SPECIAL PROJECT FINAL REPORT

All the following mandatory information needs to be provided.

Project Title:	Short-range re-analysis and forecast to investigate extreme weather events using COSMO and ICON model
Computer Project Account:	SPITGARB
Start Year - End Year:	2022 - 2024
Principal Investigator(s)	Valeria Garbero (mcy0), valergar@arpa.piemonte.it
Affiliation/Address:	Arpa Piemonte, Italy
Other Researchers (Name/Affiliation):	Massimo Milelli (mcy), massimo.milelli@cimafoundation.org

The following should cover the entire project duration.

Summary of project objectives (10 lines max)

The aim of the project is to use the most advanced numerical modelling to analyse case studies from the recent past, in order to identify critical issues and improve the forecast of future events, not only in case of strong precipitation, but also in case of heat waves, strong wind, etc. The COSMO and ICON models will be used at high horizontal resolution to re-analyse and re-forecast past extreme events. Different model configurations will be tested using new physical parameterization schemes and different initial and boundary conditions to find out which is the best configuration representing the severe events on rather small time and space scales. Temperature, relative humidity and wind will be compared with the observations provided by meteorological stations and radiometers using standard statistic indices (MB, RMSE, etc.). Precipitation will be verified using the innovative fuzzy technique that compares the data estimated by the national radar mosaic with the simulated maps.

Summary of problems encountered

(If you encountered any problems of a more technical nature, please describe them here.)

None.

Experience with the Special Project framework

(Please let us know about your experience with administrative aspects like the application procedure, progress reporting etc.)

I have had a positive experience with the Special Project framework overall. The application procedure is clearly outlined and relatively straightforward, with well-defined deadlines and requirements. Regarding progress reporting, the expectations are clear, and the reporting templates provided make it easy to structure updates.
The communication channels (e.g., email updates and the project portal) were effective in keeping participants informed about important dates and procedural changes. Overall, the administrative framework supports the scientific goals of the project without being overly burdensome.

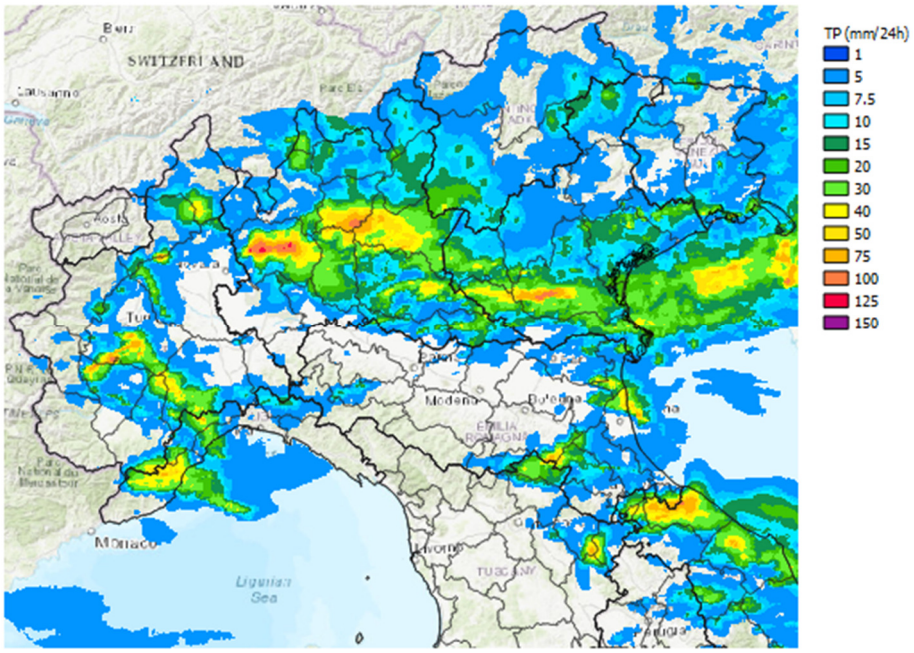
Summary of results

(This section should comprise up to 10 pages, reflecting the complexity and duration of the project, and can be replaced by a short summary plus an existing scientific report on the project.)

