Sensitivity study with global and high resolution meteorological model

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1. INTRODUCTION AND MOTIVATION OF WORK

The aim of this paper is to present the numerical results obtained with global a non-hydrostatic computational model to predict severe hydrometeorological mesoscale weather phenomena on complex orographic area. In particular, the performed experiments regard the impact of heavy rain correlated to a fine topography. Within an agreement between CIRA and the Earth Simulator Center (ESC) it has been possible to test on the European area the new Global Cloud Resolving Model (GCRM)[1]; this model was developed by Holistic Climate Simulation group at ESC. More specifically, the selected forecast test cases were focusing on the North-Western Alpine area of Italy, which is characterised by a very complex topography [2].

The GCRM model is based on a holistic approach: the complex interdependences between macroscale and microscale processes are simulated directly. This can be achieved by exploiting the impressive computational power available at ESC.

In standard models the microscale phenomena have spatial and time scale smaller than the minimum allowed model grid resolution; thus, a parameterization is necessary in order to take into account the important effect that the interaction between phenomena at different length scales produces on weather. However, this parameterization introduces some arbitrariness into the model. On the other hand, by using the Earth Simulator it is possible to adopt a resolution higher than that ever tested so far, thus decreasing the model arbitrariness.

Another advantage of using GCRM is that both global (synoptic) and local (mesoscale) phenomena can be simulated without introducing artificial boundary conditions (which cause some "side effects" in regional models); the latter being the approach adopted in the nested local model.

Computational meteorological models with higher resolution, as emphasized before, have a more correct representation of the terrain complex orography and also a more realistic horizontal distribution of the surface characteristics (as albedo and surface roughness). These characteristics are very interesting compared with those of LAMI (Italian Limited Area Model) [3] [4], the numerical model operatively used in Italy to forecast mesoscale-phenomena. The non-hydrostatic local model LAMI uses a computational domain covering Italy with a horizontal resolution of about 7 km . It is driven by initial and boundary conditions from the European global models (ECMWF [5], GME [6]), which have a resolution of about 40 km. In LAMI the influence of the wave drag on upper tropospheric flow is explicitly resolved, while in the global models the wave drag can only be simulated adopting a sub-grid orography scheme, as the small scale mountain orography is at subgrid scale level. LAMI model provides a good forecast of the general rain structure but an unsatisfactory representation of the precipitation distribution across the mountain ranges. Adopting a not-operative version of the LAMI model with higher resolution (2.8 km) an improvement of the rain structure was reported [7]. Furthermore, the convection phenomena are explicitly represented in the LAMI version with higher resolution, and smaller and more realistic rainfall peak have been computed.

This background was useful to analyze and give suggestions in order to improve the GCRM. An easy way to approach this work is to study the model performances in some test cases [8].

It has been decided to investigate the evolution of the Quantitative Precipitation Forecast (QPF), one of the most complex and important meteorological variables. An accurate estimation of spatial and temporal rainfall is also important to forecast floods [9] . The runs performed aimed to investigate the QPF sensitivity with respect to some physical and numerical parameters of the computational model.

2. THE TEST CASES

The GCRM performances were studied on test cases regarding two events of intense rain happened on November 2002: the first one from 14th to 16th and the second one from 23th to 26th. The chosen phenomena occurred in Piemonte, a region in the North-Western part of Italy; it is a predominantly alpine region, which extension is about 25000 km^2. Piemonte is situated on the Padania plain and bounded on three sides by mountain-chains covering 73% of its territory. One of the problem to well forecast the meteorological calamitous in this area is due to its complex topography in which steep mountains and valleys are very close to each other.

In the first event a precipitation exceeding 100 mm/24 hours (observed precipitation cumulated on 24 h starting from 15 November 2002 at 00 UTC) was recorded over most of the Northern Piemonte, where sparse peaks were even above 150 mm, and along the Southern border of Piemonte. In the second event the precipitation exceeded 50 mm/24 hours over a vast Alpine area, with peaks above 100 mm over Northern Piemonte and also 150 mm in the South-Eastern Piemonte (observed precipitation cumulated over 24 hours starting from 25 November 2002 at 12 UTC).

