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RESEARCH

High-impact weather in Italy: a workshop to exchange the experience of weather forecasters and researchers

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Abstract
A workshop on high-impact meteorological events in Italy was jointly organized by the newly formed Italia Meteo Agency (AIM) and the Italian Association of Atmospheric Sciences and Meteorology (AISAM) on September 27, 2022. The aim of the workshop was to promote the sharing of the experiences that all operational and research meteorological centers in Italy have gained on specific types of high-impact events, favoring the establishment of a common know-how of Italian operational meteorology.

Keywords High-impact weather · Weather forecasts · Meteorology

1 Introduction

The idea of a workshop on high-impact meteorological events in Italy was triggered by the need for a discussion across the Italian meteorological community, bringing together

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forecasters and modelers. Same (or similar) meteorological events are often analyzed in different regions, using different tools and approaches. As such, sharing the experience gained by meteorologists from different regional institutions can be an advantage for colleagues from neighboring regions and can provide a complementary perspective to their interpretation.

The meeting was organized in Bologna (RAI headquarters) by the Italian Association of Atmospheric Sciences and Meteorology (AISAM) and the newly formed Italia Meteo Agency (AIM) on September 27, 2022, in the form of five short communications, each lasting 20–25 min, followed by 35–40 min of discussion. This type of format allows for a broader and more in-depth discussion, but it restricts the number of possible contributions to a few selected institutions. Approximately 40 participants attended the meeting on site and 80 remotely. The discussion allowed to untangle different aspects of common interest and to share comments or considerations of potential interest to other participants. The organizers intend to plan similar events at least with annual frequency and to extend the invitation to present their work to other institutions.

The short-term objective of the workshop was to initiate and promote the sharing of the experiences that all operational and research meteorological centers in Italy have gained on specific types of high-impact events. In a long-term perspective, we expect this approach to reduce the barriers that still exist among meteorological centers in Italy and to foster full support for the AIM, which is going to collect and promote meteorological activities in Italy following common standards and practices, favoring the establishment of a common know-how, i.e., a sort of shared background of Italian operational meteorology, which is still missing and is necessary given the establishment of AIM. The absence of an Italian school in dynamic meteorology has limited the capacity of analysis of these cases. Competencies to interpret these events are sometimes gained locally with the forecasting practice; hence, meetings like the present one, which allow the sharing of know-how, go in the right direction to overcome this limitation. In Germany, there has been a strong interaction between the national weather service and the universities: this line of action can be a guide for AIM. For these reasons, we think that the publication of the workshop extracts can be appreciated by weather forecasters from different agencies and can represent a first step in this direction.

2 Workshop contributions

Five contributions populated the workshop, which concerned either single events or general issues on forecasting severe weather in Italy. A summary of the main points that were presented and of the following discussion is reported hereafter. A more extensive presentation of the results is provided in the articles published in the same issue of the journal.

2.1 Supercells and severe convection in Friuli Venezia Giulia (FVG) region (ARPA FVG)

2.1.1 Presentation

The presentation focused on the forecasting activity at ARPA FVG. The “a-posteriori” objective interpretation of meteorological events is an important activity of the center aimed at supporting the understanding and prediction of severe weather. The FVG region is affected by the highest rainfall amount in the Alpine region (Isotta et al. 2014), the highest number of lightning flashes (Manzato et al. 2022), one of the highest frequency of hailstorms in the Alpine area; it is also a hotspot for tornadoes and waterspouts (Giaiotti et al. 2007; Miglietta and Matsangouras 2018). Three case studies are discussed:

- 8 August 2008 (Pucillo et al. 2020), characterized by the transition of intense scattered supercell thunderstorms, with large hailstones, into a bow echo-like system (Fig. 1a) with observed waterspouts. The transition into a bow echo-like structure occurs when a squall line associated to the incoming cold front descends from the Alps and intercepts a supercell (as in French and Parker 2014; Taszarek et al. 2019), providing very intense wind speed (up to 163 km/h).
- 12 September 2012 (Manzato et al. 2015; Miglietta et al. 2016): as in the previous event, the case was characterized by the transition from supercells (two distinct merging cells) into a bow echo with intense outflow. Overshooting tops were detected, suggesting very strong updrafts. The strong variation in space and time of several instability indices suggests the limited predictability of this kind of events.
- 8 September 2022 (Fig. 1b): it is characterized by the evolution of a supercell into a quasi-linear convective system (QLCS) and then, for a short period, into a stationary V-shaped storm, with accumulated rainfall up to 163 mm in 3 h. Corfidi (2003) vectors were helpful for forecasters to predict the correct evolution of the system. Compared to the operational prediction of the case of 2012, more precise indications on the affected areas (the east side of the region) were added by local forecasters.

