PROBABILISTIC FORECASTS OF MEDITERRANEAN STORMS WITH A LIMITED AREA MODEL

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Abstract

This work aims to contribute to the definition of a flood risk alarm system. The SMR-ARPA operational Limited Area Model (LAMBO) is nested on the ECMWF ensemble and its capability to predict at the short and medium range (from 2 to 5 days ahead) and at high horizontal resolution (about 20 km) heavy rainfall events is investigated for cases of cyclogenesis in the Mediterranean region (selected from MAP case list). A cluster analysis of ECMWF ensemble is performed, enabling to find, at forecast time, different evolution scenarios, the most likely one being relative to the most populated cluster. For each cluster, a representative member of the ECMWF ensemble is selected and used as boundary and initial conditions for LAMBO integrations. Probability maps of forecast precipitation are presented, this providing quantitative estimates of the probability of occurrence for each precipitation scenario.

1 Introduction

The main weather centers have greatly increased in recent years the use of probability forecasts in order to predict the global evolution of the atmospheric flow beyond the short range (namely, from day 2 on). The National Center for Environmental Prediction, NCEP (Toth and Kalnay, 1996), the European Centre for Medium–Range Weather Forecasts, ECMWF (Buizza and Palmer, 1995) and the Recherche en Prèvision Numèrique, RPN (Houtmaker et al., 1996) have all developed ensemble systems to estimate the predictability of the flow and determine the reliability of deterministic forecasts. In fact, ensemble systems enable to find the probabilities associated with the different evolution scenarios of the atmosphere and their operational use provides an estimate of the day–to–day evolution of the probability distribution function (PDF) of the atmospheric flow (Molteni et al., 1996). At ECMWF, like in the other centers, computer power resources have greatly increased in the last years (Buizza et al., 1998), this enabling the operational use of ensembles with more and more members and at good spatial resolution (at the time of writing, 51 members, run at about 120 km of horizontal resolution with 31 vertical levels). Nevertheless, computer availability is also the main limitation which prevents from running ensembles at even higher resolution (Buizza et al., 1999, hereafter B99; Marsigli et al., 1999, hereafter M99). Therefore, ECMWF Ensemble Prediction System (EPS) and, in general, all ensemble systems perform at their best when the medium–range predictability of the large–scale flow is involved, the forecast of local events being somewhat poorer. This is particularly true when the prediction of heavy rainfall is involved, especially over Europe during the warm season (Buizza et al., 1999).

As, in the last years, the attention is more and more focussed towards the possibility of producing probabilistic forecasts for shorter time–ranges and over localized regions, it has been necessary to enhance further the present–day configuration of ensemble systems. In order to answer some of these new questions, a targeted EPS (referred to as TEPS) has been developed at ECMWF (Hersbach et al., 1999). In the TEPS configuration, the perturbations differentiating the initial conditions of the ensemble system, are given by linear combinations of singular vectors (SVs) targeted to maximize 48–hour total energy perturbation over the European area (instead of the Extra–Tropic Northern Hemisphere, like in the EPS). Preliminary results indicate a positive impact of using targeted observations to generate the initial conditions; in particular, the better performance of the TEPS over EPS is evident for shorter ranges over the European area and for the prediction of rare events (e.g., rainfall exceeding 20 mm in a day). Nevertheless, a severe limitation still remains in the horizontal resolution of TEPS members (the same as in EPS), which prevents the spatial–detailed prediction of those fields (e.g., rainfall, surface temperature) where orographically related processes can play a crucial role.

