SPECIAL PROJECT FINAL REPORT

All the following mandatory information needs to be provided.

Project Title:	Very high resolution simulations of past flood events with COSMO model and ERA5
Computer Project Account:	spitmile
Start Year - End Year :	2019 - 2019
Principal Investigator(s)	Massimo Milelli, Valeria Garbero
Affiliation/Address:	Arpa Piemonte via Pio VII 9 10135 Torino Italy
Other Researchers (Name/Affiliation):	Gianpaolo Balsamo ECMWF

The following should cover the entire project duration.

Summary of project objectives

(10 lines max)

The reanalysis of past flood episodes is necessary to understand the dynamics of the events and to get proxies of the reality, especially when the observations are scarce. The aim of this project is to reproduce the November 1994 flood in Piemonte, on the occasion of the 25th anniversary of the event. Arpa Piemonte will run the operational model COSMO (www.cosmo-model.org) at very high horizontal resolution (about 1-2 km), using the initial and boundary conditions given by ECMWF analysis, then there will be runs in forecast mode to understand the importance of some physical scheme.

Summary of problems encountered

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

No problem to be reported.

Experience with the Special Project framework

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

The procedure is user-friendly, no problem at all, from the submission to the reporting.

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.)

This work was presented during a meeting organized by Prof. Enrico Ferrero (University of Piemonte Orientale) in occasion of the 25th anniversary of the flood: "*Alluvione 1994: il punto sulla situazione in Piemonte a 25 anni dalla tragedia*". Moreover a paper has been submitted for a special issue of BAST dedicated to the event and at the moment (June 2020) we are waiting for the reviewers comments. Therefore, we present here only a summary of the whole project.

The scope of this work was to investigate the behaviour of the Italian operational model COSMO in forecasting past extreme events. We simulated the November 1994 event in Piedmont with the COSMO model forced by ERA5 reanalysis and reforecast and we compared the results with the original forecast and with observations. In particular, hindcast simulations have been conducted in order to create a proxy of the observed precipitation field, since the observation network was much coarser then today. Then, the observations were used to evaluate the high-resolution forecast simulations of COSMO model in order to assess the progress made in meteorological modelling during these years and what remains to be done.

In the first days of November 1994, Piedmont was hit by a disastrous flood. The persistence of a wide depression over Western Europe caused heavy rains on a large part of Piedmont region from 4 to 7 November 1994 (see Fig. 1). The strong confluence of surface currents from southeast and upper level flow from south and southwest, as explained in the Arpa Piemonte Report, caused exceptional rainfall peaks over the mountain basins of Tanaro and Bormida (Maritime Alps) and the north-west sector of the region. Rainfall led to large floods along the rivers and numerous rock block slides that were responsible for considerable damages and numerous victims.

