Activities between CIRA and ESC under MOU

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The work described in this paper has been done in collaboration with ESC/JAMSTEC (Earth Simulator Center/Japan Agency for Marine-Earth Science and Technology). CIRA (The Italian Aerospace Research Center) and ESC signed such agreement to study hydro-geological (landslides, floods, etc.) and local meteorological phenomena. It is well known that meteorological models are computationally demanding and they require either accurate and efficient numerical models either high performance parallel computing. Such needs are strictly and directly related to the high resolution of the model. In this report, preliminary results of the two main theme of our collaboration such as the impact of high resolution weather forecasting with a non-hydrostatic atmospheric model, which has been developed at the ESC by Multiscale Simulation Research Group, and the computational features of the model have been described.

Keywords: Non-hydrostatic AGCM, Regional forecasting, High performance computing, Earth Simulator

THEME I: High Resolution Simulations and Preliminary Results of Weather Forecasting with the Regional Non-Hydrostatic Atmospheric Model of ESC

1. Introduction and motivation

The aim of this research is to present the impact of simulation results obtained with the non-hydrostatic atmosphere model, which has been developed at the ESC by the Multiscale Climate Simulation Project Research Group, to predict severe hydrometeorological mesoscale weather phenomena on complex orographic area. The selected forecast test cases were focusing on the North-Western Alpine area of Italy which is characterised by a very complex topography.

Computational meteorological models with higher resolution have a more correct representation of the complex orographic terrain and also a more realistic horizontal distribution of the surface characteristics (as albedo, surface roughness). These characteristics are very interesting compared with that ones of LAMI (Italian Limited Area Model) [10], 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 [19], GME [20]), 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 subgrid orography scheme, as small scale mountain orography is at a 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 [18]. Furthermore, the convection phenomena are explicitly represented in this version with higher resolution, and smaller and more realistic rainfall peak have been computed.

Furthermore, one of advantages of the non-hydrostatic atmosphere model of ESC is that using the same model both global (synoptic) and local (mesoscale) phenomena can be simulated without introducing artificial boundary condition; the latter being the approach adopted in the nested local model.This background was useful to analyze and give suggestions in order to improve the non-hydrostatic atmosphere model of ESC.

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. 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 performances of the non-hydrostatic atmosphere model of ESC 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 23rd to 26th. The chosen phenomena occurred in Piemonte, a region of the North-West Italy; it is a predominantly alpine region covering 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).

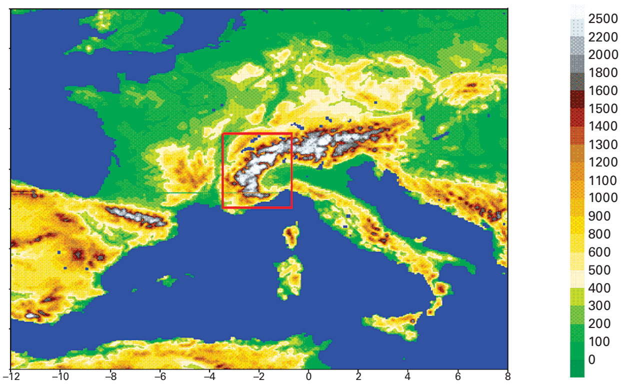


Fig. 1 Studied domain: inside the red box the heavy rainfall area for the test cases.

3. Analysis of model performances and proposals for its improvement

3.1 Study about the microphysical schemes and its improvement

The Italian test cases with the non-hydrostatic atmosphere model of ESC 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 in GCRM parameterization, in order to have a better forecast of QPF.

It is known from the literature that the Reisner scheme [3] for bulk microphysical parameterization has some overprediction of snow and graupel amount. Other teams that develop meteorological models (as WRF model [16]), that previously used the Reisner parameterization, decided to change it with an improvement due to Thompson [4]. In particular the principal improvements concern 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.

