Mediterranean Storms
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ASSIMILATION OF PRECIPITATION INTO A REGIONAL MODEL

S. Davolio[1] & A. Buzzi[1]

(1) ISAC-CNR, Via Gobetti, 101, 40129 Bologna, ITALY
e-mail: s.davolio@isac.cnr.it

ABSTRACT

A physical assimilation technique based on humidity nudging has been developed for application to satellite derived rainfall fields, in the framework of the European project "Eurainsat". The aim of the forcing procedure is to improve the short-range precipitation forecast with particular attention to specific meteorological phenomena, such as heavy orographic precipitation and small-scale "hurricane-like" vortex in the Mediterranean area. The nudging scheme forces the model humidity profile in order to get closer to the observed precipitation. The forcing is a function of the difference between the rain rates, observed and forecasted, and of the type of precipitation, convective or stratiform. Idealised experiments have been performed in order to evaluate the scheme performance.

1 INTRODUCTION

Accurate quantitative forecasting of precipitation, especially during severe weather episodes, is one of the most challenging tasks of meteorological modelling and data assimilation techniques are devoted to attain this aim. In particular, the frequent assimilation of variable directly related to the formation of precipitation and the water cycle may contribute to a better definition of model latent heating, divergence and moisture and consequently may lead to improvement of the short range precipitation forecast (*Manobianco et al.,* 1994). That is why the problem of assimilating precipitation data from different sources (satellite, radar, rain gauge, etc.) into limited area meteorological models has received increasing attention in the last years, not only in the tropical area, but also in mid-latitudes.

Since rain rate is not a model prognostic variable, it is not possible to assimilate directly precipitation data; however rain observations may be used to correct humidity and temperature profiles in order to obtain simulated precipitation closer to the reality. Even if it is somehow empirical, the nudging technique is a quite simple, physically based method that can solve this data assimilation problem.

The present study describes the development of a nudging procedure applied to BOLAM limited area, primitive equation, σ-coordinate, hydrostatic model (*Buzzi and Foschini,* 2000), aimed at improving the forecast skill by using satellite derived rainfall estimates. After a description of the main concept of the scheme, preliminary results are presented. Idealised experiments have been performed in order to assess the performance of the scheme and the impact of satellite rainfall assimilation.

2 THE NUDGING SCHEME

The precipitation assimilation scheme has been developed on the basis of a procedure recently proposed by *Falkovich et al.* (2000) that modifies the specific humidity profile of the model according to the difference between observed and forecast rain rate. Moisture changes lead to changes of temperature and other dynamical variables through the model precipitation scheme (explicit and convective parameterisation). Since the technique was originally devised for assimilation in tropical area, major modifications have been introduced for mid-latitude application.

The procedure starts comparing the forecast (R_{mod}) and target (R_{sat}) precipitation accumulated over a period of time. The lenght of the accumulation period depends both on model characteristics and on the (potential) availability of the satellite data. The best accumulation interval was established to lie in the range of 1 to 3 hours. After rain rate comparison, moisture profile are nudged according to the following equation:

$$\frac{\partial q(k)}{\partial t} = -\nu_{S,C}(k)\,\tau^{-1}\left\{q(k) - \varepsilon_{S,C}\,q^{*}(k)\right\} \qquad (1)$$

where k is the model σ-level, q(k) is the specific humidity profile before nudging, q*(k) is the saturation humidity profile (from model), τ is the relaxation time, $\varepsilon_{s,c}$ is the over/under saturation coefficient and $\nu_{s,c}(k)$ is the vertical modulation profile, whose value may vary in the interval [0-1].

The scheme does not adjust instantaneously the rain rate at each time step, but rather adjusts the rain accumulated up to the current time step.

Convective precipitation and stratiform precipitation are treated differently. Model generated precipitation is used in order to discriminate the precipitation type at a specific grid point. If the model fails to forecast rainfall, it is provisionally assumed that rainfall is of stratiform nature, unless at least in one of the surrounding grid points the convective scheme (Kain-Fritsch) is active. Different vertical modulation profiles $\nu_{s,c}(k)$ and different coefficients $\varepsilon_{s,c}$ are used in the two cases in order to introduce/remove humidity only where it is needed:

- For stratiform precipitation: $\nu_s(k)$ is such that the humidity is changed only in the middle-lower troposphere, where most of the large-scale condensation takes place.

  If $R_{mod} < R_{sat}$, q(k) is increased gradually toward a slightly super-saturated profile ε_S^+ q*(k).

  If $R_{mod} > R_{sat}$, q(k) is decreased gradually toward a sub-saturated value ε_S^- q*(k).

- For convective precipitation: $\nu_c(k)$ is such that humidity is changed mainly in the boundary layer, which is the source of humidity for convective motion.

  If $R_{mod} < R_{sat}$, q(k) is forced gradually toward a slightly under-saturated profile ε_C^+ q*(k).

  If $R_{mod} > R_{sat}$, q(k) is decreased gradually toward a low relative humidity value ε_C^- q*(k).