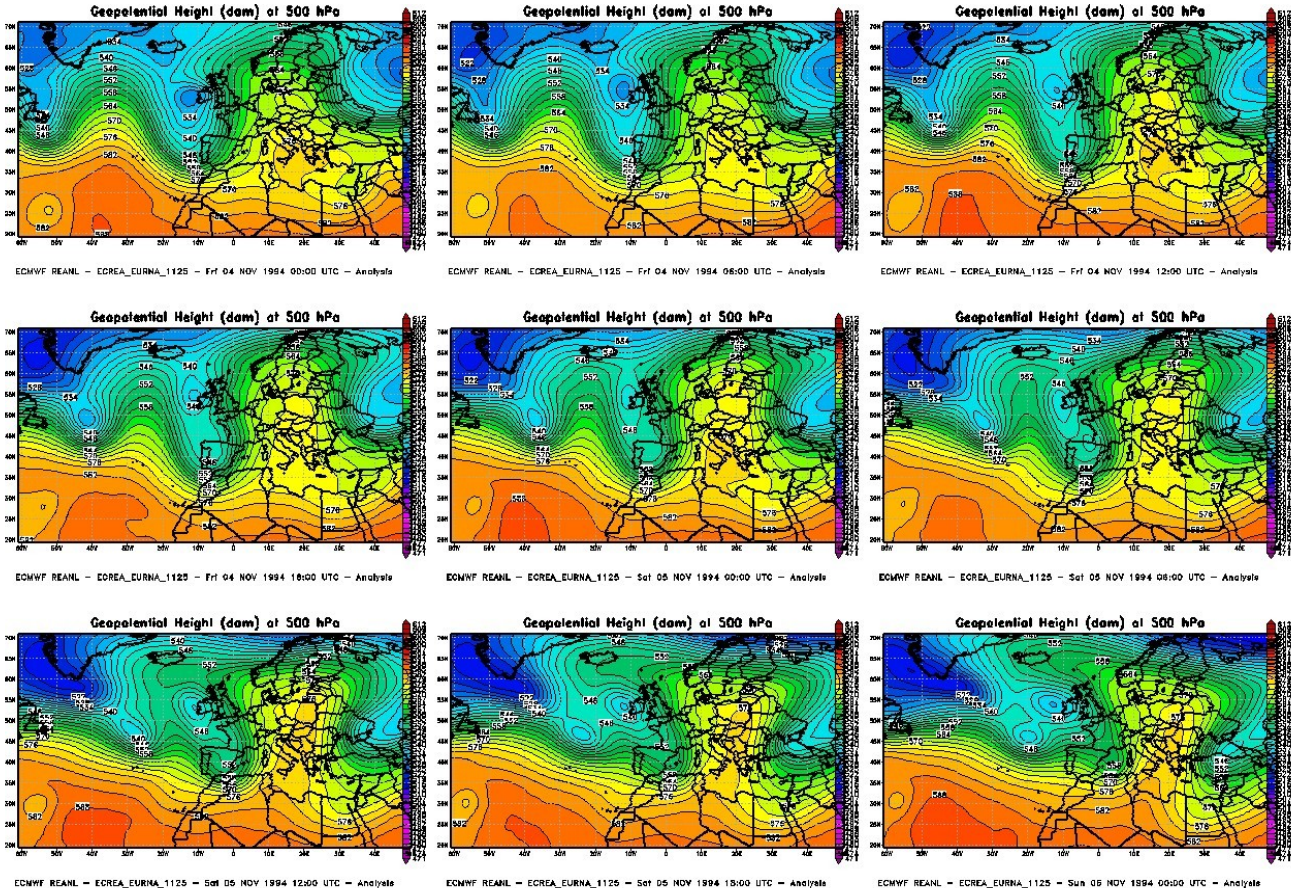

Fig. 1. ERA5 charts of 500 hPa Geopotential from 4 November 1994 00UTC to 6 November 1994 00UTC.

In the operational configuration, COSMO-5M provides numerical predictions on the Mediterranean area with a 5 km grid step up to +72h, while COSMO-2I covers only the Italian territory with a grid step of 2.2 km up to + 48h. Both simulations are initialized twice a day, at 00 and 12UTC. COSMO-5M uses IFS boundary conditions and initial conditions provided by the LETKF method, while COSMO-2I is nested directly into COSMO-5M and uses initial conditions provided by a data assimilation cycle based on Kenda system.
In our configuration, we performed two types of experiments:

- COSMO-5M hindcast runs, forced by ERA5 HRES re-analyses [23] from 3 November 1994 00UTC to 7 November 1994 00UTC and COSMO-2I hindcast runs nested into COSMO-5M on the same period;
- COSMO-5M forecast runs, forced by ERA5 reforecasts [23] from 4 November 1994 00UTC up to +48h and COSMO-2I forecast runs nested into COSMO-5M on the same period.

The ERA5 boundary conditions were used with 3h frequency, both in the analysis and in the forecast. The whole configuration of COSMO was the same as the operational one, with the exception of the COSMO-2I domain which was partially reduced as shown in Fig. 2.

Fig. 2. Domain of COSMO-2I simulations.

Although the event was mainly advective and orography-driven, a simple sensitivity test on the parameterization of convection has been performed: in COSMO-2I we compared the (default) Tiedtke scheme and the (optional) Bechtold scheme. By employing 1 to 3 km grid spacing for operational forecasts over a large domain, it is expected that deep moist convection, and the associated feedback mechanisms to the larger scales of motion, could be explicitly resolved. Therefore, in the COSMO-2I runs we tested the described parameterizations of convection only for the shallow convection. Moreover, we performed a simulation with no convection parameterization at all, neither deep nor shallow.

