The flood event near Venice of 26 September 2007: was it forecast by the D-PHASE models?

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Introduction

The strong impact that heavy precipitation events have on human activities and environment have led to a great effort devoted to improve numerical weather prediction models, that are the main tool for quantitative precipitation forecasting (QPF). Heavy precipitation events are usually related to deep moist convection whose occurrence is tied to various processes acting on different scales, and to their complex interactions. Small errors in initial conditions or in simulating the involved processes can cause large error in QPF. Moist convection is an intrinsic source of forecast uncertainty, therefore limiting predictability of heavy precipitation events (Walser et al., 2004).

The increase of model horizontal resolution, allowed by the raised computing power, has been introduced as one of the possible strategies to improve short-range QPF. Several recent studies were performed to analyse the ability of high-resolution models in reproducing heavy precipitation events and to verify benefits brought by increased horizontal resolution. Buzzi et al. (2004) analyzed three cases of heavy orographic precipitation; they argued that the high horizontal resolution allowed to resolve physical processes, different from those reproduced through parameterization, leading to a more realistic representation of precipitation fields. Anquetin et al. (2005) statistically evaluated the performance of different models in forecasting a flash flood event: high-resolution models (with horizontal grid resolution ranging from 6 to 2 km) showed better results than lower-resolution models, but still retaining their drawbacks in terms of precipitation amount bias and location. Richard et al. (2007) compared four convection-resolving models run over the same domain with the same horizontal resolution (2 km) for the most intense orographic precipitation episode occurred over the southern flank of the Alps during the Mesoscale Alpine Programme (MAP) Special Observing Period: large variability in precipitation forecasts was found but high-resolution models showed more intense precipitation and better objective scores than coarser-resolution models.

In this context, we compare precipitation forecasts of four high-resolution models, operational during the MAP D-PHASE project. We consider a heavy convective precipitation event occurred over the flat area adjacent to the Venice Lagoon, on 26^{th} September 2007. This work aims at showing the overall performance of the different selected models.

The event

During the morning of 26 September, a mesoscale convective system (MCS) affected the flat area west of the Venice Lagoon causing floods in the nearby towns of Marghera and Mestre. Satellite image (Fig. 1 (a)) shows the wide V-shaped cloud shield of the MCS and different convective cells over the southern side of the Alpine range, indicating that the large-scale environment was favourable to deep and widespread convection.

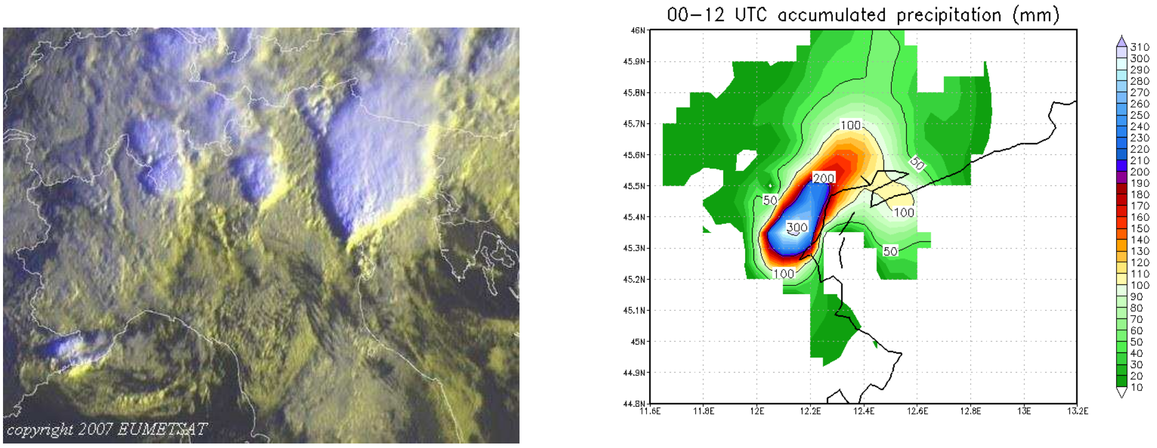

Figure 1: Left: Satellite image at 06:00 UTC. Right: observed accumulated precipitation for the 12-h period from 00 UTC to 12 UTC, 26 Sep. 2007