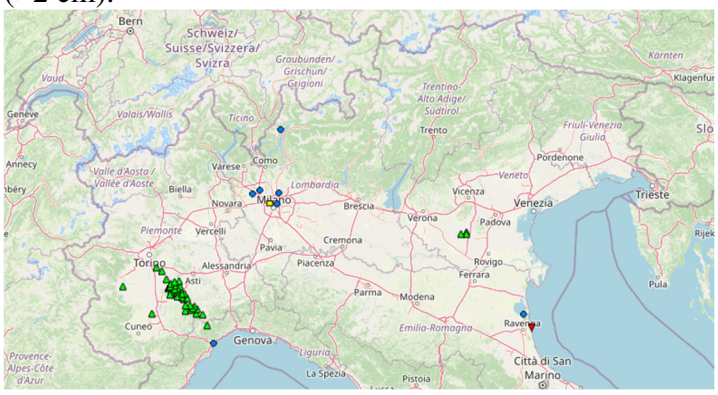
During this 3-years project, re-analysis and re-forecast of extreme weather events in Italy were carried out using COSMO and ICON in various configurations.
The simulations of two major events occurred in 2022 - the heavy and persistent rainfall in the Campania region on 21–22 November, and the flash flood in the Marche region on 15 September — are detailed in the Special Project report submitted in June 2023.
This report focuses on two additional events that took place in northern Italy in July 2023, both characterized by exceptional hailstorms.

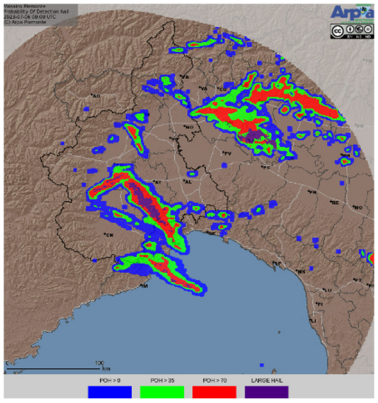
6 July 2023, Piemonte region

On July 6, 2023 the northern Italy was interested by intense thunderstorm; particularly a convective cell evolved into a supercell south of Turin, producing large hail, strong downdrafts, and locally intense rainfall on southern Piedmont.

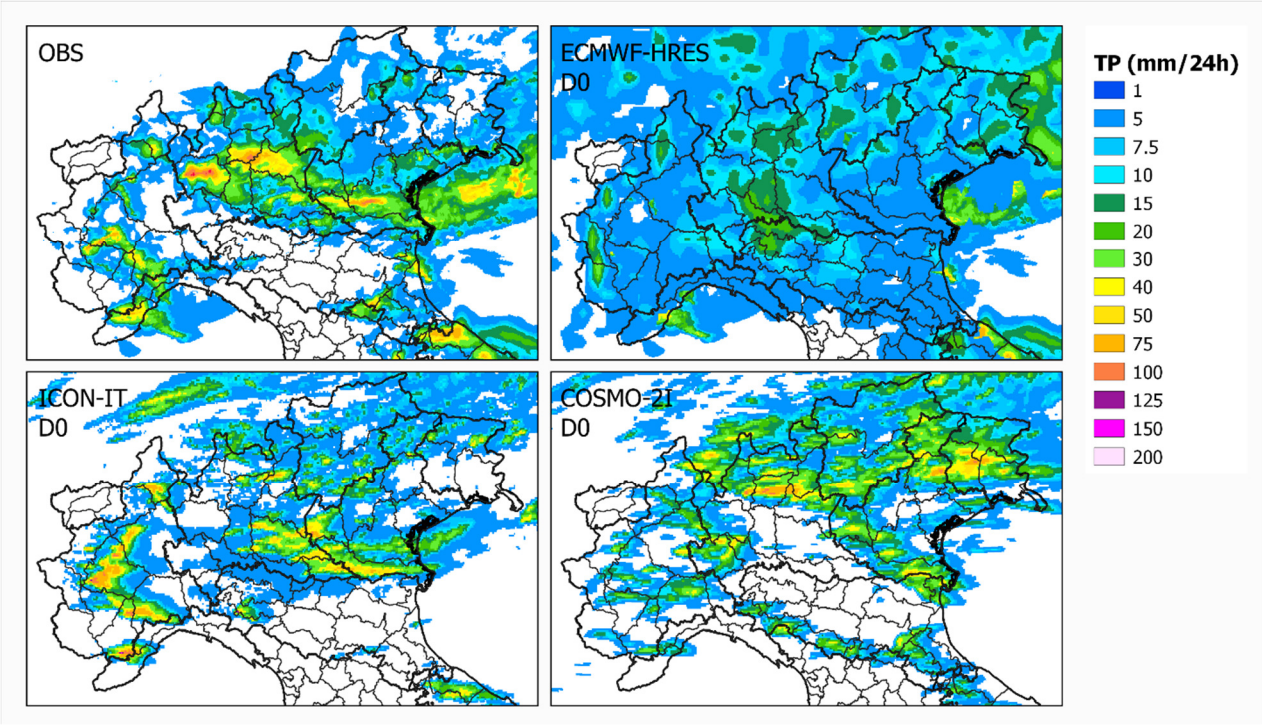


Evidence of the event's severity includes numerous large hail reports (European Severe Weather Database) and a hail probability map from Arpa Piemonte, which indicated areas affected by large hail (>2 cm).