3. CHARACTERISTIC OF THE MODEL AND PERFORMED RUNS

A very special topic of the GCRM is the Yin-Yang grid system, characterized by two partially overlapped volume meshes to cover the Earth surface. One grid component is defined as part of the low-latitude region between 45N and 45S, extended for 270 degrees in longitude of the usual latitude-longitude grid system; the other grid component is defined in the same way, but in a rotated spherical coordinate system [10]. The upper surface of both meshes is located 30000 m above sea level. The flow equations for the atmosphere are non-hydrostatic and fully compressible, written in flux form [11]. The prognostic variables are: momentum, perturbation of density and perturbation of pressure (calculated respect to hydrostatic reference state). Smagorinsky-Lilly parameterization has been used for sub-grid scale mixing, Reisner scheme for cloud microphysics parameterization and, finally, a simple radiation scheme has been adopted. The ground temperature and ground moisture are computed by using a bucket model as a simplified land model. No cumulus parameterization scheme is used, with the hypothesis that the largest part of the precipitation processes is explicitly resolved with a 5.5 km grid resolution[1]. Silhouette topography is interpolated to 5.5 km from the 1 km USGS Global Land One-kilometer Base Elevation (GLOBE) terrain database. In the GCRM, as in LAMI, the influence of the wave drag on upper tropospheric flow is explicitly resolved.

The GCRM programming language is Fortran90. On Earth Simulator (ES) are available 640 NEC SX-6 nodes (5120 vector processors). The runs were performed using 192 nodes for a configuration with 32 vertical layers and 240 nodes for 48 vertical layers; the CPU time for each run was about 6 hours. For each run the forecast time was 36 hours.

4. THE SPIN UP

Since observation data are not incorporated into this version of GCRM, some period is required by the model to balance the information for the mass and wind fields, coming from interpolation data by analysis (data from Japan Meteorological Agency, JMA). This feature gives rise to spurious high-frequency oscillations of high amplitude during the initial hours of integration. This behaviour is called "spin up". For GCRM the spin up is also amplified because the precipitation fields (graupel, rain and snow) are set to zero at initial time. It is possible to reduce the "spin up" problem by using a small ratio between the horizontal resolution of the analysis (data to initialize the model run) and that of the model one, in order to obtain a more accurate interpolation. In our test cases the horizontal resolution of the analysis is 100 km while the GCRM resolution is 5,5 km (in some test cases also 11 km was used). Test performed with similar

[1] As Dare underlined [14] different research group noted that approximately 3 km, 4km, 5 km, may be the upper limit for highly-accurate grid scale resolution of convection.

meteorological models have shown that a good resolution ratio is realized between 1:3-1:6 [12] [13]. The spin up "window" occurs for 6 to 12 hours (in the forecast time) after initialization; in order to avoid spin up problems the compared results are obtained by cumulating QPF data on 24 hours, beginning from +12 to +36 forecasts hours.

Without a sufficiently long spin-up period the output data may contain, as verified in our runs, strange transient values of QPF. In particular one typical spin up problem has been identified in the runs performed, consisting in an erroneous structure of rainfalls (with "spot" of rain maxima).

5. ANALYSIS OF MODEL PERFORMANCES AND PROPOSALS FOR ITS IMPROVEMENT

5.1. STUDY ABOUT THE MICROPHYSICAL SCHEMES AND ITS IMPROUVMENT

The Italian test cases with GCRM underline a systematic overestimation of graupel and snow fall. This overestimation is one of the main cause of the strong underestimation of rain amount forecasted for these two test cases. The results obtained from our tests underline the necessity to improve the Reisner parameterization in GCRM, in order to have a better forecast of QPF.

It is known from the literature that the Reisner scheme [15] for bulk microphysical parameterization has some overprediction of snow and graupel amount. Other teams developing meteorological models (as WRF model [16]), that previously used the Reisner parameterization, decided to change it with an improvement due to Thompson [17]. The principal improvements concern in particular the replacement of primary ice nucleation and of auto-conversion formula, a new function for graupel distribution, and other corrections about formation of snow, rain and graupel.

5.2. TUNING OF SOME PARAMETERS THAT DEFINE THE PROPERTY OF THE AIR

In the GCRM the values of the Prandtl number and of the turbulent Prandtl number are used. The first one is defined among the properties of planetary boundary layer; the second one is used to characterize the properties of horizontal and vertical turbulent fluxes (using Smagorinsky-Lilly scheme).

The value of the Prandtl number is uniquely defined by the fluid chemical composition and by its state (temperature and pressure); in the atmosphere it is about 0.7. The turbulent Prandtl number is defined by coefficients that are not air physical properties, but functions of flow and of numerical grid characteristics. Therefore the turbulent Prandtl number depends by the horizontal numerical resolution and it changes as the turbulence changes.

In the reference version of the GCRM the Prandtl and the turbulent Prandtl numbers are set to the same value. Some runs to evaluate the model sensitivity to these two parameters has been made [18].