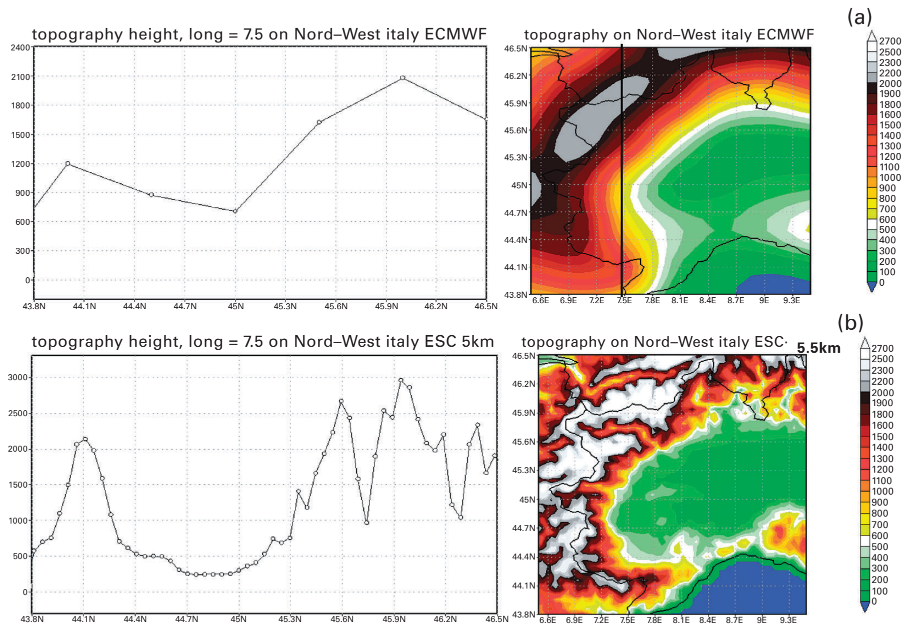


Fig. 2 Detail of Piemonte topography: (a) ECMWF global model; about 40 km of horizontal resolution; (b) ESC global model: 5.5 km of horizontal resolution. In the first model there is no information on the actual peaks and valleys.

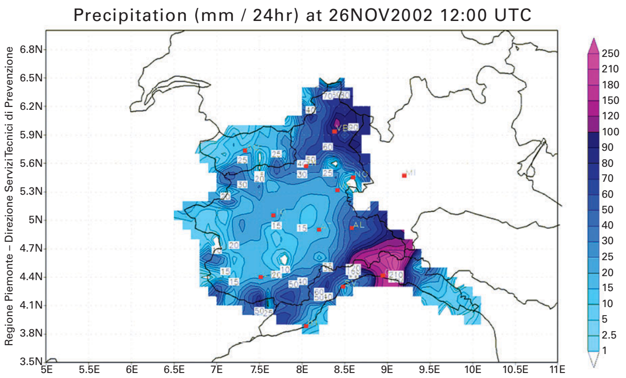


Fig. 3 Total amount of rain (mm) observed by ground stations in 24 hours: 25/11 12UTC–26/11 12UTC.

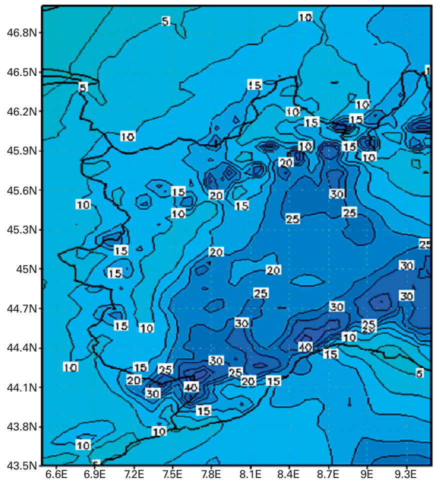


Fig. 4 Forecast results of QPF cumulated on 24 hours (from 12UTC of 25th November to 12UTC of 26th November) for the CTRL run with the non-hydrostatic atmosphere model of ESC.

3.2 Tuning of some parameters that define the property of the air

In the non-hydrostatic atmosphere model of ESC, the values of Prandtl number and 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). In the atmosphere the value of Prandtl number is 0.7 and it is uniquely defined by the fluid chemical composition and its state (temperature and pressure). Instead 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 horizontal numerical resolution and it changes as the turbulence changes.

In the reference version of the non-hydrostatic atmosphere model of ESC, these numbers are set to the same value. Some runs to evaluate the model sensitivity to the values of these two parameters has been made.

THEME II: Computational Features of the Regional Non-Hydrostatic Atmospheric Model of ESC

1. Implementation details of the non-hydrostatic atmosphere model of ESC

The algorithm is implemented by a hybrid parallelization model: intra- and inter-node parallelisms are performed by micro-tasking and by MPI, respectively. Moreover, such algorithm is based on a SPMD (Single Program Multiple Data) program. The computational domain has a sponge area (inside the physical domain) and a halo area (outside the physical domain); in the first one prognostic variables are relaxed, while in the latter relaxation values of prognostic variables are defined by interpolation from the coarser grid or by a Newman condition. The selected test refers to an intense precipitation event occurred during November 2002 on North-Western of Italy.