Convective events are challenging to predict at sub-regional scales. While operational models predicted precipitation, their spatial accuracy was limited. IFS forecasted weak widespread rainfall without capturing the most intense cells. High-resolution models (ICON-IT, COSMO-2I) better estimated intensity but struggled with localization—e.g., ICON-IT captured storms in Piedmont, while COSMO-2I did not.

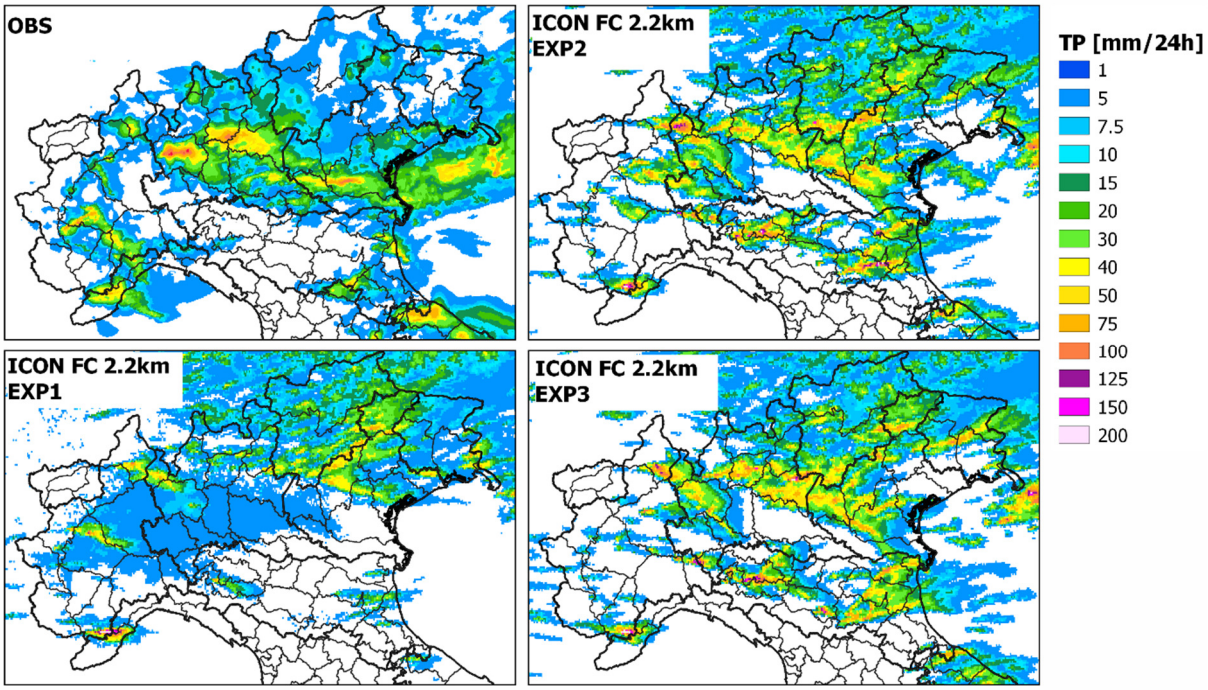


Several re-forecast experiments using ICON at 2 km resolution were performed to evaluate the impact of different physical parameterizations:

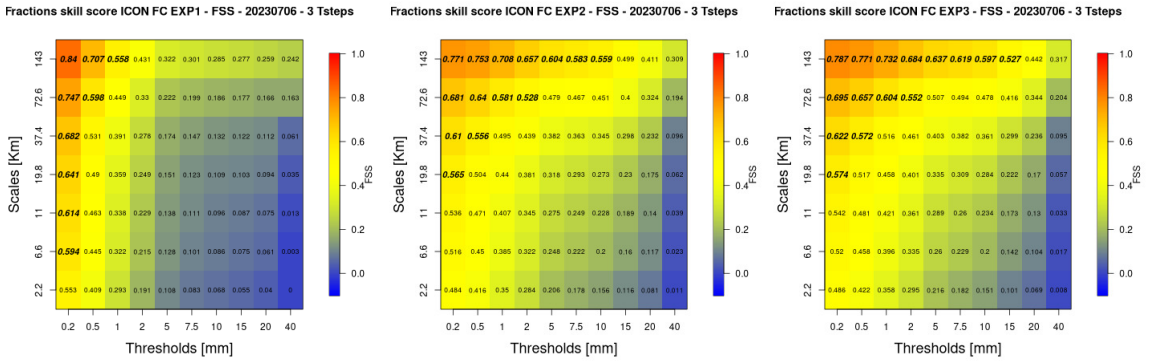
- Varying convection schemes (shallow, deep, or none).
- Comparing single- and double-moment microphysics (latter allows hail prediction).