2.1.2 Discussion

The discussion focused on the aspects that should be considered to issue a forecast for such cases of severe convection. The first step should be the dynamical and thermodynamic

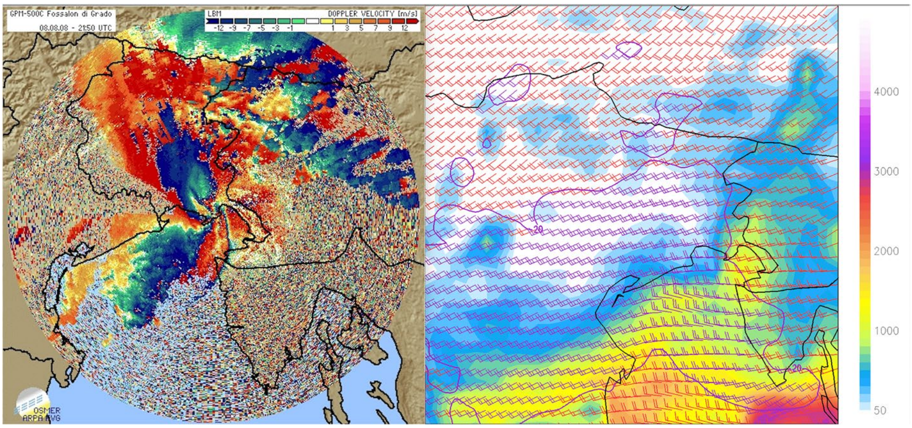

Fig. 1 **a** (left) The Doppler radar lowest beam map during the most intense stage of the 8 August 2008 storm. Multiple folding of the radar signal is present, which is typical of very intense wind speeds. A linear storm (bow echo-like) can be identified; **b** (right) deep layer shear and CAPE as predicted by ECMWF-IFS in the event of 8 September 2022 at 1200 UTC. The combination of the two parameters assesses conditions favorable to severe weather. In conclusion, small differences among three relatively similar cases determine dramatic changes in the evolution of the systems. The transition among different features is very difficult to predict, since it occurs at very small temporal and spatial scales that have limited predictability, but it has a significant impact on the events associated with the different storms

analysis, for which each forecaster has, however, a different sensibility. Therefore, warnings are issued only after the merging of different forecasters' opinions, to take into account different perspectives in the prediction. The application of some propagation vectors, well known in the scientific literature, such as Corfidi (2003) and Bunkers et al. (2006) vectors, can be helpful to identify the right conceptual model, although they are mainly diagnostic tools for the a posteriori analysis.

Limited area models are analyzed to provide support to the correct interpretation of the scenario, but often they do not provide exact information on the occurrence of the event in time and space. The opinion of the ARPA FVG forecasters is that, due to the overconfidence in the models, false alarms have even slightly increased in the last few years; however, this does not represent the main concern in forecasting activity, which is instead represented by missed cases.

Precipitation warnings at ARPA FVG are mainly based on model outputs, also considering separately the contribution of convective and stratiform precipitation. The availability of a plethora of model outputs represents an added value, in terms of spread for long-range forecasting and of evaluation of extreme values for very intense events, although the analysis of different models may produce more spread among the forecasters' opinions (each forecaster has his/her own favorite model). Forecasters evaluate positively the use of a poor man's ensemble based on different large-scale and limited area numerical models to give some objective indications; in the future, the analysis of the poor man's ensemble shall be directly used in rainfall prediction. Considering the limitations in the model and the difficulty of making users understand how the predictions should be interpreted, e.g., in terms of probability, sometimes the forecasts are not as detailed as they could be. The issue of communicating the risk is important and worthy of further investigation in a future meeting. The development of nowcasting tools would be an important added value for the forecasts in the future, but they require a lot of resources for their development and application in the forecasting practice.

2.2 Waterspouts affecting the Tuscany coast (LaMMA)

2.2.1 Presentation

The municipality of the small town of Rosignano Marittimo (Tuscany region, Central Italy) asked LaMMA to determine the reasons for the recursive occurrence of waterspouts crossing its coast: in approximately 10 years, four waterspouts affected the same area, two of them damaging the same houses. Solvay Chimica Italia, a chemical plant located a few hundred meters onshore the Rosignano coast, discharges its wastewater into the open sea at temperatures higher than the sea surface. The request of the municipality is to determine if the artificial seawater warming may have favored, or reinforced, the occurrence of such high-impact weather events.

To fulfill this request, short-range numerical simulations were performed with the Meso-NH limited-area model for the four cases of waterspouts using ERA-5 as large-scale forcing, with two one-way nested domains of integration (grid spacing of 2.5 km and 500 m). For one case study (occurred on September 25, 2020), simulations using an additional inner grid, with 100-m grid spacing, were also performed. For this case, sensitivity simulations were undertaken by changing the value of the sea surface temperature (SST) in the coastal area directly affected by the water drainage (extension approximately 10 km^2) in two ways: by increasing the SST by 1.5 °C (representative of the effect of the flow of water from the Solvay drainage ditch into the open sea) and setting the SST uniformly equal to 28.7 °C, which is the average water drainage temperature from 1 to 25 September 2020 (Fig. 2).

