Predictability, ensemble prediction and heavy rain
A case study

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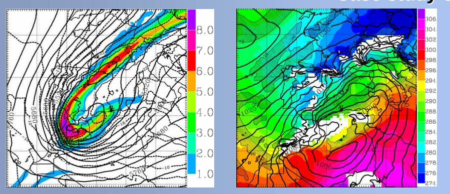
HyMeX — HYdrological cycle in Mediterranean EXperiment

Introduction

In the last years, development of high resolution numerical models and their associated physics has improved the ability of models to simulate heavy rain events. However, some meteorological situations still appear hardly predictable even when models are used at the cloud-resolving scale. Indeed, small perturbations in the initial state provided to models may increased rapidly and involved large errors in the precipitation forecast. In this study, we focus on the influence of lateral boundary conditions provided to the French non-hydrostatic Meso-NH model used at high resolution (2 km), allowing an explicit representation of the convection. This predictability study is applied to the November 2001 "superstorm" which dramatically affected Algiers and Balearic Islands. In a second part, a simple ensemble prediction strategy is proposed using a global model (ARPEGE), Meso-NH (2 km resolution) and a potential vorticity inversion method.

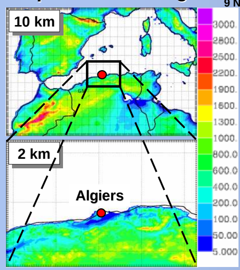
Influence of lateral boundary conditions

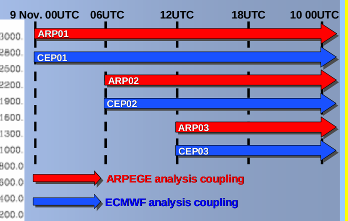
Case study & Experimental design



10 November 06 UTC ARPEGE analysis : (Left) 500-hPa geopotential height (solid black, m) and temperature (dashed, °C) and 350-hPa PV (colours, PVU) ; (Right) Mean sea level pressure (solid black, hPa), 900-hPa relative humidity (shaded, values greater than 70% only) and potential temperature (colours, K)

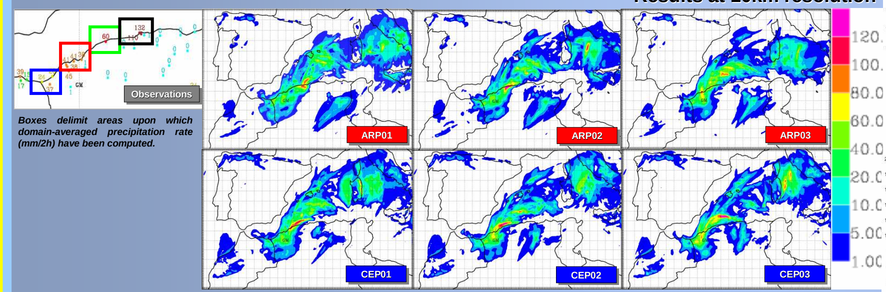
The combination of low- and upper-level conditions promoted convection over a wide area over Algeria and Morocco and implied flooding in Algiers





Characteristics of Meso-NH simulations : integration domains with topography (left, m; the red dot denotes Algiers) and model chain (above)

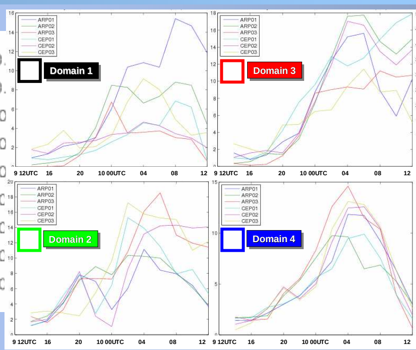
Results at 10km resolution



Boxes delimit areas upon which domain-averaged precipitation rate (mm/2h) have been computed.