Among the different approaches attempted to overcome these problems (Tracton et al., 1998; Stensrud et al., 1999a and 1999b), here the attention is focussed on the development of the Limited Ensemble Prediction System (LEPS), proposed in B99 and M99. From ECMWF EPS (after 120 hours of integration), first a clustering algorithm is applied to group the members in 5 clusters; then, a representative member (RM) is selected from each cluster, representative of the possible evolution scenarios highlighted by the model, the possibility of occurrence being proportional to the population of the cluster. Finally, each RM is used as boundary and initial conditions for the integrations with a high–resolution limited area model (LAM), run for 120 hours. The 5 LAM integrations can be treated as a small high–resolution ensemble over a limited domain and the usual probability products, characteristic of EPS, can be prepared. From the results obtained so far, it appears that LAM integrations have a greater spatial detail in the precipitation patterns, predicting a few days ahead the occurrence of intense precipitation over localised regions and enabling the issue of flood alert. LEPS gives higher probabilities of heavy precipitation than EPS and verification carried out against observed values confirms the higher accuracy of LEPS predictions of rainfall.

The step forward attempted in this paper is the combination of the benefits gained by TEPS and LEPS. For a particular case study, the work investigates the extent to which the configuration TEPS+LEPS can provide information about the possibility of flood occurrence at different time ranges, so assisting the forecaster in the confirmation or dismissal of flood alert. The 4–day, 3–day and 2–day predictability of the event is assessed as well as the assistance provided to a forecaster by the probability products for the different forecast ranges. Once the occurrence of the flood seems to be likely, we will also consider the information provided by the output of the LAM run in a high–resolution configuration, to enhance the spatial detail of the regions affected by the event and to have a more accurate quantitative estimate of the amount of expected rainfall. Therefore, the paper is organized as follows: in section 2, the followed methodology is described, while in section 3 the experiment configuration is reported. Section 4 presents the results of the runs performed with the LAM and a comparison between these and the TEPS results. Finally, conclusions are drawn in section 5.

2 Methodology

As described by Hersbach et al. (1999), TEPS consists of 51 integrations of ECMWF operational model, at the resolution T_L159 L31 (corresponding to about 120 km in the horizontal with 31 vertical levels). One integration (the control) starts from the unperturbed analysis; in all the others, the analyses are perturbed in 50 different ways by adding, subtracting and re–scaling the initial perturbations (SVs optimized to maximize the growth over the region extending between 35N–75N and 40W–30E). Unlike Hersbach et al. (1999), where the optimization time interval is lengthened to 72 hours, it was decided to maximize the energy over a shorter time interval (48 hours), because we think that the linear assumptions under which SVs are calculated, are more closely respected in the first 2 days of perturbation evolution (Buizza, 1994a). Therefore, the configuration of TEPS we use in this paper, is almost identical to that of EPS (Molteni et al., 1996), the only difference being the region where the total energy of the perturbations is maximized.

As concerns LEPS, we briefly outline the methodology, approximately the same as in B99 and M99, followed to perform the cluster analysis and, then, to select the representative members. More precisely, all members of TEPS are integrated for a certain number of hours. Then, the 51 members are grouped into 5 clusters of different population, using as discriminating variable the 700 hPa geostrophic wind vector (calculated from the geopotential) over the Mediterranean region. Hence, one representative member (RM) is selected from each cluster using the total precipitation, cumulated in the last 24 hours of the run, to discriminate among the members. Therefore, we are left with 5 TEPS members (one RM for cluster), each of them representative of a possible evolution scenario, the probability of occurrence being proportional to the population of the cluster. Once the RM have been determined, they are used as boundary and initial conditions for the integration with a LAM. One LAM integration is performed for each RM, the duration of the run being the same as in TEPS. This will produce a small (5–member) ensemble over a limited area (hence, LEPS). LAM integrations have been shown to provide a more accurate prediction (already 5 days ahead) of the extreme weather events over the involved area (B99, M99). If every LAM integration is weighted according to the cluster population of the RM on which it was nested, it is possible to construct all those probability products (e.g. probability maps for rainfall, temperature) on the basis of the information provided by the LAM alone.

As in M99, the LAM we employ, is the Limited Area Model BOlogna (LAMBO), operational at the Regional Meteorological Service of Emilia–Romagna since 1993. LAMBO (20 km of horizontal reoslution with 32 vertical levels) is operationally run twice a day for 72 and 60 hours (nested on ECMWF high–resolution deterministic forecasts of 00 and 12 UTC, respectively); in this work, the model is integrated up to 96 hours.