Miglietta and Matsangouras (2018) and Avolio and Miglietta (2022) reported that the Tyrrhenian coast is a hotspot for waterspouts in the Mediterranean, and that they are more frequent in fall and summer. Since waterspouts cannot be explicitly resolved in the numerical simulations, some instability indices are used to diagnose conditions favorable to their occurrence. Bagaglini et al. (2021) identified the typical values associated with the occurrence of tornadoes in the area. Simulation results demonstrate that the values of the instability indices in the four cases analyzed here are higher than those reported in the climatology (Bagaglini et al. 2021); this holds in particular for Convective Available Potential Energy (*CAPE*), low-level shear and storm relative helicity in the lowest 1-km layer above ground level (see Fig. 3 for the case of 10 September 2017); however, the values are not significantly affected by the increase of SST in the case of September 2020.

2.2.2 Discussion

In the discussion, the morphology and orography of the Tyrrhenian coast were suggested to favor the occurrence of waterspouts, in some cases generating convergence lines that trigger convection. The role of other topographic features can be identified more clearly by using larger domains: for example, the analysis of the recent tornado in Civitavecchia (Avolio and Miglietta 2022) indicates a key role of Corsica in deflecting the flow and in determining a convergence line near the point of tornado occurrence. The fact that higher SSTs in a small sea portion facing the study area do not remarkably affect the simulations is consistent with the results for the Tyrrhenian tornadoes reported in Bagaglini et al. (2021),

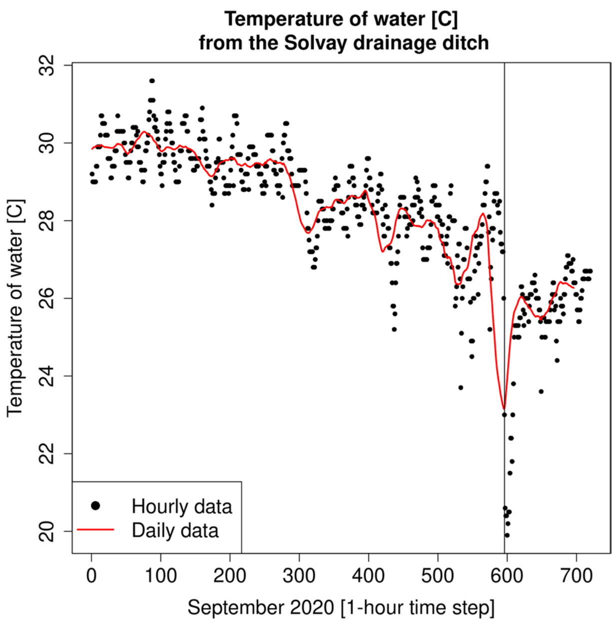

Fig. 2 Temperature (in °C) of water from the Solvay drainage ditch during the month of September 2020. Black dots indicate hourly values; the red line indicates a 24-point running mean. The black vertical line indicates the hour of the occurrence of the waterspout crossing Rosignano Solvay. Data provided by Solvay Chimica Italia

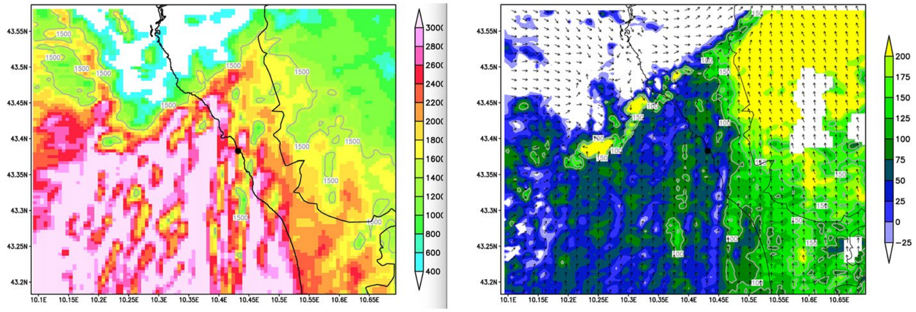

Fig. 3 **a** (left) CAPE (J/kg) and **b** (right) 1-km storm relative helicity (m^2/s^2) provided by the Meso-NH model simulation (grid spacing 500 m) at 0330 UTC, for the waterspout reported on September 10, 2017. The black dot in the center of the domain indicates the location of Rosignano Solvay

who deduced that their origin is mainly related to dynamic forcings. However, these conclusions should be taken with caution: uncertainty persists regarding the actual extent of the sea interested by the Solvay drainage flow; a wider area where the SST was changed, and a more complex and realistic evaluation of the drainage flow should be applied in the future to better assess the impact of higher SSTs on numerical simulations.

Currently, PRETEMP (pretemp.it) makes experimental forecasts for tornadoes and in general severe weather in Italy. In the future, the exceeding of climatological thresholds of instability indices may be considered in the operational practice to predict the occurrence of tornadoes; obviously, the thresholds proposed in Bagaglini et al. (2021) are based on ERA-5 reanalyses and should be adapted to higher resolution model outputs. As regards the numerical setup, very high–resolution simulations with cloud models, using a LES approach, can be attempted in the future to directly simulate the eddies and investigate the impact of perturbed SSTs on their generation or reinforcement.

