ANALYSES OF HEAVY PRECIPITATION EVENTS OVER LIGURIAN REGION

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ABSTRACT
Some of the most intense flood events in the Mediterranean coastal areas are due to quasi-stationary convection that may insist on the same place for many hours, producing impressive amounts of accumulated precipitation. During last autumn season, three heavy precipitation events, characterized by the development of intense and organized convective systems, affected the Liguria Region (Northern Italy), leading to severe floods.
The present study aims at identifying the main characteristics of the convective events and the physical/dynamical mechanisms responsible for the heavy precipitations, through a combination of in-situ measurements, satellite data and numerical model simulations.
Passive microwave observations, elaborated through the 183-WSL fast rain rate retrieval algorithm, are used to recognize the area affected by heavy rainfall and to identify some characteristics of the convective systems. Moreover, a number of numerical simulations have been performed implementing a modelling chain based on the hydrostatic model BOLAM and the non-hydrostatic model MOLOCH, nested in BOLAM.
The present analysis allows to identify common features among the three events, at different scales: a very similar large scale pattern, the presence of a convergence line triggering convection, low-level intense moist flow over the sea feeding convection and strong vertical shear. Moreover, a detailed mesoscale analysis is provided.

Keywords: heavy precipitation, passive microwaves, numerical models.

INTRODUCTION
During the autumn season, when the sea is still relatively warm and the thermal difference with the atmosphere is responsible for intense heat and moisture fluxes, the Mediterranean basin is affected by heavy rainfall and floods, which are the most destructive natural hazards in the region. At large scale, the favourable conditions for triggering high-impact events have been identified (Rotunno and Ferretti, 2001; Nuissier et al., 2011), as the presence of a deep trough entering the Mediterranean associated with strong flows in the lower levels over the sea. However, heavy precipitations, leading to hydro-meteorological consequences, are often associated with the development of intense mesoscale convective systems (MCSs), possibly related to strong orographic forcing, whose scientific understanding and prediction is still an open problem.
Liguria region, located in Northern Italy and characterized by steep and complex orography in the vicinity of coastal areas, has been recently affected by severe weather and flood episodes during autumn 2010 and 2011. This study eventually aims at identifying the main characteristics and mechanisms responsible for heavy precipitations and floods in the analysed area. To attain this aim a combined numerical and observational approaches, which proved to be suitable in previous studies (e.g. Laviola et al., 2011), will be undertaken.

CASE STUDIES, METHODOLOGY AND RESULTS
For sake of brevity, only one case will be described in detail. During 25 of September 2011, a V-shape MCS developed over Liguria Sea and was responsible for heavy rainfall, exceeding 500 mm in 12 hours (Figure 1). Typical large scale patterns can be identified (Figure 2): a deep trough extending over the Mediterranean Sea, associated with a low pressure system over the

Atlantic, generated intense warm and moist low level flow over the Tyrrhenian Sea. A strong anticyclone, centred over Eastern Europe, slowed down the eastward propagation of the trough and of the associated frontal system. Moreover, at upper levels (not shown), the strong vertical shear and diffluent flow in the mid-upper troposphere over Liguria represented favourable conditions for the development of intense convective systems. It is worth mentioning that the other two events (4 October 2010 and 4 November 2011) are characterized by similar large scale features.

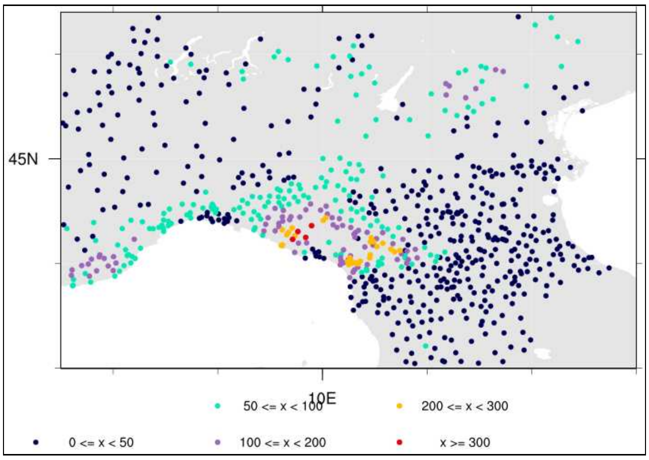

Figure 1: 24-h observed accumulated precipitation for 25 Oct. 2011.