	IC	BC	Convection	Microphysics
EXP1	ICON-EU analysis at 6 km	ICON-EU forecast at 6 km	Shallow convection	Single-moment scheme
EXP2	ICON-EU analysis at 6 km	ICON-EU forecast at 6 km	Shallow and deep convection	Single-moment scheme
EXP3	ICON-EU analysis at 6 km	ICON-EU forecast at 6 km	Shallow and deep convection	Single-moment scheme
EXP1b	ICON-EU analysis at 6 km	ICON-EU forecast at 6 km	Shallow convection	Double-moment scheme
EXP3b	ICON-EU analysis at 6 km	ICON-EU forecast at 6 km	Free convection	Double-moment scheme

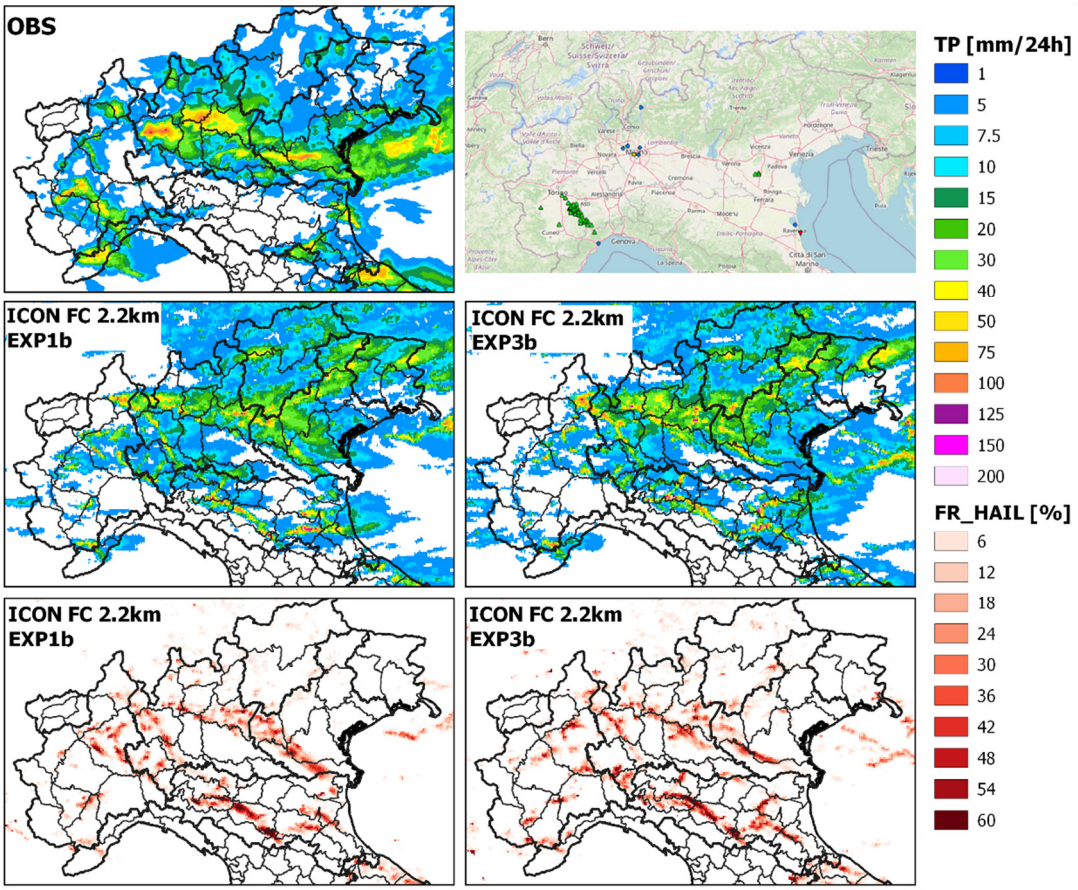
These experiments did not assimilate observational data (unlike operational models), thus limiting performance. None successfully captured the violent storms over southern Piedmont. EXP1 underperformed across all areas; EXP2 and EXP3 incorrectly predicted storms over Emilia-Romagna.