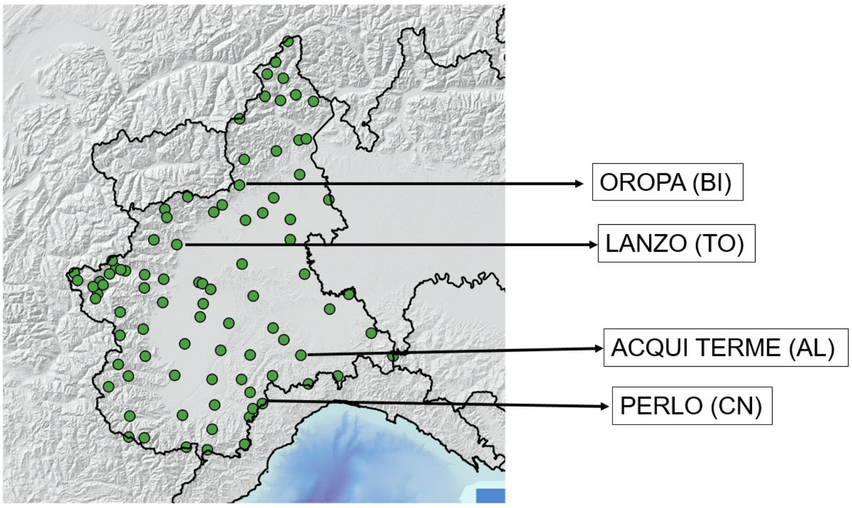

Fig. 3. Raingauges network of Piedmont Region in 1994 and the stations selected for comparison.

Concerning the analysis, the precipitation maps refer to the hindcast runs with the shallow convection parameterized by the default Tiedtke scheme. The figures show the simulated 24h precipitation during 4, 5 and 6 November respectively, compared to the corresponding field interpolated from the raingauges. The pattern of precipitation is correctly reproduced, both in the northwest areas and over the Apennines. There is a slightly overestimation in the north part during 5 November. It has to be underlined also a slight underestimation over the south plains. During 6 November, the agreement is good but the slight overestimation in the north area remains. However, the event was fairly well represented and these reanalyses could be used as a proxy of the real field, avoiding the errors related with any interpolation technique. See Fig. 4 as an example.

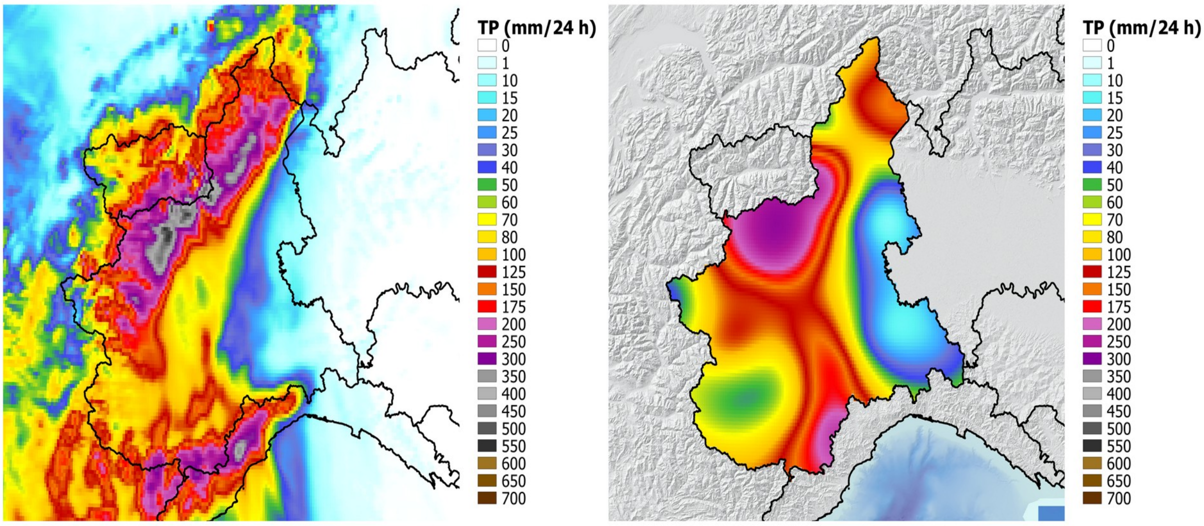

Fig. 4. 24h precipitation for 5 November 1994: on the left COSMO-2I analysis and, on the right, field interpolated from the original observations.