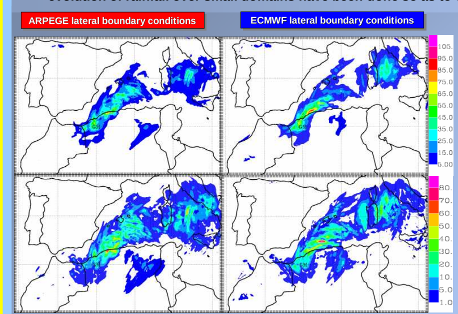
Results at 10-km resolution: (Left) Observed and (Right) 6h-accumulated precipitation (mm) from 10 November 2001 06UTC to 12UTC.

Each couple ARP0X-CEP0X (X=1, 2 and 3) of forecasts provides quasi-similar results on the large-scale. However, looking at a finer scale, heavy rain cores locations (mainly in Algier's area) seem to depend on lateral boundaries provided to Meso-NH. Time evolution of rainfall over small domains have been done so as to verify quantitatively these results (see graphs on the right).



Results at 10-km resolution: Time series of domain-averaged precipitation rate (mm/2h) for each forecast. The subdomains cover areas of about 150 x 150 km and are located as indicated on picture of oberved rainfall.

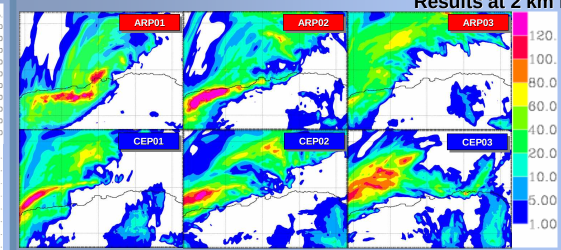
Except for domain 4 where predictability is high, calculations highlight the large dispersion of forecasts on other coastal areas. Indeed, graphs of domains 1, 2 and 3 exhibit time and spatial shifting for each ARP0X-CEP0X. The picture concerning the 4 domains (upper-right) confirms the good agreement between forecasts on the large scale.



Results at 10-km resolution: (Top) Mean and (Bottom) standard deviation of the 6h-accumulated precipitation (mm) from 10 November 2001 06UTC to 12UTC for each group of forecasts.

Forecasts are also comparable in terms of "ensemble" mean and variance. Nevertheless, ECMWF lateral boundary conditions involve a slight shift of the overall rainfall pattern to the north, in respect to simulations coupled with ARPEGE.

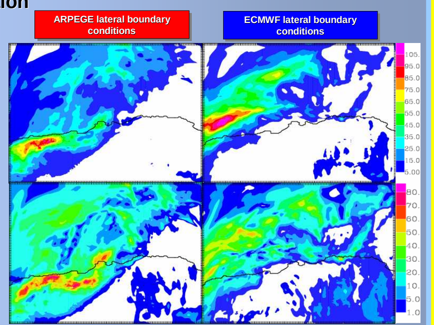
Results at 2 km resolution



Results at 2-km resolution: 6h-accumulated precipitation (mm) from 10 November 2001 06UTC to 12UTC.

ARPEGE coupled forecasts (ARP01 and ARP02) simulate realistic accumulated rainfall whereas CEP01 and CEP02 failed to reproduce the heavy precipitation observed over Algiers.

Contrary to results at 10 km grid spacing, the dispersion of each sub-ensemble is very different. In fact, ARPEGE coupled forecasts give quite good results on average and exhibit a very high dispersion inland in opposition to ECMWF coupling which creates high rainfall values and dispersion on the sea, offshore Algiers.



Results at 2-km resolution: (Top) Mean and (Bottom) standard deviation of the 6h-accumulated precipitation (mm) from 10 November 2001 06UTC to 12UTC for each group of forecast.