Fuzzy 3D verification showed that **EXP1** is best for low thresholds (useful scale of 5 km at 0.2 mm/3h) and **EXP3 is** slightly better than EXP2 for higher thresholds (useful scale of 143 km at 15 mm/3h).

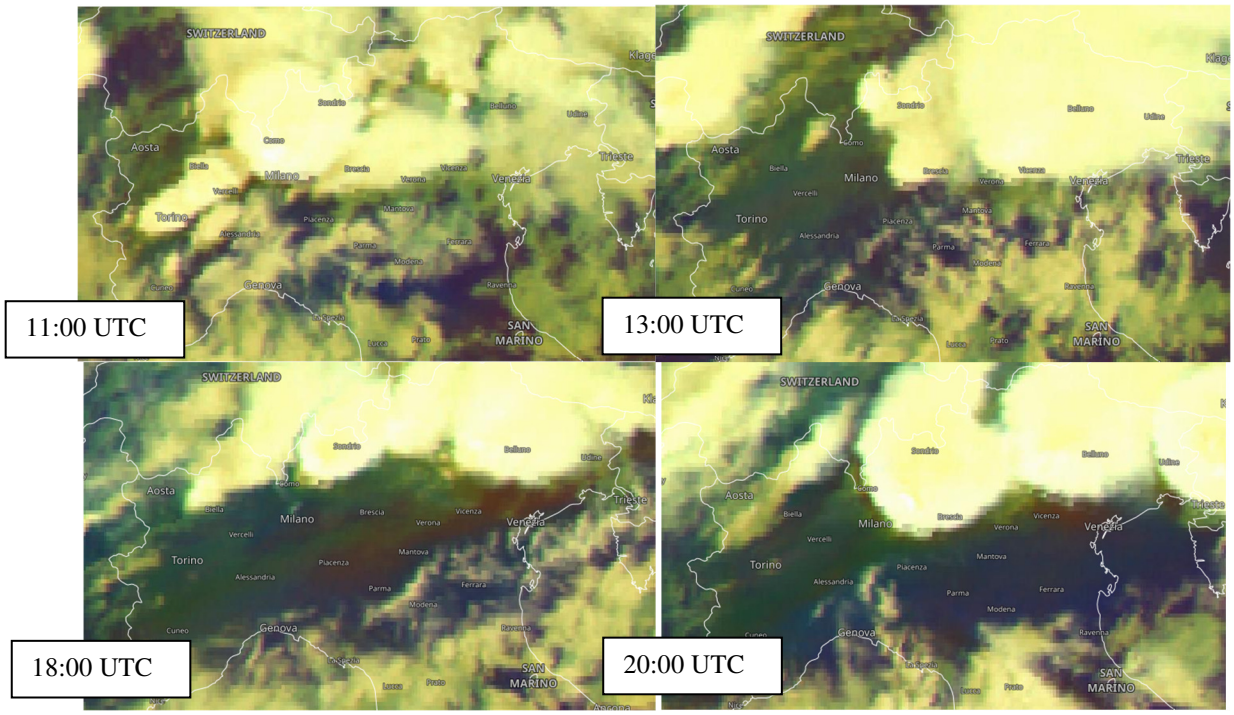


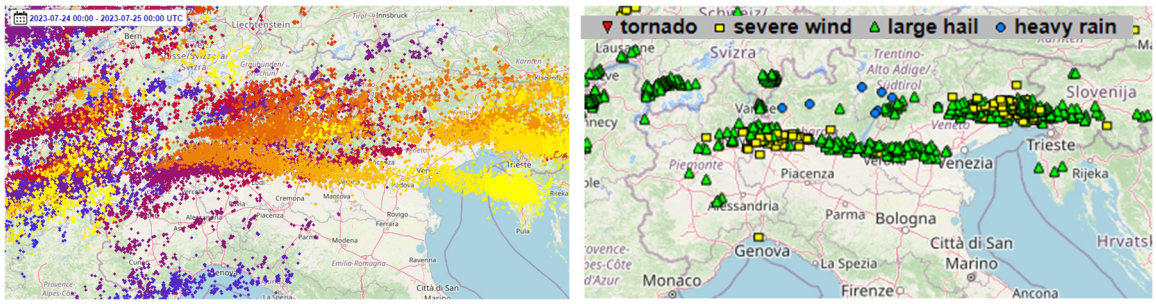
EXP1b and EXP3b, with double-moment microphysics, were evaluated for hail prediction. Although the percentage of hail within total precipitation was high—indicating the potential for severe hail—the incorrect spatial distribution of precipitation implies hail location errors. Further development is needed to improve hail forecasting capabilities.



