PP-AWARE: Appraisal of "Challenging WeAther" FoREcasts

Version 6, 08.06.2019

Project Duration: *Start 09.2019 – End 08.2021*

Total FTE request: 4.15FTEs

Project leaders

Flora Gofa (WG5) and Anastasia Bundel (WG4)

Introduction

The necessity to tackle scientific problems, which step beyond the concerns of a single strategic area and a Working Group, is described in Science Plan and one of the cross cutting issues is addressed within the project plan AWARE.

The importance of accurate forecasting of challenging weather occurrences is obvious. With the term challenging weather (CW) or high impact weather (HIW), we consider the events the local society is not routinely accustomed to experiencing. Such events could be extreme in amplitude (intense winds, or heavy convective precipitation), rare (lie in a tail of climatological distribution for a particular location) or high impact by being prolonged 'regimes' (droughts, heat-waves or cold-spells), while others even if not very rare can be considered challenging if society is particularly vulnerable to them (e.g. impact of fog on transportation). In theory, a weather event could be high-impact when it is inherently less predictable and society does not have sufficient forewarning to take mitigating action.

Despite significant progress in short-range forecasting, HIW continue to cause most part of damage to the economy and society, up to losses of human lives. WMO initiated a project dedicated to HIW research (*WMO HIW implementation plan*). The overall objective of the High Impact Weather (HIWeather) project is to: "Promote cooperative international research to achieve a dramatic increase in resilience to high impact weather, worldwide, through improving forecasts for timescales of minutes to two weeks and enhancing their communication and utility in social, economic and environmental applications". One component of the project is the verification and the research is focused on approaches with relevance to hazard predictions. PP AWARE is intended to follow closely the advances of the WMO HIW project.

In COSMO consortium, there have been several studies partially related to CW aspects. However, up to now there have been no project explicitly focusing on evaluation and development of HIW forecasts.

Forecast methods and verification are important aspects of any CW consideration. While traditional verification methods have limited usefulness in this context, many of the newer diagnostic approaches may provide useful information to aid understanding of errors in model processes for such weather regimes. Verification of multi-scale prediction of CW has much in common with routine verification performed at most national meteorological centers. It mainly concerns surface variables such as

precipitation, wind, temperature, etc., using both pointwise and spatial approaches to meet the needs of a variety of users. On the other hand, CW phenomena as fog or lightning are usually not directly forecasted by NWP models, and thus appropriate post-processing methods are applied for their prediction.
Known deficiencies to be addressed are:

- Models may not capture the intensity of high impact events (Sub-grid scale processes, Coarse resolution, Difficulty representing processes)
- Often a mismatch between what models can provide and what warnings need to be made for: Lightning, hail, wind gusts, fog, etc.
- Large uncertainty with extreme events (Ensemble/probabilistic forecasts to measure "extremeness“).

Key forecast quality and verification aspects to consider in this project include, therefore:

- How well high-impact weather is represented in the observations, including biases and random errors, and their sensitivity to observation density.
- How well high-impact weather is represented in models, including systematic and stochastic errors, and their sensitivity to model resolution.
- How well high-impact weather is represented in postprocessing.
- The predictability, current predictive skill, and the user’s interpretation of forecast value in high-impact weather situations (observed and/or forecast).

Motivation and goals

The increased demand to provide accurate forecasts of extreme weather leads to the question to how objectively to evaluate forecasts of extreme weather. The main weather phenomena of interest are: thunderstorms (heavy precipitation, lightning), severe wind (and wind gusts), min-max temperature (persistence), visibility (fog), and other extreme phenomena like tornadoes, dust devils, clear-air turbulence (CAT), etc.

As the resolution of state-of-the-art NWP models is growing, there is more detailed and precise information on the variables necessary for calculating, for example, the electrical properties of the atmosphere as dependent on temperature, humidity, wind, ice, water content of particles, etc. The physical and microphysical processes leading to local CW of convective nature are better reproduced in modern NWP models. This should improve the direct forecasting of CW of convective nature, such as thunderstorms, hail, squalls, and showers. However, the models cannot satisfy as yet all the needs for CW predictions. Thus, different postprocessing methods are required. It is important to compare the forecasts based on direct model output (DMO) and postprocessing, where it is feasible.

Standard verification approaches for medium range NWP have limited usefulness for very high resolution (mesoscale and convective scale) forecasts. Several new verification methods have been proposed for evaluating the spatial structures simulated by high resolution models and this remains an active area of research. While most of these spatial methods measure forecast quality, some of them (e.g., variograms) address the realism of the forecast, which may be of particular interest to modelers.

Spatial verification approaches are now starting to be applied to high resolution ensemble forecasts, but much remains to be done to understand what can be learned from these approaches, both in terms of quantifying ensemble performance, and in calibrating and postprocessing ensembles to improve forecast quality and utility. The utility of spatial verification for evaluating hazard impact forecasts (e.g., flood inundation, fire spread, blizzard extent and intensity, pollution cloud) needs to be explored, especially since graphical advice and warnings are becoming more common.

The goal of the proposed PP is to try out a number of forecast methods and evaluation approaches that are linked to high impact weather (not necessarily considered extreme to all users) and to provide COSMO Community with an overview and recommendations as to how CW/HIW situations should be handled.

Based on the experience of the COSMO countries and the study of the state-of-the-art methodologies in the world, a series of observed and predicted CW/HIW cases will be investigated and evaluated, and a number of most successful and promising CW/HIW methods will be identified and further developed as needed.

