Preliminary Activities between CIRA and ESC on Meteorological Modelling

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Keywords: AGCM, cloud micro-physics, meteorological forecasting, cloud resolving model, nested boundary condition

Introduction

The activities reported in this paper are based on the collaboration agreement between ESC/JAMSTEC and C.I.R.A. (the Italian Aerospace Research Center - www.cira.it). In brief, C.I.R.A. is a governmental organisation assigned by the Italian Government to define and implement the Italian Aerospace Research Program. CIRA is also one of the members of the CMCC project (Euro-Mediterranean Center for Climate Changing) approved and funded by the Italian Minister for Research.

Goal of the first performed activity is an overview of the most important boundaries conditions used in meteorological models developed. The second activity regards a preliminary sensitivity study with the Global Code Resolving Model developed at the Earth Simulator Center.

Boundary Conditions Overview within a Limited Area Model

Nowadays the study of nested techniques, in order to improve high-resolution meteorological models, is one of the most demanding research activities. Using fine grid model nested in a coarse one a suitable boundaries treatment is necessary to reduce the computational reflection of wave energy.

The analysis was devoted to understand the theoretical aspects and some numerical [9] and computational [10] details related to the parallel implementation [11] on the Earth Simulator (ES).

BCs can be classified in two main sets: the first one concerns the sponge-like BCs, the second one the radiative-like BCs.

Sponge-like BCs

Within this set the sponge/relaxation and tendency modified BCs were analyzed.

The basic idea of the sponge/relaxation BCs is to add a damping layer in the marginal zone of the model so that wave energy can be absorbed while approaching the boundary; such layer can be defined by a diffusion coefficient non-zero in the marginal zone [1,2]. Another way to minimize the wave energy can be obtained by using a relaxation value for each prognostic variable and a relaxation function. As lateral BC, usually the relaxation function is non-zero, continuous and non-negative space function in the marginal zone to allow a smooth flow transition. On the other hand, the relaxation function is not related to the vertical coordinate and the vertical velocity is unchanged by this boundary treatment [1,2].

The tendency modified scheme [2] is defined by a parameter varying from zero (inside the domain) to "values infinitely big" (close to the boundary); such parameter is used to define a modified wave speed. Moreover, the RHS of the Transport Equation takes into account such parameter and the relaxation value of the prognostic variable. Inside the domain the parameter is zero, the modified wave speed is equal to the physical wave speed and the RHS is zero; this means that inside the domain, the Transport Equation is unchanged. In the marginal zone the parameter approaches "infinity" (from a numerical point of view), then modified wave speed approaches zero and so wave doesn't propagate.

Radiative-like BCs

As discussed in [3], this BC has to "radiate away" the difference between the coarse variable and the nested variable.

At first Sommerfeld proposed in [4] to define the wave speed as a constant related to the prognostic variable.

Such BC was furthermore studied by Orlanski in [5]: he proposed another definition for the wave speed and distinguished between outflow and inflow, depending if the wave speed is positive or negative, respectively. Moreover, Orlanski used the leapfrog 2nd order FDM to discretize this BC and a time-average to calculate the boundary point.

The radiative BC was furthermore studied by Camerlengo and O'Brien [6]. In this work it was proposed a variation of the Orlanski's wave speed definition that, in some case studies, appeared to be more efficient and promising.

This procedure was also studied and modified by Miller and Thorpe in [7], that proposed another FDM to discretize the BC: the chosen method is the upstream 1st order scheme and it is computationally less expensive. Moreover the numerical results show that the boundary becomes "transparent" to wave energy, stable and able to transmit large amplitude disturbances as well as remarkably.

Another radiative-like BC is the independent radiative-dependent nested one, proposed by Chen in [8]. The basic idea is that the time rate of the fine grid solution depends both on the time rate of the coarse grid solution and on the advection in the space of so-called "unwanted wave". This last one is generated when the fine grid solutions differs from the coarse grid solution one. Such BC takes into account both information interpolated from the coarse model (dependent nested) and it allows the free passage of disturbances through the boundary (radiative BC). Numerical results in an atmospherical model nested grid show that it handles very well acoustic and gravity wave reflection, allowing the unwanted wave energy to propagate away from the boundaries [8].

Future collaboration will be devoted to implement and validate a particular boundary condition (BC) in the Non-hydrostatic Limited Area Model developed by Dr. Eng. K. Takahashi's team.

Sensitivity study with Global Cloud Resolving Model

This research activity, in collaboration with the Multiscale Simulation Research Group of the ESC, regards sensitivity studies with the non-hydrostatic atmospheric global model (Global Cloud Resolving Model - GCRM [12]), developed by Dr.Eng. Takahashi's team. The goal is to handle atmospherical simulations on ESC supercomputer.

The sensitivity studies of the GCRM is performed for an intense precipitation event on the North-West Italian area of November 2002. The total amount of the rain observed during this event has shown in Figure 1 (courtesy of ARPA Piedmont).

This study permits an easy approach to the GCRM knowledge and in particular to the simulation of some typical mesoscale atmospherical phenomena.