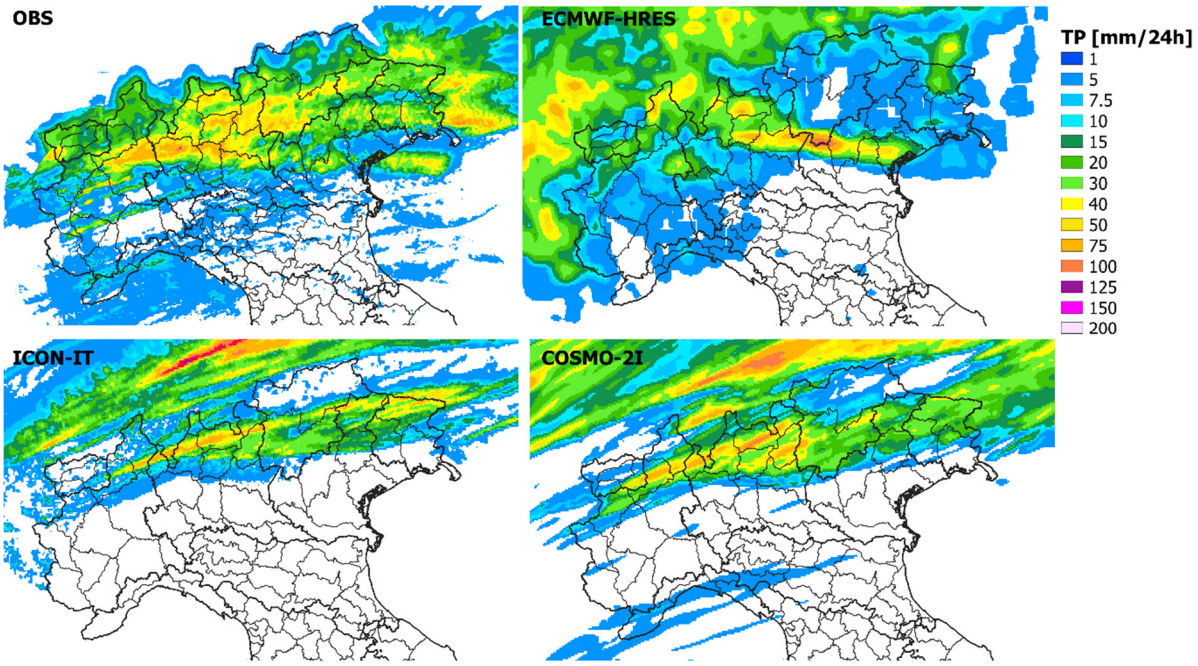
24 July 2023, northern Italy

On July 24, 2023, several thunderstorm cells, formed over France and transported by a strong south-westerly upper flow, affected regions including Piedmont, Lombardy, Veneto, Trentino, and Friuli Venezia-Giulia. These organized convective systems produced large hail and severe downdrafts. Satellite images show the evolution of supercells, while 24-hour lightning data from LightningMaps.org and severe weather reports from the European Severe Weather Database confirm widespread hail and damaging winds in Northern Italy.