Status and available expertise within COSMO

Most COSMO NMSs have gathered experience and expertise in the handling of high impact weather forecasts which will be shared also through the Task work of PPAWARE. Below, some examples are given indicatively.

In MeteoSwiss, a number of postprocessing techniques are in practice: Kalman filter, MOSMIX, on point-forecast at stations. The production chain includes man-machine interactions, mixing supervised values and model outputs. Recently, a PostprocVeri project was initiated aimed at postprocessing methods yielding spatial, probabilistic, multivariate, and seamless forecasts and also to refine the verification analysis at the forecast service of MeteoSwiss. The main elements of PostprocVeri are:

- **Probabilistic postprocessing**: well in line with NWP developments at MeteoSwiss and international developments in the field of postprocessing → Ensemble postprocessing routines, aiming at delivering calibrated ensemble predictions
- **Spatial output:** given the increasing importance of local forecast information, the postprocessing approaches aim at delivering output for any surface location of interest in Switzerland.
- **Start with basic meteorological variables:** introduce postprocessing for four basic meteorological variables (temperature, precipitation, wind, and cloud cover), build up knowhow to apply to derived variables later on
- **Limit** NWP data sources to COSMO and IFS ensembles (models operationally used in today's forecast production), but ensure applicability to other NWP models

At IMGW-PIB (Polish National Weather Service) CW/HIW was the subject of interest and cooperation with road and air maintenance services. Starting from 2004, collaboration with roads maintenance services resulted in procedures of forecast of fog (or visibility range, VR), road icing (esp. occurrence of "black ice") and intensive precipitation of snow, also in coincidence with strong wind that can blow snow on the roads. As far as aviation services are concerned, IMGW-PIB cooperates with PAZP (or NAA, National Aviation Agency). This cooperation includes – among others – forecasts of wind shear, runway visibility range (RVR), thunderstorms etc. The information delivered to PAZP contains not only absolute values, but also the probabilities (Bayesian approach) of occurrence of certain phenomena.

In RHM, many forecasters issue CW warnings based on different indices calculated from NWP production. For example, the thunderstorm probability is calculated using different instability indices, such as Whiting index (Richter H., 2004) taking into account the differences between temperature, dew point temperature, and dew point deficit at different isobaric heights or Peskov index estimating instability in the middle of convective cloud, humidity, vertical wind shear, and near-surface convergence (Guidelines, 1965). It should be noted that there exist about 26 such indices in the world. In work (Gubenko, 2016), a comparison of the accuracy of thunderstorm forecasts using these indices is given, as well as the quality estimates of different types of measurements.

Links to other projects

The PP AWARE is linked to the WMO Severe Weather Forecasting Demonstration Project and HIWeather Project. The mission of the latter is to promote cooperative international research to achieve a dramatic increase in resilience to high impact weather, worldwide, through improving forecasts for timescales of minutes to two weeks and enhancing their communication and utility in social, economic and environmental applications.

There is a link to SURF (Study of Urban Rainfall and fog/haze) (experiment to study urban pollution and extreme precipitation in Beijing) through the collaboration of RHM.

The PP AWARE is linked to the EUMETNET SRNWP EPS project, whose phase II ended in December 2018. The main aim of this project is to contribute to build very high-resolution ensemble systems in Europe, resolving the convection-permitting scale phenomena. This is achieved through

- the enhancement of cooperation on Limited-area Ensemble Prediction System (recognized as a high priority goal by EUMETNET members when composing the Forecasting Roadmap)
- the development of convection-permitting ensemble prediction capabilities in Europe (crucial for forecasting a range of weather phenomena and in particular to improve severe weather prediction)

The PP AWARE will benefit from the mutual exchange of experience with the EUMETNET SRNWP EPS project, in particular in what concerns the application task of the latter, where new products and methodologies for calibration of LAM ensembles for extremes and for probabilistic prediction of thunderstorms and fog are developed (calibration of ensemble outputs, mainly for extreme wind, precipitation and temperature by AEMET; products for probabilistic prediction of thunderstorms and fog, focus being on selected phenomena by COMET).

Finally, in terms of verification software availability, PP AWARE is linked to PP CARMA that has the goal to provide COSMO community with the MEC-Rfdbk software developed by DWD, to perform traditional point verification both for the surface and the upper air using conventional methods, which arise from operational and research activities.

Description of individual tasks

Task 0. Administrative Tasks

Due to the distributed nature of the project participation team, administrative activities will be included in this task, in order to maintain a good collaboration and information flow between all participants (regular web conferences, workshops, etc.). A mailing list for the project will be used in order to support communication and information exchange between project participants.

Deliverables

Project coordination, meetings, preparation of plans/reports, workshops and regular web-conferences organization.

Contributors

Task 0: Flora Gofa (0.20) and Anastasia Bundel (0.20)**,** 0.4 FTE, Start 09.2019 – End 08.2021

Task 1. Challenges in observing CW/HIW (WG5 and WG4 related)

Question: How well high-impact weather is represented in the observations, including biases and random errors, and their sensitivity to observation density?

HIW phenomena studied: visibility range (fog), thunderstorms (w. lightning), intense precipitation, extreme temperatures and winds.