2. Experiments to estimate computational performance on the ES

To study scalability of the code (performance changing varying problem size or number of processors) experiments have been carried out keeping constant the problem size and varying the number of processors. The sizes along x-, y- and z-direction of the considered computational domains are 600 × 1152 × 32, 1200 × 1152 × 32 (twice bigger) and

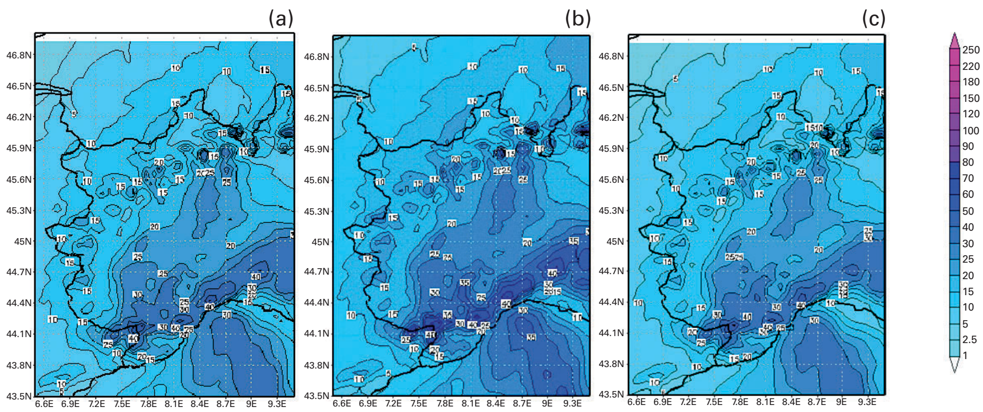
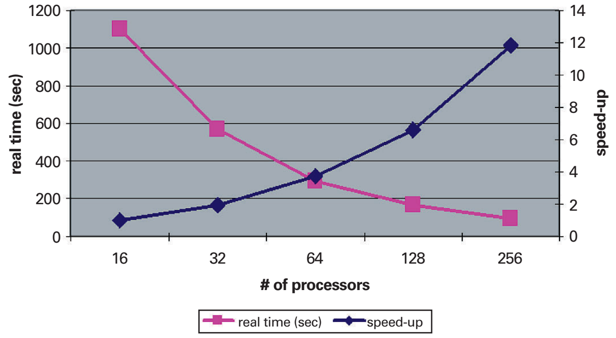


Fig. 5 QPF distribution results of sensitivity experiments. (a) run1:Pr = 0.7, Pr_turb = 0.7, kappa = 2,10E-5, (b) run2: Pr = 0.7, Pr_turb = 0.7, kappa = 1,00E-10, (c) run3: Pr = 0.7, Pr_turb = 7,2E+2, kappa = 2,10E-5.

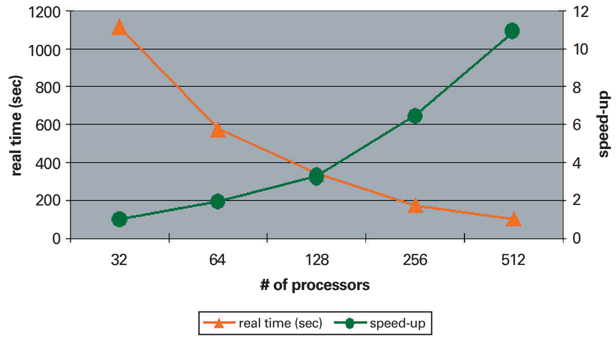
1200 × 2304 × 32 (four times bigger). In order to reduce the communication cost a block-wise processors grid is adopted in horizontal for all the performed tests; consequently each processor works on a sub-domain having 32 vertical levels. The number of used processors varies between 16 and 512 (that means 2 and 64 nodes on the ES, respectively); in all cases the step incrementing the number of processors is by powers of two.

The programming language is Fortran90 and to evaluate runtime performance suitable compilation options and environment variables have been set. In particular, the performance analysis tool *ftrace* has been used to collect detailed information on each called procedure (both subroutine and function) ; we emphasize that it is better to use this option just for tuning since it causes an overhead. Such collected information is related to elapsed/user/system times, vector instruction execution time, MOPS (million of operations per second), MFLOPS (million of floating-point operations per second), VLEN (average vector length), Vector Operation Ratio (vector operation rate), MIPS (million of instructions per second) and so on. Criteria to achieve best performance are: vector time has to be close to user time; MFLOPS should be as high as possible; VLEN should be as much as possible close to the vector length (= 256) because it is the average vector length processed by CPUs (best performance are obtained on longer loops); vector operation rate (%) should be close to 100. Such information has been took into account for each performed experiment.