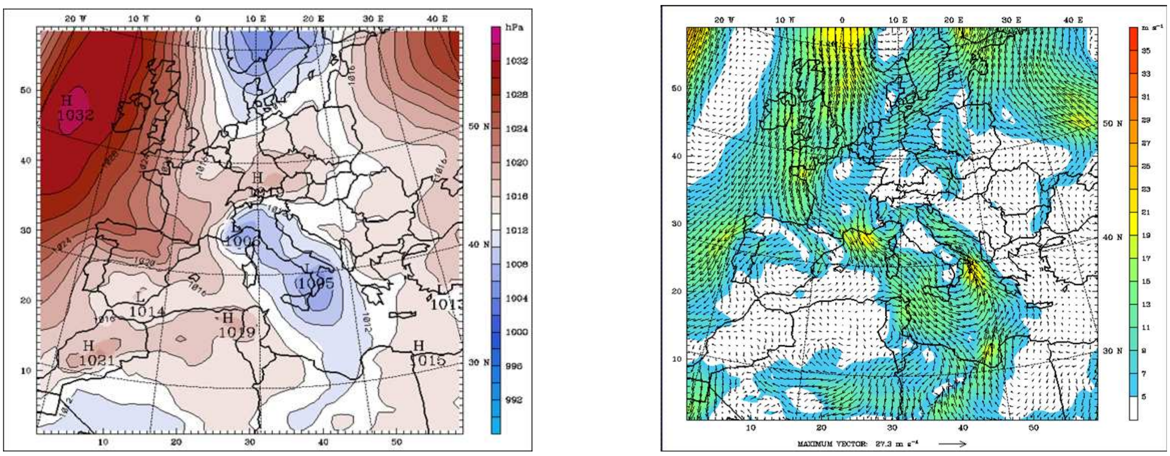

Figure 2: NCEP-GFS analyses of 00 UTC, 26 Sep. 2007, at 925 hPa. Left: mean sea level pressure (hPa). Right: wind vectors and speed (m/s)

The approaching of a mid-tropospheric trough towards the western Alpine region favoured a lee cyclogenesis over the Gulf of Genoa that, together with a minimum previously located over Tunisia, contributed to generate a wide low-pressure area over central Mediterranean and northern Italy (Fig. 2). The resulting cyclonic circulation strengthened the pre-existing south-easterly flow that affected the eastern Po valley coming from the Adriatic sea, advecting moist and unstable air. Colder air was already present over the central and eastern Alps, associated with a cold front moving slowly to the south east. As typical, cold air was turning anticyclonically around the eastern Alps, while west of them the cold outbreak had already penetrated over the Mediterranean as Mistral flow.

Some scattered convective cells were observed over the central and eastern Po Valley after about 02 UTC. Two hours later, a MCS started developing along a line roughly oriented from southwest to northeast in the area between Venice and the Prealps. Observed surface rainfall and wind data recorded by 49 automatic stations in the area indicate that convective cells organized in a zone of low-level convergence between the more intense south-easterly wind, blowing from the sea, and a weaker north to north-easterly wind, blowing over inland plain (Fig. 3 (b)). Rain gauges data show that intense precipitation (rain-rate > 40 mm/hr) affected the same area for almost 5 hours. A peak of hourly rainfall amount of about 126

	Resolution [km]	Initial time (UTC) [h]	Forecast range [h]	IC - BC (run)
AROME*	2.5	00, 26 Sep	30	ALADFR* ARPEGE (00, 26 Sep)
COSMO_CH	2.2	00, 26 Sep	24	COSMOCH7* ECMWF (00, 26 Sep)
MOLOCH_GFS	2.2	09, 25 Sep	39	BOLAM GFS (00, 25 Sep)
MOLOCH_ECMWF	2.2	00, 26 Sep	48	BOLAM ECMWF (18, 25 Sep)

Table 1: Main characteristics of models configurations. *Indicates models that use an assimilation scheme

mm in one hour was recorded around 06 UTC.

The surface wind configuration and related convergence zone persisted throughout the MCS activity, suggesting that the moist south-easterly flow had a relevant role in feeding convection. The MCS then slowly moved eastward, over the sea. After about 10 UTC, the north-easterly flow, following the MCS translation, invaded the area previously affected by the south-easterly wind. The 12-hour accumulated precipitation, from 00 to 12 UTC of 26 September is reproduced in Fig. 1 (b), which shows a narrow area of high rainfall amounts, oriented from southwest to northeast, with a maximum of 324 mm, of which almost 250 mm fell in 3 h. This event produced the highest rainfall amount observed during the D-PHASE Operations Period.