5.3. CHECK THE MODEL SENSITIVITY VARYING THE VERTICAL LAYERS

Currently there are 32 vertical levels in the reference version of GCRM (but is also possible to define 40 vertical levels or, in general an 8 multiple number [1]), these are defined by using the Gal-Chen terrain-following vertical-coordinate [19]. The top of the GCRM is fixed at 30000 m (12 hPa in standard atmosphere). For meteorological models in which the upper boundary is supposed to be a rigid lid, the best choice, in order to avoid the spurious reflections of gravity waves, is 0 hPa; nevertheless this requirement is computationally quite expensive. A good compromise for the height-top in the global model is around 10 hPa for standard atmosphere (as ECMWF with 63 model levels [20]). Furthermore, to improve the representation of the near-bottom flow, is necessary to increase the amount of vertical levels in the lower part of the troposphere (the bottom of the physical domain). This is useful especially in steep areas, as those involved in our test cases. This feature also requires an high computational cost. Looking at the literature, for meteorological model with a horizontal resolution of about 5-10 km, a good choice for the lowest level height is 40-80 m.

Taking into account all these considerations, during this research activity two different settings have been proposed, both with 48 vertical layers. Some runs have been performed using these new proposals and the results have been compared.

References:

[1] Takahashi K., Goto K., Fuchigami H., Yamada M., Peng X., Komine K., Ohdaira M., Sugimara T., Nagano K., 2006: Ultra high performance computation with coupled non-hydrostatic atmosphere-ocean-land GCM. Newsletter Earth Simulator Center.

[2] Rabuffetti, D., Milelli, M., Graziadei, M., Mercogliano, P., Oberto, E.: Evaluation of the hydro-meteorological chain in Piemonte region, north western Italy- analysis of the Hydroptimet test case, Advances in geosciences, 2, 321-325, 2005.

[3] COSMO Newsletter 5, 2005 www.cosmo-model.org.

[4] G.Doms and U.Schattler, 2003: A description of the Nonhydrostatic Regional Model LM, Part 1- Dynamics and numerics. www.cosmo-model.org

[5] http://www.ecmwf.int/research/ifsdocs/CY28r1/index.html

[6] http://www.dwd.de/en/FundE/Analyse/Modellierung/Modellierung.htm

[7] Elementi, M., Marsigli, C. Paccagnella, T.: High resolution forecast of heavy prrecipitation with Lokall Modell: analysis of the two test case studies in the Alpine area.

[8] Lakhtakia, M. N., Yu, Z., Yarnal, B., White, R. A., Miller, D. A., 1999: Sensitivity of simulated surface runoff to mesoscale meteorological model resolution in a linked-model experiment. Climate Research, Oldendorf/Luhe, Germany, 12(1), 15-27.

[9] Jasper, K., J. Gurtz and H. Lang, 2002. Advanced flood forecasting in Alpine watersheds by coupling meteorological observations and forecasts with a distributed hydrological model. Journal of Hydrology 267 (1-2): 38-50

[10] Kageyama, A.and Sato, T. 2004 " The Yin Yang Grid": An overset grid in spherical geometry. Geochem.Geophys.Geosyst., 5, Q09005, doi:10.1029/2004GC00734

[11] Satomura, T. and Akiba, S. 2003. Development of high precision non-hydrostatic atmospheric model (1): Governing equations, Annual of Disas. Prev. Res. Inst., Kyoto Univ., 46B, 331-33

[12]http://atmet.com/html/docs/rams/rams_techman.pdf (RAMS technical description)

[13] http://www.mmm.ucar.edu/mm5/documents/ , PSU/NCAR Mesoscale Modeling System Tutorial Class Notes and Users Guide (MM5 Modeling system version 3), MM5

[14] Dare, R., 2003 : Modelling and parameterization of convection on the mesoscale. 15th Annual BMRC (Bureau of Meteorology Research Centre) Modelling Workshop.

[15] Reisner, J., R.M. Rasmussen, R.T. Bruintjes, 1998: Explicit forecasting of supercooled liquid water in winter storms using the MM5 mesoscale model. Quart. J.Roy. Meteor. Soc., 124, 1071-1107

[16] A description of the Advanced Research WRF version 2, NCAR technical note June 2005. http://www.wrf-model.org/wrfadmin/docs/arw_v2.pdf

[17]Thompson, Gregory, R.M. Rasmussen, K. Manning, 2004: Explicit forecasts of winter precipitation using an improved bulk microphysics scheme. Part 1: description and sensitivity analysis. Mon. Wea. Rev., 132, 519-542

[18] An introduction to boundary layer meteorology, Stull R.B., Atmospheric Sciences Library

[19] Gal-Chen, T. and R.C.J. Sommerville, 1975: On the use of the coordinate transformation for the solution of the Navier-Stokes equations. J. Comput. Phys,.17, 209-228

[20] http://www.ecmwf.int/products/data/technical/model_levels