SENSITIVITY TO INITIAL CONDITION AND MODEL RESOLUTION OF PRECIPITATION FORECASTS MODELLED BY THE HYDROSTATIC BOLAM MODEL OVER THE MEDITERRANEAN BASIN

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I. INTRODUCTION

In the numerical weather prediction community, the question about the capability of an increase in model resolution to improve forecast quality is still under investigation (see, e.g., Mass et al., 2002; Davis et al., 2010 and references therein).

Focusing on limited-area model (LAM) precipitation forecast, the added value of the reduction of horizontal grid spacing (both on the newly-represented scales and on the larger ones) is conditioned to many factors, namely: the amount of information driving small-scale motions (and their large-scale feedback) provided by the "coarse" initial and boundary fields; the added value of a better surface (orography, land-sea distribution, etc.) representation; the impact of uninitialized small-scale motions on the whole forecast, and so on.

The issue is simplified when considering a hydrostatic LAM, since an independent vertical velocity field and explicit moist convection are not part of the problem. Moreover, when the integration area displays complex topography, the domain choice is another crucial issue. This is the case for the Mediterranean basin, which is an outstanding source of secondary weather due to its complex topography (Speranza, 2001). Including or not, for instance, a mountain range in the LAM domain means making the related weather-shaping effects to be represented by the LAM or by the global model.

The development activity on the Italian Institute for Environmental Protection and Research (ISPRA)'s meteo-marine integrated forecasting system SIMM (*Sistema Idro-Meteo-Mare*, Speranza *et. al,* 2007) inspired the present work. After the recent update of the hydrostatic BOlogna Limited Area Model (BOLAM), which is the core of the forecasting system, we are interested to investigate the potential forecast quality improvement as a consequence of a configuration improvement in terms of resolution, domain extension, and input data quality. With this respect, it is worth to note that hydrostatic modelling can be successfully employed also pushing horizontal grid spacing well below the 10-km hydrostatical limit (see, e.g., the 0.5° BOLAM version running at Sardinia Regional Environmental Protection Agency, http://www.sar.sardegna.it/servizi/meteo/mappebolam_it.asp).

QPF statistical verification can be employed for such a model intercomparison study, provided that an adequate (both in space and time) observation and model database is available. Thus, the 6-month MAP D-PHASE observational dataset available over the Alpine region has been employed, along with correspondent model reforecast sequences built under different model configurations.

A systematic sensitivity study, testing separately any factor potentially affecting QPF quality, by producing a large number of reforecast time series, should be confusing and computationally unaffordable. So, it was chosen to "cluster" the possible improvements in the system design in only two groups (namely changes in the input dataset and changes in the model configuration), resulting in only two "experimental" forecast data sets, to be intercompared with the present operational configuration. Results, which are partly presented here, will lead further studies, aimed to a finer and more robust identification of the factors able to make a higher-resolution hydrostatic BOLAM to provide a better forecast.

II. MODELS, DATA SETS AND METHODOLOGY

The SIMM, operational at ISPRA (formerly APAT) since the year 2000, is a cascade of four numerical atmospheric and marine models, running on a SGI-Altix parallel platform. The BOLAM model, fed by ECMWF initial and boundary conditions, provides a 10-km grid step forecast on the Mediterranean region, then driving a wave model over the whole Mediterranean Sea and two sea elevation models on the Adriatic Sea and the Venice Lagoon. A hydrological model, tailored over two Italian river basins, is also integrated in a research configuration into the SIMM forecasting chain in cascade to BOLAM.

This latter model has been recently fully updated by implementing the new parallel version developed by the Institute of Atmospheric Sciences and Climate of the Italian National Research Council (ISAC-CNR). Such new version contains, among others, more efficient parameterization schemes for cumulus convection, radiation, soil and turbulence. Its configuration includes a 30-km "father" model employing 6-hourly, 50-km grid step, 15 vertical pressure level ECMWF analysis and forecast data and providing 3-hourly forecasts to the nested, 10-km "son" model; the "son" forecast starts 12h later than the "father" (spin-up time). Anyway, at present, the model configuration still needs to be further upgraded. It is planned to employ higher-resolution, full-level, 3-hourly ECMWF data to drive BOLAM directly (without nesting) on a less-than-10km grid, possibly wider than the present one.