This task is basic for the understanding of the nature of phenomena studied within the project. The task will consider which observations are necessary to verify HIW forecasts, as well as issues related to observation sparseness, quality, and thresholds. Furthermore, through the Task, work effort will be given to identify the dependence of HIW prediction improvements on dense observations, to identify observation requirements for monitoring the selected hazards and/or for assessing forecast accuracy, and quantify the role of observation uncertainty. The study on observation uncertainty was initiated within the INSPECT project (COSMO technical report 37, chapters 4.1.3 and chapter 5).
The outcome of this task is the description of available HIW observations (including non-standard ones) and their characteristics.

SubTasks

Task 1.1 Overview of CW/HIW observational data sources characteristics
Review of available sources, estimation methodologies, and associated error.

Task 1.1.1 (RHM)
To grant a good description of HIW phenomena, an adequate source of observational data should be provided. This is of high importance especially in connection with task 3 (verification) and 4 (overview and improvement of existing forecast methods.

Work steps:

- Assessment of usefulness of particular observational data sources, keeping in mind the criteria of validity, long period of observation, “whitelisted” quality, accessibility, etc. Recommendations of the usage.

Deliverables

Intermediate reports on the consequent steps of work, with particular attention paid to the recommendations, mainly in terms of easy access to data.

Task 1.1.2 (IMGW-PIB)
CW events often require additional sources of observations besides traditional measurements made at national networks.

Work steps:

- Description of methods to diagnose areas of thunderstorm activity
- Estimates of accuracy of lightning detection networks, worldwide and at the national levels, including the radar and satellite data

Deliverables
Intercomparison of diagnostic methods for thunderstorm activity, including accuracy estimates based on selected test cases.

Task 1.2. Approaches to introduce observation uncertainty
Analysis of observation uncertainty contribution to verification scores focused on HIW forecasts. Quantification of observation uncertainty is important for forecasting all the hydrometeorological variables. For HIW events, which are often the rare ones, it is of extreme importance. Accounting for observation uncertainty can change verification results and it becomes even more important at present when the forecast quality tends to approach the level of observational errors.

Work steps:

- Analysis of literature about the methods to introduce observation uncertainty for the HIW phenomena of intense precipitation, extreme temperatures and winds.
- Analysis of available datasets
- Tests with the new scores accounting for observation uncertainty

Deliverables:
Report on existing methods to introduce observation uncertainty and an overview of novel verification scores accounting for observation uncertainty (e.g., CRPS adapted for observation ensemble).

Contributors
Task 1.1: Andrzej Mazur, FTE 0.1, Start 09.2019 – End 02.2020, Anastasia Bundel, FTE 0.05, Start 10.2019 – End 02.2020
Task 1.2: Anastasia Bundel, FTE 0.05, Start 10.2019 – End 04.2020
Total Resources Task1: 0.2FTEs

Task 2: Overview of appropriate verification measures for HIW (WG5 related)

Question: How well high-impact weather forecast quality is represented with commonly used verification measures? What is the most appropriate verification approach?
HIW phenomena studied: intense precipitation, thunderstorm (lightning activity, visibility range (fog).

The verification of many HIW events requires metrics that remain useful for rare events. Their main characteristics are that must be less dependent on the base rate (climatology of the event), the dependency on spatial and temporal scales and sampling of observational data should be minimized and the dependency on the verification grid should be minimized. Hits and false alarms should be taken into account.
As **no single score** exists that addresses all these properties, the response of commonly used scores on HIW for these properties will be studied through this Task on

selected test cases. Scores behavior for the evaluation of both the deterministic and ensemble forecasts of HIW (SEDI, EDS, EDI, SEEPS, CRPS) will be addressed. Global scores tuned over extreme events will be also tested.
Proper scoring rules for extremes, downscaling of precipitation extremes will be studied.

SubTasks

Task 2.1 Survey for assessment of proper verification of phenomena – continuous vs. discrete verification (occurrence vs. specific values).

This task should provide arguments for choosing a particular method that should be used to verify HIW phenomena. Continuous phenomena are easier to describe, and a mathematical apparatus for this purpose is huge and wide and easily accessible, however, it may be tempted to check whether other methods could be used in the verification (see task 3). One should also keep in mind that usually very sophisticated and complicated methods are not particularly useful (law of parsinomy, Ockham's razor).

Work steps:

- Brief researches (case studies) to assess applicability of particular method(s);
- When (if) possible, comparison and judgment whether continuous or discrete methods may/should be applied.
- Overall final recommendations

Deliverables:

(Intermediate) reports on the consequent steps of work, possibly papers in peer-reviewed journals and suggestions/recommendations of method to be selected.

Task 2.2 Role of SEEPS and EDI-SEDI for the evaluation of extreme precipitation forecasts.

Combining data from a larger number of stations during the evaluation process of NWP forecasts can produce false skill if climatologically diverse regions are combined. In particular, when interest is driven by the presence and implications of heavy precipitation events, one must aggregate regions of similar climatology that will be reflected in the precipitation thresholds that constitute an 'extreme' event in the specific area. Consequently, it is important for HIW events to analyse the relative strengths and weaknesses of commonly used statistical measures but also to highlight the importance of threshold choice especially during the aggregation of results of stations with different climatological characteristics.
Stable Equitable Error in the Probability Space (SEEPS) uses the categories 'dry', 'light precipitation' and 'heavy precipitation' based on the climatological cumulative precipitation distribution (observation derived -30 year database). In addition, the supplementary application of categorical scores like the Symmetric External Dependency Index (SEDI) suitable for extreme events but adjusted to the climatological characteristics (model derived) of a specific region, can further contribute to the objectives of an operational meteorological service, including long term monitoring of model performance and assistance in the decision-making process when forecasting rare events.