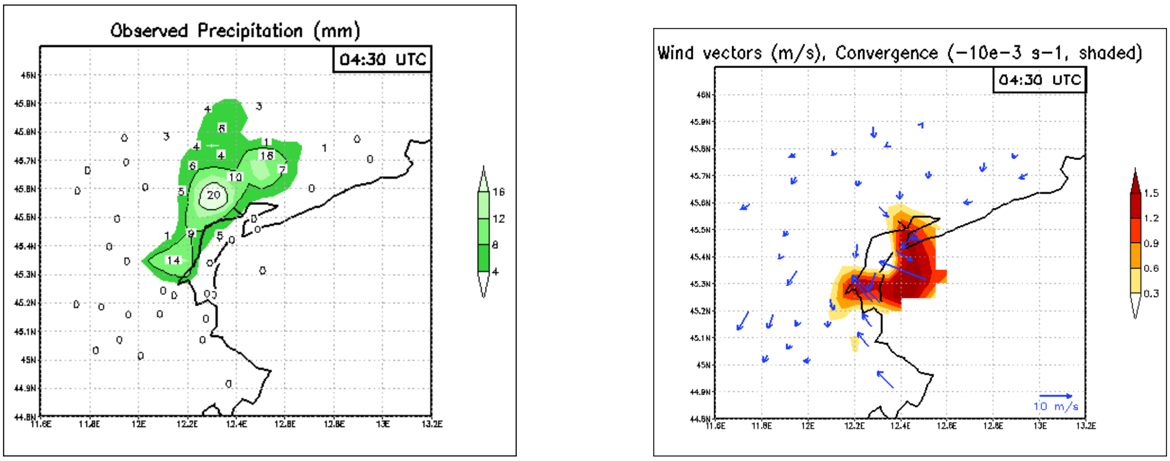

Figure 3: Left: 30-min accumulated precipitation (mm) at 04:30 UTC. Right: observed surface wind vectors (m/s) and convergence ($-10^{-3}s^{-1}$) at the same time

The high-resolution models

We selected the forecasts provided by 3 models, namely AROME, COSMO_CH and MOLOCH, whose domains suitably covered the area of interest. The modelling chain comprising the MOLOCH model was run with 2 different initial and boundary conditions so that a total of 4 forecasts were analysed in this work. Main characteristics of model setup are summarized in Table 1. The AROME forecasts were performed daily by the CNRM of Meteo-France. Each run started at 00 UTC and covered a period of 30 hours; numerical integrations were computed on a three-dimensional grid with horizontal resolution of 2.5 km and 41 levels. Initial and boundary conditions were provided every 3 hours by the non-hydrostatic ALADIN-France model implemented on a domain with horizontal mesh-sizes of 9.5 km and 46 levels. Such model was initialized and updated every 3 hours using the ARPEGE global spectral model outputs.

The selected COSMO_CH simulation was performed by MeteoSwiss that implemented a modelling chain based on initial and boundary conditions derived from the European Centre for Medium-Range Weather Forecast (ECMWF) global model forecasts initialized at 00 and 12 UTC. The COSMO_CH model was run on two 1-way nested domains with horizontal resolution of 7 and 2.2 km respectively. Two runs per day, with a forecast range of 72 hours, were performed on the outermost domain. Outputs from these runs were used to initialize every 3 hours a new forecast performed on the high-resolution domain, with a time step of 20 sec. The selected run, with forecast range of 24 hours, was initialized at 00 UTC of 26 September.

The MOLOCH model, developed at the Institute of Atmospheric Sciences and Climate - National Research Council (ISAC-CNR) in Bologna, produced two forecasts per day: one using NCEP-GFS analysis and 3-hourly forecast at 0.5 degree resolution, the other using ECMWF analysis and 3-hourly forecast at 0.25 degree resolution. The modelling chain employed at ISAC was based both on the hydrostatic model BOLAM and the non-hydrostatic model MOLOCH, nested in BOLAM. BOLAM was run with a horizontal resolution of 0.11 degree and 40 levels. The MOLOCH run using GFS data (MOLOCH_GFS, indicated also as ISACMOL in the D-PHASE database) started at 09 UTC each day, i. e. at the 9th forecast hour of the BOLAM run. The MOLOCH run using ECMWF data (MOLOCH_ECMWF, indicated also as ISACMOL2) started at 00 UTC each day, i.e. at the 6th forecast hour of the BOLAM run. MOLOCH was implemented with a horizontal resolution of 0.02 degree and 50 levels. We selected the MOLOCH forecasts obtained through the BOLAM runs initialized with 18 UTC ECMWF analysis of 25 September and with 00 UTC GFS forecast of 25 September, respectively.