Looking at the time series in the selected stations (Fig. 5), there is a very good agreement in Oropa and Lanzo (northwest area), where the highest peaks have the correct position and intensity. Close to the Apennines (Acqui Terme and Perlo), there is a slight shift in the peaks and, especially in Perlo, a strong underestimation. It is well known though that very-high resolution models suffer from the double penalty effect. They produce small-scale realistic patterns that can be misplaced. This penalization actually occurs twice: firstly, for not having the pattern where it should be, and secondly, for having a pattern where there should not be one. For this reason, it is often misleading to make point-to-point comparisons. This is the reason why from an operational point of view there is more interest in considering warning areas averages.
Considering the differences among different convection treatment, they are small as expected.

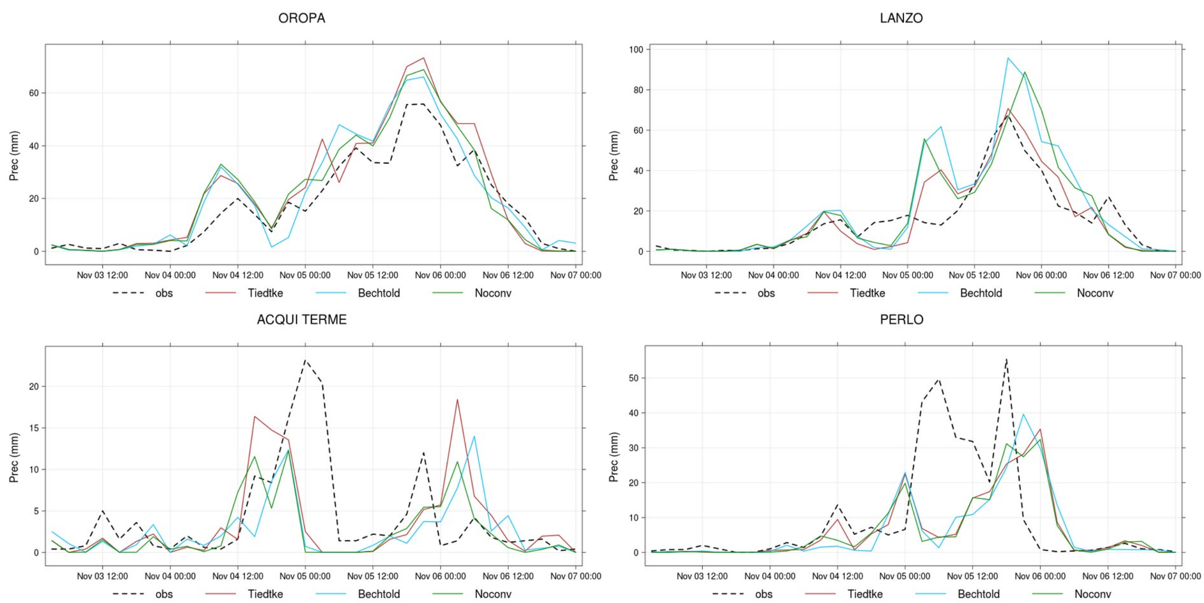

Fig. 5. Time series of precipitation from 3 November 1994 00UTC to 7 November 1994 00UTC: observations (black dashed line), COSMO-2I analyses (continuous lines) with different shallow convection parameterization (red: Tiedtke, cyan: Bechtold, green: none).

Concerning the forecast, the precipitation maps refer to the forecast runs obtained by parameterizing the convection with the default Tiedtke scheme, since no significant difference has been noticed by changing convection parameterization or removing it. Fig. 6 shows the second day of forecast (5 November). In this case, the agreement is good both with the reanalysis and with the observations.

In Fig. 7, the time series of the selected stations are plotted (analogously to Fig. 5). In accordance with the analysis, also in the forecast the impact of the convection parameterization is negligible, with the exception of Acqui Terme where some difference in the peaks can be noticed.