Work Steps:

- Description of the theoretical basis and methodology of application of score suitable for high precipitation events (deterministic forecasts)
- Analyze the variation in precipitation climatology for various geographical regions and seasons around Greece

- Selection of intense precipitation events and application of the SEEPS and Extremal Dependency scores for COSMO4, COSMO1, ICON-GR and ECMWF forecasts for different stations.
- Determine what perspectives these scores provide, if any, on precipitation forecast when climatology of stations is taken into consideration.

Deliverables:

Overview of commonly used statistical metrics suitable for extreme precipitation events.
Short report on the description of the method that is followed for the evaluation of precipitation forecasts over Greece.
Statistical results based on chosen case studies followed by conclusions/recommendations on using the methods.

Task 2.3 Extreme Value Theory (EVT) approach- Fitting precipitation object characteristics to different distributions:

EVT is a branch of statistics which studies the properties of extreme values, and enables them to be fit with theoretical distributions (or probability models). The common approach to form a two-way contingency table for the joint distribution of forecasts and observations is of limited utility, because of sparse entries for extreme classes. This joint distribution could be represented by some parametric form, representing the behavior in the extreme tails. The adapted theory of extreme values is lately adopted and provide a family of parametric distributions with flexible tail behavior. Making use of the calibration-refinement factorization, the focus is on modeling the extreme tails of the conditional distribution of the weather observation given a forecast.

Work Steps:

- Statistical analysis of precipitation object characteristics based on the radar data for Central Russia for warm and cold seasons.
- Work with R Extremes library, fevd function (fitting extreme value distributions to data, plotting histograms, parameter estimation, probability densities, qq-plots, return periods, and other functionality).
- Fitting distributions of large object sizes (and probably, intensities) using fevd, qq-plots and pdf for observations of warm and cold periods.
- Choosing the best fitting distribution.
- Comparison of parameters of extreme value distributions of precipitation object characteristics during warm and cold season.
- Preliminary research idea: to interpret parameters of Pareto distribution for forecasts and observations as systematic errors and to formulate recommendations for forecasters

Deliverables:

Histograms of statistical parameters of precipitation objects, comparative analysis of extreme value distribution parameters for precipitation objects during the warm and cold period. Proposals for forecast improvement using the information obtained.

Contributors

Task 2.1: IMGW-PIB Andrzej Mazur, FTE 0.2, Joanna Linkowska, FTE 0.15, *Start 10.2019 – End 05.2020.*
Task 2.2: HNMS: Flora Gofa, FTE 0.10, Dimitra Boucouvala, FTE 0.15, *Start 12.2019 – End 08.2020.*
Task 2.3: RHM: Anatoly Muraviev, FTE 0.3, Start 09.2019 – End 08.2020.

Total Resources Task1: 0.9 FTEs

Task 3: Verification applications (with a focus on spatial methods) to HIW *(WG5 and WG7 related)*

Question: Can spatial verification methods contribute to the proper evaluation of HIW phenomena and in what way?
HIW phenomena studied: intense precipitation, thunderstorm (lightning activity LPI, visibility range (fog).

This task will make use of the analysis and outcomes of Task 2. It is also connected with and continued from PP-INSPECT (http://www.cosmo-model.org/content/model/documentation/techReports/docs/techReport37.pdf) and MesoVICT project on the spatial methods.

<u>**SubTasks**</u>

Task 3.1 Verification of forecasts of intense convective phenomena (thunderstorms w. lightning) and visibility range (fog)

This subtask should supply with the extended knowledge of quality of HIW phenomena' forecasts, in connection with selected spatial verification methods (this study should supplement task 2, subtask 2.1 – see above – by the application of spatial methods) and from the point of view of parameterization/forecasts methods (task 4, see below).

Work Steps:

- Verification of HIW phenomena using spatial methods (eg. SAL- the structure (S), amplitude (A) and location (L)) vs. archived data.
- Verification of operational forecasts with current data (observations)
- Recommendations

Deliverables:
Report on the verification approach and results of visibility range and thunderstorms intensity with the use of predefined methods, recommendations and considerations.

Task 3.2 Lightning potential index (LPI) in mountain regions
Strong convection, storms are potentially phenomena that can cause significant damages, which could be prevented by accurate weather forecasts. The outcome of this subtask should be the estimation of quality of the local LPI (Lightning potential index) forecasts received by MeteoSwiss end users. LPI will be integrated into the COSMO operational chain at MeteoSwiss and will be used to supply several products (See Task 4.3.1.)
Work steps:

- Integration in the operational chain of COSMO-1, and COSMO-e
- Tests of the flash conversion rate LPI to flash numbers
- Case studies, and verification
- Comparison with the IFS products for end users

Deliverables
Reports on the quality of LPI forecasts at MeteoSwiss

Task 3.3. CRA (Contiguous rain area) and FSS analysis on intense precipitation

This task relates to two of the project key aspects: a. how well high-impact weather is represented in models, including systematic and stochastic errors, and their sensitivity to model resolution and b. the predictability, current predictive skill, and the user's interpretation of forecast value in high-impact weather situations. This task continues the corresponding INSPECT task, but with a focus on intense precipitation events. In addition to precipitation data, the potential of using reflectivity will be explored.