Generation of a mesoscale ensemble forecast : Ideas

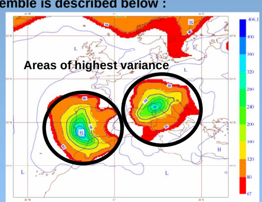
Motivations: These last two decades, numerical models have proven their ability to predict intense weather phenomena such as severe winds and heavy rainfall. It is mainly due to improvement of physical parametrisations (convection scheme, microphysical scheme…) and horizontal resolution decrease (which allows to correctly simulate topography and its complex interactions with the atmospheric flow). However, deterministic prediction using such models regularly failed to reproduce extreme events, on the large scale (for example the 1999's Christmas storms) as well as on smaller scales (for example, intense convection on a localised area). Starting from this

Method: Mesoscale heavy precipitation systems (like cyclone, MCS, isolated convection) can depend on large-scale flow and small-scale features that can only be simulated with high resolution numerical models. Therefore, our ensemble strategy is based on perturbations of synoptic scale structures as well as mesoscale structures. The generation of this ensemble is described below :

1. Perturbations on the synoptic scale.

This part of the method is based on perturbations introduced by potential vorticity (PV) inversion. So as to generate perturbation objectively, the following technique is used :

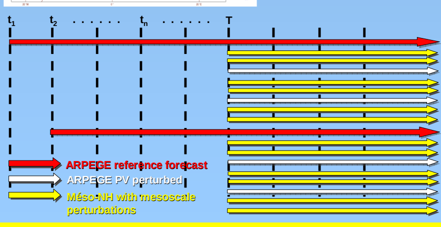
- First, N ARPEGE forecasts are produced by shifting the initialisation date (t_1,…,t_N);
- At time T, P potential vorticity perturbations are introduced in areas where the variance of the 500 hPa geopotential height of the ARPEGE ensemble exhibits highest values (see picture on the right). Therefore, (N + NxP) ARPEGE forecasts can be obtained from this method.



Example on 9 November 2001 16UTC: Standard deviation (m) of the 500 hPa geopotential height obtained from five ARPEGE forecasts starting at 8 November 12UTC, 18UTC, 9 November 00UTC, 06UTC et 12UTC.

2. Perturbations on the mesoscale.

(N + NxP) atmospheric states have been obtained from the precedent part of the method. They can serve to generate the same number of high resolution (2 km) Meso-NH simulations on a limited domain. However, in order to modelling uncertainties at the mesoscale, K perturbations (of low-level temperature for example) have to be introduced in each initial state of the high resolution forecasts (directly on the high resolution grid). Thereby, the ensemble will be generated using [K x (N + NxP)] members.



Example of ensemble generated with 2 ARPEGE forecasts, 2 PV perturbations for each forecast and 2 types of mesoscale perturbations introduced in Meso-NH. Thus, 12 Meso-NH simulations are obtained.

Summary & Perspectives

In the framework of a more complete study, the Algier's 2001 flood has been used so as to assess the impact of lateral boundary conditions provided to the French Meso-NH model run at the cloud resolving resolution. Some remarks arise from this work:

- First, it has been shown that moderate rainfall forecast is almost the same when lateral conditions change if the model is used at 10 km horizontal resolution. Nevertheless, the prediction of smaller scale features such as heavy rain cores can vary with boundary conditions. The time evolution of each precipitation forecast leads to the same conclusion that is to say lateral boundary conditions modification involves a spatial shift (mainly due to a different timing) of the precipitation forecast at 10 km grid spacing.
- Second, Meso-NH exhibits a higher sensitivity when used at 2 km. In fact, the choice of lateral boundaries leads to large changes of location and intensity of rainfall. Moreover, each sub-ensemble (ARP and CEP) has a larger dispersion than those obtained at 10 km resolution.

In order to complete this work, it is necessary to point out reasons leading to large differences between forecasts coupled with ARPEGE and those with ECMWF analysis. Furthermore, it is envisaged to apply the same type of study on other intense precipitation cases and to think at its possible use for high resolution ensemble forecasting. The generation of an ensemble prediction based on perturbations at the synoptic scale (by potential vorticity modifications) and the mesoscale has not been performed yet but it is envisaged to test this method on previous selected case studies.

First Mediterranean HyMeX workshop

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