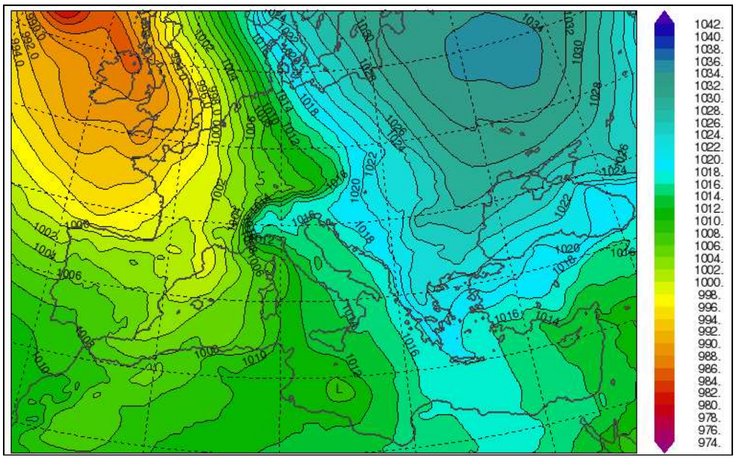

Figure 2: Mean Sea Level Pressure at 00 UTC, 25 Oct 2011. GFS analysis interpolated on the BOLAM grid.

Several numerical simulations have been performed implementing a modelling chain based on BOLAM (hydrostatic, about 11 km of horizontal resolution) and MOLOCH (non hydrostatic, convection permitting, up to 1 km of horizontal resolution) models, developed at CNR-ISAC (Malguzzi et al., 2006). The model chain has been initialized using different initial conditions, provided by two different global models (GFS and ECMWF) at different initialization times. Then, the most realistic simulations have been selected in order to perform additional experiments

aimed at evaluating the convection-resolving model performance at different horizontal resolution (4, 2 and 1 km).
In addition, a satellite precipitation retrieval algorithm, 183-Water vapour Strong Lines (183-WSL; Laviola and Levizzani, 2011), using the Advanced Microwave Sounding Unit-B (AMSU-B) sensor data, is applied to retrieve rain rates and classify the scenario into large scale and convective rainfall.

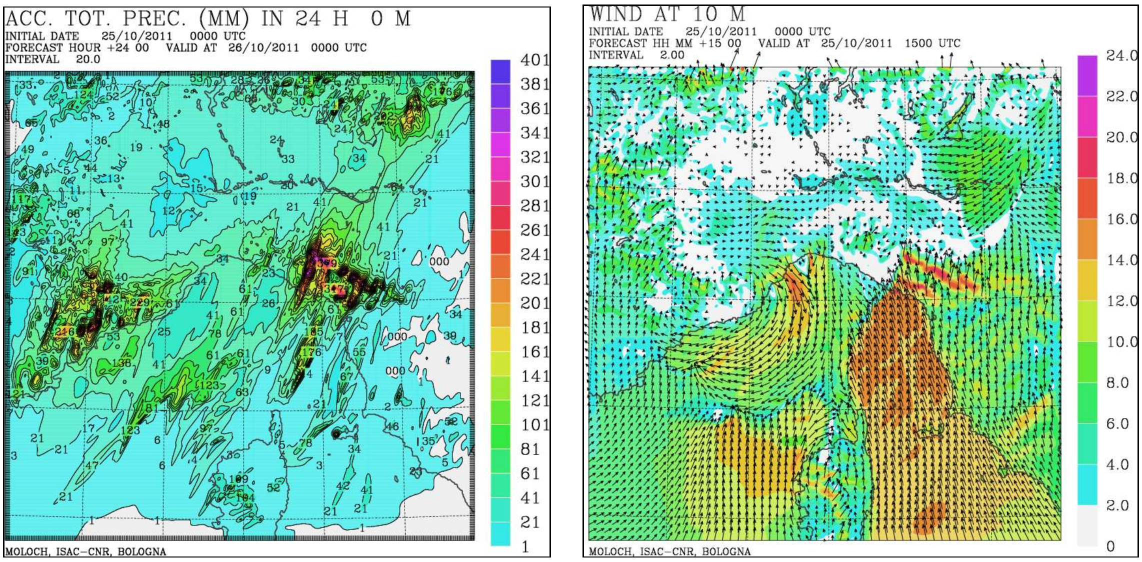

Figure 3: MOLOCH simulation at 1 km resolution, initialized at 00 UTC, 25 October 2011. Left panel: 24-h accumulated precipitation for 25 Oct. The maximum of 379 mm is in good agreement with the observations. Right panel: wind field at 10 m at 15 UTC, 25 Oct. clearly displaying the convergence line over the sea.