Work steps:

- Preparation of idealized cases for testing.
- Bug-fixing in craer R SpatialVx function (partially based on idealized cases).
- CRA and FSS analysis on MesoVICT cases (more cases will be considered compared to INSPECT work)
- Running CRA and FSS on summer and winter periods for the Central Russia COSMO-Ru and radar fields.
- Possibly, the work in step 4 will be performed for reflectivity fields directly.

Deliverables

CRA scores and the FSS analysis for intense precipitation and (possibly) reflectivities.

Task 3.4 DIST methodology tuned on high-threshold events for flash floods forecast evaluation

The main goal of the methodology, an evolution of the DIST methodology *(see Marsigli, C., Montani, A., and Paccagnella, T.: A spatial verification method applied to the evaluation of high-resolution ensemble forecasts, Meteorol. Appl., 15, 125–143, 2008)*, is to verify the products developed to estimate the QPF over catchment areas used operationally for issuing Civil Protection alerts. Verification results can be used directly to interpret how to use the forecast system and to decide in which situations one system is better than another.

The proposed methodology has been developed as a spatial method for the verification of heavy precipitation issued at high resolution. This task proposed to explore (or highlight) its suitability for verification of HIW.

In fact, it permits the use of a high-resolution rain-gauges network, but gridded observations, such as radar precipitation analysis, can be used as well. The main advantage of this approach is that no precipitation analysis is required and information about localized maxima of precipitation can be taken into account, as well as the variability of the precipitation field inside the area of interest. Similarly all the grid points that belongs to the selected area are considered, in this way the ability of the model in reproducing high precipitation events, even if with some possible positioning errors, is evaluated.

Work steps:

- For each catchment area, several parameters of the distribution of both the observed and forecast values will be computed.
- Verification using a categorical approach, using a set of indices.
- Verification of average values of precipitation over catchment areas will be used to investigate the ability of models in reproducing different amounts of precipitation.

Deliverables:

Reports on verification results using model with different resolution for different period of time.

Task 3.5 LPI verification and correlation of convective events with microphysical and thermodynamical indices.

The distribution analysis of a number of convective events in both space and time will allow lightning/thunderstorm regimes to be determined. On the other hand, lightning potential index (LPI), is a measure of the potential for charge generation and separation that leads to lightning flashes in convective thunderstorms and can be calculated from COSMO model. While the connection between cloud microphysics and lightning seems apparent, the common indices used for forecasting thunderstorms and the potential for lightning usually rely on stability and thermodynamical indices (e.g. CAPE). An effort will be given to correlate LPI with observed lightning. In this way, it will be evaluated if for Greek territory LPI can be useful parameter for predicting lightning as well as a tool for improving weather forecasting of convective storms and heavy rainfall. Statistical evaluation of precipitation forecasts with SAL spatial method on selected intense precipitation events will be also performed by comparing gridded observation datasets (satellite and radar precipitation estimates), as well as lightning data with model outputs (convective precipitation, LPI, CAPE).

Work steps:

- Selection of intense precipitation events preferably for various weather regimes.
- Analysis of lightning activity as derived by HNMS network and comparison with LPI (COSMOGR1).
- Construction of gridded observation datasets based on HNMS lightning network
- Application of spatial methods techniques on lightning forecasts derived from models with different resolution mainly focused on structural characteristics
- Analysis of lightning distribution characteristics in comparison with precipitation and other thermodynamic indices in order to determine what is the preferable tool for forecast of highly convective events.

Deliverables:

Application of the methodology and results on selected case studies. Conclusions based on the performed analysis.

Task 3.6 Work on the comparative verification of NWC and NWP results using spatial verification methods as part of the SINFONY project at DWD.

Germany is exposed to various kinds of high impact weather phenomena. Strong impacts are expected from convective events during summer time which happen to be especially hard to predict. The project SINFONY at DWD has the goal to improve forecasts of such events in the short range up to 12h. On the observation side, high-resolution reflectivities from the German radar network are used. Such reflectivities give the instantaneous state of the current precipitation situation, where HIW is correlated with high reflectivities. On the model side (COSMO-D2-EPS and later ICON-LAM) reflectivities are derived from the forward operator EMVORADO. One goal will be to compare the 1-moment with the 2-moment convection scheme. As the latter is able to produce higher reflectitivies, it is expected to better capture extreme events. Another goal will be to compare pixel and object-based reflectivity nowcasting for their potential to predict development of HIW. For the nowcasting, it is planned to perform life-cycle analyses and to use curved tracks, ensemble-nowcasting, etc. In the end, verification hopefully has contributed to the development of a combined product for the seamless prediction of the evolution of thunderstorms in summer. Hence, there will be a rich data base and tools that should be useful for the objectives of AWARE.