2.3 The heavy rain event affecting Liguria on October 4, 2021 (ARPAL)

2.3.1 Presentation

The presentation focused on a case study that was interesting for its unusual occurrence on the downwind (northern) side of the Ligurian Apennines and its unexpected evolution, especially in terms of rainfall amounts: up to 172 mm in 1 h, 337 mm in 3 h, 496 mm in 6 h, and 883.8 mm in 24 h (Fig. 4). The event started in the morning of October 3, 2021, with isolated thunderstorms near Genoa (200 mm in 8 h), but the most intense rainfall occurred in the afternoon of October 4 on the west side of Genoa (Fig. 5). The most intense rainfall was prefrontal; the frontal passage was very fast, although intense, and its rapid evolution was not predicted by numerical models.

While MOLOCH was able to reproduce the rainfall distribution well in time and space (although it underestimated the amount), the run of COSMO initialized on October 3 was able to suggest the imminent occurrence of a heavy rainfall event in the 48-h forecast window, although its occurrence was anticipated on October 3.

The LEPS and the poor man ensemble, which are available to ARPAL forecasters, also provided a clear signal of an intense event, although mainly concentrated on the

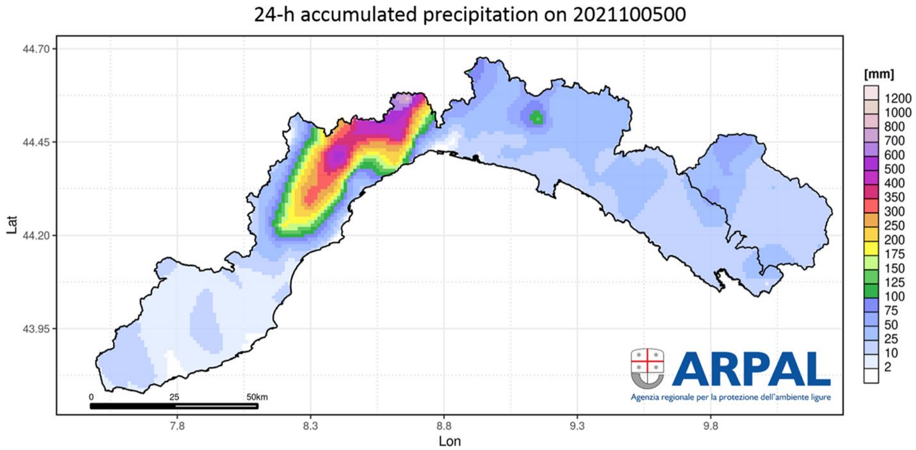

Fig. 4 24-h accumulated precipitation (mm) on October 4, 2021. Rain-gauge data are interpolated by a geostatistic method named GRISO (Petracca et al. 2018; Bruno et al. 2021)

coastal area (Fig. 6). The reason for the intense rainfall on the downwind side is not very clear. This behavior may be the consequence of an incorrect representation of the interaction of the flow with the orography, possibly due to a stronger-than-expected wind speed or a misrepresentation of the humidity, which implies a simulated flow regime different from that observed (Miglietta and Rotunno 2009).

On October 3, the hodograph shape is short and irregular (not shown), revealing weak wind speed and strong directional shear, an indication of disorganized convection. In the initial phase of the event, the precipitation seems to be mostly driven by orographic uplift due to southeasterly wind, responsible for intense water vapor transport; in the second part, the northerly wind appears to first displace most of convection towards the sea and then to advect it toward the central part of the region. Shallow convection and weak lightning activity are reported.

On October 4, the atmosphere is more unstable, and the hodograph more linear (not shown), an indication of more organized convection. CAPE and low-level shear are

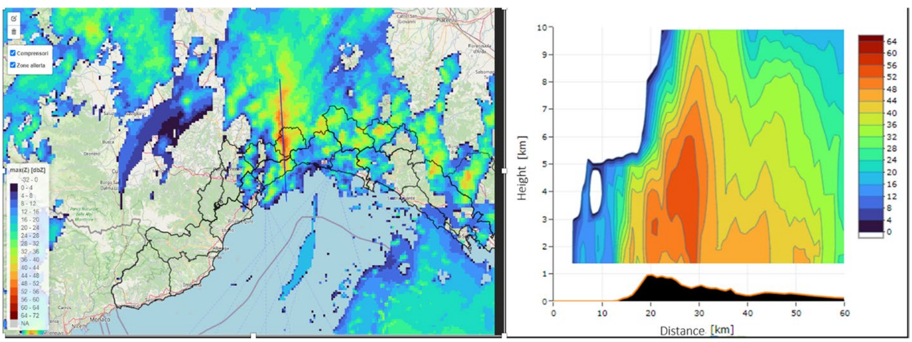

Fig. 5 Radar maximum reflectivity (dBZ) on 4 October 2021 afternoon, namely at 1420 UTC (left), and vertical cross section along the blue line west of Genoa showing a well-developed linear convective system with an echo top higher than 10 km (right)