MOLOCH simulations were able to provide realistic forecasting of the heavy precipitation episode in terms of both rainfall intensity and location (Figure 3a), as a consequence of the correct description of a stationary mesoscale convergence line over the sea (Figure 3b), responsible for the triggering and the localization of the MCS over the same area for several hours. The MCS dynamics, its effects in terms of rainfall and the mechanism generating the convergence line (cold outflow from the Po Valley) are remarkably better described in the 1-km resolution simulation.
Remote sensing observations from satellite, processed by 183-WSL algorithm, clearly localize the isolated MCS over Liguria coast where the maximum of rain rates is calculated (Figure 4a). In particular, the algorithm classifies the clouds as convective (Figure 4b), providing an estimate of the cloud top around 7000-8000 m. It means that, in spite of the impressive amount of rainfall (observed rain rate up to 150 mm/h), the MCS seems to be characterized by a moderate vertical development probably sustained by the stratiform clouds (Figure 4a, blue and cyan colours for stratiform clouds in the low and middle atmosphere, respectively) surrounding the convective clusters. Model simulations correctly reproduce this feature: the vertical cross section of cloud water and ice (Figure 4c) displays convective cloud reaching 8 km.
Similar results have been also obtained for the other two events.

CONCLUSIONS
Several common features at large scale have been identified for the analysed heavy precipitation events. Moreover, at the mesoscale, further similarities have been recognized

among the three events through high resolution modelling simulations. In particular, the presence of a convergence line, due to the cold air outflow from the Po valley and the strong southerly flow over the sea, seems to be an important mechanism for triggering the MCSs and localize the intense precipitation over the same area for several hours. It turns out that the high horizontal resolution (up to 1 km) of the simulations is a critical factor for a realistic description of the MCSs dynamics and an accurate forecast of their effects.

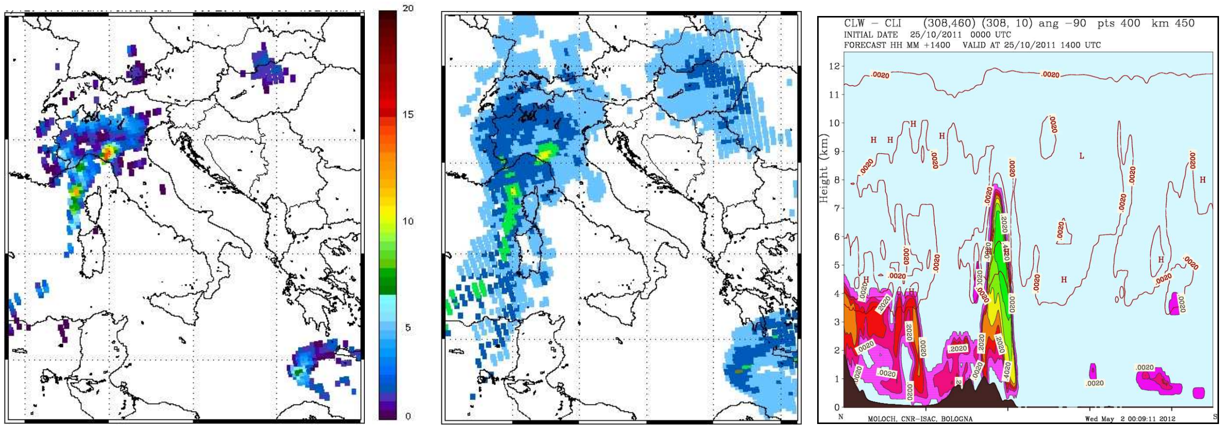

Figure 4: Left panel: 183-WSL rain rates showing the convective region where the utmost rainfall is calculated. Middle panel: cloud identification based on 183-WSL algorithm. The MCS is shown over Liguria at 12:51 UTC within the yellow area, indicating convective cloud with moderate vertical development. Right panel: MOLOCH cross section (cloud water, colors; cloud ice, contour lines) across the MCS at 14 UTC, 25 Oct, corresponding to the period of maximum rainfall intensity.

Satellite observations allow to describe the cloud scenarios and in particular reveals an interesting characteristics of the MCSs both in terms of evaluation of waterfall and in terms of vertical growing of clouds demonstrating that the vertical development of the convective clouds is substantially constrained in the first 7-8 km of the atmosphere.

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