Work steps:

Data basis:

- Observation: Grid-based reflectivities and identified objects from volume radar scans. Objects contain a variety of properties which can be used for verification
- Nowcasting: Grid-based reflectivity extrapolation in the future (currently linearly later including development tendencies, curved tracks, etc.). Object-based nowcasting (currently linearly later including life-cycle analyses of thunderstorms, curved tracks, error estimation with Kalman-Filter, etc.). For both, an ensemble will be developed.
- Model: Reflectivities estimated by forward operator EMVORADO. Comparison of 1-moment and 2-moment convection scheme. As the latter is able to produce higher reflectivities, it is expected to better capture extreme events. Besides, many different attributes will be assimilated, e.g. radar reflectivities, reflectivity objects, satellite data (VIS), etc., to improve the forecast. A faster update cycle of the assimilation process will be developed.
- Combined product: seamless combination of nowcast and model forecast, grid-based and object-based

Spatial verification:

- Neighborhood: We will use common neighbourhood verification methods (FSS, Minimum Coverage, pragmatic approach, etc.). Probably, extension of methods for verification of ensemble forecasts.
- Focus on feature-based methods:
  - case and parameter studies with Interester from MODE (Davies et al., 2009) over Germany. Estimation of limit parameters (for centroid distance, area ratio, intersection area, min. boundary separation, and more) in Germany.
  - Parts of SAL will be used
  - Try to combine neighbourhood and feature-based methods. This results in “gridded objects”. Within boxes, we will compare object properties without any matching algorithm. The quality of the forecast will then be provided by comparative measures.
  - Application of all methods on ensemble forecast data
- Development of an R-package which will provide the above mentioned methods.

Deliverables

Reports on development of the work

Applications of above mentioned methods to a chosen case study period in May/ June 2016

Presentation of results

Contributors Task 3

Subtask 3.1: IMGW-PIB: Joanna Linkowska, FTE 0.3, Andrzej Mazur, FTE 0.2 Start 09.2019 – End 08.2021

Subtask 3.2: MCH: Daniel Cattani, FTE 0.1 Start 09.2019 – End 08.2021

Subtask 3.3: RHM: Anastasia Bundel, FTE 0.3, Start 09.2019 – End 08.2020

Subtask 3.4: ARPAE: Maria Stefania Tesini, FTE 0.1 Start 09.2019 – End 09.2020

Subtask 3.5: HNMS: Dimitra Boucouvala, FTE 0.15, Flora Gofa, FTE0.15, Start 10.2019 – End 08.2020

Subtask 3.6: DWD: Michael Hoff, FTE 0.1 Start 09.2019 – End 02.2021

Total Resources Task3: 1.4FTEs

Task 4. Overview of forecast methods, representation and user-oriented products linked to HIW (WG4 related)

Question: How well is HIW is represented in postprocessing? What are the pros/cons of DMO vs. PostPro with respect to HIW phenomena predictions? What is the current predictive skill, and the user's interpretation of forecast value in high-impact weather situations (observed and/or forecast)?
HIW phenomena studied: fog/visibility, convection related CW (thunderstorms, lightning, hail, squalls, showers, flash floods)

HIW forecasts are not always a direct model output (DMO) product. In particular, the forecasts of the following meteorological variables are often a result of postprocessing:
- Fogs and visibility
- Thunderstorms (heavy precipitation, lightning)
- Other severe phenomena (tornadoes, super-cell storms, CAT)
- Wind hazard forecasting, wind metrics that relate to impacts.

There are many methods and indices to predict these variables. This task will summarize them. Moreover, if not-HIW forecasts begin to be issued based on direct model output (DMO) in some weather services, human analysis is almost necessarily required when there is a possibility of HIW phenomena occurrence. Thus, the role of forecaster is considerable in relation to this task. The task will provide an overview of direct model output and postprocessing methods: describe the state of the art in predicting HIW; identify processes that lead to high impacts; make recommendations for targeted work to address weaknesses in understanding and predicting them. This task also touches on the question of decision-making based on CW/HIW forecasts.
This task relates to the following key project aspects: what models can provide and what warnings need to be made for (lightning, hail, wind gusts, fog, etc.) and the user's interpretation of forecast value in high-impact weather situations (observed and/or forecast).
The output of this task is improvement in providing COSMO users with forecast/warnings of the most important HIW events.

<u>SubTasks</u>

Task 4.1. Postprocessing vs. direct model output for HIW

This task relates to the following key project aspect: How well high-impact weather is represented in postprocessing and modeling. In order to be able to choose the best method to predict HIW, we need to understand the state-of-the art in this field, both in direct modelling and processed model data. This task will provide an overview of the forecast methods for some of the most important HIW parameters. This task will also provide a comparison of post-processing techniques for HIW forecasts vs. direct model output and human forecasts, where possible.

Work steps:

1. Studying the literature, internet search to understand the state-of-the art in fog/visibility modelling, and in postprocessing methods to predict fog/visibility and convection related CW (thunderstorms, lightning, hail, squalls, showers) and the overview of these methods
2. Comparison of postprocessing techniques vs. DMO and human forecasts, where possible

Deliverables

An overview of existing DMO methods for fog/visibility forecasts
An overview of existing postprocessing methods for fog/visibility forecasts
An overview of most widespread postprocessing methods for forecasting CW events related to convective processes (thunderstorms, lightning, hail, squalls, showers)
Comparison of the scores of post-processing techniques, direct model output, and human forecasts for HIW events
Recommendations to the COSMO community as to the best choice of the forecast method of the events considered in this subtask.

Task 4.2 Improving existing post-processing methods

Exploring new approaches. Machine learning. Use of multi-linear regression (MLR), adaptive (recursive) least squares (A-RLS) and/or artificial neural networking (ANN) techniques. The feasibility and the usefulness of any particular method may be increased. Existing methods would profit from use of archive data. Especially, post-processing or hind-casting (back-testing) should improve current forecasts' quality and reliability. Advantages and disadvantages may be easily assessed on the basis of training methods such as Adaptive Least–Squares Regression (ALSR), Multi-Line Regression (MLR) or Artificial Neural Networking (ANN) using archival data, and then it can be suggested to the present.