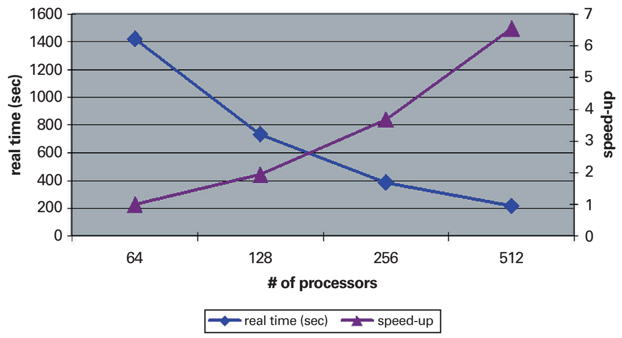
Scalability has been evaluated in terms of speed-up and efficiency. Since the program cannot be run sequentially, both speed-up and efficiency have been calculated using the elapsed time obtained running the parallel program with the minimum number of processors. In particular, speed-up has been evaluated by Amdhal's Law. Obtained values in all performed tests show a nearby linear speed-up; on the other hand, it has been shown also that efficiency stays always above 70% and the sustained performance is greater than 50% of theoretical peak performance related to the number of used processors.



(a) DOMAIN: 600 × 1152 × 32



(b) DOMAIN: 1200 × 1152 × 32



(c) DOMAIN: 1200 × 2304 × 32

Fig. 6 Elapsed time and speed-up in the each case of DOMAIN.

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キーワード：Non-hydrostatic AGCM, Regional forecasting, High performance computing, Earth Simulator

本共同研究は、(独)海洋研究開発機構地球シミュレータセンターとCIRA (The Italian Aerospace Research Center)とのMOUに基づく国際共同研究として推進されている。本共同研究の目的は、開始当初より、地球シミュレータを使用して大規模なシミュレーションを行い、その経験を通じて、気象・気候分野におけるシミュレーションのインパクトと重要性についての考察、および、大規模並列計算機を効率よく活用できるシミュレーションコードの開発技術の習得、という教育的な側面が強い。平成16年度から平成17年度にかけて、CIRAの研究者が地球シミュレータセンターに常駐し、主に以下の2つの研究テーマについての研究が進められた。(I)イタリア領域における豪雨事例を、地球シミュレータセンターで開発した非静力学・大気シミュレーションコードを用いて、高解像度予測シミュレーションを行い、そのインパクトとモデルの物理的性能についての検討を行う、(II)上記の非静力学・大気コードの計算領域と問題の規模、および分割領域のとりかたによって計算効率がどのような影響を受けるか、についての検討と高い計算性能を確保するための超並列化の計算技術の検討を行う。各テーマの結果についての詳細は、英文の内容をご参照いただきたい。また、各テーマのシミュレーション結果は、CIRAの研究者が結果データを持ち帰り、現在も解析を進めており、学術論文としてまとめている。

