARAMETER PHASED ARRAY WEATHER RADAR (MP-PAWR)

DOPPLER SPECTRA AND MICROPHYSICAL RETRIEVALS FROM A G-BAND RADAR

PHASED ARRAY RADAR OBSERVATION OPERATOR SAMPLING OF A DOWNDRAFT WITH MELTING HAIL

EXAMINING THE BENEFITS OF A FUTURE OPERATIONAL PHASED ARRAY RADAR NETWORK IN THE UNITED STATES USING RAPID-SCAN RADAR OBSERVATIONS AND NUMERICAL SIMULATIONS

UNDERSTANDING WHAT YOUR RADAR CAN AND CAN'T DO: A FRAMEWORK FOR TESTING PROOF-OF-CONCEPT WEATHER RADARS

DEVELOPMENT IN PROGRESS ON C-BAND PHASED ARRAY WEATHER RADAR WITH COMB BEAM TRANSMISSION

AIRBORNE PHASED ARRAY RADAR (APAR): THE NEXT GENERATION OF AIRBORNE POLARIMETRIC DOPPLER WEATHER RADAR

POLARIMETRIC QUALITY AND STABILITY OF CALIBRATION OF THE SKYLER-II PHASED-ARRAY RADAR SYSTEM

THE HORUS DIGITAL PHASED ARRAY RADAR PROGRAM AT THE UNIVERSITY OF OKLAHOMA – STATUS UPDATE AND INITIAL WEATHER OBSERVATIONS

SCIENCE APPLICATIONS OF PHASED ARRAY RADARS

POLARIMETRIC PHASED-ARRAY MOBILE RADAR OBSERVATIONS TO UNDERSTAND THE RAPID EVOLUTION OF PRECIPITATION STRUCTURES WITHIN A UNITED STATES EAST COAST WINTER STORM

PULSE COMPRESSION FOR SOLID STATE WEATHER RADARS

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Pulse compression is a radar technique that combines the advantages of long pulses and short pulses. It improves the range resolution and enables adequate sensitivity for lower peak power solid state transmitters. A tool developed by GAMIC generates an optimal pulse waveform to improve ground clutter supression and weather detection while reducing false detection of weather echoes.

USE OF X-BAND DUAL POLARISATION PHASED ARRAY WEATHER RADAR FOR DETECTION OF INCLEMENT WEATHER IN HONG KONG

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The Hong Kong Observatory (HKO) installed a X-band Dual-Polarization Phased Array Weather Radar (PAWR) at its Sha Lo Wan wind profiler station in 2021 for enhancing its capability of monitoring and predicting high impact weather in Hong Kong. The PAWR's antenna performed electronic and mechanical scanning in the elevation and azimuth directions respectively. Using digital beamforming technology, a maximum of 7 beams could be simultaneously used in electronic scanning. A volume scan comprising 68-elevation layers could be completed in 1 minute. Rapid update of radar imageries with a maximum range of 60 km and resolution of 30 m could be made for detection of inclement weather. The performance of PAWR in detecting several inclement weather events in 2021 was evaluated. These included the occurrence of hails on 16 September 2021 and heavy rain associated with tropical cyclones Lionrock and Kompasu in October 2021. Comparison with the measurements of HKO's S-band Doppler weather radars at Tai Mo Shan and Tate's Cairn and C-band Terminal Doppler weather radar at Brothers Point was also made. Preliminary observations showed that the PAWR revealed better the structures of intense radar echoes including hail-embedded convection because of its higher range resolution. In addition, the PAWR, with a low antenna height of only around 34 m above the mean sea level, usefully complements the long-range S-band radars, which are installed on mountain top to avoid beam blockage in the detection of precipitation near the ground. This paper presents HKO's work in establishing the PAWR and the experiences gained in using PAWR data. Future plan of further development of PAWR products in operational weather monitoring and forecasting is briefly described.

OBSERVATIONS OF SEVERE CONVECTION WITH A PASSIVE MULTISTATIC RADAR NETWORK

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Multistatic radar architectures have the potential to provide a cost-effective source of 3D wind information from both operational and research radars, owing to a system design of one transmitter and several receivers. A prototype multistatic network consisting of two passive receivers and the KTLX WSR-88D has been constructed in the Oklahoma City metropolitan area. To achieve sufficiently precise Doppler frequency estimates while reducing cost, transmitter/receiver synchronization is done through measurements of the WSR-88D's sidelobe radiation, rather than an expensive GPS-based system. This yields an exceptionally simple system capable of producing bistatic moment data with virtually no cooperation from the transmitting radar system. Since the initial deployment of the prototype system, several datasets of severe convection have been collected, including several instances of quasi-linear convective systems (QLCSs) and supercells. Multi-Doppler retrievals done with the multistatic data are able to resolve important structures in the horizontal and vertical wind fields, including mesocyclones and horizontal rotors. These retrievals are shown to be comparable in accuracy to simultaneous multi-Doppler retrievals done with only monostatic radar data, though the deleterious effects of sidelobe contamination are apparent in the multistatic retrievals in some cases. Simulated retrievals of an expanded polarimetric multistatic system utilizing a phased-array weather radar will also be shown.

A CALIBRATION METHOD OF PHASED ARRAY RADAR USING METAL BALL MOUNTED ON UNMANNED AERIAL VEHICLE

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Phased array technology is gradually applied in the field of weather radar now. Due to the influence of the array antenna structure, the radar's beamwidth, transceiver gain and other system parameters will change with the antenna scanning angle, which affects the data consistency of different elevation angles. Especially for the observation mode that uses digital beam forming technology (DBF) to transmit wide beam and to receive multiple narrow beams at the same time, the calibration methods are much more complicated than the traditional weather radar. Therefore, the test and calibration of the phased array radar system is an important part to evaluate the accuracy of radar detection data. This paper proposes a method of using a high-performance UAV to mount a metal ball equipped with a GPS module to do the one-dimensional scanning phased array weather radar test and calibration. Three different calibration procedures performed at different periods of the Shanghai X-band array weather radar sites were selected, combined with flying modes such as drone hovering and constant speed cruise, and two different types and scattering cross-sectional sections of metal balls were used. Combining the information such as the coordinates of the metal ball, the scattering cross-sectional sections, and the GPS movement trajectory, it can simultaneously calibrate the radar's antenna spatial pointing precision, beam width, radial velocity and reflectivity factor. The results show that: the antenna space pointing compensation value of the radar can be evaluated and given; the average difference between the radar radial velocity and the flying speed of UAV is 0.17m/s; the radar azimuth and elevation beamwidth can be calculated and verified with the metal ball reflectivity factor.

NOVEL MEASUREMENTS OF G-BAND DOPPLER SPECTRA IN CLOUD ICE

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The GRaCE 200GHz (G-band) Doppler radar has been designed to obtain novel measurements of liquid water and ice in the atmosphere at a higher frequency than traditional cloud radars. A clear benefit of G-band operation is the capability to size smaller particles. Combining G-band and lower frequency radar measurements allows the investigation of differential attenuation and scattering by hydrometeors. Theoretical studies (e.g. Battaglia et al., 2014) showed that the use of higher frequencies in the G-band should result in a larger dynamic range in measured dual-frequency parameters, which would be beneficial for sizing smaller particles. Furthermore, utilising multiple frequencies could provide information on particle shape, consequently allowing improvements to retrievals of the particle size distribution and ice water content. The GRaCE radar is currently located at Chilbolton observatory in the U.K. and has been used to obtain measurements on multiple days over the past year. A recently published article by Courtier et al. (2022) presented the first G-band Doppler spectra in rain, measured during a light precipitation event in May 2019. Here we present measurements of the first G-band Doppler spectra in ice. Using in-situ measured particle size distributions along with model particles from the ARTS scattering database, we simulate the Doppler spectra and compare to the measurements, allowing validation of ice particle scattering models. We also compare simulated and measured multi-frequency parameters, such as the spectral dual-frequency ratio. We discuss our interpretation of the comparisons performed in this study, with a focus on how G-band measurements could reduce uncertainties in the representation of ice microphysics in numerical models.

DESIGN CRITERIA FOR PRECIPITATION MEASUREMENT SYSTEMS BASED ON SATELLITE DOWNLINK MONITORING

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Opportunistic rain rate retrieval from rain-induced attenuation on GEO-sat downlinks (>10GHz) is a very promising technique, because of its sensitivity to rain intensity and the availability of low-cost receivers. Comparison experiments recently carried out using raingauges and weather radar have demonstrated both feasibility and effectiveness of this approach and its potential to improve worldwide precipitation monitoring including scarcely or ungauged regions. However, to implement systems based on this approach, different design options need to be considered. This contribution discusses the following design criteria.

1. Operating frequency. The most popular frequency interval for direct-to-home (DTH) satellite broadcasting is the Ku-band (10.7–12.75GHz). Satellite operators are also moving to Ka-band (17.3–21.2GHz), which offers greater bandwidth, but is also much more susceptible to rain attenuation.
2. Type of signal to be monitored. A GEO broadcast satellite radiates both DVB-S/S2 signals which can be received inside the satellite footprint area using cheap DTH equipment and beacons for tracking purposes which require special receivers.
3. Rain-sensitive link parameter to be measured. Either received signal power or signal-to-noise ratio vary in the presence of rain and are to be extracted from the received signal.
4. Receiving hardware. Depending on the monitored signal and measured parameter, it can be either a cheap off-the-shelf DTH device or a dedicated implementation.
5. Rain retrieval algorithm applied to measurements.
6. Auxiliary information necessary for rain retrieval algorithm, e.g. radio link geometry and meteorological data.

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PRECIPITATION OBSERVATIONS BY MULTI-PARAMETER PHASED ARRAY WEATHER RADAR (MP-PAWR)

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An X-band multi-parameter phased array weather radar (MP-PAWR) was develop in late 2017 (Takahashi et al., 2019), and it began operation from March 2018. Since then, MP-PAWR has been observing various types of precipitation. The major characteristics of MP-PAWR are 1) electronical scan in elevation and the azimuthal observation is implemented by the mechanically rotating antenna, 2) therefore, it takes only 30 seconds to complete three dimensional observation (elevation of 0° to 90° and azimuth of 0° to 360°) in 60 km range up to 15 km in height and 3)precise precipitation rate and precipitation characteristics are deduced by the dual-polarization parameters (Z, ZDR, KDP and ρhv). In this presentation, various types of precipitation systems such as isolated convective cloud, organized convective system accompanied by lightening, stratiform precipitation but not precipitating on the ground, stratiform precipitation accompanied with typhoon. Several cases are compared with the time-lapse camera images. On the isolated precipitation clouds (cases on August 2 and 16, 2018), detailed life cycle of precipitation clouds is described by temporal change of three-dimensional structure together with the dynamical information from dual Doppler analysis and precipitation types in the cloud from dual polarization observation. On the organized convective systems are analyzed by comparing with the analyses on lightening activity and wind field. Additional analysis was implemented for stratiform precipitation systems. The VAD method with constant radius was applied for cases on 27-28 July and 6 September 2018 to estimate the vertical motion.

DOPPLER SPECTRA AND MICROPHYSICAL RETRIEVALS FROM A G-BAND RADAR

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The first Doppler spectra acquired by an atmospheric radar at 200 GHz (G-band) are presented. Observations were taken at Chilbolton Observatory, UK, during a light precipitation event in May 2021 (rain rates < 2 mm per hour), with coincident Ka-band and W-band Doppler radar measurements, and also from low-level stratiform cloud in March 2022. The G-band spectra in rain show good agreement with Mie theory predictions, with the presence of multiple peaks and "Mie notches" in correspondence to the maxima and minima of the raindrop backscattering cross sections. These G-band radar measurements allow the application of, in rain, Mie notch vertical wind retrievals and multi-frequency drop size distribution microphysical retrievals to smaller rain rates and smaller characteristic sizes than before. The triple frequency rain spectra are used to perform an optimal estimation retrieval of the particle size distribution. The non-Rayleigh scattering at small droplet sizes (~1 mm) in the G-band spectra allow for a retrieval of vertical air motion in drizzle that improves estimates of rain microphysics as compared to triple frequency retrievals using longer wavelength radars. Doppler spectra are also presented from within and above the melting layer. Particle size distribution retrievals from above the melting layer are compared against those from below it, paving the way for new insights into the microphysical changes occurring across the melting layer.

PHASED ARRAY RADAR OBSERVATION OPERATOR SAMPLING OF A DOWNDRAFT WITH MELTING HAIL

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Progress in quantitative precipitation estimation (QPE) is an important outcome of advances in radar technology. Adequately capturing strong vertical gradients of precipitation fluxes is an outstanding challenge in radar QPE. Continuous and high resolution spatiotemporal observations of vertical variations of the Particle Size Distribution (PSD) are needed to improve QPE, which can be uniquely achieved by phased-array radar technology. This study performs preliminary investigations on QPE applications in downdrafts with phased-array radars (PARs) by using radar simulators based on high-resolution weather models. A one-dimensional Lagrangian cloud model with spectral bin microphysics is used to simulate PSDs at high resolution as they fall through the downdraft in varying environmental conditions. A one-dimensional radar forward operator (RFO) developed at the National Oceanic and Atmospheric Administration (NOAA) uses scattering theory to simulate radar variables including horizontal reflectivity, differential reflectivity, specific differential phase, and cross-correlation coefficient. This framework is used to investigate the benefit of novel PAR sampling. All-digital radar imaging provides an opportunity for simultaneous interrogation of a complete vertical downdraft column, eliminating current polarimetric radar gaps in vertical coverage and sweep-time sampling delays present in current dish-type scanning strategies. However, the sampling will continue to be impacted by range/resolution constrains, beam broadening, atmospheric refraction, and non-hydrometeor blockage. We will discuss the sampling impact using the RFO and evaluate the improved interpretation of microphysical processes with melting hail.

EXAMINING THE BENEFITS OF A FUTURE OPERATIONAL PHASED ARRAY RADAR NETWORK IN THE UNITED STATES USING RAPID-SCAN RADAR OBSERVATIONS AND NUMERICAL SIMULATIONS

David Bodine[1]; Brandon Cohen[1]; Connor Pearson[1]; Laura Shedd[1]; Mark Yeary[1]; Tian-You Yu[1]; Anthony Reinhart[2]; Jeff Snyder[2]; Sebastian Torres[2]; Howard Bluestein[1]

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Leveraging rapid and adaptive scanning, phased array radars (PARs) offer unique capabilities for next-generation operational radar networks and improving prediction of severe hazards. Phased array radars have been developed in several countries to advance fundamental science research and explore their future potential in operational radar networks. In this study, the benefits of phased array radars for a future operational radar network in the United States are examined using a combination of rapid-scan radar observations and numerical simulations of tornadoes, hailstorms, and microbursts. Archived tornado data from the Rapid X-band Polarimetric (RaXPol) radar are used to emulate PAR scans at different standoff ranges and phased array scanning techniques. From this analysis, the vertical evolution of tornado vortex signatures will be characterized to assess how a future operational PAR's improved temporal sampling can better observe tornado formation and intensification, as well as evaluating whether or not these improvements extend to longer standoff ranges and different PAR scanning techniques. In addition to tornadoes, large hail and microbursts require both rapid volumetric updates and dense vertical sampling since these hazards develop aloft and rapidly descend to the surface. Using rapid-scan data from RaXPol and the National Severe Storms Laboratory (NSSL's) KOUN radar, the vertical evolution of polarimetric signatures preceding and during hailfall are examined to characterize hail size sorting and temporal variations in along-track hailfall. Finally, numerical simulations are used to explore the benefits and limitations of electronically formed pencil beams and imaging for detecting polarimetric precursors to microbursts.

UNDERSTANDING WHAT YOUR RADAR CAN AND CAN'T DO: A FRAMEWORK FOR TESTING PROOF-OF-CONCEPT WEATHER RADARS

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Evolutionary observing requirements in support of weather research and operations continually drive the development of proof-of-concept (POC) radars. While the design of these radars is typically driven by specific functional needs, actual system performance rarely matches design and implementation expectations. Thus, comprehensive system testing before deployment is critical, not only to address significant deviations from expectations but also to provide key information to users about capabilities and limitations of the new radar system. Unfortunately, it is rare for radar engineers to have a complete and accurate set of requirements against which the performance of a POC weather radar can be assessed. Instead, radar engineers must develop system tests with associated performance metrics that are practical, comprehensive, and provide meaningful results. In this work, we present an example of such an effort using the National Severe Storms Laboratory's (NSSL) Advanced Technology Demonstrator (ATD). The ATD is the first full-scale, S-band, dual-polarization, active, electronically scanned phased-array radar for weather observations. As the last phase of the project, a collection of tests was developed as part of ATD System Testing to establish readiness of the system to support engineering and meteorological research at NSSL. Based on the functionality being tested, tests were created under three categories: core, operations, and research. These so-called end-to-end tests were designed to measure the performance of the radar as a whole. They rely on external targets and involve analyzing ordinary radar outputs and information available at the human-machine interface. While developed for the ATD, this framework is suited for adaptation to other POC weather radars.

DEVELOPMENT IN PROGRESS ON C-BAND PHASED ARRAY WEATHER RADAR WITH COMB BEAM TRANSMISSION

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Phased array technology enables weather radars to complete observations rapidly. As proposed by Wurman (2001), Yoshikawa (2013), and so on, phased array weather radars radiate with elevationally wide transmission beams and perform digital scans in reception, with which they accomplish several times faster observation. Because of the fast observation capability, phased array weather radars are considered to be promising to realize early detection and warning of intense weather that are localized and short-lived. Don't someone feel that the observation strategy with wide transmission and digital reception is too much? When the observation strategy forms a ten-degree transmission beam and one-degree reception beams, for example, it is able to observe ten directions at the same time with a constraint "the ten directions must be adjacent". If the constraint is solved and separated beams are formed, we can design scan strategies of phased array weather radar with more flexibility and efficiency. The separated beams are called a comb beam which is focused in this presentation. The comb beam transmission has been proposed by Yoshikawa (2021), where its principle and simulation-based evaluations are discussed. This presentation shows its following research and development of a C-band phased array weather radar with comb beam transmission; designed comb beams, and their expected performances with respect to mainlobe widths, sidelobe levels, and so on.

AIRBORNE PHASED ARRAY RADAR (APAR): THE NEXT GENERATION OF AIRBORNE POLARIMETRIC DOPPLER WEATHER RADAR

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This paper presents a configuration of a novel, airborne phased array radar (APAR) motivated by major advances in cellular technology, component miniaturization, and radar antenna simulation software. This has paved the way for a next-generation radar being designed by NCAR/EOL to be installed on the NSF/NCAR C-130 aircraft. The APAR system will consist of four removable C-band active electronically scanned arrays (AESA) strategically placed on the fuselage of the aircraft. Each AESA measures approximately 1.5 x 1.5 m and is composed of 2368 active radiating elements arranged in a total of 37 line replaceable units (LRU). Each LRU is composed of 64 radiating elements that are the building block of the APAR system. Polarimetric measurements are not available from current airborne tail Doppler radars. However, APAR, with dual-Doppler and dual polarization diversity at a lesser attenuating C-band wavelength, will further advance the understanding of the microphysical processes within a variety of precipitation systems. Such unprecedented observations, in conjunction with the advanced radar data assimilation schema, will be able to address the key science questions to improve understanding and predictability of significant weather. A Mid-scale Research Infrastructure proposal is submitted to the National Science Foundation to request the implementation cost. The development is expected to take ~5 years after the funding is in place. It adopts a phased approach as an active risk assessment and mitigation strategy. The authors will review the overall design and current progress of APAR and outline ambitious future development work needed to bring this exceptional tool into full operation.

POLARIMETRIC QUALITY AND STABILITY OF CALIBRATION OF THE SKYLER-II PHASED-ARRAY RADAR SYSTEM

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Polarimetric data have been shown to be critically important for our understanding of microphysics within given precipitation fields. These datasets have been limited exclusively to conventional dish radar systems until recently because of the way that phased-array radar (PAR) systems steer individual beams. Attempts at previous polarimetric PAR systems have suffered from considerable polarimetric data quality issues stemming from their electronic beam steering. Calibrating these systems has also proved difficult because of calibration drift and decreasing quality near scanning sector boundaries. The new SKYLER-II polarimetric PAR system has made strides to rectify these issues. The presented study will use vertically pointing scans of snow aggregates and light rain to assess the ease of calibration and any calibration drift. Sector scans will also be analyzed after calibration and compared to Weather Surveillance Radar–1988 Doppler (WSR-88D) data to survey any potential degradation in polarimetric quality approaching the sector boundaries.

THE HORUS DIGITAL PHASED ARRAY RADAR PROGRAM AT THE UNIVERSITY OF OKLAHOMA – STATUS UPDATE AND INITIAL WEATHER OBSERVATIONS

Robert Palmer[1]; David Schvartzman[1]; David Bodine[1]; Boonleng Cheong[1]; Caleb Fulton[1]; Pierre Kirstetter[1]; Jorge Salazar[1]; Hjlati Sigmarsson[1]; Mark Yeary[1]; Tian Yu[1]

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Sampling of existing mechanically scanning radars is insufficient to capture the four-dimensional evolution of atmospheric dynamics and microphysics. The scientific community has shown intense interest in the development of rapid-scanning polarimetric radars to address these needs and strongly desires community-wide access to the necessary phased array radar technology. To meet the desired update times and polarimetric quality, it is expected that a fully digital phased array architecture will be necessary. The Advanced Radar Research Center (ARRC) at the University of Oklahoma (OU) is working with NOAA's National Severe Storms Laboratory (NSSL) on the development of a digital-at-every-element, S-band, dual-pol phased array radar. With an aperture of approximately 1.63 m, the Horus radar will have 1024 (32x32) dual-pol channels and will be capable of extreme flexibility in terms array segmentation, channel-independent waveforms, adaptive beamforming, etc. Given the importance of radar polarimetry to the weather community, its most-important feature will be the capability of performing real-time and frequent array and polarimetric adaptive calibration as a routine part of the Horus scanning strategy. By exploiting mutual coupling between individual radiating elements that make up the array and the waveform independence of an all-digital array, the ARRC is currently developing automatic algorithms for array/polarimetric calibration. Initial field measurements will occur in May of 2022. The need for an all-digital design will be discussed along with certain design choices of the Horus radar. Project status, initial weather observations, and plans for future larger-scale systems exploiting the scalable design of Horus will be provided.

SCIENCE APPLICATIONS OF PHASED ARRAY RADARS

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Phased array radars (PARs) are a promising observing technology, at the cusp of being available to the broader meteorological community. PARs offer near instantaneous sampling of the atmosphere with flexible beam forming, multi-functionality, low operational and maintenance costs, and without mechanical inertia limitations. These PAR features are transformative compared to those offered by our current reflector-based meteorological radars. The integration of PARs into meteorological research has the potential to revolutionize the way we observe the atmosphere. The rate of adaptation of PARs in research will depend on many factors including i) the need to continue educating the scientific community on the full technical capabilities and trade-offs of PARs through an engaging dialogue with the science and engineering communities and ii) the need to communicate the breadth of scientific bottlenecks that PARs can overcome in atmospheric measurements and the new research venues that are now possible using PARs in concert with other measurement systems.

POLARIMETRIC PHASED-ARRAY MOBILE RADAR OBSERVATIONS TO UNDERSTAND THE RAPID EVOLUTION OF PRECIPITATION STRUCTURES WITHIN A UNITED STATES EAST COAST WINTER STORM

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Winter storms along the east coast of the United States are often associated with heavy snowfall, strong winds, and icing. Mesoscale structures within these storms such as snow bands have been fairly well studied using conventional radars and models. The Stony Brook University Mobile Observatory (SBUMO), a mobile truck affixed with meteorological instrumentation, provides a unique opportunity to observe these winter storms rather than relying upon fixed ground instruments. The SBUMO facilitates cutting-edge weather research with a phased array X-band radar, SKYLER-II. Phased array radar systems allow for rapid scanning (< minute) and rapid changes in scan strategy, which make them ideally suited for observing short-lived mesoscale structures. The high sensitivity of dual polarization measurements provided by this X-band radar also make it ideal to understand cloud processes. The SBUMO traveled to Elmira, NY on 17 January 2022 for the NASA Investigation of Microphysics and Precipitation for Atlantic Coast-Threatening Snowstorms (IMPACTS) campaign. As the surface cyclone approached, SKYLER-II sampled short-lived snow bands using a full 90 deg volume scan out to 45 km. Volume scans of high azimuthal (1 deg) and elevation (⅓ deg) resolution were completed every three minutes for the first two hours of sampling. For the remainder of the sampling period, every 35 seconds 10 RHIs of 1-deg elevation resolution were concurrently run with 2 PPIs (3 and 15 deg elevation) of 1-deg azimuthal resolution. This first of a kind dataset will help explain some of the transient behavior of these bands, which is hypothesized to result from 5-10 km regions of fallout and horizontal advections of snow. This presentation will highlight some of these observations and findings for this event.

POLARIMETRY

ANALYSIS OF POLARIMETRIC SPECTRAL DENSITIES IN SEVERE THUNDERSTORMS FOR THE IDENTIFICATION OF LIGHTNING-INDUCED SIGNATURES

REFRACTION OF RADAR BEAMS IN PRECIPITATION

A NEW POLARIMETRIC METHOD FOR THE MELTING LAYER DETECTION AND DETERMINATION OF ITS HEIGHT

CALIBRATION OF MULTI-PARAMETER PHASED ARRAY WEATHER RADAR (MP-PAWR)

IDENTIFICATION OF BRIGHT BAND ECHOES USING OPERATIONAL S-BAND DUAL-POLARIZATION RADAR

IMPROVED DUAL POLARIZATION RADAR RETRIEVALS OF BULK ICE MICROPHYSICAL PARAMETERS

RETRIEVING THE MEDIAN VOLUME DIAMETER OF RAINDROPS WITH A POLARIMETRIC CLOUD RADAR

PIA–ΦDP RELATIONSHIP IN THE MELTING LAYER OF PRECIPITATION OBSERVED AT X-BAND

QUALITY CONTROL TECHNIQUE BASED ON OBSERVATIONAL CHARACTERISTICS IN DUAL-POLARIZATION MEASUREMENTS

AN IMPROVED KDP COMPUTATION FOR THE RADAR DATA QUALITY ASSURANCE OF DWD WEATHER RADARS

HYDROMETEOR CLASSIFICATION PERFORMANCE EVALUATION

ONE-DIMENSIONAL SIMULATIONS OF DOWNBURST GENERATION WITH A COUPLED FORWARD POLARIMETRIC RADAR OPERATOR

IMPACTS OF VERTICAL NONUNIFORM BEAM FILLING ON THE OBSERVABILITY OF SECONDARY ICE PRODUCTION DUE TO SUBLIMATION

VERIFICATION OF A HYDROMETEOR CLASSIFICATION SCHEME WITH THE RUISDAEL CLOUD RADAR AT CABAUW

DUAL-POLARIZATION X-BAND RADAR DATA AT VERTICAL INCIDENCE, AND WHAT IT TEACHES US

MULTI-WAVELENGTH DEPOLARIZATION SIGNATURES OF SNOWFLAKES

USE OF DUAL-POL OBSERVATIONS, NWP OUTPUT AND CROWD-SOURCED REPORTS TO IMPROVE THE HYDROMETEORS CLASSIFICATION AT GROUND LEVEL IN BELGIUM

ANALYSIS OF POLARIMETRIC SPECTRAL DENSITIES IN SEVERE THUNDERSTORMS FOR THE IDENTIFICATION OF LIGHTNING-INDUCED SIGNATURES

David Schvartzman[1]; Eric Bruning[2]; Tian-You Yu[1]; Vanna Chmielewski[3]; David Bodine[1]; Howard Bluestein[4]

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Spectral polarimetry can be used to study microphysical properties in relation to the dynamics within a radar resolution volume by combining Doppler and polarimetric measurements. The polarimetric spectral densities may unveil additional information about the characteristics of groups of scatterers moving at different Doppler velocities in a radar resolution volume. Of particular interest is the study of storm regions which may be associated with a lightning channel. Previous studies show that strong electric fields induced by a lightning channel are capable of vertically aligning ice crystals above the melting layer, typically in the storm updraft region. This crystal alignment results in a radially decreasing differential phase signature. This is more apparent in the field of specific differential phase (KDP), as large negative KDP regions are manifested aloft. In this paper, we use polarimetric spectral analysis to evaluate two specific storm cases of interest. Both datasets were collected with the Rapid X-band Polarimetric (RaXPol) radar at the ARRC. The first one includes observations from a line of convective storms moving SW to NE through the OKC metropolitan area, where lightning flashes were visible at 30-40 km from the radar. In this case, RHI scans were obtained every 5 sec. through a convective core. The second one includes observations of a supercell in W OK, that developed a tornado near Clinton, OK. In this case, several PPI and RHI scans were collected. We evaluate the polarimetric spectral densities for these cases, and discuss spectral signatures that may indicate storm electrification.