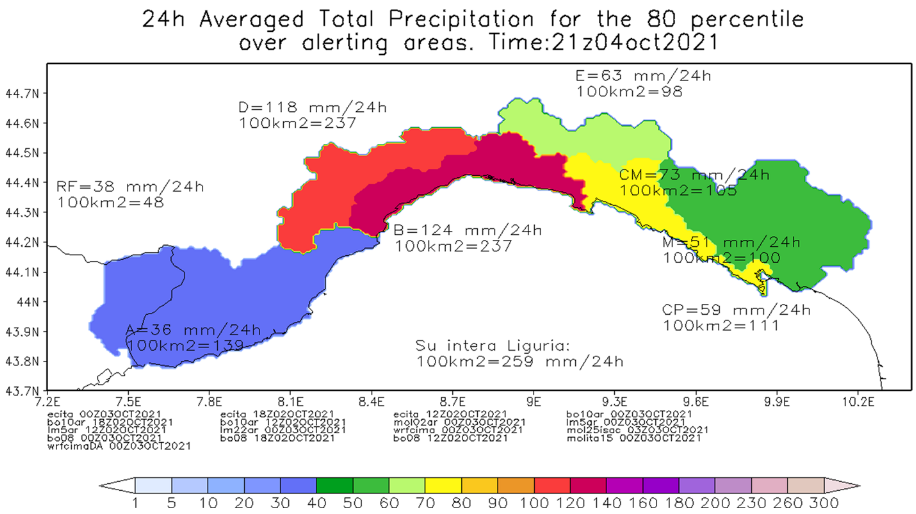

Fig. 6 Poor man's ensemble 80th percentile of predicted 24-h precipitation (mm), averaged over the different alerting areas of Liguria region. Valid time is October 4, 21 UTC, and models initialized between 12 UTC, October 2 and 00 UTC, October 3 are considered in the ensemble (for more details, see Corazza et al. 2018)

moderate, and convection is shallow. During the morning, the entrance of northwesterly flow over the central-western sector of the region shifts the rainfall eastward during the most intense phase, which is characterized by stationary orographic precipitation, with embedded deep convection. Possibly, the cold pool generated in the first phase may have affected the following development.

Hence, the factors that characterize the event can be summarized as

- Initial convergence
- Interaction of a warm and moist low-level jet (LLJ) with the orography (the high humidity content favors the air to overpass the orography)
- Cold pool interaction with LLJ, which may have been important for the stationarity of the rainfall (e.g., Ducrocq et al. 2008)
- Transport of humidity from the Mediterranean Sea concentrated in a small area

2.3.2 Discussion

Initially, the discussion at the workshop focused on the aspects relevant to a better understanding of the dynamics of this case. The vertical profile of the airmass impacting on the orography is critical: small differences in the profile may affect the interaction of the airflow with the Apennines and with the cold pool and the consequent development of convection (Miglietta and Rotunno 2014). The triggering of convection is affected by the ratio of the mountain and of the cold pool height with LFC (Davolio et al. 2016) and by the difference between LFC and LCL: in fact, large differences between the latter two parameters may have inhibited the development of convection over the sea and favored its triggering over the mountains. Numerical experiments, which were run to check the sensitivities of the results to specific parameters or boundary conditions, showed that the Apennines were not sufficiently high to trigger convection, and a cold pool was necessary; also, a strong sensitivity to CAPE was observed, as higher (lower) CAPE favored upwind (downwind) convection. This point will be discussed in detail in a forthcoming paper (Cassola et al. 2023). Wind rotation was also important for the orientation of the convergence line and the triggering of the system especially in the early stage.

The general opinion emerging in the discussion was that improving our understanding of the interaction between the large-scale and the mesoscale forcing with the local scale is necessary if we want to improve the prediction of this kind of event.

Lastly, the discussion focused on the current activities on model verification. ARPAE and ARPA-Piemonte do some shared verification, also in the framework of the COSMO Consortium and considering several models, over the Italian macro-areas defined by the Civil Protection. ARPA FVG does the verification of different models on precipitation and thunderstorms in its macro-areas. CNMCA makes traditional verifications using synoptic data for ECMWF and COSMO-IT (and, recently, ICON-IT) models, but it is also applying an object-oriented verification for intense events, and verification for phenomena of aeronautic interest (e.g., fog) in specific airports.

2.4 High-resolution ensemble products for the prediction of high-impact weather (Arpae-SIMC)

2.4.1 Presentation

Ensembles are crucial for Civil Protection to issue warnings. Currently, Arpae-SIMC forecasters use mainly the large-scale ECMWF ensemble to form an opinion about the uncertainty associated with the forecasted scenarios, while the short-range, high-resolution ensembles are still judged difficult to use. Two different chains of high-resolution ensembles are available: COSMO-LEPS, which is a downscaling of ECMWF EPS, run by Arpae-SIMC for the COSMO Consortium; COSMO-2I-EPS (1 run per day, up to + 51 h, 2.2 km grid spacing, 20 members), which is generated using the COSMO-ME-EPS of CNMCA running over the Mediterranean as boundary condition, and KENDA-2I, the ensemble data assimilation hourly cycle at Arpae-SIMC based on LETKF (local ensemble transform Kalman filter), as initial condition. In KENDA-2I, also 3D reflectivity data from the Italian radar network are assimilated (Gastaldo et al. 2021).