3 Experiment configuration

The case study investigated in this paper deals with the flood event which took place in September 1992, affecting, among other places, the town of Vaison la Romaine, in southern France (at about 44N, 4E). The development of mesoscale convective systems due to the passage of a cold front and to the forcing of orography caused severe precipitation in that area (Senesi e al., 1995; M99). As reported in fig. 1, very high values of rainfall were measured between the 22 and the 23 September 1992 (the 24–hour period ending at 6 UTC), with a maximum of about 200 mm in a day, this causing severe damages as well as casualties.

Since we want to investigate the predictability of this extreme weather event for different time ranges, it has been necessary to perform a series of TEPS+LEPS integrations. The 4–day, 3–day and 2–day predictability are studied, with forecasts starting at 12 UTC of the 19, 20 and 21 September 1992, respectively, and all verifying at 12 UTC of 23 September. Table 1 reports the results of the cluster analysis performed after 96, 72 and 48 hours of integrations for the 3 sets of experiments. Therefore, in all cases, the cluster analyses and the representative members are valid at 12Z of 23 September 1992. In this way, it can be noticed how the cluster population varies as the forecast range shortens.

4 Results and conclusions

The results of the experiment performed at different forecast ranges have been compared when using TEPS and LEPS configuration, with special emphasis to the quantitative prediction of rainfall over a limited area. For this purpose, probability maps for rainfall exceeding particular thresholds (10, 20, 50, 100, 150 and 200 mm in a day) have been prepared. In case

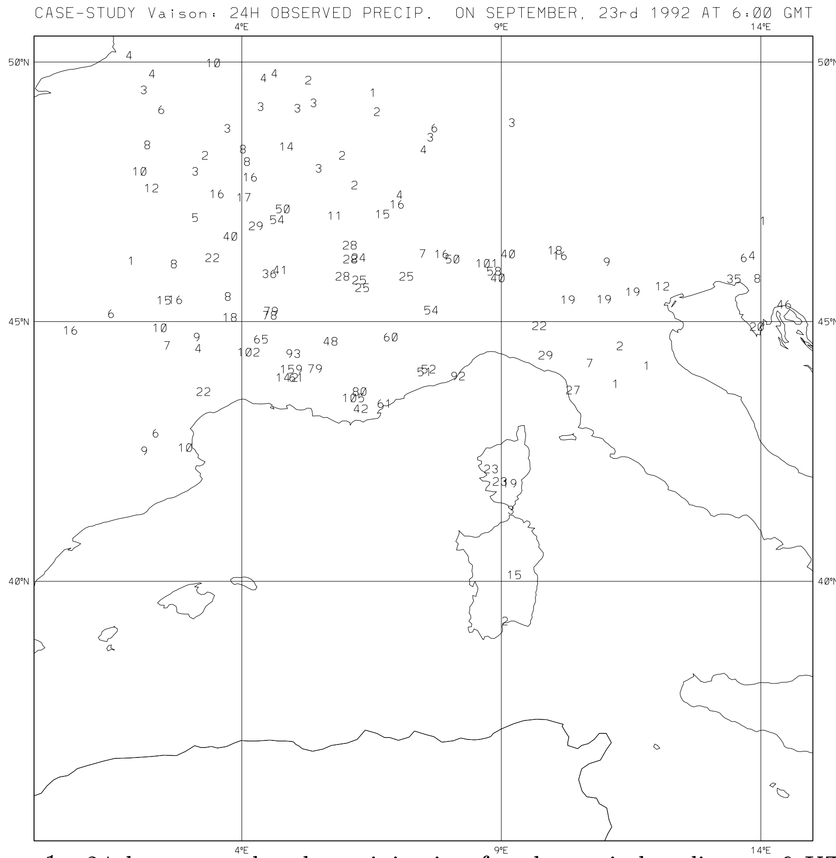

Figure 1: 24–hour cumulated precipitation for the period ending at 6 UTC of 23/9/1992; the values reported are in mm (data from MAP web site).