REFRACTION OF RADAR BEAMS IN PRECIPITATION

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Phenomenon of refraction (bending) of radar beams in free atmosphere is well known. Refraction in the atmosphere free from clouds and precipitation depends on the gradients of the temperature, pressure, and humidity. Refraction in free atmosphere is responsible for anomalous propagation (super-refraction and ducting) of radar beams. A new phenomenon of refraction of radar beams in precipitation is discussed. Theory of refraction is presented based on considerations of forward scattering of radar waves. It is predicted that the radar beam can be bent significantly in thunderstorms having strong reflectivity gradients. It follows from theory that horizontally and vertically polarized radar waves experience different refraction. This leads to degradation of the dual polarization radar variables with range in heavy precipitation. Refraction of radar beams in precipitation impacts detection of the cloud tops, ZDR and KDP columns, and estimations of the height of melting layers. Radar data where refraction in precipitation is evident are discussed.

A NEW POLARIMETRIC METHOD FOR THE MELTING LAYER DETECTION AND DETERMINATION OF ITS HEIGHT

Alexander Ryzhkov[1]; John Krause[1]

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A novel polarimetric radar algorithm for melting layer detection and determination of its height has been developed and tested for a large number of cold-season weather events. The algorithm uses radial profiles of the cross-correlation coefficient (ρhv or CC) at the lowest elevation angles (less than 5 - 6°). The effects of beam broadening on the spatial distribution of CC have been taken into account via theoretical simulations of the radial profiles of CC assuming intrinsic vertical profiles of polarimetric radar variables within the melting layer (ML) with varying heights and depths of the ML. The model radial profiles of CC and their key parameters are stored in lookup tables and compared with the measured CC profiles. The matching of the model and measured CC radial profiles allows the algorithm to determine the "true" heights of the top and bottom of the ML, Ht and Hb, at distances up to 150 km from the radar. Integrating the CC information from all available antenna elevations makes it possible to produce accurate maps of Ht and Hb over large areas of radar coverage as opposed to the previous ML detection methods including the existing algorithm implemented on the US network of the WSR-88D radars. The initial version of the algorithm has been implemented in C++ and tested for a multitude of cold-season weather events characterized by low ML with different degrees of spatial nonuniformity including cases with sharp frontal boundaries and rain / snow transitions. The new MLDA exhibits robust performance, demonstrating spatial and temporal continuity, and showing general consistency of the ML designations matching those obtained from the regional model and the quasi-vertical profiles (QVP) methodology output.

CALIBRATION OF MULTI-PARAMETER PHASED ARRAY WEATHER RADAR (MP-PAWR)

Nobuhiro Takahashi[1]

[1]*ISEE Nagoya University, Japan*

An X-band multi-parameter phased array weather radar (MP-PAWR) was develop in late 2017 (Takahashi et al., 2019). The major characteristics of MP-PAWR are electronical scan in elevation (RHI scan) and the azimuthal observation is implemented by the mechanically rotating antenna. The RHI scan is implemented by combining the fan-beam transmission and pencil-beam reception which is realized at the post processing with the digital beam forming technique. Because of this transmission/reception configuration, it is difficult to calibrate the Z and ZDR. In other words, the calibration parameter of Z and ZDR for MP-PAWR may vary with elevation angle which is almost fixed for the parabolic antenna configuration. In this study, calibration of Z and ZDR of MP-PAWR is presented. This study applied the method by Gourley et al. (2009) that uses the ZDR-KDP/Z relationship to implement the absolute calibration of Z of C-band radar assuming that the ZDR is well calibrated. In this study, calibration of ZDR is implemented by comparing the Z-ZDR relationship of observed value with the Marshall-Palmer distribution. Because the Z-ZDR relationship is also affected by the absolute calibration of Z, both Z and ZDR bias are estimated simultaneously. The actual analysis method was to search for the pair that minimizes the error with the Z-KDP/Z relationship by changing the bias of Z and ZDR. The result is evaluated by comparing the spaceborne radar (GPM/DPR) for Z and simple Z-ZDR calibration method using Z-ZDR relationship for weak precipitation.

IDENTIFICATION OF BRIGHT BAND ECHOES USING OPERATIONAL S-BAND DUAL-POLARIZATION RADAR

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The falling snowflakes, passing through the zero-isotherm layers, slowly melt from its surface and cause an overestimation in the radar rainfall estimates (called as the bright band, hereafter BB). Previous studies constructed the vertical structure of reflectivity to designate the bright band (BB). These algorithms have shown the poor performance, especially in low-elevation angles and in cold seasons, since the structure of BB is frequently anisotropic and cannot be fully identified. For these reasons, it is so challenging to identify BB regardless of the elevation angle. In this study, we proposed the BB identification technique that can be applied at every sweep of volumetric radar scan based on the fuzzy-logic. The quasi-vertical profiles (QVPs) of polarimetric observations at a high elevation angle (>7°) was used to extract the BB signatures. The fuzzy logic classifier was constructed from normalized frequency distributions (NFDs) of six feature parameters (polarimetric observations and radial texture of them). The membership functions and their weights were determined based on the overlapping area of the NFD between the non-BB and BB. The threshold for total membership value was optimized to detect BB. The height of identified BB at each elevation angle was validated by comparing to the freezing level from the radiosonde. The BB identification algorithm was applied to various precipitation systems. The case studies clearly showed that the BB regions well capture the thermodynamic structure around radar. We concluded that the proposed technique shows suitable performance for identifying BB on every elevation angle. Furthermore, the technique for reflectivity correction at BB will be developed based on this algorithm to improve the QPE performance in cold seasons.

IMPROVED DUAL POLARIZATION RADAR RETRIEVALS OF BULK ICE MICROPHYSICAL PARAMETERS

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The fidelity of ice water content, snow precipitation rate, number concentration, and mean volume diameter dual polarization radar retrievals hinges on both theoretical assumptions and instrumental limitations. This study considers both sources of error and improves dual polarization radar retrieval equations by comparing ice microphysical retrievals from NRC Convair 580 airborne X-band (NAX) radar data and Multi-radar/Multi-sensor (MRMS) data with aircraft in situ cloud probe data from nine separate cases of the In-Cloud ICing and Large-drop Experiment (ICICLE). The NAX aircraft radar and measured particle size distributions (PSD) are used alongside a cascading, ensemble Markov chain Monte Carlo (MCMC) algorithm to estimate regions of plausible ice particle shapes, orientations, and densities throughout each flight. It is discovered that forward simulated radar variables using the in situ measured PSDs generally require that particle aspect ratios are much lower than what is actually suggested by direct in situ aircraft measurements even when considering a broad uncertainty in observed radar variables. We show that this inconsistency in particle aspect ratio can be reconciled by introducing new ice PSD retrieval equations which are derived using soft triaxial ellipsoids instead of soft oblate spheroids, anisotropic inclusions, and multiple ice particle habits. In particular, anisotropic inclusions are necessary to properly simulate polarimetric variables for PSDs, especially ones that have large (> 1 cm) aggregates. The result of this analysis yields a new set of simple equations that researchers and forecasters can use to map radar variables such as reflectivity and specific differential phase to bulk microphysical variables such as ice water content.

RETRIEVING THE MEDIAN VOLUME DIAMETER OF RAINDROPS WITH A POLARIMETRIC CLOUD RADAR

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The knowledge of the raindrop size distribution (DSD) is key for characterizing precipitation. Several polarimetric and spectral techniques were proposed for cm-wavelength radars. What about the mm-wavelength radars, which have a better spatial and time resolution and can still measure light and moderate rain? Knowing that 90% of the rain volume in Europe comes from rainfall rates between 0.1 mm/h and 10 mm/h, this is worthwhile to investigate. Here, the attempt is to retrieve the median volume diameter, during stratiform rainfall events using a slantwise profiling dual-frequency polarimetric cloud radar. Focus is given to phase measurements, which are not affected by attenuation. Simulations show that the differential backscatter phase strongly depends on the median volume diameter. At mm-wavelength, backscattering and propagation effects need to be disentangled first. To achieve this, an automatic algorithm to detect and characterize Rayleigh plateaus is proposed and implemented. Next, a methodology to estimate the differential backscatter phase and its error is given. The 95% confidence interval of this variable is obtained with the resampling method bootstrapping. Using simulation results, an attempt is made to find combinations of median volume diameter and the DSD shape parameter that match with the confidence interval of the differential backscatter phase. This technique is applied for both the 35 and 94 GHz frequency of the new cloud radar at Cabauw (Ruisdael Observatory). The resulting 95% confidence intervals of the median volume diameter with 35 and 94 GHz and their overlap are compared with in-situ disdrometer measurements.

PIA–ΦDP RELATIONSHIP IN THE MELTING LAYER OF PRECIPITATION OBSERVED AT X-BAND

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X-band radars capture the fine-scale weather dynamics in the mountainous terrain but suffer from significant attenuation in the heavy rain and the melting layer (ML). Differential phase shift ΦDP is immune to attenuation and absolute radar calibration errors, and provides a robust way to correct attenuation. Almost linear in rain, the path integrated attenuation (PIA) vs ΦDP relationship is still poorly characterized in the ML. RadAlp experiment, two radar clusters placed 11 km apart with an altitude gradient of 1700 m in the French Alps, offers a unique opportunity to study the PIA–ΦDP relationship within ML. We propose an iterative algorithm to estimate ΦDP from measured differential phase shift. ΦDP is cumulative along the beam path and iterations on maximum allowed jumps between successive range gates provides a simple regularization mechanism of its range profiles. PIA is estimated using the mountain reference technique. Both, PIA and ΦDP are estimated from the PPI scans at 0° elevation angle of the mountain-top X-band radar and complemented by information on the altitudes of ML limits from valley-based radars. Study of 43 stratiform events, between Nov 2016 and Dec 2020, reveals that the prefactor of the linear fits between PIA and ΦDP varies significantly with the evolution of melting process, between 0.27 and 0.54 (dB/°). The prefactor is ~0.18 in snow at around 250 m above the ML top. It increases rapidly approaching the ML top and continues to increase in the upper part of ML with a max value ~0.54 at the center of ML. In the lower part of the ML, moving towards the ML bottom, it decreases quickly to ~0.27 at around 130 m above the ML bottom.

QUALITY CONTROL TECHNIQUE BASED ON OBSERVATIONAL CHARACTERISTICS IN DUAL-POLARIZATION MEASUREMENTS

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The introduction of the dual polarization radar has improved the performance of the quality control (QC) technique, as well as the accuracy of quantitative application such as rainfall estimation, data assimilation, etc. Many QC techniques for operational radar were developed to distinguish precipitation echo (PRE) and non-precipitation echo (NPE) in real time, and is mainly based on statistic or deterministic methods. These methods showed good performance in typical PRE and NPE, but the false alarm of the QC algorithm increases in atypical PRE such as hail, non-uniform beam filling (NBF) and bright band. In addition, its accuracy decreases in severe NPE such as abnormal ground and sea clutter, and anomalous propagation (AP) due to super refraction and ducting. This study developed new QC algorithm for operational radars to improve the performance of echo classification. The algorithm consists of five steps, including 1) dynamic and static classification for ground clutter; 2) determination for omnidirectional interference occurrence; 3) the offset determination and unfolding for differential phase; 4) attenuation estimation and NPE classification; and 5) radial continuity check and speckle removal. Especially, newly-defined classification parameters of each step were developed based on observational characteristics in polarimetric measurements. Each parameter is individually operated and their threshold value varies with observation range and height, monthly echo top height and intensity of AP and ducting to completely remove severe NPE while preserving atypical PRE. This QC algorithm has applied to operational S- and C-band dual polarization radars in Korea and showed higher performance in all-weather conditions compared to the statistical method.

AN IMPROVED KDP COMPUTATION FOR THE RADAR DATA QUALITY ASSURANCE OF DWD WEATHER RADARS

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The radar data processing chain at DWD used to process the polarimetric radar data includes a variety of algorithms to assure the quality of the measured radar moments. One of those polarimetric radar moments, the specific differential phase shift KDP, which is not measured directly but is derived from the differential phase shift PhiDP, requires a high quality of the input data and good algorithms with regard to the follow-up procedures. KDP is a valuable quantity for various products, e.g. to determine the rain rate in areas with heavy precipitation, since it is hardly prone to attenuation or partial beam blocking. A computation for KDP data of high quality has to address different problems in different situations, e.g. a noisy PhiDP, a backscatter phase that is not negligible, folding of PhiDP, non-uniform beam filling, non-liquid phases of precipitation such as hail or mixed phases, and other difficulties need to be considered. In addition to the existing algorithm used at the DWD, we developed a variant that, as a conglomerate of the existing method with algorithms known from the literature combines the advantages of the individual methods: The need to unfold PhiDP profiles is avoided by interpreting PhiDP as argument of a complex number, which also yields a measure of fluctuations of PhiDP and thus KDP. Critical range gates at the edge of precipitation areas that may be corrupted due to partial beam filling are omitted by iteratively taking finite differences of PhiDP across a medium sized window. KDP in precipitation areas with low PhiDP noise is then computed as weighted combination of a cubic spline interpolation and a least square linear regression. We present the new approach and evaluate the data quality compared to the previous DWD method.

HYDROMETEOR CLASSIFICATION PERFORMANCE EVALUATION

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Météo-France operates a fuzzy-logic based hydrometeor classification algorithm based on the work by Al-Sakka et al. (2013). This algorithm (hereby OPER) has some limitations, chief among them is the fact that relies heavily on a single iso-0° reference value for the entire radar domain and makes use of the information issued by a melting layer detection algorithm, which is again a single reference over the entire radar domain. More recently, Besic et al (2016) developed a semi-supervised hydrometeor classification algorithm. Being partially data-driven, this algorithm is, theoretically, more adaptive to the noisy nature of the radar data. In order to objectively decide a suitable replacement for operational implementation, Météo-France embarked in a large scale algorithm evaluation using various techniques: inter-comparing the results of the hydrometeor classification from two different radars at co-located range gates, looking at the correlation between range gates classified as hail and hail detected by hail pads (data provided by ANELFA) and hail sensors on the ground (data courtesy of MeteoSwiss) and, in the context of the ICE-GENESIS campaign, comparing the classification of solid precipitation by the radar with that obtained by a Multi-Angle Snow Camera (MASC) on the ground and by an air-borne Precipitation Imaging Probe (PIP). 4 algorithms have been tested: OPER, OPER but using a 2D iso-0° field (OPER2D), OPER2D but without making use of the melting layer information and the semi-supervised algorithm. Results of the evaluation will be discussed during the conference.

ONE-DIMENSIONAL SIMULATIONS OF DOWNBURST GENERATION WITH A COUPLED FORWARD POLARIMETRIC RADAR OPERATOR

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Downbursts present an acute threat to life and property. Due to the relatively short timescales over which they develop, predicting them with sufficient lead time remains challenging. In addition to descending reflectivity (Z) cores, recent work has identified an association between descending cores of enhanced specific differential phase (KDP) and the occurrence of a downburst at the surface. However, the ability to predict downburst intensity from radar data remains tenuous, and validation of such predictions remains challenging due to observability constraints. This work seeks to better understand the associations between polarimetric characteristics of downbursts and their driving forces (namely diabatic cooling and precipitation loading) by using a one-dimensional model with spectral bin microphysics coupled to a forward polarimetric radar operator. For a prescribed hail particle size distribution and thermodynamic environment, the model simulates sublimation, evaporation, melting, shedding, and drop breakup; evolves the environmental dynamics and thermodynamics in response to these processes; and simulates the attendant polarimetric variables. Results will compare the vertical profiles, gradients, and time derivatives of the polarimetric variables with the resultant downburst intensity and magnitude of the driving forces across a range of environments and particle size distributions to identify any prognostic associations that may exist.

IMPACTS OF VERTICAL NONUNIFORM BEAM FILLING ON THE OBSERVABILITY OF SECONDARY ICE PRODUCTION DUE TO SUBLIMATION

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[2]*Stony Brook University, United States*

Quasi-vertical profiles (QVPs) of polarimetric radar data have emerged as a powerful tool for studying precipitation microphysics. Enhancements in specific differential phase (KDP) have been identified in regions of suspected secondary ice production (SIP) due to rime splintering. Similar enhancements have also been observed in regions of sublimating snow, another proposed SIP process. This work explores these KDP signatures for two cases of sublimating snow (12—13 February 2020 and 31 January – 1 February 2021) using nearly collocated S- and Ka-band radars. It is found that the signature was inconsistent between the radars, prompting further exploration of alternative causes. Idealized simulations are performed using a beam-broadening model to explore the impact of nonuniform beam filling (NBF) on the observed reflectivity (Z) and KDP within the sublimation layer. It is found that, rather than an intrinsic increase in ice concentration, the observed KDP enhancements can be explained by NBF in the presence of a sharp Z vertical gradient within the sublimation zone, which results in a KDP bias dipole. The severity of the bias is sensitive to the Z gradient and radar beam width and elevation angle, which explains its appearance at only one radar. In addition, differences in scanning strategies and range thresholds during QVP processing can constructively enhance these positive KDP biases by excluding the negative portion of the dipole. These results highlight the need to consider NBF effects in regions not traditionally considered (e.g. in pure snow) due to the increased KDP fidelity afforded by QVPs and the subsequent ramifications this has on the radar observability of sublimational SIP.

VERIFICATION OF A HYDROMETEOR CLASSIFICATION SCHEME WITH THE RUISDAEL CLOUD RADAR AT CABAUW

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[2]Delft University of Technology, Netherlands

At KNMI we apply and are improving the Hydrometeor Classification (HMC) scheme from the open source wradlib code, which can discern 11 different precipitation types using the 2 dual polarization C-band Doppler radars of KNMI. For verification and optimisation it is desirable to obtain independent information on precipitation types in the upper atmosphere. For this purpose, we use the Ruisdael cloud radar, which operates at 35 and 94 Ghz and is located at Cabauw, the Netherlands. Automatic de-aliasing of measured Doppler spectra is performed by using computed wind components parallel to the Ruisdael radar beam from forecasts of the Numerical Weather Prediction (NWP) model Harmonie. Further, we use additional Doppler velocities from the 2 KNMI radars in order to compute 3D Doppler velocity vectors on the Ruisdael radar beam; thus their vertical components are known as well. The next step is to analyse the vertical Doppler spectra of reflectivity, differential reflectivity, differential phase and covariance and then (automatically) assess the precipitation type from the shape of these spectra. The obtained precipitation type from the Ruisdael cloud radar data will be used for improving and verifying the HMC scheme. The HMC output enables us to compute 3D fields of mixing ratios of rain, snow and graupel. The ultimate goal of our work is to ingest these fields in our operational NWP model Harmonie, with the aim of improving nowcasting of precipitation and convection.

DUAL-POLARIZATION X-BAND RADAR DATA AT VERTICAL INCIDENCE, AND WHAT IT TEACHES US

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For the past five years, McGill has operated one of its X-band vertically pointing radars (VertiX) in dual-polarization mode. Like many dual-polarization radars, VertiXDP simultaneously transmits and receives signals at two orthogonal channels, "H" being oriented along the 240°-60° axis and "V" being perpendicular. As such, differential reflectivity data are not very interesting except for biological echoes, but very precise measurement of copolar correlation coefficients are being made in precipitation. Furthermore, VertiXDP can also make spectral measurements of correlation in parallel to the more usual spectral measurements of echo power. These have been used to get new insights on microphysical phenomena such as the melting layer, the growth of snow, and the refreezing of ice pellets, providing useful context for understanding their signature in scanning radars. Observations of biological echoes confirm that, most of the time, insects try to head somewhere and are not the passive tracers we think of. In snow, pockets of unusually low correlation occur occasionally in between trails or near warm echo tops (~ –10C) and may be associated with needle-dominated precipitation. Correlations in snow are generally slightly smaller than in rain, and vary somewhat from one trail to the next; little correspondence with fall speed or reflectivity patterns were observed (a few overflights made by the NRC Convair this February-March may shed some light). Spectral signatures of correlation are rare or difficult to detect except in the melting layer where unusually fast hydrometeors tend to have lower correlations.

MULTI-WAVELENGTH DEPOLARIZATION SIGNATURES OF SNOWFLAKES

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[3]*Finnish Meteorological Institute, Helsinki, Finland*

Most cloud radars and lidars operate using nadir or zenith pointing. In this geometry, if compared to other polarimetric variables, (linear) depolarization ratio measurements carry a more useful information about hydrometeor properties. In this study, we are documenting depolarization properties of snowflakes at several wavelengths as observed by a W-band cloud radar, C-band vertically pointing radar and Vaisala CL61D ceilometer. The remote sensing observations collected at the University of Helsinki measurement station in Hyytiälä, Finland are supported by collocated ground-based observations of falling snowflakes collected by the University of Leipzig Video in Situ Snowfall Sensor (VISSS) and NASA Particle Imaging Package (PIP). During the winter 2021/2022, more than 20 cases were measured and analyzed. The more frequently observed snowflake habits, at various riming stages, are needles and needle aggregates, dendrite and their aggregates, and graupel. The W-band LDR values show the most variation, ranging from less than -26 dB for dendrites and small graupel, changing between -26 and -24 dB for larger aggregates of larger graupel, and >-17 dB for needles and needle aggregates. Ceilometer depolarization ratios tend to be very close to 1, but in some dendrite cases these values were somewhat lower. Using the accumulated statistics of observed LDR at C and W-bands, the existing single scattering particle properties and corresponding particle models were tested, by comparing observed and computed LDR values. Our preliminary analysis shows that these models tend to produce higher LDR values. This could indicate that the physically based snowflake models tend to produce more open-sparce snowflakes, then those observed in nature.

USE OF DUAL-POL OBSERVATIONS, NWP OUTPUT AND CROWD-SOURCED REPORTS TO IMPROVE THE HYDROMETEORS CLASSIFICATION AT GROUND LEVEL IN BELGIUM

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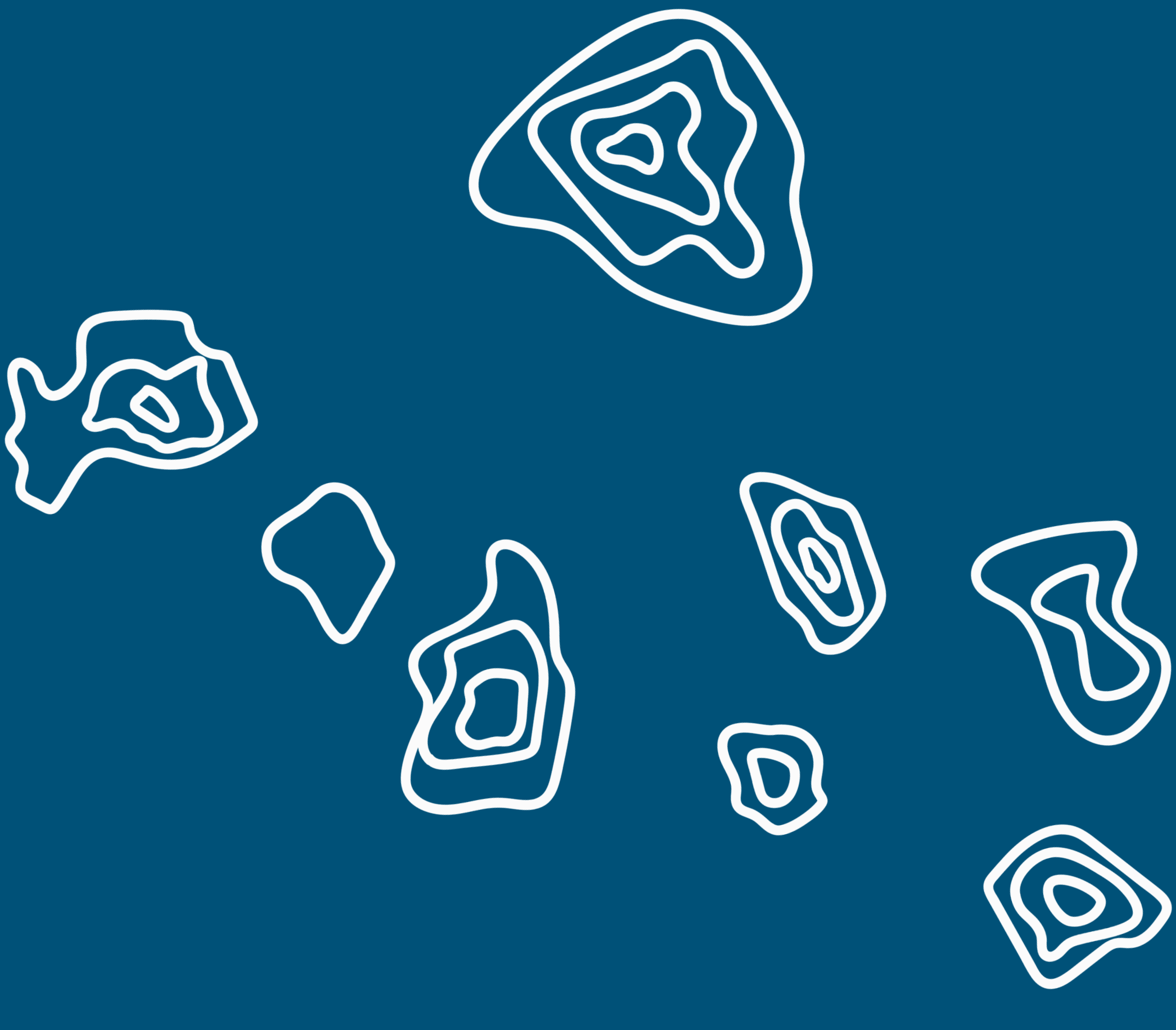
In Belgium, three dual-pol radars provide a good coverage of the country: Jabbeke, Helchteren and the brand new radar of Wideumont. Additionally, several dual-pol radars in the neighbouring countries cover the Belgian territory at least partly, providing even more information on precipitation type in Belgium. Combining this dual-pol information with NWP output through a fuzzy logic scheme allows us to derive the precipitation type at a certain height. The result of this step is then post-processed through a melting scheme also using NWP output to finally get an estimate of the precipitation type close to the ground. In 2019, the Royal Meteorological Institute of Belgium (RMIB) launched an app allowing every user to report in real-time various weather events, among them the precipitation type in a very detailed way. Those reports are gathered in a database that is used for a preliminary validation of our precipitation type product. An overview of the many possibilities of further developments of this product will also be given.