The information contained in the ensemble forecast needs to be summarized for forecasters' use; hence, specific products are produced at ARPAE for precipitation and wind gusts: maps of ensemble mean, minimum, 90th percentile and maximum of the ensemble; maps of probability of exceedance of different thresholds, selected on the basis of the values used for issuing warnings; interpretative tables (Fig. 7), which condense and highlight the information provided by the probability maps, or represent maximum and mean values over the different macro-areas, thus taking into account also the spatial uncertainty of the high-resolution forecasts. Some case studies focused on high-impact weather, including the recent flood in the Marche region, were shown during the presentation to represent the contribution that the use of the ensemble can provide to the forecasting activity. Some issues related to the interpretation of the ensemble forecasts are also highlighted, pointing to the need of further developing a "probabilistic thinking" in the forecast practice.

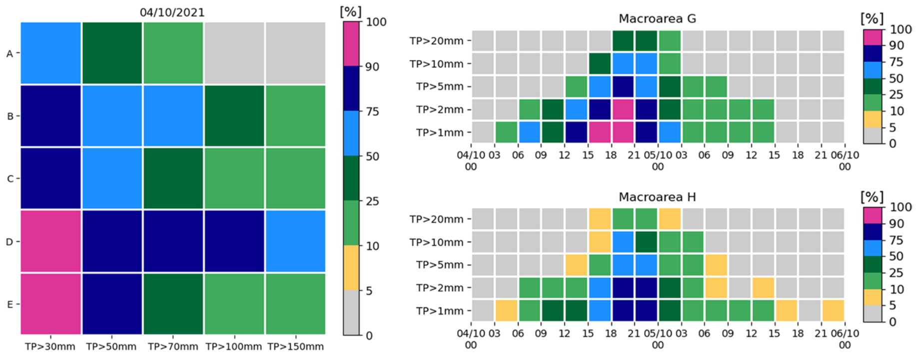

Fig. 7 Two different types of interpretative tables (checkerboard plots). Left: the maximum of the probabilities of exceedance for the 24-h precipitation forecasted by the ensemble members over the alert areas is shown for each alert area (indicated with capital letters, *y* axis). For example, on the alert area *D* of the Emilia-Romagna region, the maximum of the forecasted probability of exceeding 150 mm/24 h is greater than 50%. Right: for two alert areas (*G* and *H* of the Emilia-Romagna region, upper and lower panel, respectively), the maximum probability is shown for the 3-h precipitation. The event is the heavy precipitation on 4 October 2021

New developments are planned for COSMO-2I-EPS: perturbations of model parameters and of the tendency of the parameterization schemes to increase the model spread, direct use of the ECMWF ensemble as boundary condition, a new product for the prediction of thunderstorms, the change of model from COSMO to ICON. The perturbation of model parameters has been already tested in summer 2021 and has been shown to improve the quality of the forecasts (note that it has been implemented operationally during the writing of this article); the change of boundary conditions from COSMO-ME-EPS to ECMWF-EPS is expected to provide some improvement too (Marsigli et al. 2014), as well as the change in the model formulation. Massive use of remote sensing data in assimilation is another important direction of development. A promising approach for model perturbation is the development of new parameterization schemes that include a stochastic component to represent the uncertainty at subgrid scale, thus merging the deterministic with the ensemble approach. These developments are currently on-going in the COSMO Consortium, as well as in the other European modeling consortia. Coupling meteorological and hydrological models is another frontier to effectively transfer the ensemble information in terms of impacts.

2.4.2 Discussion

A first point emerging in the discussion was the need to separate the issue on how to improve the modeling system and its operational use from its use in terms of civil protection, which depends also on the communication of the risk and on the vulnerability of the territory. Unless the next generation of models can reproduce the right precipitation amount in the right location, we will have to continue to fight against too many false alarms for many more years.

A verification of the ensemble system is needed over the entire national territory. In this perspective, it would be interesting to understand which phenomena the ensemble is able to reproduce. Forecasters should be specifically trained in using high-resolution ensemble products: as an example, a forecaster should be able to evaluate if an event is under-predicted in aggregated products derived from an ensemble system, because its scale is not resolvable by the system or because it has low probability of occurrence. Forecasters should have specific knowledge on ensemble spread, resolution, and climatology as modeling systems are continuously being upgraded. The experience of the forecasters is that high-resolution models provide an added value especially for high thresholds; anyway, a systematic way to include the information provided by the ensemble in the operational practice is not clearly defined yet, and this is currently an issue in all the weather forecasting centers in Europe running ensemble forecasts.

2.5 Use of very high-resolution models in the prediction of meteorological events (CNMCA)

2.5.1 Presentation

One of the tasks of CNMCA is to provide support to the air traffic. In this framework, a prediction can be considered useful when it is an added value for the pilot, i.e., its absence or wrong prediction may produce damage. The meteorological information that a pilot receives before taking-off is based on several products: an overview of the meteorological conditions along the route (significative weather maps), which allows identifying the risks and planning the amount of fuel to be loaded; the low-level significant chart near the destination airport; the latest predictions (TAF) and observations (METAR and SPECI) specific for the destination and the alternate airports.