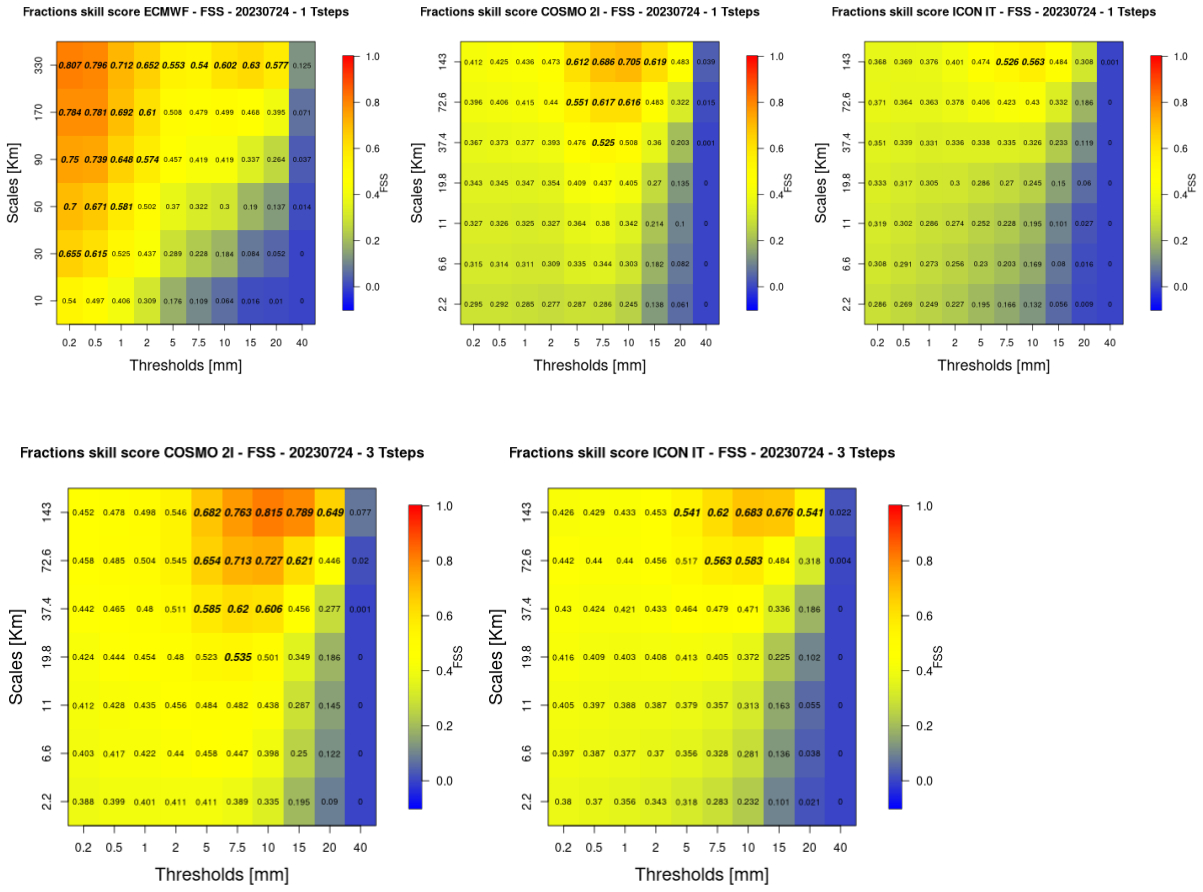




Convective events remain difficult to accurately pinpoint in space and time. Analyzing the precipitation forecasts from operational models, it can be observed that. IFS shows a scenario of moderate widespread instability over northern Italy, with the most intense phenomena forecast between Lombardy, Trentino, and Veneto. In contrast, the higher-resolution models COSMO-2I and ICON-IT primarily place precipitation over the Alpine areas, which is inaccurate, as the most severe thunderstorms occurred over the plains.



A more quantitative assessment of model performance was carried out using the fuzzy verification technique, comparing observed and forecast 3-hour precipitation. The results show that IFS performs best at lower thresholds, with a useful scale of 30 km for 0.5 mm/3h, while COSMO-2I performs better at medium-to-high thresholds, with useful scales of 37 km for 7.5 mm/3h and 143 km for 15 mm/3h. When the verification also includes the 3 hours before and after the forecast time, the high-resolution models improve at medium-to-high thresholds, with COSMO-2I reaching useful scales of 20 km for 7.5 mm/3h and 143 km for 20 mm/3h. However, they remain ineffective at lower thresholds, failing to reach any useful scale. These results once again highlight the difficulty in accurately locating intense convective events in time and space, especially when relying on the precipitation field from a single model.