QUANTITATIVE PRECIPITATION ESTIMATION



EVALUATION OF HIGH-RESOLUTION PRECIPITATION ESTIMATES USING ELECTROMAGNETIC WAVE RAIN GAUGE (EWRG)

AUSTRALIA-WIDE HIGH RESOLUTION PRECIPITATION DATA: WHAT IS POSSIBLE?

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EVALUATION OF RADAR-DERIVED POLARIMETRIC RAINFALL ESTIMATES FOR EXTREME RAINFALL CASES

A DUAL-POL VPR CORRECTION FOR OPERATIONAL RADAR QPE

COMPARISON OF THE RADAR PROFILING ALGORITHMS FOR S-BAND RADAR BY SIMULATION : CONSEQUENCE OF THE HYPOTHESIS OF CONSTANT SCALED DROP CONCENTRATION (NW) OVER RANGE

ADDRESSING DATA QUALITY ISSUES FOR GAP-FILLING SOLID-STATE POLARIMETRIC X-BAND RADARS

VPR CORRECTION METHODS FOR MF RADARS

A RADAR-BASED QUANTITATIVE PRECIPITATION ESTIMATION ALGORITHM TO ADDRESS NEAR-SURFACE VERTICAL GRADIENTS OF PRECIPITATION IN WARM-RAIN PROCESSES: THE FLOOD IN WESTERN GERMANY ON 14 JULY 2021

USING A RANDOM FOREST APPROACH TO IMPROVE THE QUANTITATIVE PRECIPITATION ESTIMATION FROM THE DUAL-POLARIZED WEATHER RADAR NETWORK IN SWITZERLAND

RAINFALL ESTIMATION USING SPECIFIC ATTENUATION WITH A NEW ALPHA OPTIMIZATION METHOD

HALF-HOURLY EVALUATION OF GPM-IMERG PRECIPITATION PRODUCTS USING RAIN-GAUGE DATA IN CATALONIA

CORRECTION OF RAINFALL-INDUCED ATTENUATION AT C-BAND IN SOUTHEASTERN SOUTH AMERICA WITH S-BAND CROSS-VALIDATION

ESTIMATION AND ANALYSIS OF EXTREME RAINFALL IN BELGIUM DURING THE JULY 2021 FLOOD EVENT

SUPPORTING WEATHER RADAR OBSERVATIONS WITH THE VAISALA FD70

RADAR QPE FOR THE NETHERLANDS

ADDED VALUE OF MULTI-YEAR X-BAND WEATHER RADAR OBSERVATIONS AT URBAN SCALES

USING QUALITY INFORMATION FOR MERGING RADAR AND RAIN GAUGE DATA

QUALITY CONTROL ALGORITHMS FOR PRECIPITATION DATA FROM PRIVATE METEOROLOGICAL STATIONS USING WEATHER RADAR DATA

THE ASSESSMENT AND VALIDATION OF RADAR QPE FOR LOCAL GOVERNMENT IN THE AUCKLAND REGION, NEW ZEALAND

DETECTION OF BEAM BLOCKING USING A LONG TERM STATISTICAL CHARACTERISTICS OF DUAL-POLARIZATION OBSERVATION

ANOMALOUS ELECTROMAGNETIC WAVE PROPAGATION AND RAINFALL ESTIMATES WITH MICROWAVE LINKS

TROPICAL RAINFALL MONITORING WITH COMMERCIAL MICROWAVE LINKS IN SRI LANKA

FUSION OF MULTIPLE PRECIPITATION SENSORS IN SKÅNE, SWEDEN

AUTOMATIC OBJECTIVE EVALUATION OF RADAR PRODUCTS IN THE OPERATIONAL PRODUCTION CONTEXT AT ENVIRONMENT AND CLIMATE CHANGE CANADA

GUIDING THE IMPROVEMENT OF THE GLOBAL PRECIPITATION MEASUREMENT MISSION WITH RADAR NETWORKS

PROBABILISTIC QUANTITATIVE PRECIPITATION ESTIMATION WITH GROUND- AND SPACE-BASED RADARS

POLARIMETRIC RADAR RAINFALL RETRIEVAL IN EASTERN SÃO PAULO

EVALUATION OF HIGH-RESOLUTION PRECIPITATION ESTIMATES USING ELECTROMAGNETIC WAVE RAIN GAUGE(EWRG)

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Recently, the number of natural disasters caused by inclement weather conditions such as localized torrential downpours, heavy snow, strong wind, etc. is increasing in Korea, which requires relevant prevention and water management measures. In order to prevent and manage localized torrential downpours, quantitative observation and projection of precipitation are necessary. The ground rain gauge used for general rainfall observation is a cylindrical ground rain gauge that is 20cm in diameter. When calculating the area precipitation based on Thiessen method, the area represented by the ground rain gauge is several or dozens of km^2 which lacks measurement representativeness compared to the spatial distribution. In order to develop an electromagnetic sensor capable of distribution of precipitation, the present research has developed a multi-purpose precipitation gauge of 17GHz with narrow beam of mm wavelength ku-band that can measure rainfall and snowfall, which are all the core indices for inclement weather observation. Moreover, a low-altitude measurement technology has been developed, capable of accurately measuring ground precipitation, which is essential for increasing the accuracy of flood forecast. The precipitation spatial distribution observation network was established in Yeoncheon SOC Center with radius of 1km, in order to verify the performance of EWRG precipitation measurement. Since converting rainfall intensity of EWRG moment data is crucial for quantitative rainfall observation, multiple non-electromagnetic sensors(multiple pit gauge(MPG), tipping-bucket rain gauge, weighting-type rain gauge, PARSIVEL, etc.) were used comprehensively to evaluate the accuracy of the precipitation measurement.

AUSTRALIA-WIDE HIGH RESOLUTION PRECIPITATION DATA: WHAT IS POSSIBLE?

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Within the Horizon 2020 Project WaterSENSE, different requirements for precipitation data were identified for agricultural and hydrological applications. Therefore, a modular approach was developed for this data, incorporating user needs as well as data constraints. This approach was initially tested in Australia with the potential to be extended worldwide. If available quality-controlled gauge adjusted radar data is considered to be the best option. For Namoi, a focus area of the project, radar data delivered by the Bureau of Meteorology was meticulously inspected and improved. After gauge adjustment this data is provided in two different qualities, near-real-time (basic quality) and automatically post processed with a delay of 24 hours (high quality), to cater for different user needs. Satellite based precipitation products offer an option for less data rich regions. Level 3 GSMaP and GPM IMERG products were analyzed with high quality gauge adjusted data of Namoi radar serving as a benchmark. Our analysis highlighted the potential of sensing precipitation from space as well as the need for further improvements especially with respect to the spatial resolution. We address this issue by incorporating other remotely sensed data with a strong link to precipitation, namely soil moisture (SM) and normalized difference vegetation index (NDVI). We explore the ability to provide EO based precipitation data with a high resolution not previously possible. Capitalizing on high quality and high-resolution SM and NDVI data also derived as part of this project predominantly based on data from the Copernicus Programme we aim at a half hourly timestep and a 1 km spatial grid. This offers the potential for further improvements of the accuracy of this data through gauge adjustment.

QUANTITATIVE RAINFALL ESTIMATION METHOD FOR X-BAND DUAL POLARIZATION RADARS IN KOREA

Jae In Song[1]; Sanghun Lim[1]; Kyusoo Chong[1]

[1]*Korea Institute of Civil Engineering and Building Technology, South Korea*

Currently, the Ministry of Environment is operating two X-band dual polarization radars for the purpose of resolving the observation gap in the east coast of Korea for the existing S-band rainfall radar network and preventing hydrological disasters. The X-band rainfall radar is an observation device that can observe precipitation in a wide area in a short time. The radar rainfall accuracy varies greatly depending on the relation applied between radar parameters and rainfall intensity. Also, since the shielded area is different for each azimuth, hybrid surface rainfall (HSR) is sometimes used to increase the accuracy. In this study, the rainfall amount by applying HSR was estimated based on data from two X band radars installed in Uljin and Samcheok (as shown in Fig. 1). The relationship between rainfall intensity (R) and specific differential phase difference (Kdp) for QPE was empirically derived from the rainfall observed in AWS and derived Kdp. The estimated rainfall intensity was verified with data of a period different from the data for establishing the empirical formula, and compared with the accuracy when using the R-Kdp relational expression of the X-band radar presented in the previous study.

IMPROVEMENT OF AUTOMATIC RAIN GAUGE CHECKS RELEVANT TO RADAR DATA ADJUSTMENT

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Rain gauge data have to be controlled for implausible values before they can be used for further processing. Besides manual checks by experienced observers, automatic checks are important tools to speed up the control methods. The past experience has shown, that the spatio-temporal behaviour of rainfall (especially of convective cells) leads to problems in automatic checks. Therefore, already existing methods of rain gauge quality control have been combined with new variability methods with the objective to only use rain gauge data for adjustment procedures, which are spatially comparable to radar data. The existing methods include first of all the detection of unrealistic high values, which never occurred before in this region. Thresholds can be adjusted to different return periods, e.g. 5 or 10 years. The second established method is the detection of too low and too high daily values, as compared to neighbouring stations. Spatial information between neighbours should be consistent within a confidence interval for the middle station. The third method compares rainfall durations with those of neighbouring stations, because they should be consistent as well. The new methods are comparisons between characteristics of radar and rain gauge measured data: the spatial variability in rain amounts of both data sources should be comparable. Additional steps under consideration are temporal checks on the temporal variability of rainfall duration, the number of rainfall intervals and mean time between precipitation (MTBP).

GENERALIZED SENSITIVITY ANALYSIS OF ATTENUATION IN PRECIPITATION AT X-BAND FREQUENCY USING THE MOUNTAIN REFERENCE TECHNIQUE

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The RadAlp experiment aims at improving quantitative precipitation estimation (QPE) in the Alps thanks to X-band polarimetric radars and in-situ measurements deployed in the region of Grenoble, France. We revisit the physics of propagation and attenuation of microwaves in rain. The idea is to implement 5 attenuation algorithms in the framework of a generalized sensitivity analysis to establish useful parameterizations for QPE. The parameter structure and the inherent mathematical ambiguity of the equations make it necessary to organize the optimization procedure in a nested way. The core of the procedure consists in (i) exploring the space of the parameters allowed to be variable from one target to the other and from one time step to the next, (ii) computing a cost function (CF) quantifying the proximity of the simulated profiles and (iii) selecting parameters sets for which a given CF threshold is exceeded. This core is activated for series of values of parameters supposed to be fixed, e.g. the radar calibration error for a given event. Results of the sensitivity analysis are presented for a three convective events using the 0°-elevation PPI measurements of the Météo-France weather radar located on top of the Moucherotte Mount (1901 m asl). Critical parameters for radar QPE were thus estimated using radar data alone, including radar calibration error, radome attenuation and the coefficients of the power-law models relating the specific attenuation, the specific differential phase shift and the reflectivity. The A-Z and A-Kdp relationships were found to be consistent with those derived from concomitant drop size distribution measurements at ground level. We note a slightly non-linear A-Kdp relationship (A=0.275 K_dp^1.1) and X-Band radome attenuations as high as 15 dB.

EFFECTS OF RADAR DATA RESOLUTION ON THE ANALYSIS OF EXTREME EVENTS

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Recent studies have shown that extreme value statistics from radar tend to show systematically lower values for short time intervals < 1 hour than statistics from rain gauges. Furthermore, radar data with a coarser resolution display significantly lower peak intensities than high resolution radar data.
For a case study the effects of several radar and a rain gauge data set on the results of adjusted radar data on extreme events were compared. The case study comprises a time period of one year (01 November 2018 – 31 October 2019) in North Rhine-Westphalia, Germany. The radar data for the investigation are:
- Single radar product; polar; spatial resolution 1° x 250 m
- Single radar product; polar; spatial resolution 1° x 1 km
- Composite radar product; cartesian; spatial resolution 1 km x 1 km; based on single radar products (1° x 250 m)
- Composite radar product; cartesian; spatial resolution 1 km x 1 km; based on single radar products (1° x 1 km)
The quality of the radar data sets was enhanced by data quality control algorithms for ground clutter, beam blockage, attenuation and advection correction on the single radar product. For the analysis, quality checked precipitation data of up to 800 continuously measuring rain gauges were available. The radar and rain gauge data were combined in an adjustment procedure based on a factor field and a difference field on a daily time interval. Adjustment factors and differences were calculated at the rain gauge locations and interpolated. The evaluation is based on a comparison of the statistical behaviour of radar and rain gauge data for intervals between 5 and 120 minutes. As a result, the influence of high-resolution radar data for small-scale intensive rainfall events can be shown.

CHALLENGES AND POTENTIAL USE OF HIGH-RESOLUTION X-BAND WEATHER RADAR DATA IN AGRICULTURE IN NORTHE-AST GERMANY

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In June 2020 a ground-based, dual-polarization Doppler X-band weather radar supplied by FURUNO Germany was installed in Neubrandenburg in northeast Germany and data were recorded continuously since October 2020. Between autumn 2020 and July 2021 the scan settings were changed repeatedly in order to figure out the optimum settings of the radar. From August 2021 onwards FURUNO performs a set of scans with an update time of five minutes. Each five-minute scan includes eight elevation angles and finally a 90° scan. The aim is to use the high spatial and temporal resolution weather radar data for real time information about precipitation events in the regional test area DEMMIN, which covers 900 km², in future. The intensively agriculture test area is located between 30 and 50 km from the weather radar and real-time information on local precipitation events has the potential to help farmers plan irrigation measures in this area, because irrigation will be more important due to climate change in future. To provide farmers temporally and spatially highly resolved precipitation products, the weather radar data have to be carefully calibrated and processed. For the calibration of the weather radar data we will use the GPM satellite data and RCA method. Phase processing and attenuation correction are performing according to the ZPHI method. After the attenuation correction different rain rate retrievals are used to obtain a precipitation product. The precipitation product of Furuno were compared with precipitation data of climate stations and the weather radar product RADOLAN (RW) from the German Weather Service within the scan radius of Furuno. The study presents the processing steps of the weather radar data and challenges in processing as well as a precipitation analyses.

IMPROVEMENTS TO DWD'S QPE WITHIN SINFONY

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Deep summertime convection associated with heavy rain and flooding endangers life and property. To improve forecasts of these events, the SINFONY project (Seamless INtegrated FOrecastiNg sYstem) at DWD develops an ensemble prediction system for seamless forecasts on the convective scale from observation time up to 12 h. One part of the project is to improve the QPE for nowcasting products. The QPE at DWD currently consists of reflectivity based rain rate relations, which are selected depending on the results of a hydrometeor classification algorithm. Recent literature shows the benefits of polarimetric QPEs at C-band especially for liquid hydrometeors. Therefore, different algorithms are tested for operational use and are compared to previous products. First results of this comparison, also verification with station data, are presented at the conference. While polarimetric QPEs might improve precipitation forecasts at higher rates, lower QPE rates suffer from the effect of evaporation. This effect is not yet captured in our operational algorithms and we will present first results of a correction based on information from NWP.

EVALUATION OF RADAR-DERIVED POLARIMETRIC RAINFALL ESTIMATES FOR EXTREME RAINFALL CASES

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Radar-derived quantitative precipitation estimation (QPE) has become an important data source for numerous meteorological and hydrological applications. In particular, QPE products are commonly used as main input to drive rainfall-runoff models for streamflow prediction, and their errors contribute to predictive uncertainty. The QPE method for the U.S. Weather Surveillance Radar-1988 Doppler (WSR-88D) radars has advanced along with their hardware and polarimetric upgrades since their deployment in the early 1990s. Many QPE studies during the last decade have focused on utilizing the benefit of polarimetric capability and assessing a variety of approaches based on different polarimetric variables. The results from those studies demonstrated the improved accuracy and potential of polarimetric estimates in many different conditions and cases. In this study, the authors evaluate rainfall estimates derived from two polarimetric QPE algorithms primarily based on (1) specific differential phase and (2) specific attenuation for extreme rainfall cases observed from radars in Iowa, Missouri, and Kansas in the central United States. The performance of these estimates is compared with that of the conventional ones derived from radar reflectivity using hourly rain gauge observations densely distributed over the radar domains. The authors also examine range-dependent features of the two polarimetric estimates for an overlapping area monitored by a dense network of 171 rain gauges in Kansas City. They discuss strengths and weaknesses of each estimation methods, as well as probable QPE improvement by accounting for heterogeneity of the primary parameter (i.e., alpha) in the specific attenuation method.

A DUAL-POL VPR CORRECTION FOR OPERATIONAL RADAR QPE

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Radar based quantitative precipitation estimation (QPE) has range dependent errors with the bright band (overestimation) and with the radar beam overshooting the melting layer (underestimation). The bright band is caused by melting ice hydrometeors and results in inflated reflectivity observations. The radar beam overshooting the melting layer results in weakened reflectivity values. If uncorrected, these effects can cause large errors in radar-derived QPE. In the operational Multi-Radar Multi-Sensor (MRMS) system up to version 12.1, the effects of the bright band are corrected through a reflectivity-only, tilt-averaged apparent vertical profile of reflectivity (tilt-VPR). This study utilizes dual-pol observations to identify the bright band top and bottom heights for individual radials of radar data. Then a radially-dependent dual-pol VPR (dpVPR) model was developed to correct for the bright band and beam overshooting effects in the reflectivity field. This algorithm has been tested on 14 varying bright band events across the CONUS. The radially-dependent dpVPR correction provided a more accurate detection of bright band areas and a more effective reduction in QPE errors within and above the bright band than the tilt-VPR correction, especially for precipitation events with low melting layers or with strong spatial variability of the melting layer. The bright band delineation and dpVPR methodology are also evaluated in the real-time MRMS testbed for their robustness and computational efficiency. It will be transitioned into operations in MRMS version 12.2.

COMPARISON OF THE RADAR PROFILING ALGORITHMS FOR S-BAND RADAR BY SIMULATION : CONSEQUENCE OF THE HYPOTHESIS OF CONSTANT SCALED DROP CONCENTRATION (NW) OVER RANGE

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The profiling algorithms are widely used for the radar attenuation correction. Recent studies have shown the advantages of using specific attenuation (Ah) for the quantitative precipitation estimation (QPE). In this study, we investigate 4 radar profiling algorithms (distribution of Ah according to reflectivity, linear ZPHI, non-linear ZPHI and Self-consistent method of Bringi) by numerical simulations. We focus on the impacts of the hypothesis of constant scaled drop concentration (Nw) over range on precipitation estimation. The sensitivity of each algorithm to radar measurement errors are studies as well. The results suggest that the benefice of introduction of Nw in QPE can be significantly reduced if Nw isn't constant in reality and/or if the radar measurements aren't perfect.

ADDRESSING DATA QUALITY ISSUES FOR GAP-FILLING SOLID-STATE POLARIMETRIC X-BAND RADARS

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Existing weather surveillance radars have to be complemented by lower-cost gap filling (GF) radars in the areas of poor coverage by operational radars. Weather echoes received by solid-state radars are commonly characterized by discontinuities at the border between the “blind range” and “visible range” zones. This results in discontinuities in the maps of radar variables and QPE products obtained from these variables. The GF radars usually operate at X band where radar reflectivity Z and differential reflectivity ZDR can be significantly biased by attenuation / differential attenuation along the propagation path in rain and by additional attenuation due to a wet radome. Standard polarimetric correction methods account for attenuation caused by propagation in rain but not wet radome. Herein we describe the methodology for obtaining robust estimates of Z and rain rate R which are not biased by radar miscalibration, partial beam blockage, attenuation in precipitation and wet radome, and which are free of discontinuities at the border between the blind and visible ranges. This routine implies estimating the radial profiles of specific attenuation A separately within the blind and visible range intervals and converting them into the radial profiles of Z and rain rate. This technique has been tested for a number of rain events observed with the EEC Ranger X5 solid-state polarimetric radar. The fields of Z and R obtained from Ranger X5 were checked for consistency with the corresponding products available from the nearby S-band WSR-88D radar and the suggested methodology demonstrated its promising potential for quantification of precipitation in areas of poor WSR-88D coverage, particularly for a “warm rain” generated at lower altitudes.

VPR CORRECTION METHODS FOR MF RADARS

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This paper describes several methods for detecting the bright band (BB) and correcting the vertical profile of reflectivity (VPR) of Météo-France (MF) radars. This study investigates five methods for calculating VPR from volumetric radar data in order to improve precipitation estimates: 1) reflectivity with predefined adaptable parameters, 2) polarimetric variable combinations (such as reflectivity, differential reflectivity, and co-polar correlation coefficient)) with different thresholds, 3) polarimetric variable combinations with predefined adaptable parameters, 4) polarimetric variable and threshold combinations with variable adaptable parameters according to elevation angle, 5) VPR models with consistent 0o isotherms and BB peaks. The methods produce reliable VPR profiles and corrections at higher elevations (>3°) but are ineffective at lower elevations. Among all the methods, the 4 and 5 methods produce the best results for both lower and higher elevations. Method 1 determines the BB solely through reflectivity with predefined parameters, resulting in a fixed or incorrect BB. Method 2 employs thresholds that are insufficient for some rainfall situations encountered by the radar (e.g. light or heavy rainfall) and method 3 works well at higher elevations but is unable to select reliable BB patterns at lower elevations (caused by beam broadening) due to the use of fixed parameters. Because of the variability of the adaptable parameters and polarimetric combinations, method 4 selects mostly reliable BB parameters for all elevations. Method 5 is a model-based technique that selects reliable VPR profiles for all elevations by combining ISO0 from NWP models and BB peak from polarimetric combinations.

A RADAR-BASED QUANTITATIVE PRECIPITATION ESTIMATION ALGORITHM TO ADDRESS NEAR-SURFACE VERTICAL GRADIENTS OF PRECIPITATION IN WARM-RAIN PROCESSES: THE FLOOD IN WESTERN GERMANY ON 14 JULY 2021

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Accurate, near real-time quantitative precipitation estimation (QPE) and derived nowcasting products are key to feed hydrological models and enable reliable flash flood predictions. On 14 July 2021, long-lasting intense stratiform precipitation caused disastrous floods in western Germany. Three state-of-the-art radar-based QPE products are derived for the affected region, which was covered by four polarimetric C-band radars operated by the German Meteorological Service (DWD, Deutscher Wetterdienst): the ones retrieved from reflectivity (Z), from the combination of Z and differential phase (KDP), and the joint use of specific attenuation (A) and KDP. While the use of polarimetric information improved the performance, all three products did significantly underestimate the precipitation totals most likely due to considerable vertical rainfall gradients below the melting layer, which are typical for warm-rain process. To address this issue, we thus propose two approaches: i) the inclusion of a local polarimetric X-band radar, JUXPOL, for the provision of low-altitude observations, and ii) the vertical profile correction for Z and KDP using range-defined Quasi-Vertical Profiles (RD-QVPs). When evaluated with rain gauge measurements, both approaches successfully improved QPE performances by 10-30% reduction of normalized root-mean-squared error and normalized mean bias. In addition, the vertical profile correction showed comparable results to a DWD's operational rainfall product, which is based on Z only but adjusted to nearby rain gauge measurements. This greatly increases the value of radar-based QPE application for warm-rain events and potential flash flooding warnings associated with this type of rain.

USING A RANDOM FOREST APPROACH TO IMPROVE THE QUANTITATIVE PRECIPITATION ESTIMATION FROM THE DUAL-POLARIZED WEATHER RADAR NETWORK IN SWITZERLAND

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Quantitative precipitation estimation (QPE) is crucial for hydrological, climatological and meteorological studies. Weather radars provide remote observations of hydrometeors with a wide-range coverage. However, an accurate retrieval of precipitation intensity from weather radar observations remains a challenge, especially for solid precipitation (snowfall). In this study, we present a novel approach using a random forest regression to derive QPE from polarimetric radar observations. Random forest regression is a machine learning approach based on an ensemble of decision trees. The model "Rainforest" (RF) is trained with a database containing four years (January 2016 to December 2019) with observations from 288 rain gauges and polarimetric radar observations from five dual polarization Doppler C-band radars (Swiss weather radar network). The trained model is able to produce QPEs on a 1x1km2 Cartesian grid at the temporal resolution of 5 minutes. The performance of the fitted model, which is averaged over a five-fold cross-validation, is assessed using gauge observations as reference, and is also compared to the performance of currently available operational non-polarimetric QPE products from MeteoSwiss. These products are derived from radar measurements only and from merging radar and gauge observations (CombiPrecip). RF produces improved precipitation intensities compared to the radar-only product, especially for large and solid/mixed precipitation. Furthermore, several case studies with snowfall reveal realistic precipitation fields with no visible radar artefacts and more accurate snowfall amounts. In general, the results of RF are promising and show the great potential for this model for the operational estimation of precipitation.

RAINFALL ESTIMATION USING SPECIFIC ATTENUATION WITH A NEW ALPHA OPTIMIZATION METHOD

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As dual polarization technology is widely adopted for weather radars, the methodology for using specific attenuation A to estimate rain rate becomes more attractive for radar QPE due to its low sensitivity to the variability of DSD and immunity to radar miscalibration, attenuation, and partial beam blockage. The net parameter α = A/KDP which depends on differential reflectivity ZDR and DSD plays a key role in the accuracy of R(A) QPE. The current version of R(A) in the operational MRMS system utilizes a single value of α in rain for a whole radar coverage area and this value is updated on a scan-by-scan basis. Strong spatial variations in DSD are common in precipitation systems, especially when a convective squall line and a trailing region of stratiform rain coexist in the radar field of view. Thus, a single value of α may not be representative of a complex precipitation system. A new alternative methodology for estimation of α is proposed that captures the azimuthal variability of α. An average value of α (<α>) for each radar radial is computed from the radial profiles of Z and ZDR. Then radial profiles of A are calculated for azimuthally dependent α. The impact of the ZDR biases is investigated and found that ZDR bias of +/- 0.2 dB causes the overall bias in the integrated rainfall less than 1% for moderate and heavy rain The new method has been applied for several precipitation events observed by the WSR-88D radars and the radar QPE is compared with rain gauge measurements to evaluate its performance. The bias ratios of R/G (radar QPE/rain gauge measurements) indicate obvious improvement compared to the current version of R(A).