In case of coexistence of both types of precipitation, the sum of the modulating profiles does not exceed unity.
As for the computed convective (and all physical) tendency, the nudging adjustment is distributed over all the time steps in the interval between two times at which rain rates are compared.

3 SIMULATED SELF NUDGING

Using an OSSE-type strategy, a preliminary phase in defining the nudging procedure was devoted to the determination of the best coefficient and to the set up of the scheme. Assuming a perfect model, a control forecast (C) has been performed in order to obtain 3-hour accumulated precipitation to be used as target data. For the same period and from the same initial condition of (C), another forecast (S) has been carried out by adjusting the forecast precipitation toward the "pseudo-target" data of (C). This procedure, that can only deteriorate the forecast, allows to characterise the differences between a full time dependent latent heating (C) and a latent heating, which is forced to be nearly constant over the selected 3-hour interval (S). In this test, only minimal deviations from (C) are expected for a proper assimilation scheme. Moreover, exploration of sensitivity of the model to changes of the nudging parameters has been done.

A limited set of "good" coefficients have been selected during this test phase by visually comparing precipitation fields and evaluating the convergence of the scheme in terms of number of grid points in which the difference between target and forecast precipitation exceeded some fixed thresholds. These coefficients have been employed also in a realistic assimilation framework to assess which is really the best (see below). This double-check, in principle, should assure that the scheme can improve the short-range precipitation forecast by introducing a "minimal" forcing to the model trajectory.

4 LAGGED FORECAST EXPERIMENTS

The performance of the nudging procedure has been further evaluated by implementing a lagged forecast scheme in which two realistic simulations, control and perturbed, are obtained starting from different initial condition (Figure 1). In details, while the control run starts at 00 UTC, 19 November 1999, the perturbed simulation starts at 12 UTC of the same day. These days have been characterised by heavy precipitation over the Alpine area and correspond to a case study of MAP (Mesoscale Alpine Programme). The control run represents the reference state and provides target rain rate.

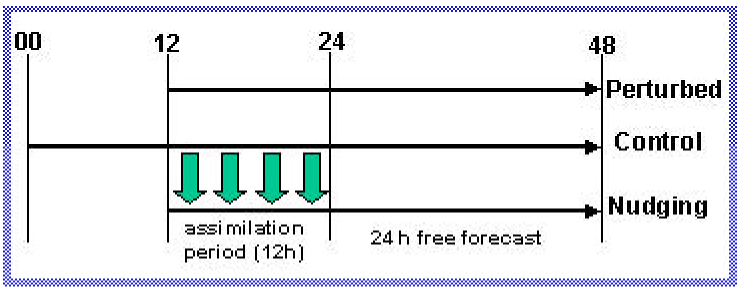

Figure 1. Scheme of the simulations for the Lagged Forecast experiment.

The 12-hour accumulated precipitation shown in Figure 2(a) and Figure 2(b) points out remarkable differences between the two simulations. In particular, the perturbed simulation does not reproduce a large rain band over the western Mediterranean Sea; moreover the areas of heavy precipitation over southern France are displaced and a maximum appears over central-western France. These differences have to be considered as forecast errors.

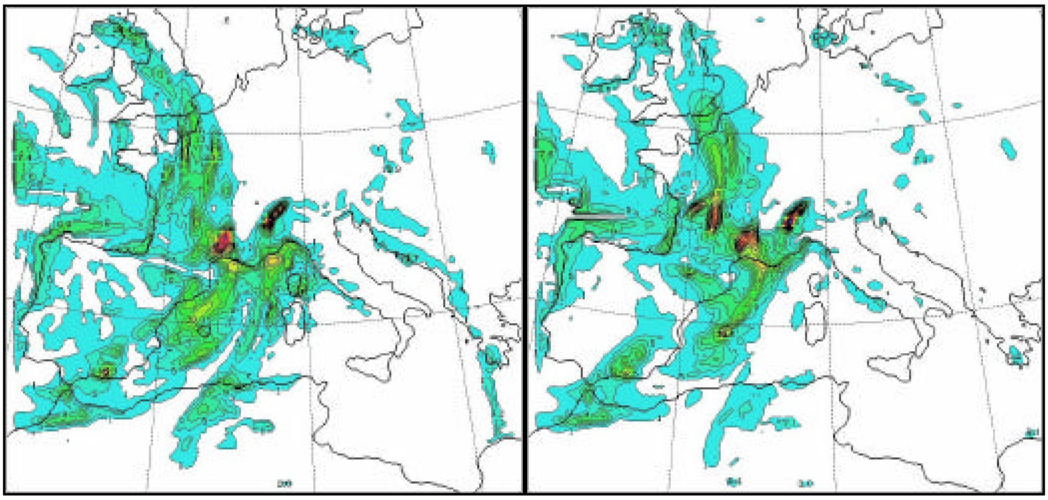

Figure 2. (a) 12 hours accumulated precipitation for the control run (left panel), which represents the target data, verifying 20 September 1999, 00 UTC, after 24 hours of integration. (b) 12 hours accumulated precipitation for the perturbed run, valid at the same time as (a), after 12 hours of integration.