Several parameters are provided by the model to support the aviation forecasters' predictions. Additional information can be extracted by the model outputs: for example, a prediction that is consistently provided by model runs starting at different initial times (a time-lagged ensemble) represents an indication of the robustness of the forecast; simulated thermodynamic soundings upstream (even several hundreds of km far away from the meteorological event) can be helpful to understand the instability conditions of the incoming flow.

Recently, new post-processed products have been developed, such as the maximum lightning potential index and the supercell index, to estimate, respectively, the possible development of lightning and supercells. New ensemble products relevant for aviation, such as the probability of severe weather phenomena, of low visibility, are now being tested although the forecasters need some time to validate and get used to such new tools.

On the other hand, pilots can benefit from the ICAO watch office that, through the Air Force for Italy, provides continuous monitoring of the weather conditions; thus, the air traffic control informs pilots of adverse weather conditions along the route (e.g., SIGMET messages). Pilots have extensive training in meteorology to correctly interpret the weather information they receive.

2.5.2 Discussion

Elements to improve the quality of the aviation forecasts are the feedback from the users and the verification of the model products. However, it should be considered that the impact of weather events depends also on non-meteorological factors, such as the kind of airplane, the capacity of the pilots, the type of airport, and the availability of traffic control services.

A Rapid Update Cycle can be helpful in model operational chains to produce continuously updated forecasts in the airports, integrated with techniques of artificial intelligence. Machine learning techniques are very promising tools and will be used in the future as post-processing to improve predictions at specific locations, for example correcting the model outputs based on the forecast errors collected over several years of simulations, but also as prognostic tools themself.

3 Future perspectives

The purpose of the workshop on high-impact weather events was to create a moment of confrontation between different Italian actors in meteorology. The workshop focused on topics raised by recent severe events or on the main forecasting issues in different institutions. We hope that this meeting could represent the first of a series of similar events under the common umbrella of AIM and AISAM. The final goal is to create a cohesive and competent meteorological community and take full advantage of the efforts undertaken at both operational centers and research institutions or universities. Furthermore, we hope that this paper, together with the other manuscripts in the present issue, represents a first step to document the activities of operational meteorology in Italy, also considering that the meteorology of the Mediterranean often presents peculiarities that are not well represented by conceptual models historically developed for oceanic midlatitude regions (e.g., Miglietta and Rotunno 2019; Buzzi et al. 2020). Back-building convective systems and tropical-like cyclones are just two examples of very peculiar Mediterranean phenomena which are also becoming stronger in response to global warming (e.g., González-Alemán et al. 2019).

Some points which will deserve attention by this community emerged during the discussion: the need of a good scientific understanding of the processes leading to the development of severe weather phenomena; the importance of an effective and well-organized collaboration between operational and research institutions; the need of a comprehensive and accurate verification of the weather forecasts; the difficulty of using the information contained in the ensemble forecast in the operational practice; the still challenging issue of the communication with the users of the forecasts; the increasing relevance of taking into account the impacts of the weather forecasts.

To our knowledge, a proposal is underway to promote a meeting on the recent severe drought that involved northern and central Italy in summer 2022. Another idea for a future meeting is to analyze the recent flood in the Marche region and try to investigate it from different perspectives.

Another aspect that needs to be addressed in the future is how risk is communicated. In fact, the population should be educated to deal with warnings: the recurring floods over Italy in the last few years have surely increased the awareness of the risks associated with severe weather and made clear the need to adopt more precautionary behavior. However, there is still a long way to go to reach an acceptable level; in particular, an increased consciousness about events covering a limited area is a necessary objective. This task requires some substantial background research, not just in meteorology but in social science, identifying an appropriate hazard-information flow. Looking at the best practice elsewhere in the world, e.g., the probability of occurrence versus the likelihood of the impact that the Met Office uses for its warning, could be a good example to follow.

Lastly, the very short-range forecasting, the so-called nowcasting, was proposed as another topic worthy of discussion in future meetings. The nowcasting, which demands for very accurate predictions in terms of localization and intensity, paradoxically represents the temporal range producing the greatest challenges, due both to the issues still affecting the nowcasting tools, to the lack of measures, and the difficulty to communicate in near real-time and in a continuous manner the evolution of the short-time potentially dangerous meteorological phenomena to authorities and therefore to the population. The recent flash flood, which hit the Marche region on September 15, 2022, caused twelve fatalities. The controversy and the ongoing investigations concerning the quality of the forecast and especially the monitoring of this event by the competent meteorological institutions represent a clear example of the still existing problems in the Italian meteorological warning chain, especially when dealing with rapidly evolving local severe events, not always explicitly captured by state-of-the-art meteorological models.

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Declarations

Ethical approval Not applicable.