HALF-HOURLY EVALUATION OF GPM-IMERG PRECIPITATION PRODUCTS USING RAIN-GAUGE DATA IN CATALONIA

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Sub-daily rainfall information obtained from the Integrated Multisatellite Retrievals for GPM (IMERG) is essential for the analysis of a number of hydrometeorological processes. However, it is challenging to validate this source of information due to the limited availability of ground-based data at this temporal resolution. The network of automatic weather stations of the Meteorological Service of Catalonia provides precipitation data every 30 minutes and is used to assess the performance of three IMERG products (Early, Late and Final). The analysis at this time scale, considered three terrain features (valley, flat and ridgetop) and five different categories related to rainfall intensity (light, moderate, intense, very intense, and torrential) during six years over Catalonia, Spain. Except for the Final product in areas of complex orography, IMERG shows a generalized overestimation of rainfall close to 20%, more pronounced in the central highlands and the coastal strip of the region (flat areas). The ability of IMERG to estimate rainfall events at different thresholds is frankly poor, with the highest probability values of correctly detected events and the lowest false alarm rate below 1.00mm/30min, a value slightly below the mean of the recorded observations (1.37 mm). The rainfall classified as very heavy and torrential showed the poorest results, with significant underestimates of more than 80%. This weakness of IMERG is most evident in the Final product, due to the limited number of Global Precipitation Climatology Centre stations used for calibration. The results obtained, while showing weaknesses of IMERG, also highlight the potential use of these products in the spatio-temporal representation of precipitation in areas with complex orography.

CORRECTION OF RAINFALL-INDUCED ATTENUATION AT C-BAND IN SOUTHEA-STERN SOUTH AMERICA WITH S-BAND CROSS-VALIDATION

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Southeastern South America (SESA) is known to host some of the most extreme convective storms on the planet, accounting for more than 70% of the total extended summer precipitation in the region and often associated with severe weather events. The use of C-band radar measurements for quantitative precipitation estimation demands an accurate attenuation correction, since rainfall-induced attenuation is a major source of underestimation at frequencies higher than S-band. A rain path attenuation correction algorithm for C-band is evaluated in different case studies spanning various precipitation regimes, including a case of hail. All events analyzed occurred in the area where the SINARAME polarimetric C-band radar RMA5, located in Bernardo de Irigoyen (Misiones, Argentina), overlaps with the SIMEPAR polarimetric S-band radar, located in Cascavel (Paraná, Brasil). The availability of S-band radar measurements, much less affected by attenuation, provides a source of validation for the attenuation-correction algorithm. This kind of cross-validation of an attenuation-correction scheme for C-band with S-band radar data has not been conducted in the region so far.

ESTIMATION AND ANALYSIS OF EXTREME RAINFALL IN BELGIUM DURING THE JULY 2021 FLOOD EVENT

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Extremely severe flooding occurred in Belgium over a period of 3 days during July 2021. According to the World Weather Attribution, the likelihood of such an event for the Western European region has increased with climate change. There is a strong interest of the hydrological and meteorological community to study this event. It is important to provide the best rainfall estimation for this event, combining the quality control of high resolution rain gauge measurements and a careful processing of weather radar measurements. The operational radar rainfall product matched the rain gauges in most areas but tended to underestimate the higher intensity over the hills. The effect of clutter filtering, signal attenuation, Z-R relationship, gauge bias correction, the vertical profile of reflectivity and orographic enhancement are investigated. Improvements to the existing single-pol method, a new dual-pol method and a spatial gauge merging are considered. Different statistics are also computed to characterize the event.

SUPPORTING WEATHER RADAR OBSERVATIONS WITH THE VAISALA FD70

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Attempts have been made to utilize weather radar derived Quantitative Precipitation Estimation (QPE) since its introduction. First approaches used a relationship between radar reflectivity factor Z and rainfall rate R. Better QPE performance came from the combination with ground based rain gauges. Further improvements came with the development of polarimetric weather radar. But rainfall rate relationships using state-of-the-art weather radars are still imperfect, as these are often empirically derived. The Vaisala Forward Scatter Sensor FD70 can support the accurate determination of QPE over short time periods without assuming predetermined empirical parameters. The Vaisala FD70 combines forward scatter and optical disdrometer technologies. It employs the novel use of a single thin light sheet and utilizes look-down forward scatter geometry. This results in high detection sensitivity, enabling scatter-property analysis of each single particle and allowing detection of even the smallest drizzle droplets. In the standard configuration the receiver measures forward scattered light. The extended version features a second sensor head measuring light scattered at an angle of 90 degree. This latter version assures enhanced visibility measurement in dusty conditions and provides improved identification of freezing precipitation. We compare rainfall rates reported by a Vaisala FD70 with those calculated from an QPE algorithm fed by simulated polarimetic observables. These were calculated from a drops size distribution (DSD) reported by the same sensor, and from a hypothetical DSD. For the presented case we observe 10% deviation between the calculated rain rates, and 50% discrepancy to the directly observed rain rate. Outlook and conclusion round off this contribution.

RADAR QPE FOR THE NETHERLANDS

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The Royal Netherlands Meteorological Institute (KNMI) provides both real-time and reanalysis QPE products that are used for hydrological applications. The entire processing chain to produce these products has recently been upgraded to include more advanced radar postprocessing and merging with gauge data. Radar processing steps that have been added are: 1) two clutter detection algorithms (fuzzy logic and image processing); 2) attenuation correction; 3) VPR correction; 4) advection correction; and 5) using quality indicators for merging data from different radar scans. Merging rain gauge data into the final QPE product is also done using quality indicators in a spatially distributed adjustment algorithm. We present the added value of the different steps in the processing chain by comparing to gauge precipitation estimates. In case of gauge adjustment, we use leave-one-out statistics (i.e., using all gauges except one in the gauge-adjustment step and comparing the result to the gauge that was left out). This poster is intended to discuss the value of these processing steps in different settings, but more importantly to discuss potential further improvements of the product. Either through improvements of the algorithms already implemented, or through addition of new algorithms.

ADDED VALUE OF MULTI-YEAR X-BAND WEATHER RADAR OBSERVATIONS AT URBAN SCALES

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Operational rain gauge networks provide reliable local precipitation measurements but are unable to represent rainfall variability for large domains at small temporal scales. In the urban area of Hamburg, precipitation measurements of a single-polarized X-band weather radar operating at a high temporal (30 s), range (60 m), and sampling (1°) resolution are available for more than eight years. These measurements refine observations of the German nationwide C-band radars, cover more than 20 rain gauges, and is supplemented by two vertically pointing micro rain radars within its 20 km scan radius. Studies on short time periods (several months) proof the performance of this low-cost local area weather radar. However, how well do the X-band radar observations agree with in-situ and other radar measurements on different temporal and spatial scales? Several sources of radar-based errors were adjusted gradually improving the precipitation estimate, e.g. the radar calibration, alignment, attenuation, noise, non-meteorologial echoes. This comparative study shows precipitation characteristics from different measurement types. We outline the performance and discuss open issues and limitations of the multi-year X-band radar observations. Furthermore, we demonstrate its added value to characterize the local rainfall intensity and spatio-temporal rainfall patterns.

USING QUALITY INFORMATION FOR MERGING RADAR AND RAIN GAUGE DATA

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The recent increase in availability of amateur rain gauge data has yielded many measurements of expected lower quality. In order to be able to use such data in QPE products requires a method of using quality information for merging radar and gauge data. Furthermore, it is well-known that radar data quality can be highly variable in space and time. When generating radar-only QPE and when merging radar and rain gauge data this is often not taken into account. Here we suggest to use quality information on both radar and gauge data for first making a radar-only QPE, and for merging radar and rain gauge data. We use the following variables for determining radar data quality: 1) the amount of correction applied to reflectivity; 2) clutter detection and removal; 3) uncertainty associated with corrections; 4) the height of the measurement volume; and 5) the range. These aspects are all combined to derive a quality indicator for all pixels in the radar volume. A quality-weighted average is subsequently computed to derive a 2D Cartesian reflectivity map, including a quality indicator. Composite reflectivity maps are produced by combining data from several radars using a similar technique. Merging radar and rain gauge data is also carried out using quality information on both radar and gauge data. We compute a multiplicative adjustment field to be applied to the radar data, in which the contribution of each radar-gauge pair is determined by their quality indicators. We present the performance of these merging techniques for a full year of data from the Netherlands. A comparison to more traditional methods is given in order to show the added value of this approach. The assessment is carried out using long-term statistics, and we present some case studies as examples.

QUALITY CONTROL ALGORITHMS FOR PRECIPITATION DATA FROM PRIVATE METEOROLOGICAL STATIONS USING WEATHER RADAR DATA

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Private weather stations (PWS) are more and more popular and are of great importance in the case of a not very dense network of telemetry rain gauges operated by the national meteorological services (NMS), in which one rain gauge covers more than 500 km2, real-time estimation of the precipitation field of high resolution is subject to high uncertainty, especially in the case of intense rainfall. As the PWSs provide measurements performed unprofessionally and usually on cheap equipment, so they require quality control (QC) much more rigorous than data from NMS. The used QC scheme is based on the RainGaugeQC system for QC of 10-min precipitation accumulations from telemetric rain gauges, which consists of: detection of exceedance of the climate-based threshold, and checking of the conformity with radar observations, the temporal consistency of time series, and the spatial consistency of data. The new scheme has been extended with the analysis of compatibility of precipitation time series from PWS and weather radar. This check is performed on data covering the last 5 and 10 days. If the correlation coefficient is above the preset threshold, the PWS passed the check. The methodology was tested on Netatmo PWS data from 2020 aggregated to 10-min accumulations. The presentation includes examples of the scheme performance for a few events as well as long-term statistical characteristics showing the improvements in the accuracy of the quality-controlled PWSs. In addition, the impact of including PWS data into professional NMS data and their use for multi-source precipitation field estimation taking into account the quality of individual input data is analysed. This work is carried out as part of the COST CA20136 Action OPENSENSE.

THE ASSESSMENT AND VALIDATION OF RADAR QPE FOR LOCAL GOVERNMENT IN THE AUCKLAND REGION, NEW ZEALAND

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At a local or regional government level, accurate rainfall data is crucial for a variety of areas of responsibility including flood and bathing water quality forecasting, catchment development planning and post-event investigations into performance of stormwater assets. In New Zealand, rainfall estimates utilized by local governments have almost exclusively been derived from rain gauges networks. However, the spatial and temporal resolution of gauge observations is insufficient for the majority of these applications. Radar QPE has been developed for the Auckland region (covering ~5000 km2) in New Zealand using a single-polarisation C-band radar. The approach for optimising the quality of the QPE is to initially ensure that the radar-only rainfall estimates have minimal bias and errors. Only then is a spatially dependent adjustment made using gauge observations. Radar processing incorporates many corrections for errors incorporating miscalibration, Doppler filter losses, radome and rain attenuation, vertical reflectivity profile and advection interpolation. The final stage of gauge adjustment is implemented using Ordinary Kriging of Radar Errors. Both the quality of the radar processing and the overall quality of the final QPE product have been extensively validated with a leave-one-out analysis over a network of ~100 rain gauges using a 12-year dataset. The results demonstrate a radar QPE product with the high accuracy and resolution required by regional governments for operations and planning in both urban and rural settings.

DETECTION OF BEAM BLOCKING USING A LONG TERM STATISTICAL CHARACTERISTICS OF DUAL-POLARIZATION OBSERVATION

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Two X-band dual polarimetric radars were installed in the Seoul metropolitan area to detect local heavy rainfall information with high spatiotemporal resolution and to use this information for monitoring and forecasting of flash floods. Due to their surrounding environment, significant beam blockings caused by buildings, tower, trees, hills, etc. were presented and cannot be simulated with DEM (Digital Elevation Model). Frequency occurrence of reflectivity technique (FOR, Chang et al. 2009) was extended to dual-polarization parameters (DP-FOR) in this work. FOR is the technique to detect ground clutter and beam blocking areas using climatological characteristics of reflectivity. We extend FOR using several statistical parameters (standard deviation, average, and texture), dual-polarization parameters (Z_DR, rho_HV), and derived depolarization ratio (DR). The fuzzy logic technique was used to combine these parameters. Different types of HSR (Hybrid Surface Rainfall) masks (traditional beam blocking simulation with digital elevation model (DEM), dynamic beam blocking mask, FOR mask, and DP-FOR) were applied into HSR (Lyu et al. 2015) with various rainfall estimation methods (R(Z_H), R(Z_H,Z_DR), R(Z_H,K_DP), R(Z_H,K_DP_P), and R(Z_H,A_H)) to compare their performance. Rainfall estimation results are validated with rain gauges within radar observation range.

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ANOMALOUS ELECTROMAGNETIC WAVE PROPAGATION AND RAINFALL ESTIMATES WITH MICROWAVE LINKS

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Precipitation estimation using commercial microwave links represents a valuable source of additional information to complement existing weather radar and rain gauge networks. Nevertheless, one source of error may be the change of the propagation conditions. The propagation of electromagnetic waves in the lower atmosphere depends mainly on the spatial variations of the radio refractive index. Most of the time the refractive index lies within a manageable range, which leads to propagation conditions, that don't exhibit big differences. Under certain circumstances however the propagation of the electromagnetic waves can deviate significantly from standard conditions. This is true especially when – so called – ducting layers are present, by which the wave is bend downward to the earth, or when - during subrefraction conditions - the wave gains increasingly height above the ground while propagating in space. In this study we first perform a sensitivity analysis by calculating the propagation of electromagnetic waves for several distinct refractivity profiles. For that we directly solved the beam propagation equation based on the Fermat's principle. We then estimate the deviation of the received power at the receiver at the end of a microwave link path for the different profiles from the received power at standard conditions. By this we were able to determine the profiles which lead to significant received power differences. Using the obtained 'thresholds' we then investigated how often the conditions occur in the real atmosphere. The needed profiles of pressure, temperature and humidity were extracted from high-resolution rawinsonde data of the operational rawinsonde site in Stuttgart (DWD, WMO-ID: 10739) and from data of a 200 m high measurement mast at Karlsruhe.

TROPICAL RAINFALL MONITORING WITH COMMERCIAL MICROWAVE LINKS IN SRI LANKA

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Commercial microwave links (CMLs) are close to the ground radio connections used globally in cellular telecommunication networks. Along such links, radio signals propagate from a transmitting antenna at one base station (radio site, telephone tower or node) to a receiving antenna at another base station. CMLs provide a valuable "opportunistic" source of high-resolution space–time rainfall information, complementing traditional in situ measurement devices (rain gauges, disdrometers) and remote sensors (weather radars, satellites). The greatest potential of these opportunistic environmental sensors lies in those geographical areas over the land surface of the Earth with few rain gauges and no weather radars: often mountainous and urban areas, but especially low- to middle-income regions, which are generally in (sub)tropical climates. Here, the open-source R package RAINLINK is employed to retrieve CML rainfall maps covering the majority of Sri Lanka, a middle-income country having a tropical climate. This is performed for a 3.5-month period in 2019 based on CML data from on average 1140 link paths as well as for an additional CML dataset covering a large part of 2020. CML rainfall maps are compared locally to hourly and daily rain gauge data, as well as to rainfall maps from the Dual-frequency Precipitation Radar on board the Global Precipitation Measurement Core Observatory satellite. In addition, some of RAINLINK's parameters are optimized for the local climate and network characteristics. The results confirm the potential of CMLs for real-time tropical rainfall monitoring. This holds a promise for, e.g., ground validation of or merging with satellite precipitation products. Finally, the potential of CMLs for rainfall nowcasting in Sri Lanka is illustrated.

FUSION OF MULTIPLE PRECIPITATION SENSORS IN SKÅNE, SWEDEN

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A common problem in precipitation measurements is not only the quality, but also the spatio-temporal resolution and consistency. Sweden has a network of around 700 daily rain gauges and 125 rain gauges that report every 15-minutes. Additionally, there is a network of 12 dual-pol weather radars that cover most of the country. Despite these instruments there are areas that lack data or at least lack quality data, for example due to distance from the radar. There is therefore a need for additional measurements to fill these gaps. In Skåne, the southernmost region of Sweden, there are now multiple instruments installed. These are dual-pol C-band and X-band radars, rain gauges, personal weather sensors, disdrometers, commercial microwave link network (CML) and a micro rain radar. The combination of these instruments makes quality assessment of individual instruments possible, but also the merging of data from multiple instruments into a single high-quality product. The focus of the sensor fusion is currently on merging the C-band, X-band and CML data together with rain gauge data into a single product using regression kriging and eventually expand the methodology to cover entire Sweden. To make certain that areas will, in nearly all cases, have a precipitation estimate. The methodology is set up to be flexible, so that precipitation maps can be created based on any combination of input sources, together with an indicator of quality and sources per grid point. Testing different regression models and auxiliary data as input are planned for a next phase.

AUTOMATIC OBJECTIVE EVALUATION OF RADAR PRODUCTS IN THE OPERATIONAL PRODUCTION CONTEXT AT ENVIRONMENT AND CLIMATE CHANGE CANADA

Ahmed Mahidjiba[1]; Meriem Kacimi[1]; Rabah Hachelaf[1]; Yacine Bouzid[1]; Ilyass Hajji[1]; Sudesh Boodoo[1]; Janti Reid[1]; Corinne Simard[1]

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The Operational Radar Production team (CMOI-Radar) at ECCC is pivotal for real-time generation, delivery, and support of radar products for a wide variety of clients. Ensuring quality and timeliness of products to users internally in the Meteorological Service of Canada's (MSC) such as operational forecasters and Numerical Weather Prediction (NWP) systems is critical. Additionally, CMOI-Radar provides data to many external agencies including international meteorological services and private entities, in a variety of user-required formats. CMOI-Radar is also responsible for archiving raw radar data, products and retrievals when requested. With the arrival of new S-band radars as part of the Canadian Weather Radar Replacement Program (CWRRP), one of the challenges of operational radar production before making products available to users is quantitative and/or objective scientific validation. For example, changes to scientific algorithms, or introduction of new products requires a validation procedure to ensure product validity and quality. The team is currently working on a new automated objective validation procedure utilizing available ground-based precipitation observations. The new dual polarization QPE (DP QPE) and surface precipitation type (SPTP) products are being tested and validated with this methodology. The details of this new procedure as well as preliminary results are the subject of this contribution.

GUIDING THE IMPROVEMENT OF THE GLOBAL PRECIPITATION MEASUREMENT MISSION WITH RADAR NETWORKS

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Advancing spaceborne precipitation estimation relies on analyses to identify biases and quantify uncertainties. This is critical for global scale applications including water budget studies and monitoring natural hazards caused by extreme rainfall events. Independent and accurate ground references are needed to document the Global Precipitation Measurement (GPM) Level-2 and Level-3 estimates. Ground references involving dual-polarized radar and gauge networks are derived from the NEXRAD-based NOAA/NSSL's Multi-Radar/Multi-Sensor (MRMS) platform in the U.S. and the ARAMIS radar network in France. These references are 1) accurate with known uncertainty bounds and 2) measured at a resolution below the pixel sizes of the GPM sensors and gridded products. Comparisons across regions are carried out within a common framework developed to examine the consistency of the ground and space-based estimates in term of precipitation detection, typology, and quantification. Diagnostic and prognostic analyses are performed to identify precipitation properties and the space-borne algorithm parameters that drive the space-ground discrepancies. Focusing on impactful events such as landfalling hurricanes enable to target specific sources of disagreement, such as how the ice water content relates to the liquid water content along with warm microphysics processes, and to refine the application of GPM in these contexts. Perspectives will be presented such as comparison with French overseas radars of La Reunion, an area known to receive each year one the world highest annual rainfall accumulation.

PROBABILISTIC QUANTITATIVE PRECIPITATION ESTIMATION WITH GROUND- AND SPACE-BASED RADARS

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Progress in precipitation estimation is critical to advancing science and applications in weather and water budget studies and to predicting natural hazards caused by extreme rainfall events from the local to the global scales. An interdisciplinary challenge in remote sensing, meteorology, and hydrology is the impact, representation, and use of uncertainty. Understanding hydrometeorological processes and applications requires more than just one deterministic "best estimate" to adequately cope with the intermittent, highly skewed distribution that characterizes precipitation. Yet the uncertainty structure of quantitative precipitation estimation (QPE) from ground-based radar networks like NEXRAD and satellite-based active sensors of the Global Precipitation Measurement is largely unknown at fine spatiotemporal scales. We propose to advance uncertainty's use as an integral part of QPE for ground-based and spaceborne radars. Probabilistic QPE (PQPE) was introduced across the conterminous US with the NOAA/NSSL Multi-Radar/Multi-Sensor to increase the values of QPE for risk decision processes and expended to the NASA/JAXA TRMM and GPM space-based radars. Probabilistic QPE is shown to increase the information content in QPE, mitigate systematic biases from deterministic retrievals, quantify uncertainty, and advance the monitoring of precipitation extremes for multisensor precipitation, hydrometeorological hazard mitigation, and hydrological modeling. For the first time, the Hydrometeorology Testbed MRMS Hydro Experiment (HMT-Hydro) 2019 allowed NWS forecasters and NSSL scientists to investigate the use of probabilistic grids for flash flood warning decision making. The presentation will discuss the evaluation of precipitation probability maps in this context.

POLARIMETRIC RADAR RAINFALL RETRIEVAL IN EASTERN SÃO PAULO

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Rainfall estimation based on weather radar is of paramount importance for most relevant applications such as nowcasting and flood forecasting. In the eastern region of the State of São Paulo S-band radar was recently deployed at the CEMADEN (the Brazilian center for monitoring and warnings of natural disasters) where it is presently running under operational test mode. Designated RMT 0200, the Brazilian IACIT Doppler radar features a solid-state amplifier transmitter that outputs 2.5 KW per channel and utilizes an NLFM to mitigate range side lobes. It also comprises a mechanical steering antenna with 1° HPBW. The aim of the work which this paper refers to is to define polarimetric rainfall algorithms for the area under the radar umbrella. Radar data are from PPIs at 2° elevation from volume scans completed every 10 min, for ZH, ZDR, and KDP. Supporting rain gauge data are from a network of surface stations within 250 km of the radar range. The radar data are converted to rainfall through the algorithms R=f(ZH), R=f(ZH, ZDR), and R=f(ZH, KDP) from the literature. Next, CDF (cumulative distribution function) of the radar rainfall, RRD (for each algorithm), and gage rainfall, RPLU, are constructed. A PMM based approach is then applied to optimize the parameters of the algorithms, for the best matching of each one of the RRD curves and the reference RPLU curve. Since a previous work with a single polarization radar has shown that the use of Z-R relationships stratified by daily intervals had a significant positive impact on the estimates of daily maximum flow in a watershed in Central São Paulo, algorithms for different daily intervals are derived in this investigation.

RADAR IN NUMERICAL WEATHER PREDICTION

AN ENSEMBLE SELECTION STRATEGY TO IMPROVE PROBABILISTIC PRECIPITATION FORECASTS USING LEMA (LOCALIZED ENSEMBLE MOSAIC ASSIMILATION)

EVALUATION OF HIGH-RESOLUTION NWP-BASED PRECIPITATION REANALYSES WITH ADJUSTED RADAR-DERIVED PRECIPITATION

CURRENT STATUS OF SINFONY - THE COMBINATION OF NOWCASTING AND NUMERICAL WEATHER PREDICTION ON THE CONVECTIVE SCALE AT DWD

USE OF DUAL-POLARIZATION SIGNATURES IN SUPERCELL STORMS FOR THE EVALUATION OF MESO-NH ICE3 AND LIMA MICROPHYSICS SCHEMES

ESTIMATOR-BASED ASSIMILATION OF DUAL-POLARIMETRIC RADAR OBSERVATIONS IN GERMANY

EVALUATING AND IMPROVING THE ICE MICROPHYSICS PARAMETERIZATION IN THE ICON MODEL USING TRIPLE-FREQUENCY DOPPLER CLOUD RADAR OBSERVATIONS

ASSIMILATION OF NOWCAST OBJECTS IN THE REGIONAL FORECAST MODEL ICON-LAM

A COMPARISON STUDY ON THE RADAR RADIAL VELOCITY FORWARD MODEL FOR THE KIAPS DATA ASSIMIATION SYSTEM

VERIFICATION OF PRECIPITATION AND CLOUD SIMULATION OF KIM USING RADAR MEASUREMENTS

STUDY OF RADAR DATA ASSIMILATION FOR PRECIPITATION NOWCASTING IN BASQUE COUNTRY

POLARIMETRIC RETRIEVALS OF ICE WATER CONTENT (IWC), TOTAL NUMBER CONCENTRATION (NT) AND MEAN VOLUME DIAMETER (DM) FOR IMPROVED PARAMETRIZATIONS

POLARIMETRY-BASED HYDROMETEOR CLASSIFICATION FROM SYNTHETIC AND MEASURED RADAR OBSERVATIONS FOR THE EVALUATION OF HYDROMETEOR MIXTURES IN NUMERICAL WEATHER PREDICTION MODELS

THE ICON/COSMO POLARIMETRIC RADAR FORWARD OPERATOR EMVORADO AND ITS APPLICATION FOR MODEL EVALUATION

ASSIMILATING RETRIEVED WATER VAPOR AND RADAR DATA FROM NCAR S-POLKA: PERFORMANCE AND VALIDATION USING REAL CASES

CHARACTERISATION OF RAINFALL ESTIMATES AND FORECAST SKILL OF NWP MODEL REGIONS IN AUSTRALIA

ASSIMILATION OF ADVANCED REMOTE SENSING DATA TO IMPROVE NUMERICAL MODEL PREDICTION

INTERCOMPARING RADAR DATA ASSIMILATION SYSTEMS FOR ICE-POP 2018 SNOWFALL CASES

ASSIMILATING 3D RADAR INFORMATION AT CONVECTIVE SCALES AT DWD

DEVELOPMENT OF LETKF-BASED RADAR DATA ASSIMILATION METHODS FOR HIGH-RESOLUTION FORECASTING OVER KOREA

A CHANGE IN METHODOLOGY FOR LATENT HEAT NUDGING AT DWD

OPERATIONAL ASSIMILATION OF RADAR REFLECTIVITY AND RADIAL WIND VOLUMES IN THE COSMO MODEL AT ARPAE-SIMC

CONVECTIVE CLOUD MICROPHYSICS IN NUMERICAL WEATHER PREDICTION MODELS AND DUAL-WAVELENGTH POLARIMETRIC RADAR OBSERVATIONS

A METHOD FOR INFORMATION GAIN IN THE PROCESS OF WEATHER RADAR DATA ASSIMILATION INTO WRF MODEL

OBSERVED AND SIMULATED DUAL POLARIZATION SIGNATURES IN SUPERCELL STORMS OVER FRANCE AND POTENTIAL APPLICATION FOR NOWCASTING

AN ENSEMBLE SELECTION STRATEGY TO IMPROVE PROBABILISTIC PRECIPITATION FORECASTS USING LEMA (LOCALIZED ENSEMBLE MOSAIC ASSIMILATION)

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Accuracy and efficiency are the two main issues facing ensemble numerical weather prediction, especially for precipitation which is the result of physical processes on multiple scales. Due to limited computational resources, the size of the ensemble in operational weather centers is too small to fully describe the true state of the atmosphere. In this work, we develop the localized ensemble mosaic assimilation (LEMA) sub-ensemble to improve the accuracy and efficiency in probabilistic precipitation forecast in two steps. First, the best member from a short-time integration of the full ensemble is selected at a grid point based on the smallest of the precipitation forecast error over a window area surrounding the grid point. Second, the areal coverage of the best members is used to select the sub-ensemble. The underlying hypothesis is that a high areal coverage of a best member selected by LEMA is a good indicator that longer-term precipitation forecast would improve when it is included in the sub-ensemble. As the size of the sub-ensemble is smaller than the full ensemble by excluding members with large forecast errors, both the accuracy and efficiency of the forecast can improve. The strategy is tested in the simulation of 20 precipitation events using the Weather Research and Forecast (WRF) model. When evaluated using various metrics, the results showed that precipitation forecasts from the LEMA sub-ensemble are indeed better than the full ensemble or randomly selected sub-ensembles for a forecast lead-time of at least 18 hours.