of ECMWF products, the probability maps, with 51 integrations, have been constructed in the traditional way (Molteni et al., 1996). On the other hand, when LAMBO integrations are involved, only 5 results are available; therefore, it was decided to weight each LAMBO integration according to the population of the cluster in which the RM was selected. In this way, it was possible to mimic the 51–member ensemble and, then, prepare the rainfall probability maps. The results of the experiments can be summarised as follows:

4.1 4–day predictability: figure 2 reports the LAMBO probability map for rainfall exceeding particular thresholds: it can be noticed that low–probabilities of heavy rainfall (greater than 50 mm/day) are assigned in the areas interested by the flood (around 45N, 4E), this preventing the

n^o of clusters	In. time (12 UTC)+ fc range, cluster population (RMs)		
	19/9 + 96h	20/9 + 72h	21/9 + 48h
cl 1	19 (31)	13 (48)	33 (0)
cl 2	20 (18)	8 (38)	4 (45)
cl 3	10 (32)	7 (33)	10 (12)
cl 4	1 (19)	3 (15)	2 (24)
cl 5	1 (39)	20 (30)	2 (23)

Table 1: Cluster population and representative members (RM, in parenthesis) for the different forecast ranges and for the cluster analysis with 5 clusters (rows 2–6). In all experiments, the cluster time is at 12 UTC of 23/9/92.

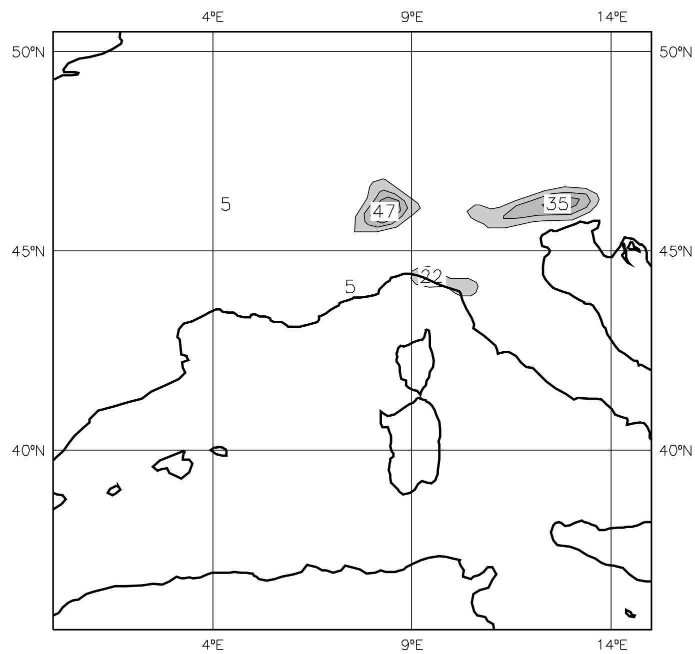

Figure 2: LAMBO probability map valid at 6 UTC of 23/9/1992 (forecast t+ 90h) for total precipitation exceeding 50 mm/day.

forecaster from providing flood alert. A comparison between this figure and Fig. 1 indicates that rainfall exceeding 50 mm/day is also forecast too much to the east. Therefore, 4–day forecast is quite inaccurate in the prediction of the amount and location of rainfall over the region of Vaison la Romaine An analogous result is obtained from ECMWF probability maps.