テーマIについての結果：

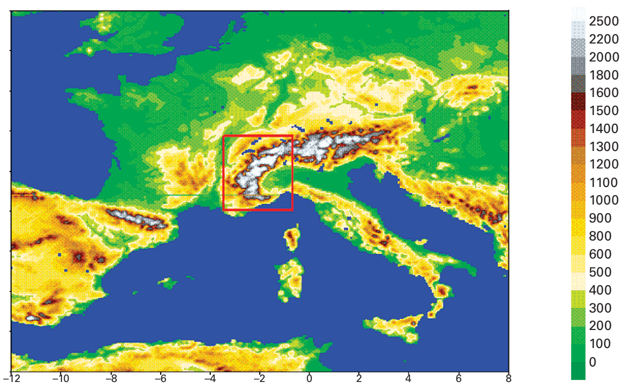

図1　事例予測シミュレーションに用いたイタリア領域（赤の四角で囲まれた領域）。

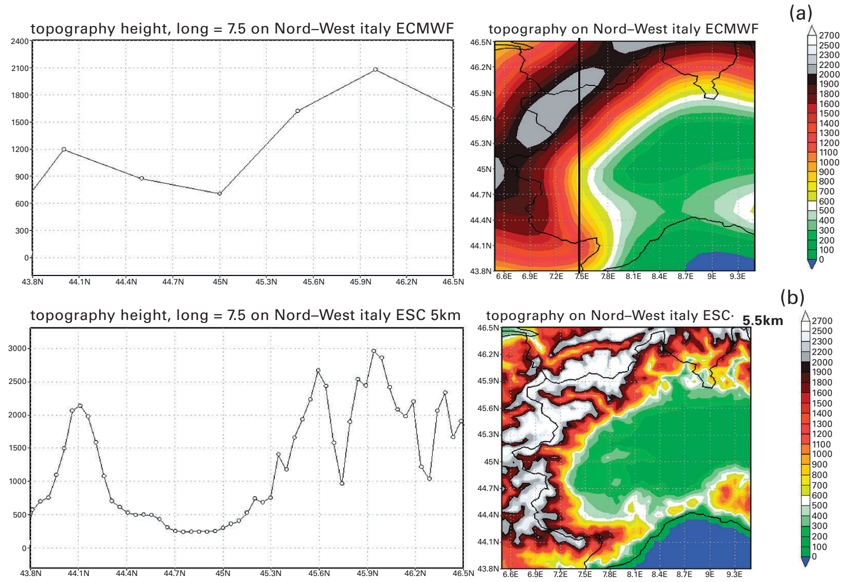

図2　予測シミュレーションに用いた山岳地形の比較：(a) ECMWF 全球モデルで使用している地形、(b) 地球シミュレータセンターで開発した、非静力学・全球大気モデルにおいて全球、水平5.5kmで用いている地形。

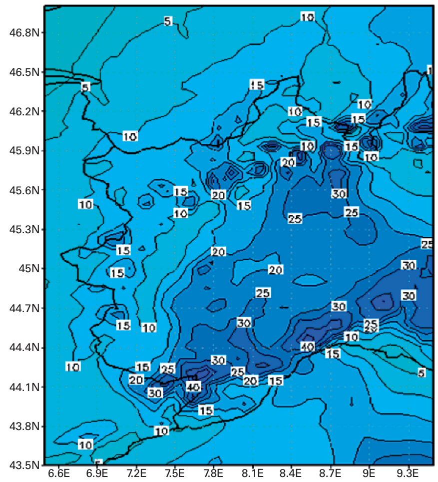

図3　事例予測シミュレーション結果：2002年11月25日12時UTCから26日12時UTCまでの24時間予測結果。

テーマIIについての結果：

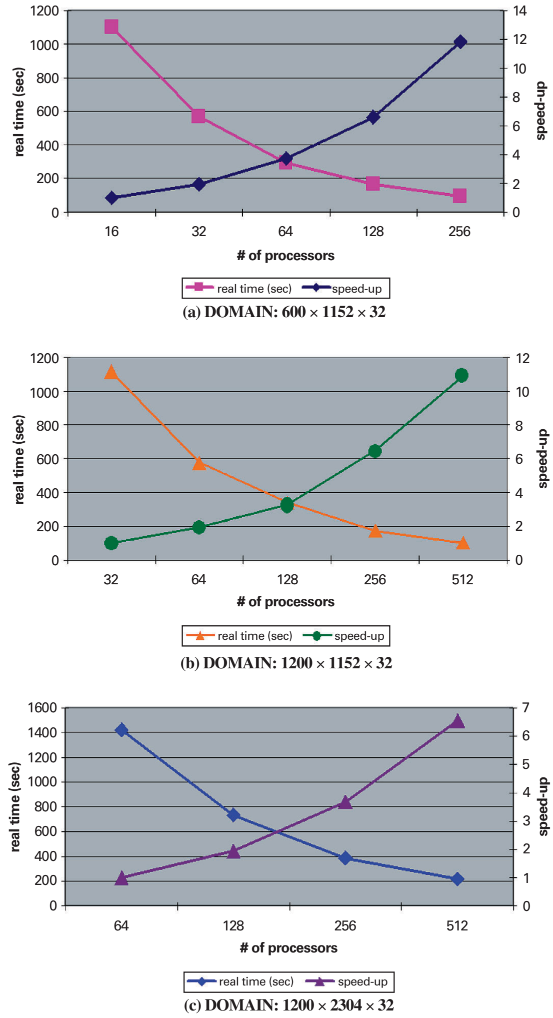

図4　地球シミュレータセンターで開発した非静力学・全球大気コードにおける、ノード数と問題の規模、および分割の仕方を変化させた時の地球シミュレータ上での計算性能。