EVALUATION OF HIGH-RESOLUTION NWP-BASED PRECIPITATION REANALYSES WITH ADJUSTED RADAR-DERIVED PRECIPITATION

Vojtěch Bližňák[1]; Petr Zacharov[1]

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Reanalyses provide information about the past state of the atmosphere at different levels and thus have been widely used to study free atmosphere dynamics and the links between the free atmosphere and surface climate. Recently, special attention has been paid to the development of high-resolution NWP-based reanalyses that can well capture space-constrained atmospheric convection-related processes, such as heavy precipitation. Their objective evaluation then provides important feedback for developers and the wider scientific community to further improve the description of physical processes in the NWP model. We have to note that the radar measurements are not assimilated into both reanalyses so the radar data are suitable because they are independent. The contribution will evaluate a 7-year period of high-resolution precipitation reanalyses COSMO-REA2 and ALADIN-CZ in the warm parts (April-October) of the years 2007-2013 over the territory of the Czech Republic. An accuracy of each product will be evaluated with adjusted radar-derived precipitation estimates that are available in 1 x 1 km square boxes. Hourly precipitation estimates will be integrated into the projection of each reanalysis (2.3 km for ALADIN-CZ and 2 km for COSMO-REA2) and will be used as ground truth. Various verification techniques (grid-to-grid/fuzzy approach) will be applied to assess the accuracy of long-term quantitative precipitation re-forecasts. The contribution will also include an evaluation of precipitation re-forecasts of selected high-impact precipitation events that caused extensive damage, and will point out the weaknesses and strengths of both precipitation reanalyses.

CURRENT STATUS OF SINFONY - THE COMBINATION OF NOWCASTING AND NUMERICAL WEATHER PREDICTION ON THE CONVECTIVE SCALE AT DWD

Ulrich Blahak[1]

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DWD's new Seamless INtegrated FOrecastiNg sYstem (SINFONY) is about to come to life in the next two years, after 5 years of research and development and with focus on severe convective events in the very short time forecast range from minutes to 12~h. There are different "optimal" forecast methods for different forecast lead times. Radar extrapolation techniques (Nowcasting) show good skill up to about 2 h ahead (depending on the situation), while numerical weather prediction (NWP) outperforms Nowcasting only at later hours. Ensembles of both Nowcasting and NWP help to assess forecast uncertainties. "Optimally" combining precipitation forecasts from Nowcasting and NWP as function of lead time leads to the seamless forecasts of the SINFONY. Radar data are at the heart of SINFONY and different interdisciplinary teams work closely together in developing
a) radar Nowcasting ensembles (gridded and cell objects),
b) hourly km-scale Rapid Update Cycle (RUC) ensemble NWP, assimilating 3D radar volume scans,
c) combinations of Nowcasting and NWP ensembles in observation space (gridded and cell objects),
d) common Nowcasting- and NWP verification (gridded and cell objects).

For c), the RUC-EPS outputs simulated reflectivity volume scans of the entire German radar network every 5' using the radar forward operator EMVORADO. Ensembles of composites and cell object tracks are generated in the exact same way as for the observations. During the last year, all these methods have been consolidated and have been run daily in a continuous test forecast mode. This presentation will give an overview on the project and selected results of the test forecast mode. Other team member's presentations will give more details of the methods.

USE OF DUAL-POLARIZATION SIGNATURES IN SUPERCELL STORMS FOR THE EVALUATION OF MESO-NH ICE3 AND LIMA MICROPHYSICS SCHEMES

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Although significant progress in convective scale numerical weather prediction models have been done these last years, the forecast of thunderstorms from a few hours to a few days remains difficult, partly because of the low predictability of these small scale phenomena but also due to deficiencies in the models, in particular in their microphysical parametrization schemes that describe the evolution of hydrometeor concentrations and sizes. Dual-polarization radar observations are very useful for microphysical schemes evaluation as emphasized by Ryzhkov et al (2020) as they provide informations related to the size, shape, composition and orientation of the hydrometeors. Recent studies have shown that supercell thunderstorms are associated with recurrent distinctive polarimetric signatures, which can yield significant insight into the microphysical and dynamical processes intrinsic to supercell storms (e.g. Kumjian and Ryzhkov, 2008; 2014; Johnson et al., 2016; Snyder et al., 2017a, b). The main goal of this study is to evaluate and improve the understanding of the behaviors of two microphysics schemes available in Météo-France research model Méso-NH (Lac et al., 2018): the single-moment scheme ICE3 and the two-moment scheme LIMA. The performance of different versions of these schemes (including or not the explicit representation of hail) will be first evaluated by examining their ability to replicate the polarimetric signatures of an idealized supercell. Detailed microphysics and budget analysis will also be presented in order to help explain the microphysic origin of the signatures. In a second step, simulations of a real supercell case will be evaluated through comparisons with dual-polarization observations from the Météo France radar operational network.

ESTIMATOR-BASED ASSIMILATION OF DUAL-POLARIMETRIC RADAR OBSERVATIONS IN GERMANY

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Dual-polarimetric radar (DPR) observations (OBS) have the potential to improve the representation of cloud-precipitation microphysical (MP) processes in numerical weather prediction (NWP) models, weather analyses and short-term quantitative precipitation forecasts (QPFs) through model evaluation and data assimilation (DA). DA of DPR OBS is still in its infancy, also because uncertainties in relations between DPR moments and model MP state variables exist. Two common radar DA approaches are 1) the use of radar forward operators and 2) the use of radar-estimated model MP state variables. We present a first step towards approach 2 for DPR OBS in Germany. Estimates of liquid/ice water content (LWC/IWC) derived from DPR OBS of the C-band radar network of the German national meteorological service (DWD) are assimilated into DWD's convective-scale NWP model ICON-D2. We compare the results from DA of A) only conventional OBS, B) conventional and radar reflectivity (Z) OBS (approach 1 for single-polarized radar data), and C) conventional and Z OBS as well as LWC-/IWC-estimates below/above the melting layer. We focus on the evaluation of two intense stratiform and convective periods in summer 2017. Configurations B and C clearly improve first guess QPFs with respect to configuration A. Configuration C shows improvements with respect to configuration B only in certain situations. Results also suggest that LWC DA is superior to IWC DA, possibly due to the larger observation errors above the melting layer and/or the higher suitability of the LWC-estimator, which is, as opposed to the used IWC-estimator, adjusted to central European climatology. Evaluation of the impact of the LWC/IWC-assimilation on QPFs with longer lead times and more events are in progress.

EVALUATING AND IMPROVING THE ICE MICROPHYSICS PARAMETERIZATION IN THE ICON MODEL USING TRIPLE-FREQUENCY DOPPLER CLOUD RADAR OBSERVATIONS

Stefan Kneifel[1]; Davide Ori[1]; Markus Karrer[1]; José Dias Neto[2]; Leonie von Terzi[1]; Vera Schemann[1]; Axel Seifert[3]

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The proper representation of cloud microphysical processes is essential for the accurate simulation of weather and climate. Despite the continuous model advancements, especially ice microphysical schemes are still affected by large uncertainties. Multi-frequency Doppler radar observations are sensitive to bulk hydrometeor properties, such as the average particle size, density, and fallspeed. In this study, we use vertically pointing, triple-frequency (X, Ka, W band) Doppler radar observations obtained at JOYCE site close to Cologne, Germany to evaluate the parameterizations of the ICON cloud model. The ICON simulations centered over JOYCE are forward simulated using the self-similar Rayleigh-Gans approximation for ice scattering. The statistical comparison between the synthetic and actual observations reveals that the cloud model overestimates the Doppler velocity at lower and warmer temperatures. Also, we found an overestimation of the snow particle sizes at warmer temperatures, which can be identified by large dual-wavelength ratios. To overcome these inconsistencies, we derived alternative particle property relations by combining a realistic snow aggregation model and hydrodynamic theory. We implemented these new relations and updated other microphysical parameters that affect the aggregation rates (e.g. formulation of the aggregation kernel, sticking efficiency). This allows us to thoroughly investigate the sensitivity of aggregation to these parameters. Finally, we repeated the radar forward simulations of the ICON output with an improved setup. The new simulations show a reduction in the biases of the Doppler velocity and snow particle size which improves modelled surface precipitation, especially in case of dry air layers close to the ground.

ASSIMILATION OF NOWCAST OBJECTS IN THE REGIONAL FORECAST MODEL ICON-LAM

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A primary goal of the upcoming Rapid Update Cycle (RUC) at the German weather service is to close the gap between nowcasts (NWC) and numerical weather (NWP) by adding cloud- and precipitation-related observations to the operational data assimilation. However, the NWP and NWC worlds differ not just by timescale but also more fundamentally in their approach: while NWCs deal with individual convective cells, i.e. coherent objects whose positions and physical features are tracked, NWP systems and their associated data assimilation deal with gridded information, i.e. pixels of data. To bridge these two worlds, we have developed a unique aproach to assimilating nowcast objects into an NWP model, by identifying objects and then gridding their features based on the distances between gridboxes. This talk will demonstrate how this approach makes it possible to assimilate various types of object based information, from a simple texture fraction to more complicated cell attrributes, and show basic experimental results demonstrating how this approach complements more traditional assimilation of radar data.

A COMPARISON STUDY ON THE RADAR RADIAL VELOCITY FORWARD MODEL FOR THE KIAPS DATA ASSIMIATION SYSTEM

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Doppler weather radar(DWR) is one of the critical observation platforms for improving the accuracy of short-range NWP forecasts. Korea Institute of Atmospheric Prediction Systems(KIAPS) is developing a new model based on a grid refinement down to ~3 km scales over the region of interest to support a very short-range prediction system with high-resolution data assimilation (DA) over East-Asia. The high-resolution DA system focused on radar and other observations that can provide useful information on the convection-permitting scales supported within the grid-refined region. The KIM Package for Observation Processing(KPOP), observation data preprocessing and quality control(QC) system, was extended to processing the radial velocity observation from the Korea Meteorological Administration(KMA) operating radars. The radar data processing system contains several procedures such as QC, spatio-temporal data fusion(thinning or super-obbing), and a background innovation check using the forward operator. We compared two kinds of radial velocity forward operators: based on Cartesian and Polar coordinate systems in the KIAPS DA system. The Cartesian coordinate-based forward operator needs to calculate the observation heights and distances between the radar station and observation points, and the observation direction is also should be concerned carefully. Meanwhile, the Polar coordinate-based forward operator can calculate the radial velocity using only the observation azimuth and elevation angles. The retrieved radial velocity was not much different, but we tested which one is more useful in the KIAPS DA system. This study will present observation impacts on analysis fields in conjunction with several statistical analysis results.

VERIFICATION OF PRECIPITATION AND CLOUD SIMULATION OF KIM USING RADAR MEASUREMENTS

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Representation of cloud and precipitation in numerical weather prediction models is one of the most challenging works, as the uncertainty of cloud in a numerical model is directly or indirectly related to various physics schemes regarding the hydrological cycle, and radiation, as well as the model dynamics. Under the limitation of the appropriate observation to evaluate three dimensional cloud and rain simulation, using radar-based satellite data gives opportunity to demonstrate model predictability and systematic errors. In this study, we evaluate the global distribution of cloud and precipitation simulated by a newly developed global prediction model, KIM, using the Dual Frequency Radar data from Global Precipitation Measurement mission (GPM DPR). The GPM DPR, consisting of a Ka-band (35.5 GHz) and a Ku-band (13.6 GHz) precipitation radar, provides relatively accurate information about characteristics of the precipitation. For the comparison, model simulated radar reflectivity is estimated from rain and snow contents by assuming a particle size distribution by the Marshall-Palmer exponential form. And the Level 2 products of DPR are remapped to a regular grid with 0.25x0.25 degree for the period of July 2017. By comparing the horizontal distribution of precipitation and vertical profiles of reflectivity of the model and observation, it is found that reflectivity of KIM is lower than observation, especially showing significant differences in the southern hemisphere. Regional characteristics of precipitation are further analyzed by comparing the vertical profiles of the radar reflectivity of KIM and DPR.

STUDY OF RADAR DATA ASSIMILATION FOR PRECIPITATION NOWCASTING IN BASQUE COUNTRY

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Nowcasting plays an increasing role in crisis management and risk prevention. Its operational realization is a highly complex and integrated task, where many different approaches are possible. These approximations goes from the monitoring of available observational data based on humans, to fully automatic complex systems with different algorithms and computational techniques. Weather radar systems, where available, are one of the most used instruments for nowcasting purposes, particularly in the field of precipitation nowcasting. Automatic schemes based on radar assimilation in numerical models, particularly 3DVAR techniques, are a plausible approximation. In order to determine in which terms these 3DVAR techniques could be used in the Basque Country in an operational context, different experiments has been done based on Euskalmet radar data available in the study area. In this work, we present some results from these tests, where radar reflectivity fields are estimated for short term (up to 6 hours) using different radar data for some representative rainfall scenarios in the Basque Country area. Selected techniques includes the assimilation of reflectivity and radial velocity fields, extracted from volumetric available data, into the WRF local area model through WRFDA capabilities. We include a comparative study between different options applied to different precipitation events. Selected events represent typical local weather conditions where some kind of impact due to precipitation characteristics (intensity and/or persistence) are plausible. A number of verification metrics (areal and punctual) is used in order to analyse the general characteristics of the nowcasting experiments in terms of consistency and goodness.

POLARIMETRIC RETRIEVALS OF ICE WATER CONTENT (IWC), TOTAL NUMBER CONCENTRATION (NT) AND MEAN VOLUME DIAMETER (DM) FOR IMPROVED PARAMETRIZATIONS

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This study aims to inform parameterizations of the ICON general circulation model (ICON-GCM) exploiting radar polarimetry, more precisely, to evaluate and improve the spatial heterogeneity of IWC at subgrid scales. QVPs (quasi-vertical profiles) and so-called range-defined QVPs successfully reduce statistical errors and provide the ideal data basis for various robust polarimetric microphysical retrievals of IWC, Nt, and Dm, but at the same time reduce information on subgrid variability compared to PPIs. A key question is the amount of averaging required for robust estimates and how to separate spatial variability from noise. Based on BoXPol (polarimetric X-band radar in Bonn, Germany) measurements, statistical errors and spatial variabilities of various retrievals are analyzed to investigate a possible reduction of the 360° azimuthal window size of QVPs and range-defined QVPs with still acceptable intrinsic uncertainties. The information entropy is utilized to test the distribution of polarimetric variables/retrievals for homogeneity, which is a mandatory assumption when applying the standard error of the mean. In addition, the minimum particle size used in ICON-GCM for the onset of aggregation is improved and variabilities of IWC for ice and snow are investigated separately. Finally, the observational statistics of IWC variability are confronted with ICON-GCM simulations.

POLARIMETRY-BASED HYDROMETEOR CLASSIFICATION FROM SYNTHETIC AND MEASURED RADAR OBSERVATIONS FOR THE EVALUATION OF HYDROMETEOR MIXTURES IN NUMERICAL WEATHER PREDICTION MODELS

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Polarimetric weather radars provide the option to derive spatially and temporally high-resolved hydrometeor distributions (HD) to evaluate the representation of hydrometeors in the operational Numerical Weather Prediction (NWP) model ICON-LAM of the German Weather Service (DWD).
In this study, a dual-strategy is proposed for model evaluation. A sophisticated hydrometeor classification (HMC), adapted to the number and types of hydrometeors in the model is developed, which allows to estimate hydrometeor partitioning ratios from radar observations in two steps. First, radar measurements are clustered based on the similarity of their multidimensional polarimetric signature and afterwards a state-of-the-art HMC is used for the hydrometeor class identification of the resulting clusters. Secondly, the centroids derived from the multidimensional polarimetric clusters and their probability distributions are used to determine the hydrometeor partitioning ratios of the individual hydrometeor classes. ICON's built-in polarimetric radar forward operator EMVORADO (Efficient Modular VOlume scan RADar Operator) simulates synthetic radar observations from modelled HD. These tools enable us within the dual strategy to compare the HD derived from the measured and simulated polarimetric moments as well as a direct comparison of the latter two, which also provides feedback regarding the performance of the polarimetric radar forward operator and the HMC. Comparisons of volumetric scans from DWD's national C-band radars network with model simulations revealed e.g. spurious graupel generation around the melting layer. Furthermore, synthetic reflectivity and differential reflectivity are too high in rain, most likely caused by raindrop size errors in the model.

THE ICON/COSMO POLARIMETRIC RADAR FORWARD OPERATOR EMVORADO AND ITS APPLICATION FOR MODEL EVALUATION

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Polarimetric measurements provide better constraints on hydrometeor microphysical properties and processes. This can improve precipitation retrievals and be used to evaluate and improve NWP models. Calculating radar observables from prognosed NWP fields, forward operators (FOs) are a crucial link in comparing measurements to NWP output. To exploit the rich information from operational polarimetric weather radar stations, it is crucial that FOs can accurately but also quickly simulate corresponding observations, which was so far a major bottleneck. We present the polarimetry-extended version of the ICON/COSMO built-in radar forward operator EMVORADO used operationally by DWD, incl. recent developments that allow T-Matrix based polarimetric calculations similarly fast as the conventional, Mie-or Rayleigh-based version. While online-coupling to the NWP models ensures full consistency, e.g. regarding hydrometeor microphysics, a range of parameters affecting FO results are not constrained by the models, like melting state, shape and microstructure, and orientation of the hydrometeors. Using model evaluation case studies, we characterize the sensitivity and uncertainites of the polarimetric FO (PFO) simulations to these assumptions. So far we have found both ICON and COSMO to produce enhanced amounts of graupel around the melting layer (ML) that often also survive too far below the ML apparent by high ZH and ZDR in the PFO simulations. On the other hand, EMVORADO fails to reproduce the observed polarimetric signatures in snow, a common issue of PFOs applying a reduced-density approach in the T-Matrix scattering calculations. We will also present early results using DDA-based scattering properties of realistic snow aggregates.

ASSIMILATING RETRIEVED WATER VAPOR AND RADAR DATA FROM NCAR S-POLKA: PERFORMANCE AND VALIDATION USING REAL CASES

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The effect of assimilating S- and Ka-band dual-wavelength-retrieved water vapor which provides environmental information before precipitation occurs was examined in this study. The S-PolKa vertical profile of humidity was obtained at low levels and thinned into averaged and four-quadrant profiles. Two different strategies were utilized to assimilate the retrieved moisture information: (1) assimilation of retrieved water vapor with radar data for the entire 2 h and (2) assimilation of water vapor data in the first hour, and radial velocity and reflectivity data in the second hour. By using the WRF local ensemble transform Kalman filter data assimilation system, three real cases of the Dynamics of the Madden-Julian Oscillation Experiment were examined through a series of experiments. The results revealed that assimilating additional water vapor data near by precipitating system markedly improved the analysis at the convective scale than assimilating radial wind and reflectivity data alone, leading to more improvements in the quantitatve precipitation forecast compared with assimilating radar data only. When moisture data were assimilated, improved nowcasting could be extended up to 4 h. Additionally, the strategy of assimilating only retrieved water vapor data in the first hour and radial wind and reflectivity data in the second hour achieved the optimal analysis, resulting in the most improvement of rain forecast compared with other experiments. Furthermore, assimilating moisture profiles into four quadrants achieved more accurate analysis and forecast. Overall, our study demonstrated that the humidify information in nonprecipitation areas is critical for further improving the analysis and forecast of convective weather systems.

CHARACTERISATION OF RAINFALL ESTIMATES AND FORECAST SKILL OF NWP MODEL REGIONS IN AUSTRALIA

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Spatial characteristics of rainfall fields in multiple regions across Australia were assessed using an extensive dataset of 16 months of gridded observed and forecast rainfall fields. A total of 22 domains were defined to cover the whole continent. These domains were created in such a way that it includes radar observations within the extent and include the overlap between domains. 60-minute observed rainfall data obtained from the operational Rainfields system was compared with the rainfall forecasts from ACCESS-G3 and ECMWF-HRES. Firstly, the spatial characteristics of both observed and forecast rainfall fields across the working domains were assessed. The average power spectrum line of rainfall forecast fields of both NWP datasets remains similar for different lead times with some sharp fluctuations in the mean power spectra lines between 6 to 20 km. These anomalies were not observed precisely at the same scales for both forecast models, but they represent similar characteristics of the data. There was also observed an offset of the forecast mean power spectrum lines at the small scales compared with the observed radar, indicating a lack of information along with the smaller scales for both forecast models. Overall, the forecast skill of ACCESS-G3 seems to be comparatively higher in the mid-latitude domains than ECMWF-HRES for the large scales and short lead times. On the other hand, the forecast skill of the ECMWF-HRES model for the tropics seems to be higher compared with the ACCESS-G3 with also a slower decay rate in function of the lead time for all regions. Also, a strong sub-daily variability in the predictability skill of both models was identified in sub-tropical and tropical regions.

ASSIMILATION OF ADVANCED REMOTE SENSING DATA TO IMPROVE NUMERICAL MODEL PREDICTION

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The assimilation of proper water vapor amount in a Numerical Weather Prediction (NWP) model is essential to accurately forecast rainfall. The benefits of assimilating radar is that it can provide three-dimensional distribution, intensity, and movement of precipitation information in the atmosphere at high resolutions. However, the estimated in-cloud water vapor amount from radar reflectivity is empirical and is based on the assumption that air is saturated when reflectivity exceeds a certain threshold. Studies show that this assumption tends to overpredict the rainfall amount at the beginning hours of NWP forecast. The purpose of this study is to improve error associated with water vapor amount in radar reflectivity by introducing advanced remote sensing data. The ongoing research shows that errors can be largely reduced by assimilating satellite all-sky radiances and Global Positioning System Radio Occultation refractivity to enhance the moisture analysis during the cycling period. The impacts of assimilating moisture variable from satellite all-sky radiances and GPSRO refractivity along with hydrometeor variables from radar reflectivity generates a proper amount of moisture and hydrometeors at all levels of the initial state. Additionally, the assimilation of satellite Atmospheric Motion Vectors improves wind information and atmospheric dynamics driving the moisture, which in turn increases the accuracy of moisture convergence and fluxes at the core of convection. As a result, the accuracy of timing and intensity of heavy rainfall are improved and the hourly and the accumulated forecast errors are reduced.

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INTERCOMPARING RADAR DATA ASSIMILATION SYSTEMS FOR ICE-POP 2018 SNOWFALL CASES

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Gangwon-do (GWD) has complex topography and land-surface characteristics due to its location to the Sea and the Mountain range. This coastal location and rugged terrain can amplify snowfall mechanisms, making it challenging to predict the amount and location. The local ensemble transform Kalman filter (LETKF) improved the water vapor mixing ratio and temperature using the covariance of the ensemble members, but three-dimensional variational (3DVAR) improved the water vapor mixing ratio and temperature through an operator that assumed the atmosphere was saturated when reflectivity was above a certain threshold. In 2018, to understand the snowfall in GWD region and support the Pyeongchang Winter Olympic and Paralympic Games. The International Collaborative Experiments for the 2018 Pyeongchang Olympic Games Projects (ICE-POP 2018) data are used to study and verify the numerical experiments. From the initial field verification using ICE-POP observation data, wind in LETKF was more accurately simulated than 3DVAR, but it underestimated the water vapor mixing ratio and temperature in the lower troposphere due to a lack of a water vapor mixing ratio and temperature observation operator. Snowfall in GWD was less simulated in LETKF, whereas snowfall of 10.0 mm or more was simulated in 3DVAR, resulting in an error of 2.62 mm lower than LETKF. The results signify that water vapor assimilation is important in radar DA and significantly impacts precipitation forecasts, regardless of the DA method used. Therefore, it is necessary to apply observation operators for water vapor mixing ratio and temperature in radar DA. This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT) (No. 2021R1A4A1032646 and 2022R1A2C1012361).

ASSIMILATING 3D RADAR INFORMATION AT CONVECTIVE SCALES AT DWD

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At Deutscher Wetterdienst (DWD), research about the assimilation of 3D radar data (reflectivity, cell objects and radial winds) has been intensified within the project SINFONY, which is related to the future seamless ensemble prediction system for convective-scale forecasting for up to 12 hours. This system integrates Nowcasting techniques for radar data with numerical weather prediction (NWP based on the new ICON-model) in a seamless way with initial focus on severe summertime convective events and associated hazards such as heavy precipitation, hail and wind gusts.

Assimilation of radial wind and reflectivity became already operational in our current short range ensemble numerical weather prediction (SRNWP) system (ICON-D2-KENDA LETKF system). This is done in addition to the "traditional" Latent Heat Nudging of 2d radar derived precipitation rates.

For both systems, SRNWP and SINFONY, the usage of 3D radar data is not only advantageous but crucial to improve the forecast skills related to convection and precipitation. We will present results of experiments with the currently operational ICON-D2-KENDA system. An appropriate quality control is key, as well as super-observations, proper localization and a proper specification of the observation error model for the LETKF. How sensitive are the results on the actual settings? For SINFONY we will apply the more sophisticated 2 moment microphysics scheme. How does this works together with the current radar data assimilation schemes?

DEVELOPMENT OF LETKF-BASED RADAR DATA ASSIMILATION METHODS FOR HIGH-RESOLUTION FORECASTING OVER KOREA

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The Korea Institute of Atmospheric Prediction Systems (KIAPS) was established in 2011 to create an atmosphere-only global NWP system for operational use at the Korea Meteorological Administration (KMA). This system was completed on schedule, and made operational at KMA in April 2020, immediately giving world-class performance. The NWP model - named the Korean Integrated Model (KIM) - is a non-hydrostatic model based on a cubed-sphere grid, utilizing the spectral element method for its dynamical core. Data assimilation (DA) is based on a hybrid-4DEnVar system for the deterministic analyses, and an LETKF for ensemble perturbation updates. With the operational version of the KIM-based NWP system now running reliably at KMA, KIAPS has three main priorities for the next 5 years:

1. Continual improvement of KMA's operational system.
2. Extension of the global NWP system to cover the main Earth System components, including development of weakly-coupled atmosphere-ocean DA system based on the NEMO ocean model and the NEMOVAR DA system.
3. Development of a new model and DA system for short-range, high-resolution NWP.