Given the impossibility to test separately all these factors, two experimental configurations are proposed. In the first one (EXP1), improved initial and boundary conditions are employed to feed directly the present "son" model. The second configuration (EXP2) provides the same input dataset of EXP1 to a 0.07° BOLAM grid, centred on the Mediterranean Sea, but with a domain significantly wider

than the operational one.

The differences between the two input datasets are listed in Table 1 (a possible alternative was to use this dataset as an input to the "father", preserving the old nesting configuration; this point will be discussed later), whereas the differences between the two grids are listed in Table 2.

Parameter	BOLAM11	EXP1, EXP2
input grid step	0.5°	0.3°
input levels	15, pressure	91, hybrid
BC time interval	6h	3h
nesting	yes	no

TABLE I: Differences in experiment design between the control run series (BOLAM11) and the two experiments. Differences concern model initialization.

Parameter	BOLAM11, EXP1	EXP2
model grid step	0.1°	0.07°
model grid points	386x210	810x498
approx. domain extension (km)	4300x2300	6200x3800

TABLE II: Differences in experiment design between EXP2 and the other two run series, namely BOLAM11 and EXP1. Differences concern model resolution and domain extension.

For a statistically robust verification study, a 6-month reforecast database has been built for EXP1, EXP2 and for the present operational configuration (BOLAM11). The MAP D-PHASE Demonstration Operation Period (DOP, June–November 2007) has been chosen as test period, so that the large observational database collected under the MAP D-PHASE project activity is available for verification purposes. It includes data from rain gauge stations over an area spanning in latitude from Central Italy to Germany and in longitude from France to Croatia. However, for the purposes of the present work, only rain gauges available over a sub-domain common to the three data sets (verification domain; Fig 1) have been considered.

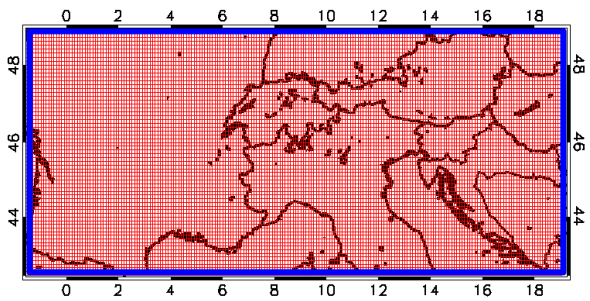

FIG. 1: Verification domain (blue solid line) and the 0.1° grid (red solid lines) used for remapping the two experiment forecast series and the control forecast series over the common sub-domain.

The statistical assessment is performed by calculating traditional categorical scores and skill scores by means of contingency tables, including the frequency bias (BIAS), the equitable threat score (ETS), the Hannsen-Kuipers score (HK), the probability of detection (POD), the false alarm ratio (FAR), and others (Wilks, 2006) are obtained for each experiment on a given set of thresholds (0.5, 5.0, 10.0, 20.0, 30.0 and 40.0 mm $24h^{-1}$). In order to build contingency tables, both observations and forecasts (from the three experiments) have been 24-h accumulated. Gridded observation analyses over the 0.1° verification grid (Fig. 1) are obtained through a 2-pass Barnes analysis scheme (Barnes, 1964, 1973; Koch et al., 1983), while model forecasts have been provided over such grid using a remapping technique (Accadia et al., 2003).

To statistically evaluate significant differences between categorical scores of two "competing" models, a bootstrap-based hypothesis test (Hamill, 1999) is applied over the series of contingency tables employed for the score calculation. In this way, EXP1 and EXP2 ("competitors") are separately compared with the control run ("reference"), thus obtaining, for any given threshold, confidence intervals for the score differences.

Finally, we should mention that an analogous verification study, employing the same methodology and observational database (Mariani and Casaioli, 2011), has been recently performed in order to evaluate the forecast improvement due to the recent BOLAM update. Results of this study will be cited in the discussion, too.

III. RESULTS AND CONCLUSIONS

This is a work in progress, and only part of the results can be shown here. Nevertheless, these are enough to draw out some conclusion, and to address further research.

BIAS score intercomparison results (Fig. 2) display a significant BIAS increase at higher thresholds for both EXP1 and EXP2 with respect to BOLAM11. In other words, when the higher-resolution initial and boundary conditions are provided, the forecast becomes comparatively wetter, especially concerning intense events. The effect is only slightly increased by the increase of resolution (Fig. 2b), so it cannot be simply explained as an increase of explicit convection in the higher-resolution model.