Work steps:

- Case studies, long-term archive evaluations, connected with verification issues (task 2 and 3 above)
- Assessment of chosen methods in terms of statistical factors and indicators
- Recommendations

Deliverables:

Partial reports on the quality of various forecasts methods, advantages and disadvantages; conclusions (recommendations) of hind-cast evaluation, esp. of ANN vs. MLR and ALSR; recommendations for future and operational use

Report on the verification results of visibility range and thunderstorms intensity with the use of predefined methods; possibly paper in peer-reviewed journal, recommendations and considerations.

Task 4.3 QPF evaluation approaches

The evaluation of the amount of precipitation over catchment areas is one of the most important use of the QPF at ARPAE for hydrological purpose and for the issuing of Civil Protection alert for possible floods. To meet the needs end-users, such as hydrologists or forecaster, we have developed some tools that provide mean, maximum and some other percentiles values of the precipitation field over the catchment areas of the Emilia-Romagna region. Exceeding predefined thresholds can give useful indications for situations of intense precipitation possibly leading to floods.

Work steps:

On a daily basis, summary tables with estimated mean and maximum precipitation over each catchment areas of the Emilia-Romagna region are produced for several deterministic model with different resolutions (COSMO-5M, COSMO-2I or IFS-ECMWF). Using the COSMO-LEPS system, we also evaluate the probability of exceeding selected thresholds as average precipitation over the selected catchment areas.

In this task we will describe the process that starting from the model QPF arrives to the final product for the end-user.

Deliverables

An overview of all the products provided to the end-user (forecaster or hydrologist)

Task 4.4. Representing and communicating HIW forecast for decision making

This subtask will describe approaches to representing and communicating HIW forecasts/warnings for a wide range of users (the kind of users depends on the country/institution) with examples (maps, test messages, symbols). It will compare data transfer channels to communicate HIW forecasts: internet sites, sms lists, e-mail, radio, mobile apps vs. “common” transfers. It will also study behavioral aspects of warnings.
Given the increasing number of HIW situations and the request to mitigate their impact, it is necessary to identify the best methods (media, applications, etc.) and forms (maps, test messages, symbols, etc.) to communicate the meteorological information to authorities, the public and specific users, depending on their specific needs.

Work steps:

RHM:

- Study of the state-of-the-art visual forms of representing forecast/warnings for different types of HIW events and modern transfer channels.
- Overview of the RHM experience in representing HIW forecasts/warnings (including the Russian system similar to MeteoAlarm).
- Overview of RHM transfer channels with recommendations on how to improve them.
- Survey of RHM users about how they prefer the warnings to be delivered to them and how they react to these warnings.

NMA:

- Study of methods used to convey meteorological information towards users in cases of HIW situations.
- Identifying suggestions (feedback) from users regarding their understanding of HIW situations, how the information reaches them and how they use it.
- Preparing an overview with the methods and forms in which the information could reach users.

Deliverables

Overview of approaches to communicating high impact weather to different categories of users.
Feedback from users.
Examples of representing HIW forecasts.

Task 4.5 Product generation and calibration of convection-permitting ensemble

An effective usage of convection-permitting ensemble forecasting requires that the predictions are post-processed in order to provide to the forecasters the information contained in the ensemble in a meaningful and synthetic way. In order to develop these products for high-impact weather situations, it is needed to assess the predictive skill of the forecasts, considering that the predictive skill depends on the phenomenon object of the prediction.
The work is part of the SINFONY Project of DWD, where a NWP ensemble (COSMO-D2-EPS) is combined with a Nowcasting ensemble, aiming at a seamless forecasting system.

The work consists in generating products from a seamless ensemble for the prediction of convective events. To pursue this aim, upscaling of the fields and calibration of the model output will be investigated. Among the project objectives, the proposed subtask deals with the predictability of high impact weather (thunderstorms) and with the generation of products for their prediction, which can be effectively used by the forecasters.

Work steps:
Specifically, this subtask deals with reporting on the generation of products, mainly for the prediction of convection, from the combined ensemble, considering both products in terms of precipitation and in terms of probabilities. A calibration of the ensemble products will be implemented and evaluated, considering also the impact of upscaling the fields prior to calibration. For doing this, it will be investigated which aggregation scale can bring most benefit. Different calibration techniques will be tested, starting from the logistic regression.
Deliverables:
Reports on the method for calibration of the combined ensemble for convective events and on the verification of the quality of the resulting product.

Contributors Task 4
Subtask 4.1: RHM, E.Tatarinovich, FTE 0.3; A.Bundel, FTE 0.2, Start 09.2019 – End 08.2021
Subtask 4.2: IMGW-PIB, Andrzej Mazur, FTE 0.15, Grzegorz Duniec, FTE 0.1, Start 09.2019 – End 08.2021
Subtask 4.3: ARPAE-SIMC, Maria Stefania Tesini, FTE 0.1, Start 09.2019 – End 12.2020
Subtask 4.4: RHM, Anastasia Bundel, FTE 0.1, Start 01.2020 – End 08.2021; NMA, Tudor Balacescu, FTE 0.1, Start 06.2020 – End 09.2021
Subtask 4.5: DWD, Chiara Marsigli, FTE 0.2, Start 09.2019 – End 09.2020
Total Resources Task4: 1.25FTEs

Total Resources: 4.15 FTEs

RHM: 1.5FTEs, IMGW-PIB: 1.2FTEs, HNMS: 0.75FTEs, DWD: 0.3FTEs, ArpaE-SIMC: 0.2FTEs, MCH: 0.1FTEs, NMA: 0.1FTEs

Risks

Small number of extreme observed event database. Definition of extreme events depends on local climatology. Dataset with observations and model outputs need to include rare events (various single test cases or long time series).