The high-resolution model will be a global rather than limited-area version of KIM, with extreme grid refinement over East Asia. DA will be based on an LETKF algorithm, and focus on observations that are important at the convective scale – particularly radar radial wind and reflectivity observations. To control the larger scales, we will regularly blend in lower-resolution data from the main global DA system. Work on the high-resolution version of KIM has only begun recently, so to enable us to start developing our radar DA methods we decided to develop a "testbed" system based on an established high-resolution model called KIM-meso – a limited-area version of WRF configured to use essentially the same physics packages as the KIM global model. Our basic strategy is as follows:

1. Develop an LETKF-based ensemble DA system for KIM-meso, with support for assimilation of conventional observations.
2. Use this testbed to develop tools and techniques for processing and assimilating radar observations. For assimilation of radar reflectivity in an LETKF-based DA system, three things are important:

1. Quality control (QC) and preprocessing of the observations.
2. Observation operators.
3. Configuration of the LETKF variables and parameters.

QC and preprocessing of the observations affect the accuracy and usefulness of the data, so, for example, consideration will be given to the various echo types (zero, missing, precipitating, nonprecipitating, etc.). Since the radar data resolution can be finer than the model grid resolution, we will make gridded data using thinning, superobbing or mosaic methods. To assimilate radar reflectivity directly, we will use observation operators appropriate for our chosen microphysics schemes, initially making use of operators developed for WRFDA. Finally, we will need to optimize the LETKF configuration by adding additional model variables, such as hydrometeor variables, and adjusting the localization and covariance inflation parameters, etc.. In this presentation, we will explain our radar observation ingestion and preprocessing systems and the main details of our DA approach, and then introduce some results from initial DA cycling experiments.

A CHANGE IN METHODOLOGY FOR LATENT HEAT NUDGING AT DWD

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Since the operational start of NWP model COSMO-DE (former also known as LMK) in 2007 at DWD radar derived precipitation is assimilated by applying latent heat nudging (LHN), based on the approach by Jones and Macpherson (1997). The goal of the approach is adapting the model dynamical state in such a way, that the model will be able to responses in simulating a precipitation rate quite close to the observed one. This is achieved by adding temperature increments depending on the discrepancy of observation and model. Increments are positive to enhance the model's precipitation but negative to decrease it. Additionally a moisture increment can be added, to remain the relative humidity unchanged, which turned out to be very important. This methodology has been proven to be very successful and beneficial, not only on precipitation scores (Stephan et al., 2008). However, experiences in summer 2021 revealed, that adding moisture increments alone, can show a similar performance and even yields to a slight improvement of scores. This is also important to know when considering an application of LHN for models running at coarser grid scales and therefore using a convection parameterization scheme (i.e. ICON-EU). And even more relevant for operational purpose of DWD is the fact that the new methodology fits much better to the 2 moment microphysics scheme, which will become operationally at DWD's Sinfony system quite soon. In the presentation results of the different approaches will be shown. In contrast to adding temperature or moisture to the model one could also think to adopt the precipitation quantities of the model directly. This is expected to be less effective. But in combination with 3d radar data assimilation with an LETKF approach, this may not so relevant anymore.

OPERATIONAL ASSIMILATION OF RADAR REFLECTIVITY AND RADIAL WIND VOLUMES IN THE COSMO MODEL AT ARPAE-SIMC

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At Arpae-SIMC, the HydroMeteorological Service of Emilia-Romagna Region in Italy, an ensemble-based data assimilation system at the convective-scale (KENDA-LETKF, developed in the COSMO Consortium) provides the analyses to high-resolution models: a deterministic forecast, COSMO-2I, and an ensemble forecast system, COSMO-2I-EPS, running both at 2.2 km horizontal resolution. The domain of model integrations covers the entire Italian territory. With this method, already used for the operational assimilation of conventional observations, from March 2021 reflectivity volumes and, from March 2022, radial wind volumes have been assimilated. The use of these observations is in combination with the assimilation of radar-estimated instantaneous precipitation via latent heat nudging. Volumetric data and instantaneous precipitation are provided by the National Department of Civil Protection. In order to make the assimilation of radar volumes operational, intensive tests have been carried out, verifying the impact of the assimilation of both reflectivities and radial winds on the quality of the analysis and the forecast initialized from them. The tests that led to the decision to operationally implement assimilation of radar volumes will be presented, focusing on the comparison with the previous operational set-up. Results include QPF verification of forecasts performed using both fractions skill score (FSS) and dichotomous scores over hydrologically homogeneous regions. Moreover, verification of upper-air and surface variables at analysis time and during forecast is provided.

CONVECTIVE CLOUD MICROPHYSICS IN NUMERICAL WEATHER PREDICTION MODELS AND DUAL-WAVELENGTH POLARIMETRIC RADAR OBSERVATIONS

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The representation of microphysical processes is a major source of uncertainty in numerical weather prediction models. We evaluate the influence of cloud microphysics parameterizations on numerical weather prediction with a convection-permitting regional weather model setup using 5 different microphysics schemes of varying complexity (double-moment, spectral bin, particle property prediction (P3)). A polarimetric radar forward operator (CR-SIM) has been applied to simulate radar signals consistent with the simulated particles. Two polarimetric research radars in the area of Munich, Germany, at C- and Ka-band frequencies and a complementary polarimetric C-band radar operated by the German Meteorological Service provide observational data. By measuring at two different frequencies, the dual-wavelength ratio that facilitates the investigation of the particle size evolution is derived. Polarimetric radars provide in-cloud information about hydrometeor type and asphericity by measuring, e.g., the differential reflectivity ZDR. Within the DFG Priority Programme 2115 PROM, we compare the simulated polarimetric and dual-wavelength radar signals with radar observations of convective clouds. Statistical distributions of simulated and observed polarimetric and dual-wavelength radar signals give insight into some microphysical characteristics of the cloud microphysics schemes. The polarimetric information is further exploited by applying a classification algorithm to obtain dominant hydrometeor classes. By comparing the frequency, intensity and area of high impact weather situations (e.g., hail or heavy convective precipitation), the influence of cloud microphysics on the ability to correctly predict high impact weather situations is examined.

A METHOD FOR INFORMATION GAIN IN THE PROCESS OF WEATHER RADAR DATA ASSIMILATION INTO WRF MODEL

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The Weather Research and Forecast – Data Assimilation (WRF-DA) module is a software tool developed for the operational assimilation of weather data provided by several types of sensors, including weather radars. As the assimilation process starts from a background atmospheric analysis state to be updated with the assimilated data, a filtering is adopted in WRF-DA to avoid numerical instability and to implement outlier detection. This filter also consists of rejecting those measurements that differ from the background values more than a threshold set as a function of the measurement error. The negative effect of this filter is the impossibility of realigning the model output with respect to observations especially if they are quite different, simply because the information useful for this purpose are discarded. Another WRF-DA feature investigated is the possibility to assimilate no-rain reflectivity data that are often ignored or not effectively used in conventional assimilation schemes as they classify in the same way low reflectivity echo signals and not detected signals (due to a receiver failure or because they are beyond the unambiguous range , etc..). This paper presents some results of test for limiting this loss of information, by forcing the assimilation of all radar reflectivity values including those very different from background analysis and low reflectivity radar echoes showing absence of precipitation. The results are discussed with emphasis on the sensitivity of the numerical model to the addition of crucial information, also in comparison with other similar studies. Although this method has been specifically implemented and tested with radar data, it can be theoretically applied to all meteorological data that can be assimilated into WRF model.

OBSERVED AND SIMULATED DUAL POLARIZATION SIGNATURES IN SUPERCELL STORMS OVER FRANCE AND POTENTIAL APPLICATION FOR NOWCASTING

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A number of studies, mainly from the USA have shown that supercell thunderstorms are associated with recurrent distinctive polarimetric signatures, which can yield significant insight into the microphysical and dynamical processes intrinsic to supercell storms (e.g. Kumjian and Ryzhkov, 2008; Snyder et al., 2017a, b). At low level, the so-called "Zdr arc" is a shallow region of very high Zdr found on the southern edge of the forward flank downdraft. The "Kdp foot" is a region of large Kdp due to high liquid water mass near the surface. "Zdr columns" are regions of high Zdr typically extending several kilometers above the environmental freezing level, that are indicative of a positive temperature perturbation associated with the updraft. "Kdp column" are characterized by enhanced Kdp values generally found on the left flank of the updraft. At midlevels, the so-called "Zdr and ρhv rings" are circular regions of enhanced Zdr and depressed ρhv, near the updraft-perturbed melting layer. The purpose of this study is to document the presence of these signatures in supercells storms observed over France and the ability of the research convective-scale model Meso-NH to reproduce these signatures. Two specific questions are tackled:
(1) Are these signatures commonly observed over France with the operational dual-polarization radar network?
(2) How can the dual-polarization signatures be used to infer the evolution of the severity of the supercell?
To answer these questions, the characteristics of a number of supercells as observed by the French dual-polarization radars will be analyzed, together with hail reports obtained through collaborative observations. The analysis of a numerical simulation performed with the Meso-NH model will also help explain the links between these signatures and the microphysic and dynamic parameters of the storm.

RADAR OPERATIONS AND NETWORKS

ANALYSIS AND DISCUSSION OF THE 2021 WMO JOINT EXPERT TEAM ON OPERATIONAL WEATHER RADARS (JET-OWR) WEATHER RADAR SURVEY RESULTS

A VARIATIONAL INTERPOLATION METHOD FOR GRIDDING WEATHER RADAR DATA

EXPLORING EFFICIENT USE OF X-BAND DUAL-POLARIZATION RADAR NETWORK IN THE KOREAN PENINSULA

CENTRALISATION IN MAINLAND FRANCE OF THE WEATHER RADAR DATA PROCESSING SYSTEM FOR THE FRENCH OVERSEAS TERRITORIES

REPLACEMENT OF THE CANADIAN WEATHER RADAR NETWORK – AN UPDATE

THE FARM (FLEXIBLE ARRAY OF RADARS AND MESONETS)

QUICKLY DEPLOYABLE/ADAPTABLE S-BAND RADAR NETWORK INTEGRATED WITH BISTATIC NETWORK

ANALYSIS OF DATA OF A RECENT DISDROMETER NETWORK TO IMPROVE THE QUALITY OF THE RADAR PRODUCTS AT THE COAST

THE NEW LOMBARDIA X-BAND RADAR NETWORK

NEXRAD RADAR IMPROVEMENT

RADAR-BASED TRACKING OF CONVECTIVE CELL LIFECYCLES USING THE MULTISENSOR AGILE ADAPTIVE SAMPLING (MAAS) FRAMEWORK

TOWARDS A SINGLE GLOBAL STANDARD FOR POLAR WEATHER RADAR DATA REPRESENTATION WITH FM301 – CFRADIAL2

MULTI-RADAR MULTI-SENSOR SYSTEM (MRMS)

ANALYSIS AND DISCUSSION OF THE 2021 WMO JOINT EXPERT TEAM ON OPERATIONAL WEATHER RADARS (JET-OWR) WEATHER RADAR SURVEY RESULTS

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Periodically, the WMO survey members on the operational aspects of their Operational Weather Radar (OWR) systems and networks. The results of these surveys are traditionally made available in various WMO Instruments and Observing Methods (IOM) reports. The last such survey was undertaken in 2017, where 86 responses were gathered from 84 countries. In 2021, the WMO JET-OWR undertook yet another survey of member nations to gather updated information regarding their OWR systems and networks. The outcomes of this latest survey, detailed in this poster, provide interesting insight into not only the state of OWR networks around the world, but also member nations' plans for OWR upgrades, replacements, network expansions and creation of new networks in developing nations.

A VARIATIONAL INTERPOLATION METHOD FOR GRIDDING WEATHER RADAR DATA

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Observations made by weather radars play a central role in many aspects of meteorological research and forecasting. These applications commonly require that radar data is supplied on a Cartesian grid, necessitating a coordinate transformation and interpolation from the radar's native spherical geometry using a process known as gridding. In this study, we introduce a variational gridding method; and, through a series of theoretical and real data experiments, show that it considerably outperforms existing methods in terms of data resolution, noise filtering, spatial continuity and more. Known problems with existing gridding methods (Cressman weighted average and nearest neighbour/linear interpolation) are also underscored, suggesting the potential for significant improvements in many applications involving gridded radar data, including operational forecasting, hydrological retrievals and three dimensional wind retrievals.

EXPLORING EFFICIENT USE OF X-BAND DUAL-POLARIZATION RADAR NETWORK IN THE KOREAN PENINSULA

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The Korea Meteorological Administration has operational S-band radar network and X-band research radar network. The radar observation network for operational use is very dense, and it observes the entire Korean Peninsula well through a customized observation strategy tailored to the characteristics of the Korean topography. The X-band research radar network has been installed over the Seoul metropolitan area and operated for spatiotemporal high-resolution observation of low-rise meteorological systems. For more efficient use, RHI observation tested in real time utilizing the lightness of X-band radar operation. We considered the operation strategy to minimize the hardware load for frequent RHI observation, the observation strategy setting for the use of data without difference with the S-band radar observation interval, and the selection of an appropriate number of samples. To analyze the detailed data of the meteorological system flowing in from the West Sea, which mainly affects the Seoul metropolitan area, RHI observations were made every 5 minutes for a total of 4 azimuths and used for three-dimensional analysis of the meteorological system. As a result, it was confirmed that there are advantages of calculating high-resolution bright band information, monitoring the upper level radar echo that cannot reach the ground, and analyzing the three-dimensional structure of the meteorological system. In the future, for the efficient use of X-band radar network, we plan to test and operate more various observation strategies.

CENTRALISATION IN MAINLAND FRANCE OF THE WEATHER RADAR DATA PROCESSING SYSTEM FOR THE FRENCH OVERSEAS TERRITORIES

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Since April 2018, Météo-France has been using a new centralized radar data processing system named SERVAL, to concentrate and process the raw polar data provided by the metropolitan France network of 31 weather radars (S, C, and X bands). Every 5 minutes SERVAL processes all the raw volume data received from each radar during the last 5 minutes, with the possibility to use all data available in the Météo-France databases. This data processing provides both volume radar products, and 2D radar products as reflectivity and quantitative precipitation estimation. These single-radar products are then merged in composites covering all mainland France and Corsica. A SQL database and an interactive Web interface were designed to facilitate SERVAL administration, production supervision and monitoring of intermediate or final products. This communication presents the extension of this centralized processing system to the French overseas territories. The concerned territories include French Antilles in the Caribbean Sea, French Guiana in South America, Réunion Island in West Indian Ocean, New Caledonia in the Southwest Pacific Ocean, and Mayotte in the Comoros archipelago in the near future. A real time data transfer was established to concentrate raw data at the Toulouse Radar Center. SERVAL was updated to process overseas radar data, and to provide composites for each territory. An outbound data transfer delivers the final radar products to the Météo-France offices and to end users in overseas territories, where these products are available in few minutes. Operational production rates and products delivery times are presented, as the system safety in the event of an interruption of telecommunications between overseas territories and mainland France.

REPLACEMENT OF THE CANADIAN WEATHER RADAR NETWORK – AN UPDATE

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On February 28th, 2017, Canada's Minister of the Environment and Climate Change announced investments to modernize Canada's weather-forecasting infrastructure. As part of this initiative, an $83-million contract was awarded to Selex ES GmbH (now Leonardo) for 20 new weather radars that were to be built across the country by 2023 with options to replace all remaining radars in the same timeframe. With the first radar successfully replaced in 2017, the Canadian Weather Radar Replacement Program (CWRRP) is now entering into the final years of the project. At the end of 2021, 26 new S-Band radar installations were completed across the country spanning from the west coast to eastern Newfoundland. The pandemic introduced significant challenges and complexities to the project, in particular for radars located in high population centres that draw significant public attention such as Toronto, Ottawa, Edmonton, Vancouver, and Halifax. Despite the COVID-19 challenges, the CWRRP team worked closely with the vendor and other enablers to successfully replace 7 radars in 2021. The project remains on schedule and within budget for the delivery of the remaining seven radars in 2022. Collaboration with key enablers is essential to ensuring a successful end-to-end project delivery. Through strong collaboration with the vendor, Science and Technology Branch and radar users, we continue to gain a better understanding of the new radar system from both hardware and software perspectives, and are working to optimize the scan strategy, improve signal processing and data quality. This paper will provide information and updates on the CWRRP in general, with a focus on challenges and mitigation measures put in place, as well as a discussion on network performance and data quality.

THE FARM (FLEXIBLE ARRAY OF RADARS AND MESONETS)

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The Flexible Array of Radars and Mesonets (FARM) Facility is an extensive mobile/quickly-deployable (MQD) multiple-Doppler radar and in-situ instrumentation network hosted by the University of Illinois. The FARM comprises four mobile / quickly-deployable radars: two X-band dual-polarization, dual-frequency (DPDF) , Doppler On Wheels DOW6/DOW7, the Rapid-Scan DOW (RSDOW), and a quickly-deployable (QD) DPDF C-band On Wheels (COW). The FARM also includes 3 mobile mesonet (MM) vehicles with 3.5-m masts, an array of rugged QD weather stations (PODNET), QD weather stations deployed on infrastructure such as light/power poles (POLENET), four disdrometers, six MQD upper air sounding systems and a Mobile Operations and Repair Center (MORC). The FARM's integration of radar, in situ, and sounding systems provides robust kinematic, thermodynamic, and microphysical observations. Components of FARM (previously called the DOW Facility) have deployed to >30 projects during 1995-2022 in North and South America and Europe (including COPS and MAP), obtaining pioneering observations of a myriad of small spatial scale and short temporal scale phenomena including tornadoes, hurricanes, lake-effect snow storms, aircraft-affecting turbulence, convection initiation, microbursts, intense precipitation systems, boundary layer structures and evolution, airborne hazardous substances, coastal storms, wildfires and wildfire suppression efforts, weather modification effects, and mountain/alpine winds and precipitation. This poster will focus on the design, capabilities, and most recent updates to the FARM Facility, including very recent and anticipated future missions.

QUICKLY DEPLOYABLE/ADAPTABLE S-BAND RADAR NETWORK INTEGRATED WITH BISTATIC NETWORK

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A next-generation long wavelength research radar network, comprising a truck-borne quickly-deployable scanning 10-cm radars S-band On Wheels (SOW) incorporating a Bistatic Adaptable Radar Network (BARN) can provide S-band dual-polarization observations of the atmospheric boundary layer, convective, and other precipitating systems while simultaneously measuring dynamically meaningful vector wind fields. SOW is a new paradigm for long-wavelength research radars, replacing large cumbersome expensive singular radars with a network of several smaller, nimbler, less expensive systems. SOW and BARN will fill critical gaps in current observing systems, providing broadly and inexpensively available long wavelength, dual-polarimetric, near-ground, fine-scale, vector wind observations. When implemented, a network of 4 SOWs, SOWNET, will replace single 10-cm large 10-cm 1° radars with an array of smaller, 5.5 m (18') antenna, quickly-deployable, 1.5° beamwidth truck-borne radars. With multiple SOWs, typical ranges to targets are much shorter, resulting in improved resolution compared to single 1° 10-cm radars. 1,2,3, or 4 SOWs can comprise a SOWNET deployment, customizing for small or large missions. Inexpensive deployments of 1-2 SOWs qualitatively broaden access to this critical observational capability BARN enables multiple-Doppler vector wind measurements over targeted regions. SOWNET provides moderate-resolution multiple-Doppler measurements, BARN provides finer-scale over smaller domains. BARN units are coupled with single or multiple SOWS, COW, or DOWs. Stationary BARN units are unattended, low power, and similar to deployable weather stations Highly redundant BARN units provide extreme reliability of multiple-Doppler operation.

ANALYSIS OF DATA OF A RECENT DISDROMETER NETWORK TO IMPROVE THE QUALITY OF THE RADAR PRODUCTS AT THE COAST

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It is not easy to find a site to install a weather radar in a complex terrain. Besides there are many regulations that it must obey and none site fulfill 100% of the hydrometeorological objectives. The site of Kapildui is one of these cases. After more than fifteen years of operation working with the optimization of the operation, improvements in the lightning protection system, new products adapted to the needs, and a large historical database, today there are still new improvements due to an increase in new users and applications. The higher density population in Basque Country is at the coast where is placed the Bilbao Port. The Kapildui weather radar is sited in an interior mountain far from the coastal area. The view of the coastal hydrometeorological phenomenon is limited for the geometry of the radar beam and the scan operation in complex terrain. For this reason, the weather data from Kapildui needs other meteorological sources such as, a high dense hydrometeorological network, other radars, and recently is being evaluated the integration of disdrometers to improve the quality of the precipitation information at this distance and at this point. The huge amount of data registered from the disdrometers at the coast combined with the complexity integration of weather radar data, demand a study in two directions, validation of the quality of the disdrometers data and analyze the best way to integrate both systems, in different meteorological conditions. The present work studies the behavior of the disdrometers at the coast and discusses the options and user benefits to integrate this information in the present radar products.

THE NEW LOMBARDIA X-BAND RADAR NETWORK

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A new X-band double polarization weather radar network has been completed in the first semester of 2022 as part of the public hydrometeorological monitoring asset operated by the Environmental Regional Agency of Lombardia (ARPA Lombardia). It consists of three radars, two fixed and one mobile, located in the plain belt of the region. Their coverage includes the most populated and infrastructured areas in Italy (Milan and Brescia), which are also very critical from the hydrological point of view. Lombardia is one of the first sites in Europe where solid state X-band radars are used for operational flood warning. The main features of the radars and the roadmap that has lead to this realization are presented together with some preliminary results in the operational use.

NEXRAD RADAR IMPROVEMENT

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The Next Generation Weather Radar (NEXRAD) program tri-agencies (Department of Commerce, National Weather Service (NWS); the Department of Defense, United States Air Force (USAF); the Department of Transportation, Federal Aviation Administration (FAA)) continue to support a long-term activity to steadily improve the science and technology of the Weather Surveillance Radar - 1988 Doppler (WSR-88D). Research and development is focused on improving the bias, variance, and coverage of the base data; the performance of clutter filtering; and the radar meteorological algorithms. The NEXRAD Radar Operations Center periodically releases WSR-88D software builds containing the approved research to operations improvements. These include new scan strategies, improvements to base data quality, and enhancements to the suite of radar-meteorological algorithms. The NWS also updates the system developed to utilize weather data from the FAA's Terminal Doppler Weather Radar (TDWR). This paper will describe recent and near term planned improvements to these weather radar functional areas, and will provide an update on longer term radar improvement projects.

RADAR-BASED TRACKING OF CONVECTIVE CELL LIFECYCLES USING THE MULTISENSOR AGILE ADAPTIVE SAMPLING (MAAS) FRAMEWORK

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In the summer of 2022, in and around Houston, TX, the Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) Mobile Facility 1 (AMF1) will conduct the Tracking Aerosol Convection interactions ExpeRiment (TRACER) and the National Science Foundation (NSF) supports the Experiment of Sea Breeze Convection, Aerosols, Precipitation and Environment (ESCAPE) field campaign. The TRACER and ESCAPE field experiments will use scanning, polarimetric C-band radars to track isolated convective cells. The goal of the cell tracking will be to collect high-quality, rapid temporal resolution (less than 90 sec) radar polarimetric measurements. In TRACER, the second-generation C-Band Scanning ARM Precipitation Radar (CSAPR2) will be used, while the ESCAPE field experiment will use the CSU-CHIVO dual-polarization C-band radar. To meet the requirement of a revisiting sampling time of less than 90 sec, the C-band radars will not conduct surveillance scans to identify the location and movement of the cells. In Houston, the Multisensor Agile Adaptive Sampling (MAAS) framework is used to guide radar tracking. MAAS uses input from the NEXRAD, GOES, and the Houston LMA to determine the location, movement, and stage of the lifecycle of isolated convective cells is used to guide the radar tracking. Here, the data processing steps for the near real-time processing of the comprehensive set of measurement inputs used to describe the atmospheric state, identify the isolated convective cells, track their movement and evolution, and select the most appropriate cells to sample with the C-band radars are described. Examples of microphysical and dynamical properties of isolated convective cells sampled in TRACER and ESCAPE will be shown.

TOWARDS A SINGLE GLOBAL STANDARD FOR POLAR WEATHER RADAR DATA REPRESENTATION WITH FM301 – CFRADIAL2

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Standardized representation of weather radar data is being addressed by the World Meteorological Organization's (WMO) Joint Expert Team on Operational Weather Radar (JET-OWR), starting with the representation of moment data in original polar/spherical coordinates. In April 2021, the WMO's Infrastructure Commission (INFCOM) approved experimental use of data representation using the Climate and Forecasting (CF) Conventions and the Network Common Form (NetCDF) file format. Two pilot data types were identified for such experiments, one of which is weather radar data. FM301 is the new WMO use of CF and NetCDF, with standardized profiles for each data type. For weather radar moment data, the FM301 profile is CfRadial version 2 (CfRadial2). Two experiments are underway under the auspices of the WMO:
1. Data representation. A software library has been prepared for reading/writing CfRadial2. This software is being used with radar data in Australia, Canada and the United States to demonstrate its use with, and the natural variability of, radar data from different countries.
2. Data exchange. Given radar data in FM301, the WMO Information System (WIS) version 2.0 Demonstrator Project will explore how these data can be integrated into future WMO data exchange functionality.

These experiments will test data representation and exchange functionalities, identifying improvements and informing INFCOM, with the objective of having FM301 approved for official use by WMO's members. FM301 specifications would then be annexed to the WMO Manual on Codes. Member guidance on data representation using FM301 is also being prepared by JET-OWR as Part G of its Operational Weather Radar Best Practices Guide. This presentation will address the status of these ongoing activities.

MULTI-RADAR MULTI-SENSOR SYSTEM (MRMS)

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The Multi-Radar Multi-Sensor System (MRMS) is a United States National Oceanic and Atmospheric Administration (NOAA) operational and research system for rapid transition of scientific research into operations. MRMS generates a suite of real-time products at the National Center for Environmental Prediction (NCEP) which are then disseminated to National Weather Service field offices, NOAA national centers, and across local and state governments and the private sector. The core of MRMS is an optimal integration of observations from multiple radar networks and observing platforms to provide meteorological guidance at high resolution and update frequency with low latency. The MRMS products are used in daily operations to support the detection and monitoring of hazardous weather, including hail, tornadoes, flash flooding, and impacts to aviation. MRMS products are a key forcing components in model data assimilation schemes for operational high-resolution, convection-allowing numerical models and national hydrological models. At the 2006 ERAD conference, the MRMS concept was introduced and initial prototype shown. This talk will over view the progress and challenges of the last 15 years in expanding MRMS to a national and international operational platform. The talk with end with research and development plans for the next five years.