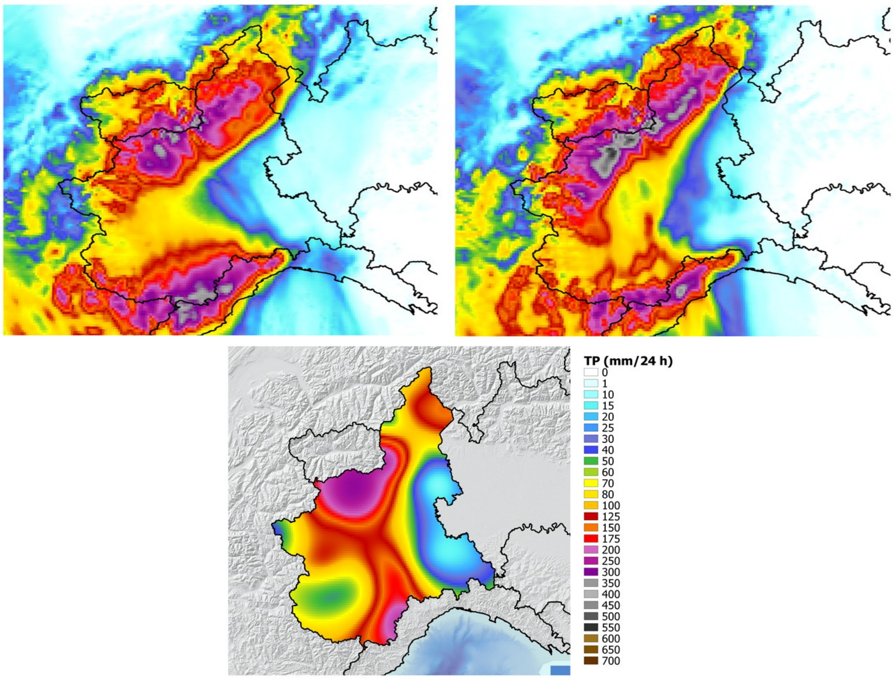

Fig. 6. 24h precipitation for 5 November 1994: on top left COSMO-2I +48h forecast, on top right COSMO-2I analysis and on the bottom the field interpolated from the original observations.

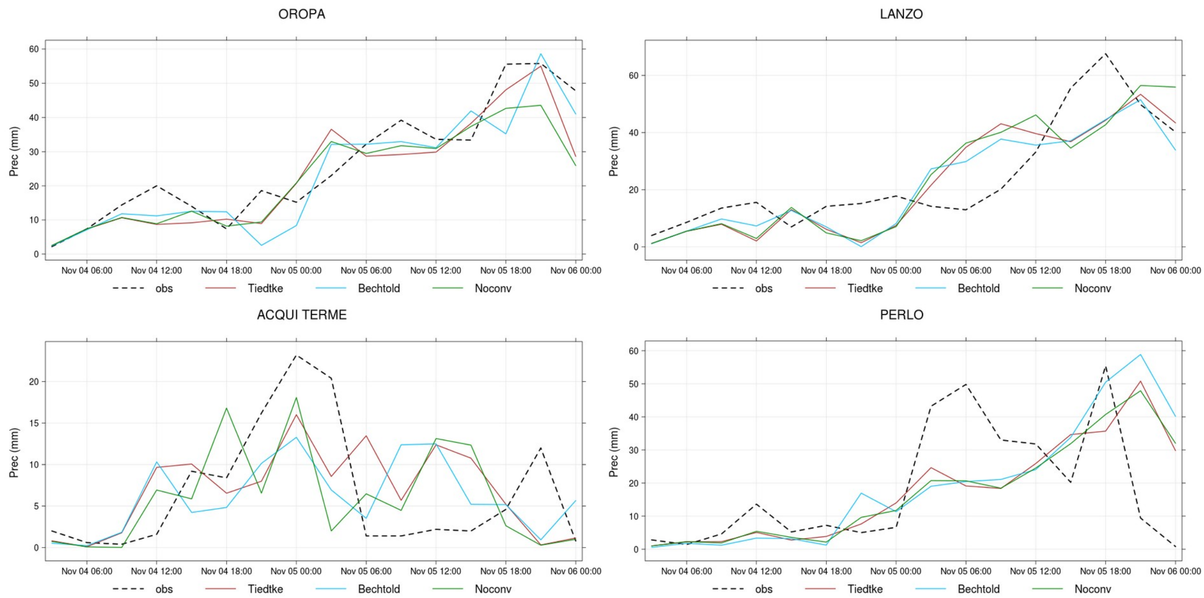

Fig. 7. Time series of precipitation from 4 November 1994 00UTC to 6 November 1994 00UTC: observations (black dashed line), COSMO-2I forecast (continuous lines) with different shallow convection parameterization (red: Tiedtke, cyan: Bechtold, green: none).