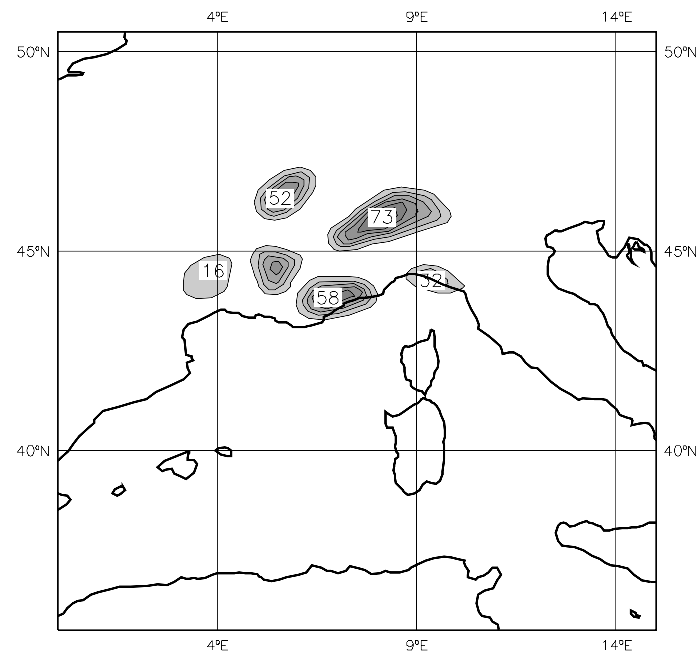

Figure 3: The same as Fig.2, but for forecast t+ 66h.

4.2 3–day predictability: figure 3 indicates an improvement in the accuracy of the forecast; the location of the region interested by precipitation is more correctly predicted and a chance, although low, of rainfall exceeding 50 mm in a day is reported in the correct location. While ECMWF probability maps (not shown) do not indicate probability of rainfall above 20 mm/day, LAMBO maps provide enough information to highlight heavy rain as a possible scenario, this giving, at least, a warning to a hypothetical forecaster.

4.3 2–day predictability: in Fig. 4, the likeliness of extreme rainfall in the correct region is confirmed, with a 86% of probability of rainfall exceeding 50 mm/day. Hopefully, this very high value would assist the forecaster at issuing flood warning, two days before the event. In ECMWF probability maps, the signal is by far less intense, almost in the right location.

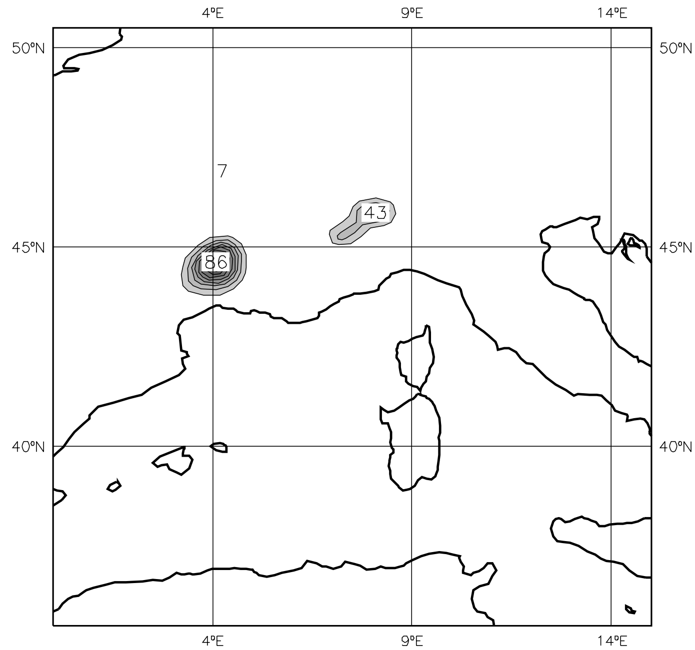

Figure 4: The same as fig.2, but for forecast t+ 42h.

Therefore, as the time–range decreases, the combination TEPS+LAM indicates a higher and higher probability of flooding in the correct region. The probability values are higher than for ECMWF TEPS and also the location of the region affected by the flood seems more accurate. Although, only 1–case study was studied, a natural extension would be to perform a systematic study by running TEPS (e.g., twice a week) and look at the performance of TEPS+LAM configuration for a long period.

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