RADAR SIGNAL AND DOPPLER PROCESSING

REGION-BASED RECURSIVE DOPPLER DEALIASING (R2D2)–AN OPERATIONAL ALGORITHM FOR DIFFICULT DOPPLER VELOCITY RETRIEVALS

UNDERSTANDING THE COMPLEMENTARITY OF WIND MEASUREMENTS FROM CO-LOCATED X-BAND WEATHER RADAR AND DOPPLER LIDAR

FORWARD METHOD FOR VERTICAL AIR MOTION ESTIMATION FROM FREQUENCY MODULATED CONTINUOUS WAVE RADAR RAIN MEASUREMENTS

PROGRESSIVE PULSE COMPRESSION: A PROMISING SOLUTION TO THE BLIND RANGE CHALLENGE FOR SOLID-STATE WEATHER RADARS

CORRECTION OF DUAL-PRF VELOCITY FOR OPERATIONAL S-BAND DOPPLER WEATHER RADAR

AN ADAPTIVE RANGE-AVERAGING TO IMPROVE THE QUALITY OF RADAR VARIABLE ESTIMATES AT LOW-TO-MODERATE SNRS

IMPROVED SPECTRAL PROCESSING FOR A KA/KU-BAND CLOUD RADAR SYSTEM

VERTICAL WIND ESTIMATION WITH A 94-GHZ CLOUD RADAR FOR ENHANCED DSD ESTIMATION USING MIE EXTREMA.

AN AUGMENTED LAGRANGIAN TECHNIQUE FOR MULTIPLE DOPPLER RETRIEVALS

JENSEN–SHANNON DISTANCE-BASED FILTER AND UNSUPERVISED EVALUATION METRICS FOR POLARIMETRIC WEATHER RADAR PROCESSING

IMPROVING THE DATA QUALITY OF POLARIMETRIC VARIABLES USING HYBRID SCAN ESTIMATORS

THE MITIGATION OF DEBRIS-INDUCED BIAS IN TORNADIC DOPPLER VELOCITY MEASUREMENTS

NEXT PHASE OF THE LIDAR RADAR OPEN SOFTWARE ENVIRONMENT (LROSE) AS A SCIENCE GATEWAY

A NEW APPROACH FOR ADDRESSING CORRELATION COEFFICIENT ESTIMATOR BIAS AT LOW SIGNAL-TO-NOISE RATIOS

ESTIMATION OF HORIZONTAL WIND FROM DOPPLER DATA

REGION-BASED RECURSIVE DOPPLER DEALIASING (R2D2)–AN OPERATIONAL ALGORITHM FOR DIFFICULT DOPPLER VELOCITY RETRIEVALS

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Reliable Doppler velocity retrievals are vital for nowcasting and research applications. When the radial velocity of a radar gate is outside the interval bounded by the negative and positive Nyquist velocity, the measured value is aliased back onto this Nyquist interval. Region-based Recursive Doppler Dealiasing (R2D2) is a novel algorithm for reliably unfolding operational Doppler velocities, even when the gate-to-gate shear approaches the magnitude of the Nyquist velocity. These difficult dealiasing situations occur in very strong shear and turbulence or when the radar operates at a low pulse repetition frequency (PRF). First, R2D2 masks high-shear areas or folds within each radial velocity sweep, creating spatial buffers around them. The data between the buffer zones are identified as continuous regions within a common Nyquist interval. Each region is then assigned its most likely Nyquist interval by applying vertical and temporal continuity constraints in the radar data as well as agreement with reference wind information from a mesoscale model. The buffered zones are subsequently resolved using gate-to-gate continuity within the sweep. The entire procedure is then reiterated, identifying fewer but larger continuous regions and fewer folds until an optimum is reached. Residual errors, often related to shear approaching or exceeding the Nyquist velocity, are limited to small areas within the buffer zones. This approach maximizes operational performance in high-shear situations and restricts errors to small areas, mitigating error propagation. As expected, R2D2 is suitable for operational implementation and performs well in stratiform or convective situations with high shear and low data coverage.

UNDERSTANDING THE COMPLEMENTARITY OF WIND MEASUREMENTS FROM CO-LOCATED X-BAND WEATHER RADAR AND DOPPLER LIDAR

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Accurate wind measurements are important in aviation for monitoring and providing warnings of hazardous landing and take-off conditions at airports. Commonly, the wind measurements are obtained with ground-based remote sensing instruments, such as weather radars and Doppler lidars. As the return signal in weather radars is mostly due to insects, cloud droplets or precipitation, and in Doppler lidars due to aerosols, the instruments provide wind measurements in different weather conditions. However, the effect of various weather conditions on the measurement capabilities of these instruments has not been previously extensively quantified. Here we present results from a measurement campaign that took place in Vantaa, Finland, from May 2021 to November 2021. During the campaign, a co-located Vaisala WRS400 X-band weather radar and Vaisala WindCube400S Doppler lidar were employed continuously to perform wind measurements. Both instruments measured plan-position-indicator (PPI) scans at 2.0 degrees elevation from horizontal. Additionally, vertical profiles of the horizontal wind components were determined using the Volume Velocity Processing (VVP) analysis with the WRS400 radar and the Doppler-beam-swinging (DBS) technique with the WindCube400S lidar. We first analyze the Doppler velocity measurements from the PPI measurements and find that the overall agreement between the two instruments is good. Secondly, we study the effect of different weather conditions, such as precipitation, horizontal visibility, and cloud base height, on the measurement availability of both instruments. Finally, we evaluate the agreement of the vertical wind profiles produced from both instruments and the effect of the weather conditions on the availability of the wind profiles.

FORWARD METHOD FOR VERTICAL AIR MOTION ESTIMATION FROM FREQUENCY MODULATED CONTINUOUS WAVE RADAR RAIN MEASUREMENTS

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Vertically-pointed Frequency-Modulated Continuous-Wave (FMCW) radar measurements of rain are greatly influenced by strong vertical winds (vertical air motion, VAM) in convective rain scenarios. Particularly, 2nd order products such as rain rate (RR) and drop size distribution (DSD) experience high estimation errors due to VAM. In this work, it is expected to estimate the VAM from vertically-pointed FMCW radar measurements in order to correct VAM-corrupted rain 2nd order products. We present preliminary research on a forward method to estimate VAM velocity at a particular height from vertically-pointing S-band FMCW radar measurements in convective rain scenarios. The method relies on the parameterization of the DSD as a gamma distribution. It estimates the VAM along with the constitutive parameters of the gamma distribution by means of a parametric solver. The methodology is tested over long-duration, high-resolution measurements by the University of Massachussetts FMCW radar and validated against a ground-based disdrometer in the context of Verification of the Origins of Rotation in Tornadoes Experiment-Southeast (VORTEX-SE). A 1-h long down-draft rain scenario is studied in terms of RR and DSD before and after applying VAM correction.

PROGRESSIVE PULSE COMPRESSION: A PROMISING SOLUTION TO THE BLIND RANGE CHALLENGE FOR SOLID-STATE WEATHER RADARS

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For solid-state radars that make use of pulse compression waveforms, part of the transmitted pulse leaks into the receiver and obscures the received signals (typically several kilometers in length). The portion of obscured data is typically referred to as the “blind range”. However, scatterers inside the blind range, with a received echo as long as the transmitted pulse, have a residual portion of their echo, which is free from contamination. That uncontaminated portion is proportional in length to the distance from the scatterers to the radar and can be used to estimate polarimetric weather variables inside the blind range. This is the principle behind the Progressive Pulse Compression (PPC) technique. PPC is a novel technique for blind range recovery on radars using pulse compression. It eliminates the need for a “fill pulse” to recover data inside the blind range, which requires additional bandwidth. It mitigates the blind range by using a partial decoding method with the remaining return from scatterers outside of the blind range. Here, experimental evidence of the superior performance of PPC is provided under a variety of meteorological conditions, such as convective, stratiform, and winter precipitation. A qualitative analysis of polarimetric estimates for widespread precipitation systems covering the entire blind-range region shows excellent PPC performance, as indicated by the smooth transition across its boundary. In particular, most estimates of co-polar correlation coefficient in the blind-range region (and beyond) are about 0.99 for a snow event, where scatterers are expected to be of the same type. Furthermore, data collected using different radar modes will be presented to illustrate the efficacy of the technique.

CORRECTION OF DUAL-PRF VELOCITY FOR OPERATIONAL S-BAND DOPPLER WEATHER RADAR

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The Weather Radar Center (WRC) of Korea Meteorological Administration (KMA) has provided three-dimensional radar wind fields based on the "WInd Synthesis System using Doppler Measurements (WISSDOM)" in real-time since February 2019. Its accuracy is significantly subject to the quality of Doppler velocity such as a velocity aliasing. For the de-aliasing of Doppler velocity, dual pulse repetition frequency (dual-PRF) technique is commonly utilized for commercial Doppler Weather radar. The Doppler weather radars of KMA have extended their Nyquist velocity up to 132 m s-1 using dual PRF of 5:4. However, the dual-PRF technique produces significant noises and losses of radial velocity. In this study, we have developed the technique of noise cancellation and recovery of radial velocity to improve the quality of WISSDOM wind fields. A proposed approach identifies and removes speckles of abnormal radial velocity by comparing a sign of median radial velocity at surrounding radar bins. And then, we recovered the eliminated radial velocity using the median interpolation technique. To recover the losses of radial velocity over a wide area by dual-PRF technique, we used the VAD curve-fitting technique of radial velocity. The techniques are straightforward and preserve spatial gradients as well as suppress the local extrema. We operated this technique as a test from May to July 2021 and verified its performance, and applied it to the operational radar quality control system from August. We concluded that the process helps to improve the quality of radial velocity and the accuracy of the WISSDOM wind field.

AN ADAPTIVE RANGE-AVERAGING TO IMPROVE THE QUALITY OF RADAR VARIABLE ESTIMATES AT LOW-TO-MODERATE SNRS

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The two main metrics for the performance evaluation of the Doppler moment and polarimetric variable estimators are bias and standard deviation. The bias may increase as the SNR decreases but standard deviation, however, always rises with SNR decline. For instance, if estimates are computed from 16 samples using a rectangular data window and the Nyquist co-interval is ~±9 m s-1, the standard deviation of reflectivity estimates increases 1.6 times as the SNR drops from 20 to 2 dB (where 2 dB is the default significant signal SNR threshold on the WSR-88D network). But for estimates of differential reflectivity, differential phase, and copolar correlation coefficient, standard deviations increase is approximately ~6.7, ~6, and 54 times, respectively. Hence, for the polarimetric variables, this effect is significantly more substantial than in the case of the Doppler moments. Such significant increases in the variability of estimates are observable in the fields of dual-polarization products as an increased spatial inhomogeneity (or noisiness) in the areas where echoes exhibit low-to-moderate SNRs. These effects can obscure visual identification of weather features as well as adversely impact the operation of algorithms. Moreover, this raises the question about the value of dual-polarization products at SNRs for which the standard deviation and/or bias are exceptionally high. One approach to improve the weather radar data quality is to reduce the statistical fluctuations of fields in the areas of low-to-moderate SNR at the expense of degradation in the range resolution. Herein, methods that achieve this are discussed with particular attention to an adaptive range averaging where the number of averaged samples depends on the estimated SNR and the correlation coefficient.

IMPROVED SPECTRAL PROCESSING FOR A KA/KU-BAND CLOUD RADAR SYSTEM

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Cloud radars are widely used in observations of clouds and precipitation. To enhance the detection sensitivity of cloud radars, the pulse compression technique has been introduced. However, the sidelobe effect can significantly degrade the quality of cloud radar observations. In this study, we present a Doppler-spectra-based data processing framework to improve the data quality of a Ka/Ku radar system. Firstly, the ground clutter is suppressed based on its different characteristics present in radar Doppler spectra observations in four observing modes. Then, the morphological features of the range sidelobe artifacts caused by the pulse compression are extracted, and a new algorithm based on the cumulative distribution of the Doppler spectrum in presence of sidelobe is developed for identifying and removing the sidelobe contamination. Finally, the spectral data from different modes are merged to generate radar moment data products. Significant improvement has been identified in the new data products compared with the raw radar data. The processed Ka/Ku-band radar data were compared with a frequency-modulated continuous-wave C-band radar observations. A stratiform precipitation event shows that such multi-frequency radar observations have the potential in revealing interesting scattering and attenuation characteristics of clouds and precipitation.

VERTICAL WIND ESTIMATION WITH A 94-GHZ CLOUD RADAR FOR ENHANCED DSD ESTIMATION USING MIE EXTREMA.

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A retrieval technique for the estimation of vertical air motion in precipitation using a 94-GHz Doppler radar is presented. The retrieval technique is an adaptation of the method that was originally proposed by Kollias et al., 2002 (Why Mie?) to estimate the vertical air motion based on the first Mie minimum. The algorithm works by identifying a hypothetical set of three Mie extrema (i.e., a first maximum, then a minimum and then a second maximum) for each Doppler line from a reflectivity spectrum. Consequently, some criteria are applied to check whether the hypothetical set of Mie extrema are valid. A set of Mie extrema is considered valid, when their values and locations are consistent with theoretical backscattering cross sections, terminal fall velocities, and some limited assumptions to allow for variability in the rain drop size distribution. An effort is made to understand for which conditions (rainfall rate intensity, etc.) the retrieval technique finds valid Mie extrema. The pixels for which no valid Mie extrema could be retrieved are gap-filled by applying an adjustment variable: the difference of vertical air velocity and Mean Doppler velocity. The vertical velocity for the gap-pixels is then estimated by using the Mean Doppler velocity and the interpolated adjustment. To further demonstrate the improvement in the DSD estimation, a comparison is made to in-situ sensors. The final goal of the work is to improve the accuracy of raindrop size distribution retrievals in vertically pointing radar, by better taking into account the vertical wind velocity component when calculating the fall velocity of raindrops as a function of their size.

AN AUGMENTED LAGRANGIAN TECHNIQUE FOR MULTIPLE DOPPLER RETRIEVALS

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Generating three dimensional wind fields from convective systems is incredibly important for studying their dynamical structure. However, retrieving such winds from a radar network is nontrivial task as radars only detect the magnitude of the wind in the direction of the radar beam. Therefore, radar meteorologists use the weak variational technique for retrieving winds from radar networks. In this technique the wind field is determined by minimizing the weighted sum of cost functions related to the difference between the wind field and the radar observations and the mass continuity equation. A drawback of the weak variational technique is that the the weights of each cost function must be chosen by the user and change depending on your radar configuration and weather being sampled. This therefore affects the reproducibility and internal consistency of multiple Doppler wind retrievals. We propose a technique that reformulates this problem as the minimization of an augmented Lagrangian that includes the cost function terms related to the radar winds and other observations and the mass continuity constraint multiplied by a vector of Lagrange multipliers. In essence, the weights for the mass continuity cost function that would appear in a penalty formulation are now treated as additional optimization variables, and are determined algorithmically such that the mass continuity equation is satisfied within a specified tolerance. Using scanning weather radar data from both the Department of Energy Atmospheric Radiation Measurement Tropical Western Pacific and the Southern Great Plains sites, we demonstrate that the augmented Lagrangian technique is more likely to to converge to a realistic solution compared to the weak variational technique.

JENSEN–SHANNON DISTANCE-BASED FILTER AND UNSUPERVISED EVALUATION METRICS FOR POLARIMETRIC WEATHER RADAR PROCESSING

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An effective filtering technique is required for rainfall rate measurement by weather radar. A Jensen–Shannon Distance (JSD) based thresholding filter is proposed to mitigate non-meteorological signals. This algorithm classifies range-Doppler bins into two classes, hydrometeors and non-hydrometeors, based on spectral polarimetric variable features. The result is a mask to be applied on the spectrograms. The variable selected here is the spectral co-polar correlation coefficient. The algorithm does first a global thresholding by finding an optimized threshold value based on the averaged clear air spectral polarimetric variable distribution. Next, classical filtering steps are carried out like a ground clutter notch filter, mathematical morphology to fill gaps in the hydrometeor areas and a removal of narrow Doppler power spectra. The second part of this work is dedicated to a first assessment of filtering techniques without ground truth. This is useful for selecting a few optimal algorithm configurations based on a relatively small data set, without the need of a full QPE assessment. A full assessment of improvement of QPE is actually too challenging because of the initial large number of algorithm configurations. Here, criteria of good filtering are primarily defined both in the spectral and time domain. Based on those criteria, subjective and objective unsupervised evaluation metrics are derived, with a focus on the objective ones. Data including clear air and rain collected from a X-band radar in urban area are used. With the proposed unsupervised evaluation metrics, the JSD-based thresholding filter is compared to two spectral polarimetric filters. Overall, the JSD-based filter performs well considering either the subjective or the objective evaluation metrics.

IMPROVING THE DATA QUALITY OF POLARIMETRIC VARIABLES USING HYBRID SCAN ESTIMATORS

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The WSR-88D routinely uses a 'split cut' strategy to resolve ambiguities of velocity aliasing and range folding for operational Volume Coverage Patterns (VCP). That is, there are two complete 360°-scans at the lowest elevations of a VCP: one with a continuous surveillance waveform at a long pulse repetition time (PRT) to resolve range ambiguities and one with a continuous Doppler waveform with a higher PRT to resolve velocity aliasing and range folding. The Hybrid-Scan Estimators (HSE) use these two scans to provide better estimates of differential reflectivity, differential phase, and correlation coefficient. Similar to split cuts, the Multiple PRF Dealiasing Algorithm VCPs use a single surveillance scan followed by two or more Doppler scans at the same elevation further reducing range and velocity ambiguities. The new WSR-88D VCPs that incorporate MPDA use the SZ-2 algorithm where each Doppler scan requires 64 pulses. In this work, we incorporate the HSE for use with these MPDA-VCPs based on each scans expected statistical performance, resulting in the same or better data quality compared to the conventional estimators. In 2022, we completed the transfer of the HSE to the Radar Operations Center (ROC) for inclusion in a future software build on the WSR-88D system. Here, we show real-data examples of the expected quality improvements in dual-polarimetric variables using HSE with 'split cut' and MPDA scanning strategies.

THE MITIGATION OF DEBRIS-INDUCED BIAS IN TORNADIC DOPPLER VELOCITY MEASUREMENTS

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Debris centrifuging is known to cause bias in tornadic Doppler velocities. In single- and dual-Doppler retrievals, debris presence is associated with anomalous radial divergence, underestimation of azimuthal winds, and negative bias in vertical velocity, which can bias interpretations of tornado intensity and structure. To mitigate these biases, a spectral velocity correction technique is developed using dual-polarization spectral density estimation and fuzzy logic classification. This technique uses the spectral polarimetric characteristics of a signal to classify velocities as either rain or debris motion with fuzzy logic. Debris motion is then filtered from the Doppler spectrum to obtain a new, corrected velocity estimate. This method shows promising potential for reducing debris-induced velocity bias. The velocity correction is applied to simulated radar scans from SimRadar, a polarimetric, time-series radar simulator that combines a high-resolution tornado model, debris trajectories, and electromagnetic scattering data. Correction performance is evaluated with comparisons of pre- and post-correction velocity bias. Overall, the technique consistently reduces velocity bias to near 0 m/s, aside from the region at the center of the vortex, where debris concentrations tend to be highest. The correction technique is also applied to KOUN radar data from the Moore, Oklahoma tornado on 20 May 2013 to evaluate its performance on observed data. Corrected Doppler velocities in the tornado are overall larger in magnitude than the original measured velocities. Given that debris is associated with underestimated rotational velocities, this suggests that the velocity correction technique can successfully reduce debris-related bias in observed tornadic Doppler velocities.

NEXT PHASE OF THE LIDAR RADAR OPEN SOFTWARE ENVIRONMENT (LROSE) AS A SCIENCE GATEWAY

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The Lidar Radar Open Software Environment (LROSE) was developed to meet the challenges of complex lidar and radar processing problems faced by the research and education communities. Through support from the National Science Foundation, Colorado State University and the National Center for Atmospheric Research a toolbox is now available, stocked with core algorithms for typical processing steps that are well understood and documented in the peer-reviewed literature. The tools focus on key building blocks for data conversion, visualization, quality control, gridding, echo, and wind. By combining the open source approach with virtual machines and cloud computing, we developed a system that is both highly capable and easy to run on most hardware. However, results from a survey of the LROSE community show there are still issues with software installation, questions about parameter settings, and the need for expert advice on how to use the tools. Enter the science gateway, which provides access to data, software, compute resources, and educational materials. With a gateway, tutorials become interactive workflows that embed knowledge from experts. A workflow guides a researcher through the order of the LROSE tools, with example data, parameter settings, and expected results. The gateway provides a mechanism and platform for an interactive learning experience. With the help of the Science Gateways Community Institute, we created a prototype gateway that guides a novice through the process of rainfall estimation and wind analysis. Experts, students, and educators all have a place in the gateway with access to a community of shared data, software, resources, and advice. The current status of the LROSE Science Gateway will be presented.

A NEW APPROACH FOR ADDRESSING CORRELATION COEFFICIENT ESTIMATOR BIAS AT LOW SIGNAL-TO-NOISE RATIOS

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With the increased use of dual-polarization weather radars, improving dual-polarization radar-variable estimators has become a growing research area. Most of the research focuses on minimizing the bias and variance of estimators using a variety of approaches. In this work, the focus is addressing the significant positive bias of the conventional lag-0 correlation coefficient estimator at low signal-to-noise ratios (SNRs). The fundamental cause of this bias comes from the ratio that is at the center of the calculation. The new approach is to utilize a more generic estimator, Beale's ratio estimator, to deal with ratio effects. A modified version of Beale's ratio estimator was developed to address the complex values in the calculation and the multiple factors in the denominator. This modified estimator greatly minimizes the bias of the conventional estimator over a wide range of weather signal characteristics without increasing the variance. In fact, it reduces the variance and increases the number of valid estimates. Integrating the new estimator with ground clutter filters is also addressed. A major advantage of this approach is that it can be applied to other estimators that incorporate ratios. This could lead to a more general way to resolve bias issues with ratio estimators.

ESTIMATION OF HORIZONTAL WIND FROM DOPPLER DATA

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Météo-France operates a network of 33 radars in mainland France, all of them using Doppler technology. This provides radial wind measurements with very good spatial (1° x 1 km) and temporal (5 min) resolution for several site angles. Today, at Météo France, the exploitation of these data is mainly done through the assimilation for the numerical forecasting model AROME and the automatic detection of mesocyclones. These radial wind observations could be also very valuable for monitoring storms or convective situations generating strong gusts. But their direct interpretation is complicated by the polar geometry. Zhou et al (2005) proposed a method for estimating the two components of the horizontal wind based on the assumption of a constant wind between two neighbouring pixels in azimuth. This method is particularly sensitive to noise and horizontal wind shear, which makes it difficult to use in many situations. We propose here to explore a new method for estimating the horizontal wind. The assumption made here is the correspondence between the direction of the horizontal wind and that of the precipitation displacement field calculated from the reflectivity fields. The performance of this method will be evaluated through different meteorological situations (storms, squall lines...) and compared to existing methods, and in particular the one proposed by Zhou et al (2005).

SNOWFALL

MASCDB: A DATABASE OF IMAGES, DESCRIPTORS AND MICROPHYSICAL PROPERTIES OF INDIVIDUAL SNOWFLAKES IN FREE FALL

CLOUD RADAR-BASED SNOWFALL ESTIMATES DURING MOSAIC EXPEDITION

GROUND-BASED, MOBILE, POLARIMETRIC, DOPPLER-RADAR MEASUREMENTS IN TWO SNOWSTORMS IN THE NORTHEASTERN U. S. DURING IMPACTS IN 2022

THE ANATOMY AND PHYSICS OF A SNOWSQUALL

A SYNERGY OF POLARIMETRIC AND DUAL-FREQUENCY RADAR OBSERVATIONS OF WINTER STORMS FOR ESTIMATING ICE WATER CONTENT

PRECIPITATION TYPE ANALYSIS USING A HYDROMETEOR CLASSIFICATION OF HIGH-RESOLUTION RADAR DATA – EVALUATION RESULTS OF WINTER SEASON 2021/2022 AT DEUTSCHER WETTERDIENST

CROSS-VALIDATION OF MICROWAVE SNOWFALL PRODUCTS OVER THE CONTINENTAL UNITED STATES

RADAR-BASED SNOWFALL ESTIMATE: WHICH REFLECTIVITY-SNOW WATER EQUIVALENT RATE RELATIONSHIP TO USE?

ERUO: A SPECTRAL PROCESSING ROUTINE FOR SNOWFALL MEASUREMENTS COLLECTED BY THE MRR-PRO

COMBINING DUAL-POLARIZATION RADAR WITH LAGRANGIAN TRAJECTORIES AND A SPECTRAL BIN MICROPHYSICS MODEL TO IMPROVE SNOW NOWCASTING

POLARIMETRIC RADAR QPE IN HEAVY SNOW

OPERATIONAL IMPLEMENTATION OF SNOW LIQUID WATER EQUIVALENT ESTIMATION FOR THE CANADIAN S-BAND WEATHER RADAR NETWORK

RADAR OBSERVATION OF THE RAIN-SNOW TRANSITION FROM SPACE AND FROM THE GROUND

MASCDB: A DATABASE OF IMAGES, DESCRIPTORS AND MICROPHYSICAL PROPERTIES OF INDIVIDUAL SNOWFLAKES IN FREE FALL

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Snowfall information at the scale of individual particles is rare, difficult to gather, but fundamental for a better understanding of solid precipitation microphysics. We present a dataset, MASCDB, of in-situ measurements of snow particles in free fall collected by a Multi-Angle Snowflake Camera (MASC). The dataset includes gray-scale (255 shades) images of snowflakes, co-located surface environmental measurements, a large number of geometrical and textural snowflake descriptors as well as the output of previously published retrieval algorithms. Noteworthy examples include: hydrometeor classification, riming degree estimation, identification of melting particles, discrimination of wind-blown snow, as well as estimates of snow particle mass and volume. The measurements were collected in various locations of the Alps, Antarctica and Korea for a total of 2'555'091 high-quality snowflake images (or 851'697 image triplets). MASCDB aims to accelerate reproducible research on precipitation microphysics and to address longstanding scientific challenges on snowflake research. Given the large amount of snowflake images and associated descriptors, MASCDB can be exploited also by the computer vision community for the training and benchmarking of image processing systems. MASCDB can be accessed on Zenodo (DOI: https://doi.org/10.5281/zenodo.5578920), while the dedicated python software pymascdb is available at https://github.com/ltelab/pymascdb.

CLOUD RADAR-BASED SNOWFALL ESTIMATES DURING MOSAIC EXPEDITION

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Reliable snowfall measurements are crucial for climate and water budget studies in the Arctic. Central Arctic snowfall data, however, have been scarce. Measurements collected as part of the one-year-long Multidisciplinary drifting Observatory for the Study of Arctic Climate (MOSAiC) expedition, which took place starting October 2019, provided an opportunity to partially fil this data gap. While the remote sensing instrumentation suite on the MOSAiC icebreaker included several cloud radars, the zenith-pointing Atmospheric Radiation Measurement Ka-band radar (KAZR) was the most reliable during the entire period of the expedition. KAZR reflectivity measurements were used to derive time series of high temporal and spatial resolution snowfall rate data. This presentation will describe the remote sensing approach for snowfall retrievals with estimates of uncertainties and provide analysis of instantaneous rates as well of daily, monthly and total snowfall accumulations during the MOSAiC icebreaker drift. Radar-based retrieval comparisons with results obtained from a number of different optical and weighing precipitation gauges and disdrometers, which also were deployed as part of the MOSAiC instrumentation suite, and also from measurement of snow on the ground will also be given. Influences of different snowfall processes (e.g., riming, aggregation) will also be discussed and frequencies of occurrence of snowfall of different intensities will be evaluated.