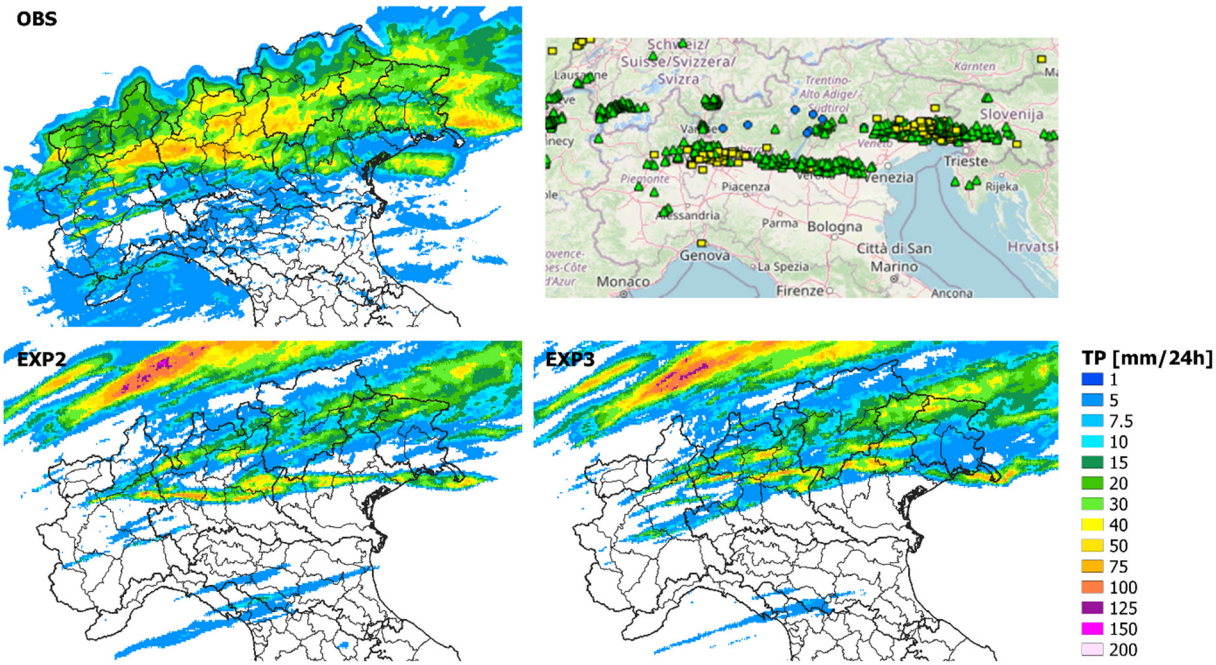
Further analysis was done using ICON simulations at 2 km resolution to test different physical parameterizations of convection and microphysics. Two configurations were tested:

	IC	BC	Convection	Microphysics
EXP3	ICON-EU analysis at 6 km	ICON-EU forecast at 6 km	Shallow convection	Double-moment scheme
EXP2	ICON-EU analysis at 6 km	ICON-EU forecast at 6 km	Free convection	Double-moment scheme

In these simulations, data assimilation was not used to determine the initial conditions, which is certainly a disadvantage in terms of performance compared to the operational model that does use it. However, the goal was to assess the impact of physical parameterizations on precipitation patterns. Specifically, the aim was to conduct a preliminary investigation of the 'hail' field provided by ICON as a potentially useful tool for forecasting severe hail events.

The figure shows a comparison between the 24-hour accumulated precipitation estimated from radar data corrected with rain gauges (DEWETRA product) and hail reports collected by the European Severe Weather Database, with the total accumulated precipitation and the hail fraction over the total accumulated precipitation in the same period.

It is noteworthy that the new simulations, although they do not fully reproduce the event, forecast intense precipitation also over the plains — particularly in the EXP2 configuration. Moreover, the percentage of hail within the total precipitation correctly indicates the occurrence of widespread hail events, suggesting this variable as a promising tool for hail forecasting. Further investigations will be conducted for this purpose.



List of publications/reports from the project with complete references

SPECIAL PROJECT PROGRESS REPORT, Short-range re-analysis and forecast to investigate extreme weather events using COSMO and ICON model, 2023
https://www.ecmwf.int/sites/default/files/special_projects/2022/spitgarb-2022-report2.pdf

Relazione tecnica annuale 2022, WP 4 – Modellistica meteorologica e post-processing, Accordo biennale tra Dipartimento della protezione civile ed Arpa Piemonte – periodo 2022 – 2023

Relazione tecnica annuale 2023, WP 4 – Modellistica meteorologica e post-processing, Accordo biennale tra Dipartimento della protezione civile ed Arpa Piemonte – periodo 2022 - 2023

Future plans

(Please let us know of any imminent plans regarding a continuation of this research activity, in particular if they are linked to another/new Special Project.)

The continuation of this research activity is currently ongoing within the framework of the Special Project “Re-analysis and Re-forecasting of Extreme Weather Events Using the ICON-LAM Model”. This project focuses on advanced numerical modeling to improve the forecasting of extreme weather events, building on the results and methodologies of the previous work.
The simulations are planned to be performed using the ICON-LAM model in various configurations:

- Runs with different initial and boundary conditions: ICBCS provided by IFS, ICON-EU and ICON-2I analysis.
- Runs with different parameterization schemes for turbulence (free convection, only shallow and deep convection parameterized, etc.), microphysics (single or double scheme).
- Runs with the urban parametrization scheme TERRA-URB activated and different dataset for external urban parameters (GLOBCOVER, ECOCLIMAP, LCZ, etc.)
- Runs at different resolutions: from 2 km to 500 m.