Results

Precipitation fields, predicted by the different models over the time interval from 00 UTC to 12 UTC 26 September, are analysed and compared with the corresponding observed rainfall. Fig. 4 shows the spatial distribution of the 12-h accumulated precipitation forecast by the four different runs. The AROME forecast (Fig. 4 (a)) produces a relevant portion of precipitation over the Adriatic sea with a maximum of about 160 mm. The northernmost precipitation peak, of about 140 mm, is reproduced over the coastal area adjacent to the eastern tip of the Venice Lagoon. Amounts of about 60 mm in 12 h are forecast over the Prealps north of the flat region of interest. The COSMO_CH model (Fig. 4 (b)) produces the smallest precipitation amount among the selected models. Some scattered peaks of about 40 mm are simulated over the coastal area east of the Lagoon; the most intense precipitation is located over and at the foothills of the Prealps northwest of the focus area, with a peak of about 80 mm. The MOLOCH_ECMWF run (Fig. 4 (c)) shows a precipitation pattern covering the region extending from the Lagoon area to the Prealps. The most intense precipitation is located over the flat area in between, with a maximum of about 150 mm. Rainfall up to 120 mm is reproduced over the area where most intense precipitation was observe, while weak rainfall affects the sea. The MOLOCH_GFS run (Fig. 4 (d)) provides the highest precipitation amount among the four forecasts. Intense precipitation is reproduced over the sea facing the area of interest and the adjacent flat region: a maximum of about

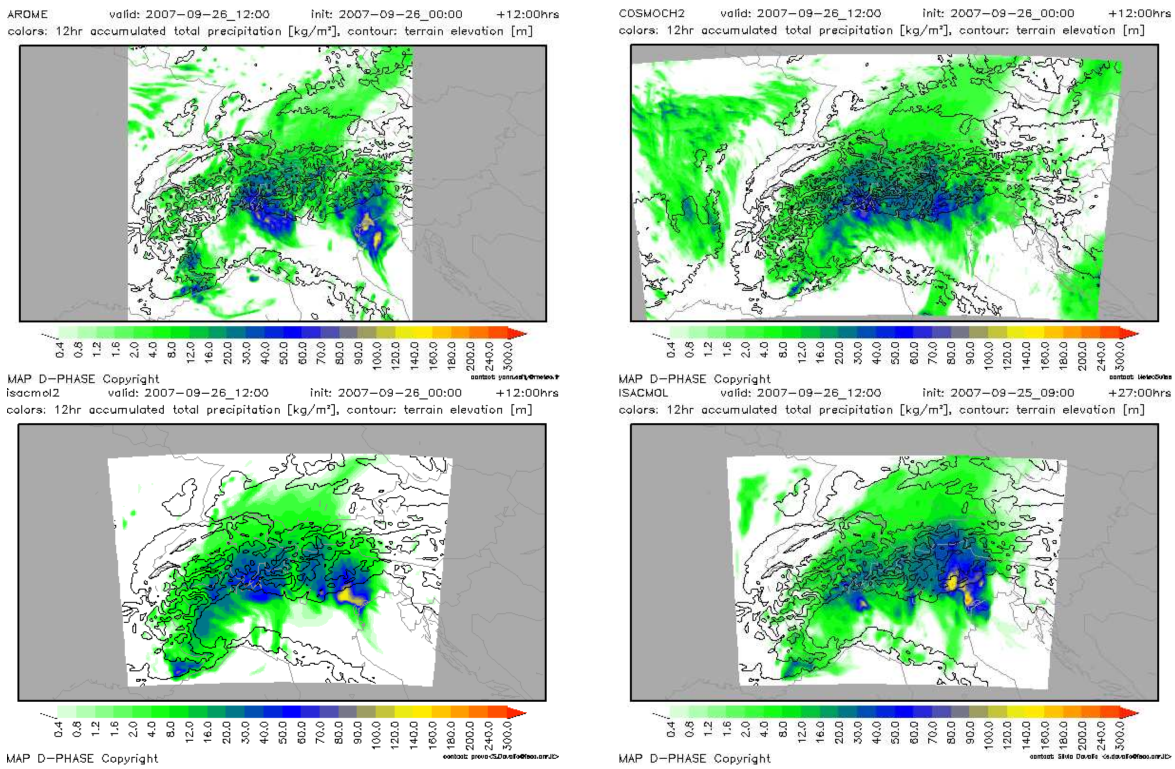

Figure 4: 12-h accumulated precipitation (mm) at 12 UTC, 26 Sep. 2007, as forecasted by AROME (top-left), COSMO_CH (top-right), MOLOCH_ECMWF (bottom-left) and MOLOCH_GFS (bottom-right)

240 mm is located close to the observed one. A wide area of intense simulated precipitation also hits the mountainous region with a secondary maximum of 180 mm in 12 h.