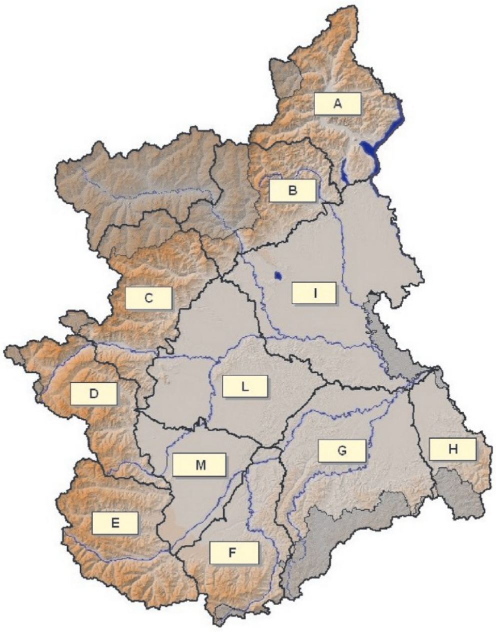

Fig. 8. Warning areas in Piemonte region (from A to M).

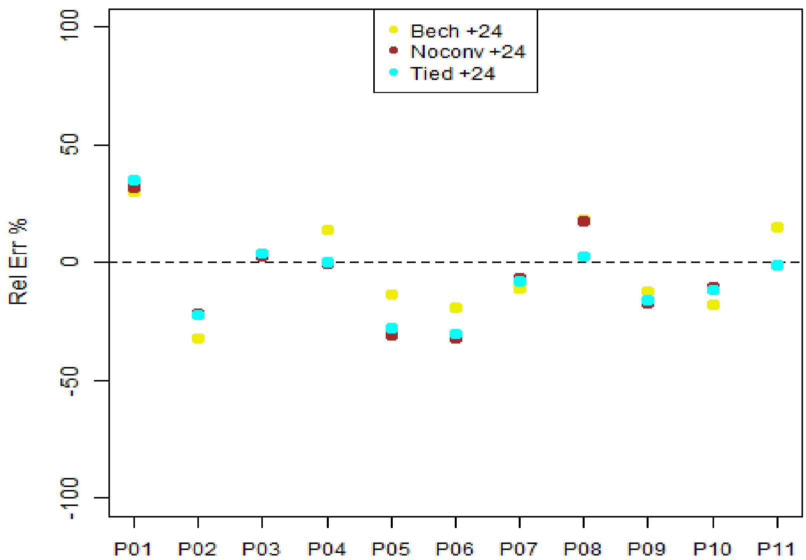

Fig. 9. Relative error for each warning area (see Fig. 8).

From a statistical point of view, we can show an example of relative error of total precipitation in 24h (from +00 to +24). The values are averaged over each warning area and compared to the observations (averaged as well). The comparison in Fig. 9 shows that for different convection schemes (or free convection) the results are similar. The area P01 corresponds to area A in Fig. 8, then analogously P02 is B, P03 is C, P04 is D, P05 is E, P06 is F, P07 is G, P08 is H, P09 is I, P10 is L and P11 is M.

Concluding, the tremendous flood of November 1994 in Piedmont has been reproduced with the meteorological models in use today operationally. ERA5 reanalyses provided initial and boundary conditions for COSMO hindcast simulations. Moreover, IFS model reforecast (driven by ERA5) provided the boundary conditions for COSMO forecast simulations.
The analysis of precipitation is in good agreement with the observed data, which were scarcer than now, considering both spatial interpolation and single point time-series. So for this case study, a very high-resolution reanalysis could be used as a useful proxy of the reality.

June 2020

The reforecast also produced a reasonable precipitation field, demonstrating that the actual models are able to forecast the flood correctly and with good details. The event in 1994 was predicted fairly well, given the technical limitations, but nowadays models are able to describe in more detail large-scale and smaller-scale phenomena.
The comparison among the different convective parameterization showed small differences, but the default Tiedtke scheme was in general closer to observations.

The authors would like to thank Gianpaolo Balsamo and his colleagues at ECMWF for the preparation of the ERA5 reforecast data.

List of publications/reports from the project with complete references

Garbero V. and Milelli M., “Reanalysis and reforecast of the November 1994 case in Piedmont using ERA5 and COSMO model”, submitted to Bulletin of Atmospheric Science and Technology

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 project is finished.