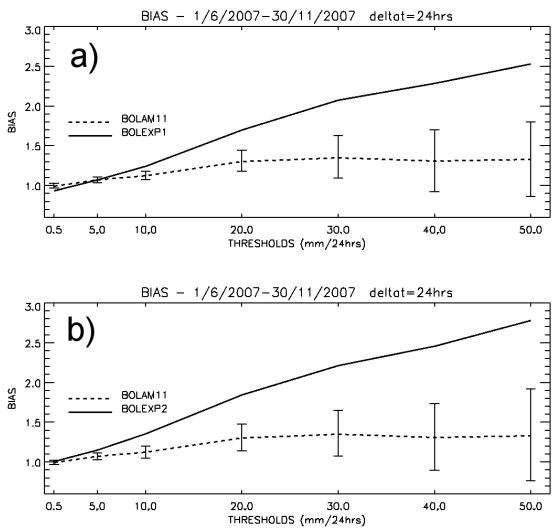

FIG. 2: Categorical BIAS score for the 6-month intercomparison. a) EXP1 *versus* BOLAM11 b) EXP2 *versus* BOLAM11.

Anyway, notwithstanding such a "wet bias", skill scores display a slight but significant improve as a result of the improvement of input data and, at a lesser extent, also after the increase of resolution. This is mostly evidenced by the HK intercomparison (Fig. 3), which displays a significant increase at medium and high thresholds for EXP1 and also at low thresholds for EXP2 with respect to BOLAM11. In other words, input data improvement seems to provide better forecast of intense events, whereas an added value of high resolution is visible on the weak events.

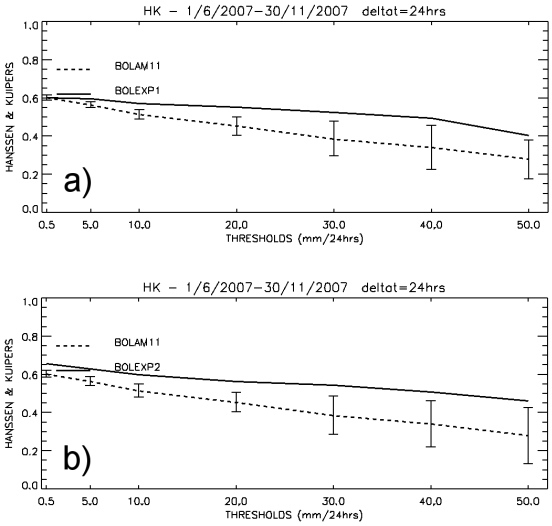

FIG. 3: Hanssen-Kuipers score for the six-month intercomparison. a) EXP1 *versus* BOLAM11 b) EXP2 *versus* BOLAM11.

These results are partly resized looking at the ETS results (not shown), which display significant differences only at the first three thresholds, even if confirming the aforementioned differences between EXP1 and EXP2. It is possible that the high-threshold improvement in HK displayed in Fig. 3 is due to chance, as a consequence of a wetter forecast. Anyway, such a wet bias does not increase, or increases very slightly, the amount of false alarms (FAR score, not shown).

Moreover, these results should be discussed in view of the other ones concerning the effect of the BOLAM update (Mariani and Casaioli, 2011). There, a major increase of skill scores (e.g., about +0.2 in ETS) and a dramatic BIAS reduction has been found. In other words, it seems likely that only minor effects (even if significant) could be expected by the input field and model configuration improvement.

These preliminary results should be considered as a basis for future work. First of all, the present intercomparison study needs to be completed through the application of other verification techniques. Model output spectral analysis, along with geographical mapping of the contingency table elements, and seasonal subdivision of the sample period could provide valid hints in order to interpret physically the intercomparison outcomes. With this aim, case-study verification could also be useful.

Further, a finer analysis should be performed, examining separately among the different input and model configuration modifications, those more likely to be responsible for the observed variations in the skill scores. The final task is not only helping us to define an "optimal" configuration of the ISPRA's BOLAM model, but, primarily, to investigate physical and numerical factors affecting the precipitation forecast quality in the Mediterranean area.

IV. ACKNOWLEDGMENTS

Authors are grateful to the partners of MAP D-PHASE for providing the rainfall dataset from their own rain gauge networks, which have been employed in the present work. Finally, a special thank goes to Dr. Oxana Drofa (ISAC–CNR, Italy) and Mr. Stefano Tagliaventi (CASPUR, Italy) for their support in implementing the new features of the BOLAM model.

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