GROUND-BASED, MOBILE, POLARIMETRIC, DOPPLER-RADAR MEASUREMENTS IN TWO SNOWSTORMS IN THE NORTHEASTERN U. S. DURING IMPACTS IN 2022

Howard Bluestein[1]; David Schvartzman[2]; Samuel Emmerson[2]; Danny Feland[2]; Dale Sexton[2]; Boonleng Cheong[2]; Tian You Yu[2]; Gerald Heymsfield[3]

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During a NASA-sponsored field program, IMPACTS (The Investigation of Microphysics and Precipitation for Atlantic Coast-Threatening Snowstorms) ground-based, mobile, polarimetric, Doppler radar data were collected using RaXPol in two winter storms in the northeastern U. S. On 29 Jan., data were collected at Plymouth, MA, in a blizzard during which almost 60 cm of snow fell and the winds gusted to at least 35 m s-1. Slow-scan data were collected from 9:58 AM – 7:14 PM EST. Most of the scans were full 360 deg PPIs, from 0 - 20 deg elevation in 2 deg increments. Some raw I/Q data were also collected. After 1:30 PM EST data collection from the vertical channel failed when the waveguide from the vertical channel became excessively rimed. The data collected documented the structure and evolution of heavy snowbands. On 25 Feb. data were collected in Albany, NY, from 4:23 – 10:09 AM EST during a winter storm in which 15 cm of snow fell and the type of precipitation varied. Volume scans collected were full 360 deg PPIs, from 0 - 20 deg elevation in 2 deg increments. Approximately every 15 minutes RHIs were collected in the N – S direction, especially along the flight track of the NASA ER-2 when it flew about 20 km above the RaXPol's site, with downward-looking radars; in addition, RaXPol collected vertically-pointing scans taken during three of the ten overpasses, in addition to some raw I/Q data. A first-look at the unique datasets collected will be presented and summarized. The structure of the snowbands on 29 Jan. and the low-level jet and other layered structures on 25 Feb. will be described.

THE ANATOMY AND PHYSICS OF A SNOWSQUALL

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Snowsqualls are progressive, linear convective snow bands that bring sudden heavy snow, visibility decreases, gusty winds, and occasional flash freezes on roadways. As such, snowsqualls can lead to multi-vehicle accidents on highways, injuries, and deaths. Despite these societal impacts, there is a paucity of scientific literature on snowsqualls, and no consensus on the mesoscale processes driving these storms. On 18 December 2019, snowsqualls impacted parts of the northeastern United States, including New York City and Long Island. One of these squalls was sampled by the Stony Brook University Ka-band Scanning Polarimetric Radar (KASPR); its unique scanning capabilities and full polarimetry allowed for observations of the kinematic and microphysical structure of the snowsquall with unprecedented detail. Analysis suggests snowsqualls can be viewed as cold-season mesoscale convective systems (MCSs), complete with analogous features to warm-season MCSs like descending rear inflow, a cold pool with leading-edge forced ascent sustained in part by potential instability in the lowest 2 km AGL, and ascending front-to-rear flow. Additionally, the Doppler spectral data from vertically pointing scans reveal strong (>10 m/s at 500 m AGL) updrafts associated with a weak echo region, and a trailing stratiform anvil with evidence of snow sublimation and associated secondary ice production. Collectively, these observations lend credence to the hypothesis that snowsqualls are cold-pool driven. The mesoscale processes leading to initiation and maintenance of the snowsquall will be discussed, and a conceptual model of the structure and airflow patterns revealed from KASPR will be presented.

A SYNERGY OF POLARIMETRIC AND DUAL-FREQUENCY RADAR OBSERVATIONS OF WINTER STORMS FOR ESTIMATING ICE WATER CONTENT

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Ice water content (IWC) estimate using radar measurements has been challenging due to the complex properties of ice particles even using polarimetric capabilities. Recently the NEXRAD network has been complemented by highly sensitive, fine spatiotemporal resolution cloud radars deployed at Stony Brook University. These radars can be used to evaluate the NEXRAD S-band polarimetric radar measurements and they also provide additional constraints to improve the IWC retrievals. We present a new approach to estimate IWC using NEXRAD, Ka-band scanning polarimetric radar (KASPR), and ground-based in-situ data. Columnar quasi-vertical profiles around the KASPR site from the nearest NEXRAD (KOKX) multi-angle PPI measurables and quasi-vertical profiles from KASPR single PPIs were used to compare and obtain reflectivity dual-wavelength ratio (DWRS/Ka) which is then used to estimate IWC. The comparison showed that the NEXRAD KDP was consistent with the KASPR KDP when accounting for the frequency dependency. This indicates that the NEXRAD KDP can be used for IWC and/or microphysical retrievals as it can be done by more sensitive cloud radars. On the other hand, it also suggests the Rayleigh scattering KASPR KDP. The mass-weighted mean diameter (D_m) retrieved from the KASPR reflectivity is significantly underestimated when a Parsivel disdrometer observes large particles and hence large DWRS/Ka is observed. We used a DWRS/Ka-D_m relationship and KDP to construct the IWC retrieval for snowstorm cases observed during the winter seasons from 2018 to 2021. The IWC estimate was in good agreement with the Parsivel and Pluvio precipitation gauge measurements. We will present and discuss the detailed methodology and theory of the IWC estimate using the two different frequency radar systems.

PRECIPITATION TYPE ANALYSIS USING A HYDROMETEOR CLASSIFICATION OF HIGH-RESOLUTION RADAR DATA – EVALUATION RESULTS OF WINTER SEASON 2021/2022 AT DEUTSCHER WETTERDIENST

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Due to the high sensitivity of winterly precipitation to its environment, the analysis and forecast of the precipitation type near ground in situations when the air temperature in the lower troposphere is near the freezing point are very challenging. A reason for this are deviations in NWP data - with e.g. impact on the distinction between snow crystals and small droplets on radar beam height - and the fact that the radar detects precipitation several hundreds, sometimes thousands meter above ground. At Deutscher Wetterdienst, a dual-polarimetric radar network was installed during the last decade. With the use of dual-polarimetric radar parameters and NWP data (e.g., ICON-D2 snow line), the hydrometeors on radar beam height are analysed (algorithm HYMEC). The use of numerical weather prediction vertical profiles of temperature, humidity and pressure enables the vertical extrapolation of the HYMEC analysis data to the ground (algorithm NASMA). With the use of individual temperature and humidity point measurements at ground level, the vertical extrapolation is optimised and precipitation type data near the ground can be analysed close to reality in the entire radar coverage area. Details of the algorithm are presented in the contribution of Schultze et al. In the beginning of the winter season 2018/2019, NASMA data had been implemented into DWD weather forecast visualisation system NinJo. In the previous winter seasons, the data of the NASMA algorithm has been evaluated under operational conditions. The evaluation results have shown that the quality of the precipitation type analysis depends on the weather situation. Details of selected case studies of winter season 2021/2022 will be presented and approaches for further improvements will be discussed.

CROSS-VALIDATION OF MICROWAVE SNOWFALL PRODUCTS OVER THE CONTINENTAL UNITED STATES

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Surface snowfall rate estimates from the Global Precipitation Measurement (GPM) mission's Core Observatory sensors and the CloudSat radar are compared to those from the Multi-Radar Multi-Sensor (MRMS) radar composite product over the continental United States to quantify the strengths and limitations of state-of-the-art space-borne products. The analysis spans a period between November 2014 and September 2020 and covers a number of the algorithms including: the Dual-Frequency Precipitation Radar product (2A.GPM.DPR) and its single frequency counterparts (2A.GPM. Ka, 2A.GPM.Ku); GPM Combined Radar Radiometer Algorithm (2B.GPM. DPRGMI.CORRA); the CloudSat Snow Profile product (2C-SNOW-PROFILE) and two passive microwave retrievals i.e. the Goddard PROFiling algorithm (2A.GPM.GMI.GPROF) and the Snow retrievaL ALgorithm fOr gMi (SLALOM). Out of all the analysed retrievals, the 2C-SNOW product has the highest Heidke Skill Score (HSS=75%) for snowfall detection. SLALOM, the algorithm trained with 2C-SNOW, ranks the second (60%) which suggests that the optimal use of the information content in the GMI observations critically depends on the precipitation training dataset. DPR, CORRA and Ku-only product achieve the HSS score of 45% while the Ka-band product shows the lowest snow detection capability, with the HSS of 10% only.

RADAR-BASED SNOWFALL ESTIMATE: WHICH REFLECTIVITY-SNOW WATER EQUIVALENT RATE RELATIONSHIP TO USE?

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Radar-based precipitation estimate is a three-quarter century long research topic. With the introduction of dual-polarization weather radars, the accuracy of radar rainfall estimates improved substantially even though power law relationships between radar reflectivity and rain rate, R(Ze), is still widely used for light rain. For snow, the operational agencies rely heavily on reflectivity versus snow water equivalent rate, SWER(Ze), relationships, especially over inhomogeneous terrain where reliable gauge coverage does not exist. The derivation of SWER(Ze) relationships require accurate measurements of size, concentration, and fall velocity of falling snowflakes from which Ze and SWER are independently calculated. The Precipitation Imaging Package (PIP) developed by NASA is able to measure critical three measurements of falling snowflakes and is the main instrument used in this study. PIP-based observations revealed that snow water equivalent in storms with uniform particle size distribution are generally well estimated by a single SWER(Ze) relationship. A number of lake-effect storms in the Upper Great Lakes, as well as over northeastern South Korea, showed uniformity in particle size parameters. However, this is not the case in most of the winter storms which are dominated by intra-storm variability and the habit and bulk density of snowflakes undergo significant changes throughout the storm. The intra-storm variability is more complicated than inter-storm variability and this study will address the complex nature of the problem. We will discuss the methods to improve the radar snowfall estimates; however, an open discussion should be beneficial for the several decades long Quantitative Precipitation Estimate (QPE) problem!

ERUO: A SPECTRAL PROCESSING ROUTINE FOR SNOWFALL MEASUREMENTS COLLECTED BY THE MRR-PRO

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The Micro Rain Radar (MRR) PRO is a frequency modulated continuous wave (FMCW) Doppler weather radar, operating at K-band (24 GHz), designed and manufactured by Metek Meteorologische Messtechnik GmbH as a successor to the MRR-2. A reliable interpretation of the variables collected by this radar in snowfall conditions benefits from high sensitivity and the absence of artifacts in the measurements. A processing library named ERUO (Enhancement and Reconstruction of the spectrUm for the MRR-PRO) has been developed using four datasets collected during two field campaigns in Antarctica and Switzerland. The first objective of the proposed method is to improve the quality of the radar variables by increasing the sensitivity and addressing velocity folding in the spectrum. Secondly, ERUO aims to minimize the effect of a series of issues plaguing the radar variables, including interference lines and power drops at the extremes of the Doppler spectrum. The validation of the algorithm has been performed in two stages. First, the reconstruction of the meteorological signal covered by interference lines has been tested separately over artificially altered Doppler spectra. Second, the radar variables computed by ERUO have been compared against the measurements of a co-located W-band Doppler radar. Information on the hydrometeor mixtures above the measurement site, provided by a close-by X-Band Doppler dual-polarization radar, has been used to exclude unsuitable radar volumes from the comparison.

COMBINING DUAL-POLARIZATION RADAR WITH LAGRANGIAN TRAJECTORIES AND A SPECTRAL BIN MICROPHYSICS MODEL TO IMPROVE SNOW NOWCASTING

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Snow often develops quickly in regions of enhanced specific differential phase (KDP) within the dendritic growth layer. Previous research has suggested that these enhanced KDP regions could be used to nowcast surface snowfall however few studies have investigated this possibility. Studies that have investigated the role of KDP enhancements for snow production have often relied on quasi-vertical profile (QVP) averaging which can obscure the role of these small-scale KDP enhancements by precluding the spatial prediction of where heavy snow will fall. This current work uses two different numerical models to directly investigate the link between enhanced KDP aloft with future snowfall at the surface 1-2 hours later. We use Multi-radar/Multi-sensor (MRMS) measurements from 9 separate cases that exhibit enhanced KDP within the dendritic growth layer. High-Resolution Rapid Refresh (HRRR) model data is then used to calculate Lagrangian trajectories of snow particles and the associated MRMS radar variables along each trajectory to determine when and where these snow particles fall. Additionally, we run a one-dimensional spectral bin model (SBM1D) for these cases during periods of enhanced KDP. This bin microphysics model calculates sublimation, vapor deposition, aggregation, collisional breakup, and melting of ice particles and determines surface precipitation types. We present results of the Lagrangian trajectories as well as a comparison of SBM1D model results with ASOS station and MRMS observations.

POLARIMETRIC RADAR QPE IN HEAVY SNOW

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The inherent uncertainty in radar snow estimates comes from variability in snow particle size distributions, changes in particle densities, and diversity among snow growth habits. These make radar snow quantitative precipitation estimation (QPE) very challenging. However, polarimetric radar data can reduce biases in snow QPE. Generalized polarimetric bi-variate power-law relations for snowfall rate estimation, S(KDP, Z), are recently introduced (Bukovčić et al., 2020). These relations depend on reliable estimates of KDP, which is low and noisy in aggregated snow, and highly sensitive to the variations in particle aspect ratio and width of the canting angle distribution (σ). Polarimetric relations are derived from the 2D-video-disdrometer snow dataset from central Oklahoma, using the aspect ratio (0.5-0.8) and σ (0-40˚) typical for aggregated snow. Additionally, we introduce a novel polarimetric relation for S estimation, which depends on ice water content (IWC) and mean volume diameter (Dm), S(IWC, Dm). Polarimetric relations for snowfall rate estimations are tested and verified with the S-band WSR-88D data against standard S(Z) and in situ measurements in several heavy snow events. If low-altitude KDP measurement is reliable (KDP>0.03° km-1), polarimetric relations exhibit smaller biases in comparison to S(Z) at the surface. The alternative approach for avoiding the unreliable low-level KDP is to use more robust estimates of S aloft in the dendritic growth layer, where KDP is much higher, and project these to the ground. Another alternative is to use S(Z) estimates in areas of weak or negative KDP if they are known to work better in given situations.

OPERATIONAL IMPLEMENTATION OF SNOW LIQUID WATER EQUIVALENT ESTIMATION FOR THE CANADIAN S-BAND WEATHER RADAR NETWORK

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Quantitative Precipitation Estimation (QPE) from radar measurements for snow is very challenging due to large variability in particle size distributions (PSDs), densities, shapes, sizes and orientations of falling snow. Almost all snowfall retrieval algorithms are based on horizontal reflectivity (Z) and are related to snowfall rate or liquid water equivalent by power law relationships. New relationships for snow water equivalent combining differential reflectivity (ZDR), specific differential phase (KDP) and Z are explored to determine whether they can improve overall snow QPE in an operational environment. Environment and Climate Change Canada (ECCC) is nearing the completion of its polarimetric weather radar upgrade and the renewed network provides polarimetric measurements in diverse weather conditions and in varied precipitation phases across the country. Principally, the Sekon and Srivastava 1970 S(Z) relationship has been used in Canada to convert snow horizontal reflectivity to liquid water equivalent. At ECCC a composite algorithm comprising of S(Z) and S(Z,KDP) from Bukovcic et al. 2018, for winter precipitation has been recently implemented in operations. S(Z) is applied for relatively low Z and low KDP and S(Z,KDP) is applied at larger values. A heavy snowfall case in Atlantic Canada illustrates the performance of the new composite snow QPE algorithm, where the estimates compared better with surface measurements than the conventional method. However, uncertainties in surface measurements must also be considered which are affected by strong winds, melting, and mix-phase precipitation during transitional events. Analysis is ongoing to assess overall algorithm performance across Canada for winter 2021, and will be highlighted in this presentation.

RADAR OBSERVATION OF THE RAIN-SNOW TRANSITION FROM SPACE AND FROM THE GROUND

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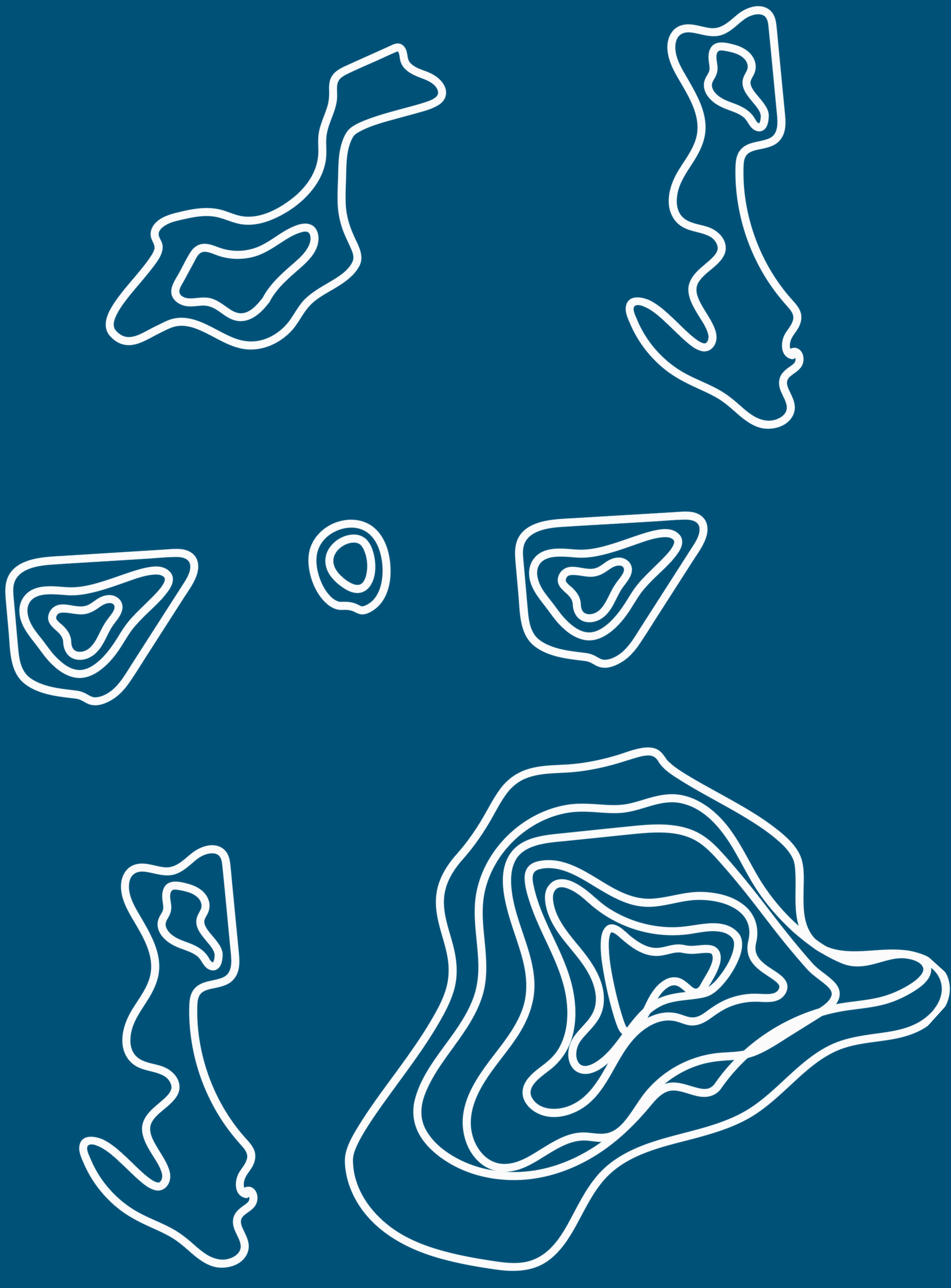
Mountain glaciers are major contributors to sea level rise but they also are of vital importance for water resources in some regions of the world. This is why they are subject to special monitoring, particularly through surface mass balances (SMB), and to modelling of their functioning and future evolution. Snow accumulation is the variable with the strongest spatial and temporal variability and the highest uncertainty in glacier SMB modelling. In highly glacierized mountain catchments, snow accumulation is directly related to solid precipitation rate. A large part of the uncertainty about recent and future glacier mass changes is thus inherited from large uncertainties in the precipitation estimation (amounts & phase). The phase of precipitation is also a key concern as it affects the surface albedo (snow versus rain) and the heat transfer in the snow layers. It is therefore a necessary information for physical approaches that explicitly describe the energy and mass exchanges between the glacier and the atmosphere. Some glaciers monitored by the scientific community have measurements of precipitation totals but rarely have information on precipitation phase. The phase of precipitation and the altitudes where it changes can be estimated by vertical pointing Doppler radar that measures the vertical profile of vertical fall speed and reflectivity. Indeed, in this snow/rain transition layer, the vertical fall speed changes and bright band effects are observed. The objective of the presented work is to evaluate the automatic detection of the melting layer from GPM products exploiting the Dual-Frequency Precipitation Radar embedded on the core-platform taking as reference observations performed by ground-based vertically pointing radars (MRR) operated in the French Alps.



LECTURES

DUAL-POLARIZATION APPLICATIONS

RADAR MEASUREMENTS OF WIND AND RAINFALL FROM SPACE

A SCALING LAW FOR THE RAINDROP SIZE DISTRIBUTION: APPROACHING ITS 30TH ANNIVERSARY, BUT STILL GOING STRONG!

ON THE GENERATION OF STOCHASTIC SIMULATIONS OF RAINFALL IN SPACE AND TIME

DUAL-POLARIZATION APPLICATIONS

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Doppler polarimetric radars become a standard for operational weather radars around the world. Compared to single-polarization radars, dual-polarization radars substantially improve data quality, precipitation estimation, hydrometeor classification, and severe weather warnings. In this lecture, a very brief and broad overview of the dual-polarization applications will be presented in the three important areas: quantitative precipitation estimation (QPE), hydrometeor classification, and microphysical retrievals. A focus will be on the novel techniques and existing challenges in all three application areas. In the QPE arena, these include a recently introduced rainfall estimation methodology utilizing specific attenuation and a polarimetric technique for snow measurements. Recent advancements in the polarimetric hydrometeor classification during cold season such as a new method for melting layer detection and utilization of simplified cloud models combined with radar microphysical retrievals will be discussed. Polarimetric microphysical retrievals are of particular value for cloud modelers and the newly introduced methods for quantifying microphysical characteristics of cloud ice will be outlined. The differences between applications of all these polarimetric methodologies in different frequency bands utilized by operational weather radars will be also mentioned in the course of a lecture.

RADAR MEASUREMENTS OF WIND AND RAINFALL FROM SPACE

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Global observations of wind and rainfall are needed for assimilation into forecast models to improve predictions of wind-storms and flooding and to provide a benchmark for the performance of climate and weather forecast models. Global coverage can only be provided by satellites. The 355nm Doppler lidar on AEOLUS, launched in 2018, dwelling at 35 deg off-nadir, detects the Doppler shift of the return from molecules and thin clouds. These winds have had a significant impact in reducing forecast errors and a follow-on mission is planned. The 'WIVERN' 94GHz scanning Doppler wind radar with an 800km wide sample, currently being studied by ESA, uses cloud particles as tracers, and would provide winds within active cloudy regions such as hurricanes and winter European and Mediterranean wind-storms. Measuring global rainfall from space is much more challenging than deriving wind from the Doppler return, because rainfall varies so rapidly in space and time and the radar return is not directly related to the rain-rate. Verification is very difficult, as rain gauges are sparse and virtually absent over the oceans, and they measure accumulated rainfall whereas satellites provide an instantaneous 'snapshot'. To achieve a 1 to 4km footprint, high frequencies must be used as for TRMM (14GHz), GPM (14 and 35GHz), CloudSat and EarthCARE (94Ghz). At these higher frequencies, attenuation by the rain is increasingly significant and so the total attenuation, estimated from the drop in the ocean surface radar return, is also used as a constraint for estimating the rainfall, but problems arise. For example, the melting layer and cloud water also contribute to the attenuation. Various approaches to avoid these difficulties will be discussed.

A SCALING LAW FOR THE RAINDROP SIZE DISTRIBUTION: APPROACHING ITS 30TH ANNIVERSARY, BUT STILL GOING STRONG!

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Nearly three decades ago Sempere Torres et al. (1994) published “A General Formulation for Raindrop Size Distribution”, in which they proposed “a general phenomenological formulation for drop size distribution (DSD), written down as a scaling law”. Their scaling law formulation accounted for all previously published parameterizations for the DSD. The main implication of the proposed expression was that the integral rainfall variables (such as rain rate and radar reflectivity) were related by power laws, in agreement with experimental evidence. The proposed formulation naturally led to a general methodology for scaling all raindrop size data in a unique plot, which yielded more robust fits of the DSD. In this presentation we will review nearly three decades of interpretations and applications of this scaling law for the DSD, with extensive references to earlier work (dating all the way back to the beginning of the 20th century) as well as an outlook to the future, including implications for ground-based and spaceborne remote sensing of precipitation. In addition, we will provide a statistical interpretation of the law’s scaling exponents in terms of different modes of control of the space-time variability of DSDs, namely size-control vs. number-control, inspired by the work of Smith and De Veaux (1994), incidentally published in the same year. Also, ongoing work concerning the parameterization of the shape of the scaled DSD will be discussed and an attempt will be made toward interpreting the values of the scaling exponents and the shape of the scaled DSD in terms of the (micro)physical processes producing the DSD. Finally, we will provide an outlook to the future of DSD parameterizations and (power-law) rainfall retrieval relations.

ON THE GENERATION OF STOCHASTIC SIMULATIONS OF RAINFALL IN SPACE AND TIME

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Stochastic simulations of rainfall in both space and time are needed for a range of hydrological applications. Simulations that are conditioned on both the spatial distribution and field statistical properties of the recent past are used to generate ensemble nowcasts. Ensembles of stochastic simulations of observed events can be generated if they are conditioned on only the field properties. A similar approach can be used to generate ensembles of downscaled low-resolution rainfall fields, say from a reanalysis of a historic extreme event or from a climate model. In this case they are conditioned on field properties that are derived from statistical models that use the properties of the low-resolution field as predictors.

These ensembles can then be used to force hydrological and other impact models so that the probability distribution of an impact (in a perfect world) can be derived. Hydrological processes filter the input rainfall field over a range of space and time scales. This implies that the stochastic fields need to reproduce the observed statistical properties of rainfall over a range of scales. This talk will review the statistical properties of rainfall in both space and time and motivate why it is necessary to use a scaling framework to describe the way that these properties vary as a function of scale. The fundamental statistical properties of rainfall that need to be reproduced for hydrological applications will be emphasised. The temporal evolution of the field at a point is dependent on both the evolution of the field as it moves over the area of interest and the motion (advection) of the field. Extreme accumulations over a small area are often caused by a combination of heavy but not extreme rain rates in a system that is moving extremely slowly. It is helpful therefore to use a framework that models the evolution of the field in a Lagrangian setting and treats the advection separately. In this case the space-time model will need:

- Field generator
- Field updater in the Lagrangian framework
- Advection field generator and updater
- Model parameter generator and updater

The talk will provide examples of how the STEPS algorithms have been adapted with varying levels of abstraction to generate stochastic simulations for a range of applications.

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