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References

Avolio E, Miglietta MM (2022) Tornadoes in the Tyrrhenian regions of the Italian peninsula: the case study of 28 July 2019. Atmos Res 278:106285. https://doi.org/10.1016/j.atmosres.2022.106285

Bagaglini L, Ingrosso R, Miglietta MM (2021) Synoptic patterns and mesoscale precursors of Italian tornadoes. Atmos Res 253:105503. https://doi.org/10.1016/j.atmosres.2021.105503

Bruno G, Pignone F, Silvestro F, Gabellani S, Schiavi F, Rebora N, Giordano P, Falzacappa M (2021) Performing hydrological monitoring at a national scale by exploiting rain-gauge and radar networks: the Italian case. Atmosphere 12:771

Bunkers MJ, Hjelmfelt MR, Smith PL (2006) An observational examination of long-lived supercells. Part I: Characteristics, evolution, and demise. Weather Forecast 21:673–688

Buzzi A, Davolio S, Fantini M (2020) Cyclogenesis in the lee of the Alps: a review of theories. Bull Atmos Sci Technol 1:433–457. https://doi.org/10.1007/s42865-020-00021-6

Cassola et al (2023) Extreme convective precipitation in Liguria (Italy): a brief description and analysis of the event occurred on October 4. Bull Atmos Sci Technol

Corazza M, Sacchetti D, Antonelli M, Drofa O (2018) The ARPAL operational high resolution Poor Man's Ensemble, description and validation. Atmos Res 203:1–15

Corfidi SF (2003) Cold pools and MCS propagation: forecasting the motion of downwind-developing MCSs. Weather Forecast 18:997–107

Davolio S, Volontè A, Manzato A, Pucillo A, Cicogna A, Ferrario ME (2016) Mechanisms producing different precipitation patterns over North-Eastern Italy: insights from HyMeX-SOP1 and previous events. Q J R Meteorol Soc 142:188–205. https://doi.org/10.1002/qj.2731

Ducrocq V, Nuissier O, Ricard D, Lebeaupin C, Thouvenin T (2008) A numerical study of three catastrophic precipitating events over southern France. Part II: Mesoscale triggering and stationarity factors. Q J R Meteorol Soc 134:131–145

French AJ, Parker MD (2014) Numerical simulations of bow echo formation following a squall line-supercell merger. Mon Weather Rev 142:4791–4822

Gastaldo T, Poli V, Marsigli C, Cesari S, Alberoni PP, Paccagnella T (2021) Assimilation of radar reflectivity volumes in a preoperational framework. Q J R Meteorol Soc 147:1031–1054. https://doi.org/10.1002/qj.3957

Giaiotti D, Giovannoni M, Pucillo A, Stel F (2007) The climatology of tornadoes and waterspouts in Italy. Atmos Res 83:534–541

González-Alemán JJ, Pascale S, Gutierrez-Fernandez J, Murakami H, Gaertner MA, Vecchi GA (2019) Potential increase in hazard from Mediterranean hurricane activity with global warming. Geophys Res Lett 46:1754–1764

Isotta FA et al (2014) The climate of daily precipitation in the Alps: development and analysis of a high-resolution grid dataset from pan-Alpine rain-gauge data. Int J Climatol 34:1657–1675

Manzato A, Davolio S, Miglietta MM, Pucillo A, Setvak M (2015) 12 September 2012: a supercell outbreak in NE Italy? Atmos Res 153:98–118

Manzato A, Serafin S, Miglietta MM, Kirshbaum D, Schulz W (2022) A pan-Alpine climatology of lightning and convective initiation. Mon Weather Rev 150:2213–2230. https://doi.org/10.1175/MWR-D-21-0149.1

Marsigli C, Montani A, Paccagnella T (2014) Provision of boundary conditions to a convection-permitting ensemble: comparison of two different approaches. Nonlinear Process Geophys 21:393–403

Miglietta MM, Rotunno R (2009) Numerical simulations of conditionally unstable flows over a ridge. J Atmos Sci 66:1865–1885. https://doi.org/10.1175/2009JAS2902.1

Miglietta MM, Rotunno R (2014) Numerical simulations of sheared conditionally unstable flows over a mountain ridge. J Atmos Sci 71:1747–1762. https://doi.org/10.1175/JAS-D-13-0297.1

Miglietta MM, Manzato A, Rotunno R (2016) Characteristics and predictability of a supercell during HyMeX SOP1. Q J R Meteorol Soc 142:2839–2853

Miglietta MM, Matsangouras IT (2018) An updated "climatology" of tornadoes and waterspouts in Italy. Int J Climatol 38:3667–3683

Miglietta MM, Rotunno R (2019) Development mechanisms for Mediterranean tropical-like cyclones (Medicanes). Q J R Meteorol Soc 145:1444–1460. https://doi.org/10.1002/qj.3503

Petracca M, D'Adderio LP, Porcù F, Vulpiani G, Sebastianelli S, Puca S (2018) Validation of GPM dual-frequency precipitation radar (DPR) rainfall products over Italy. J Hydrometeorol 19:907–925

Pucillo A, Miglietta MM, Lombardo K, Manzato A (2020) Application of a simple analytical model to severe winds produced by a bow echo like storm in northeast Italy. Meteorol Appl 27:e1868. https://doi.org/10.1002/met.1868

Taszarek M, Pilguj N, Orlikowski J, Surowiecki A, Walczakiewicze A, Pilorzf W, Piaseckid K, Pajurekg L, Polrolniczaka M (2019) Derecho evolving from a mesocyclone - a study of 11 August severe weather outbreak in Poland: event analysis and high-resolution simulation. Mon Weather Rev 110:1060–1082