Project Participants

ARPAE-SIMC: Maria Stefania Tesini
DWD: Chiara Marsigli, Michael Hoff
HNMS: Flora Gofa, Dimitra Boucouvala
IMGW-PIB: Andrzej Mazur, Joanna Linkowska, Grzegorz Duniec,
MeteoSwiss: Daniel Cattani
NMA: Tudor Balacescu
RHM: Anastasia Bundel, Ekaterina Tatarinovich, Anatoly Muraviev

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Task	Contributing scientist(s)	FTE-years	Start	Deliverables	Date of delivery
1.1	Andrzej Mazur, IMGW-PIB Anastasia Bundel, RHM	0.10 0.05	09.2019	Intercomparison of diagnostic methods for thunderstorm activity, including accuracy estimates based on selected test cases. Intermediate reports on the consequent steps of work, with particular attention paid to the recommendations, mainly in terms of easy access to data.	02.2020
1.2	Anastasia Bundel, RHM	0.05	10.2019	Report on existing methods to introduce observation uncertainty and an overview of novel verification scores accounting for observation uncertainty (e.g., CRPS adapted for observation ensemble).	04.2020
2.1	Andrzej Mazur, IMGW-PIB Joanna Linkowska, IMGW-PIB	0.20 0.15	10.2019	(Intermediate) reports on the consequent steps of work, possibly papers in peer-reviewed journals, suggestions/recommendations of method(s) to be selected.	05.2020
2.2	Flora Gofa, HNMS Dimitra Boucouvala, HNMS	0.10 0.15	*12.2019*	Overview of commonly used statistical metrics suitable for extreme precipitation events. Short report on the description of the method that is followed for the evaluation of precipitation forecasts over Greece. Statistical results based on chosen case studies followed by conclusions/recommendations on using the methods.	*08.2020*
2.3	Anatoly Muraviev, RHM	0.30	*09.2019*	Histograms of statistical parameters of precipitation objects, comparative analysis of extreme value distribution parameters for precipitation objects during the warm and cold period. Proposals for forecast improvement using the information obtained.	*08.2020*
3.1	Andrzej Mazur, IMGW-PIB Joanna Linkowska, IMGW-PIB	0.2 0.3	*09.2019*	Report on the verification approach and results of visibility range and thunderstorms intensity with the use of predefined methods, recommendations and considerations.	08.2021
3.2	Daniel Cattani, MCH	0.1	09.2019	Reports on the quality of LPI forecasts at MeteoSwiss	08.2021
3.3	Anastasia Bundel, RHM	0.3	09.2019	CRA scores and the FSS analysis for intense precipitation and (possibly) reflectivities	08.2020
3.4	Maria Stefania Tesini, ArpaE-SIMC	0.10	09.2019	Reports on verification results using model with different resolution for different period of time.	09.2020
3.5	Dimitra Boucouvala, HNMS Flora Gofa, HNMS	0.15 0.15	10.2019	Application of the methodology and results on selected case studies. Conclusions based on the performed analysis.	08.2020
3.6	Michael Hoff, DWD	0.10	09.2019	Reports on development of the work Applications of above-mentioned methods to a chosen case study period in May/ June 2016. Presentation of results	02.2021
4.1	E.Tatarinovich, RHM A.Bundel, RHM	0.30 0.20	09.2019	An overview of existing DMO methods for fog/visibility forecasts An overview of existing postprocessing methods for fog/visibility forecasts An overview of most widespread postprocessing	08.2021

Task	Contributing scientist(s)	FTE-years	Start	Deliverables	Date of delivery
				methods for forecasting CW events related to convective processes (thunderstorms, lightning, hail, squalls, showers) Comparison of the scores of post-processing techniques, direct model output, and human forecasts for HIW events Recommendations to the COSMO community as to the best choice of the forecast method of the events considered in this subtask.	
4.2	Andrzej Mazur, IMGW-PIB Grzegorz Duniec, IMGW-PIB	0.15 0.10	09.2019	Partial reports on the quality of various forecasts methods, advantages and disadvantages; conclusions (recommendations) of hind-cast evaluation, esp. of ANN vs. MLR and ALSR; recommendations for future and operational use Report on the verification results of visibility range and thunderstorms intensity with the use of predefined methods; possibly paper in peer-reviewed journal, recommendations and considerations.	08.2021
4.3	Maria Stefania Tesini, ArpaE-SIMC	0.10	09.2019	An overview of all the products provided to the end-user (forecaster or hydrologist).	12.2020
4.4	Anastasia Bundel, RHM Tudor Balacescu, NMA	0.10 0.10	01.2020	Overview of approaches to communicating high impact weather to different categories of users. Feedback from users. Examples of representing HIW forecasts.	08.2021
4.5	Chiara Marsigli, DWD	0.20	09.2019	Reports on the method for calibration of the combined ensemble for convective events and on the verification of the quality of the resulting product.	09.2020
0	Flora Gofa,HNMS (0.20) and Anastasia Bundel (0.20), RHM	0.4	09.2019	Project coordination, meetings, preparation of plans/reports, workshops and regular web-conferences organization.	09.2020
All		**4.15**	**09.2019**		**08.2021**