The largest amounts of precipitation simulated in the four runs are located along a direction roughly from southeast to northwest, that is from the coastal to the mountainous region (Fig. 5 (a)), indicating the occurrence of different lifting mechanisms, due to low-level convergence zones over the flat terrain and over the sea, and to orography near the Alps. The time evolution of the convective available potential energy (CAPE) computed upstream of the Lagoon (not shown) indicates that sensibly lower values of CAPE were simulated in the COSMO_CH run, suggesting a possible reason for the smaller amount of precipitation of this model. A key-role for the generation and maintenance of the MCS was played also by the surface south-easterly flow that developed over the Adriatic sea, in the form of a low level jet (LLJ), induced mainly by the synoptic scale environment. Model differences in the simulation of the dynamical and thermodynamic properties associated with this LLJ and its interaction with other currents, especially the north-easterly flow south of the Alps, seem to account for the main differences in forecasting precipitation amount and location.

The hourly series of observed and modelled precipitation, averaged on a domain centred on the study area, are presented in Fig. 5, in order to evaluate the main temporal features of the simulated rainfall evolution (see in particular Fig. 5 (b)). All the models except COSMO_CH reproduce a distinct rainy phase starting and culminating during the first 12 hours of 26 September. The AROME model shows the best results in terms of timing and rainy spell length. The absolute maximum is forecast one hour before the observed one, while an unobserved but significant peak is reproduced four hours after precipitation started. Such evolution is caused by the activity of several convective cells affecting the area at different times of the analysed period. For example, at the beginning of the most intense

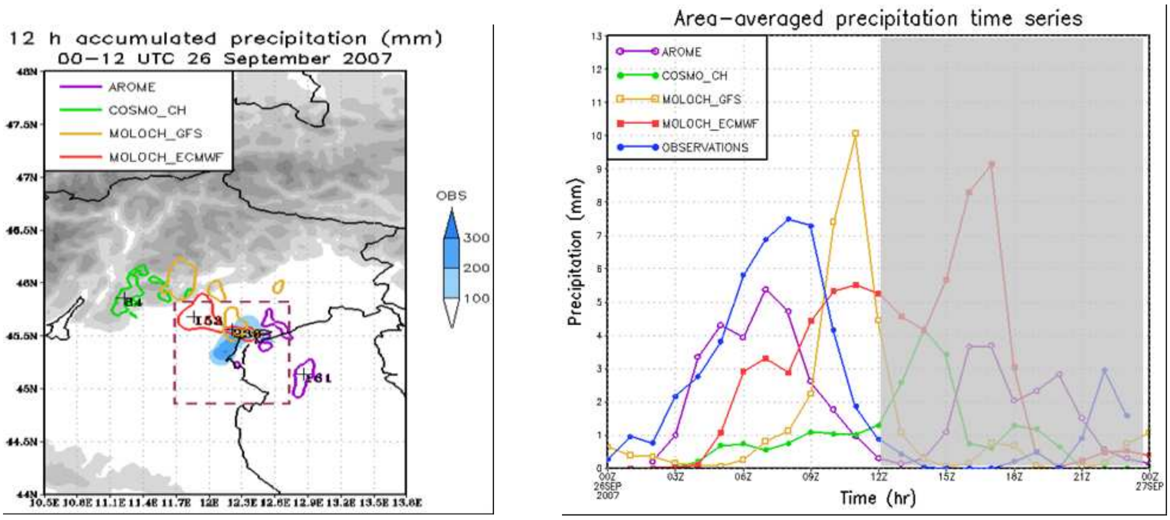

Figure 5: Left: 12-h observed (shaded) and simulated accumulated precipitation (mm), showing maximum amounts: 100 mm isoline for AROME and MOLOCH, 50 mm isoline for COSMO_CH. Right: hourly precipitation time series averaged over the 1°x1° domain depicted in the left panel