Since the perturbed simulation represents the forecast to be improved, the nudging procedure is applied for 12 hours starting from the initial condition (19 Nov. 1999, 12 UTC) with the aim of forcing the perturbed run toward the control run, whose accumulated precipitation is used as target rainfall. The encouraging result is shown in Figure 3. The precipitation field is now closer to that of the control case (Figure 1(a)): the missing rain band over the sea is recovered and the areas of heavy rainfall are now better reproduced. Also over British Islands the structure of the precipitation system is now closer to the target (control run).

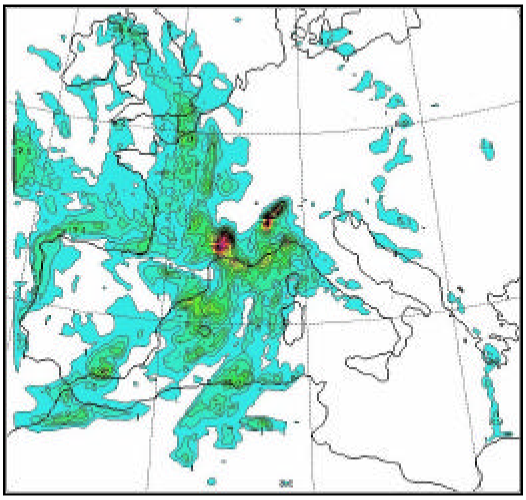

Figure 3. 12 hours accumulated precipitation for the simulation in which nudging is applied, valid at the same time as Figure 2, after 12 hours of integration.

The improvement obtained by forcing the perturbed simulation using the nudging procedure has been quantified by means of precipitation scores, such as Hit Rate, False Alarm Rate, Threat Score and Equitable Threat Score. The latter is shown in Figure 4: the evolution of ETS in time, both for low and for high values of rain rate, 2 and 15 mm/6h respectively, points out the effectiveness of the nudging, but also stress the evident tendency to loose its benefits on a time scale of the order of about 10 hours. However, improvements have been observed not only in the precipitation field, but also in the geopotential, especially in the lower troposphere. For the m.s.l.p., the RMSE (not shown) is reduced by the precipitation nudging. The positive impact seems to last for almost 18-24 hours after the end of the forcing period. Significant amelioration in the intensity of the main cyclone over Ireland is present till the end of the simulation.

Experiments using target precipitation data obtained from the control run, which differ for the lenght of the accumulation period (1, 2 or 3 hours) have shown that with 2-hourly data it is possible to make the adjustment lasts longer. Sensitivity to the assimilation windows was reported also by *Chang and Holt* (1994). At least for this case study and for this nudging procedure, it seems that the best accumulation interval for satellite-derived data is about 2 hours.

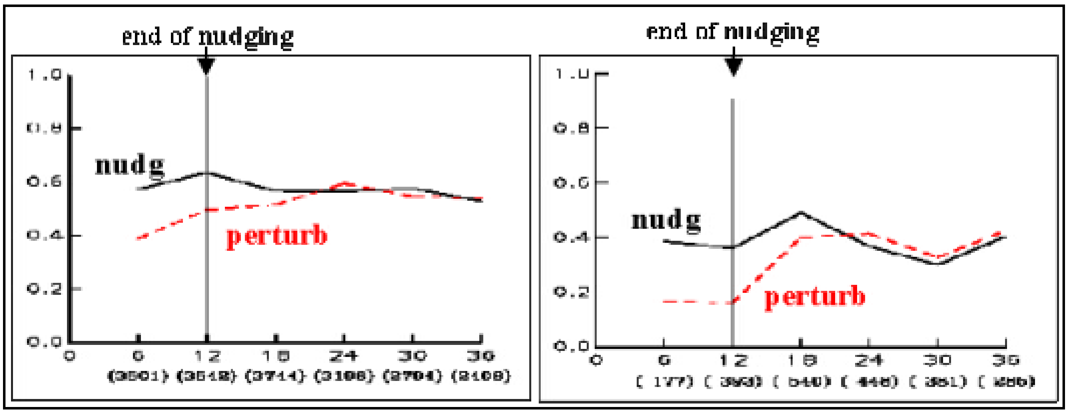

Figure 4. Equitable threat score vs. simulation time calculated for thresholds of 2mm/6h (left panel) and 15mm/6h (right panel). The black solid line represents the simulation with nudging, the red dashed line the perturbed run. Number in brackets indicates number of observations exceeding the threshold values (2 or 15 mm/6h).

5 CONCLUSION

Encouraging results have been provided by the scheme: it seems able both to increase and reduce the rain where needed Improvements in the amount and in location of precipitation are evident even if the positive impact of the nudging tends to disappear after a period of about 6-12 hours. This fact was already noted in other studies (see for example *Macpherson*, 2000).

Further experiments are still needed in order to improve the scheme, for example by introducing a weighting term that accounts for the (satellite) data error, in order to evaluate the dependence on the particular synoptic situation and to further explore the sensitivity of the procedure.

We expect further and longer lasting improvements, especially concerning the dynamical variable, if nudging is performed within an assimilation cycle and changes in the circulation introduced by the nudging improve the first guess for the next analysis.

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