hourly precipitation peak (06 UTC), the high-level cloud cover simulated by AROME (Fig. 6 (a)) indicates the presence of a convective cell over the area of interest and smaller cells over the adjacent sea. A different evolution is depicted in time series derived from the two MOLOCH runs: in both simulations, most of precipitation is accumulated during a rainy spell produced by an intense convective structure that affects the area for at least four hours. In the MOLOCH_ECMWF run, the most intense convective activity occurs after a period of weaker precipitation beginning at about 04 UTC and lasting for about four hours. The maximum is underestimated and reproduced three hours later than observed; the subsequent precipitation decay is less marked than in the observed evolution. However, the resulting overall trend realistically captures the length of the rainy period even if it is delayed by about three hours. The MOLOCH_GFS run starts to simulate significant rainfall by 06 UTC, later than the other runs. The shorter rainy spell is associated with a strong convective structure that produces, three hours later than in the observations, the highest hourly area-averaged precipitation amount, even somehow overestimating the observed peak. As shown in Fig. 6 (b), during the period of most intense hourly precipitation (10-11 UTC), MOLOCH develops a realistic V-shape cloud shield, resembling the observed MCS (Fig. 1 (a)), with convection regenerating over the area next to the vertex.

Conclusions

An intense MCS, that affected the Venice Lagoon area during the morning of the 26 September 2007 with very intense precipitation and flood of nearby towns, has provided the opportunity to evaluate the performance of a subset of the short-range, high-resolution deterministic forecasts produced during the MAP D-PHASE Operation Period.

Spatial and temporal precipitation characteristics varied significantly among the four model forecasts. All models underestimated the observed accumulated maximum amount. However, three models reproduced quite clearly the convective nature of the precipitating MCS, predicting intense precipitation, ranging from about 120 to 240 mm, within an area very close to the one where the MCS was actually observed. Therefore, the short-range, high-resolution

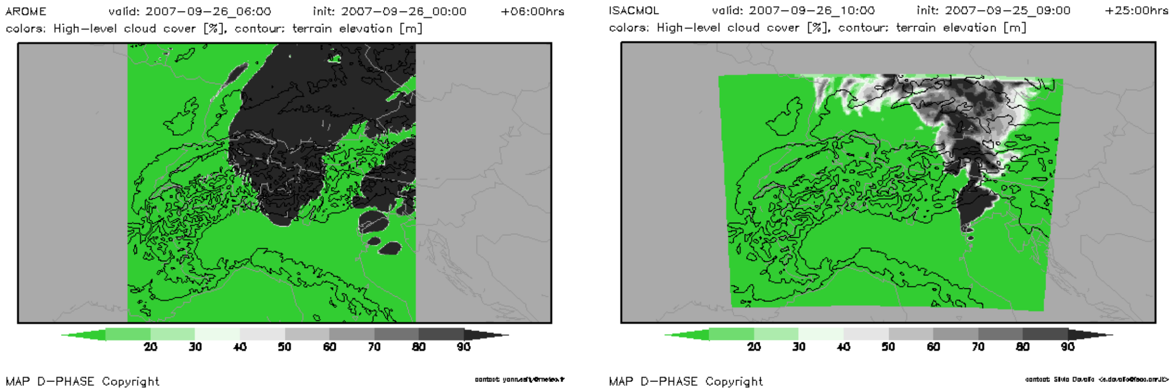

Figure 6: Simulated high level cloud cover (%). AROME at 06 UTC (left), MOLCOH_GFS at 10 UTC (right), 26 Sep. 2007

operational forecast of the analysed convective event can be considered at least moderately successful, also considering that the forecast range varied between 24 and 48 hours.

Various factors acting on different scales contributed to this result, like the presence of a moderate low over the Gulf of Genoa (lee cyclone), the CAPE distribution, the northeasterly flow over the Veneto plains, south of the Alps, and the intensity of a low level jet over the central and northern Adriatic sea. The modelled convective activity appeared to depend to a large extent on the considered model. In spite of the different initialization data, and the lack of mesoscale assimilation, both MOLOCH runs reproduced the most intense and long-lasting convective structures, resembling the observed MCS and differing from the rather scattered convection reproduced by the AROME model. The noticed space variability of precipitation was mainly related to differences in modelling the mesoscale evolution of the moist and unstable south-easterly flow over the Adriatic mentioned above. It appeares to constitute the main mesoscale feature directly involved in triggering and maintaining the convective activity. This indicates that, through the set up of a low-level cyclone and associated circulation, the large scale environment drove the convective event consequently favouring its reatively high degree of predictability.

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