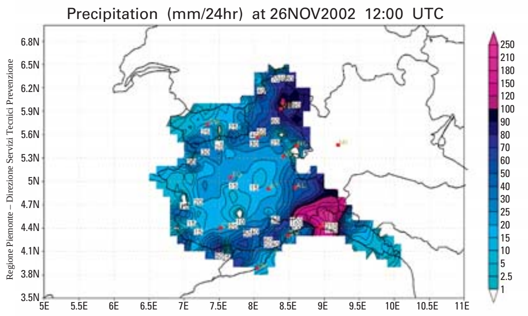

Fig. 1

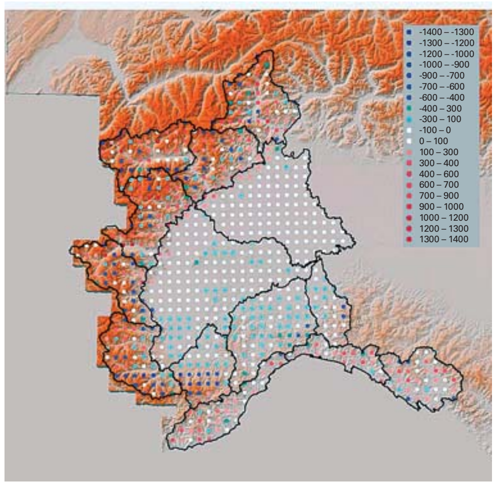

Fig. 2 differences between the height in Italian LAM (7 km of resolution) and ones from satellite (legend in meters)

Moreover, the use of a very fine grid (11 km or 5.5 km), compared with the 40 km of the European global models, is a unique opportunity; in fact in the Alpine area, where there are sharp slopes from the coast to the mountains, the better orography definition is an fundamental topic. The plot of the discrepancies between the topographic height in the grid points and the real one has shown in figure 2 (courtesy of ARPA Piedmont). This differences give localisation errors (like under prediction of precipitation on downward slopes) and displacement of the precipitation maxima.

Several simulations have been performed by using initial condition from JMA analysis and a forecast range of 36 hours. The simulations used 192 nodes of the Earth Simulator supercomputer duration of each run is about 6 hours.

Several simulations have been run according to different initial time and horizontal resolution. Also different GCRM versions have been tested (without soil process parameterization and with a simple bucket model for soil process).

For the verification of the simulation results a first qualitative approach has been used. Such approach is based on a visual comparison of the precipitation forecast maps with the observed ones. Such verification has been also performed for others variables (i.e. geopotential height, sea level pressure, wind and relative humidity) by comparing the analysis maps and the forecast ones.

As first preliminary results an overestimation of the simulated snow and graupel fall has been observed. Such systematic error is probably due to not suitable empirical formula in microphysics Reisner parameterization scheme [13].

Others simulations for this test case will be performed in the next months in order to collaborate at the improvement of the numerical and physical scheme of the GCRM.

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本共同研究報告は、地球シミュレータセンター(ESC/JAMSTEC)とC.I.R.A.（イタリア航空宇宙研究センター：The Italian Aerospace Research Center - www.cira.it)とのMOU共同協定に基づいたものである。C.I.R.A.は、Aerospace Research Programを決定するイタリア政府に属する政府機関である。また、CIRAは研究機関として、イタリア政府より出資を受けており、CMCCプロジェクト(Euro-Mediterranean Center for Climate Changing)のメンバー機関でもある。C.I.R.A.は、現時点においては、気象/気候予測研究分野を立ち上げつつある状態にあり、CMCCとの共同研究を通して、モデル構築と観測との両面から地中海・ヨーロッパ領域における気象予測に貢献する計画である。本プロジェクトは、2005年1月より具体的に開始され、2人の研究者が地球シミュレータセンターに常駐し、第1段階として6月末まで滞在する予定である。

本共同研究の初期段階における目的は、第一に、気象予測モデルにおける時系列的に変化する水平境界条件の基礎研究、第二に、地球シミュレータセンターにおいて開発した全球・非静力学・雲解像モデル(ESCコード)を用いて、ヨーロッパ領域の事例予測をし、物理的な性能評価と物理過程スキームの改善を行い、その知見をCMCCモデルへ適用する応用研究、第三に、超並列ベクトル型スーパーコンピュータにおける計算性能最適化手法の取得である。

第一課題については、すでに、時系列的に変化する境界条件の課題について調査を終了し、新たな境界条件の実装方針を決定した。今後は、計算最適化を踏まえた上でESCコードへの具体的な実装を行い、導入した境界条件の物理的性能評価を行う。第二の課題は、地球シミュレータ192ノードを使用して、全球5.5 kmの事例予測シミュレーションを行った。対象事例は、2002年11月に北イタリアにもたらされた局所的豪雨である(図1は観測データを示す)。本対象事例においては、地形の影響が大きいとされており、現在ESCで用いている地形表現を詳しく調査したところ、イタリアーアルプス領域においては、現実地形の特徴を非常によく捉えていることがわかった。また、対象事例予測シミュレーションより、微物理過程における雪や霰が過剰評価されていることがわかった。さらに、陸面の初期値や水蒸気、熱量ともに、降雨量に大きく関わっていることが示唆されたため、今後、これらのスキームの改善を行ってゆく予定である。第三の課題は、滞在前期3ヶ月に、地球ダイナモコードを具体的な題材として最適化手法を習得した。

今後は、さらにC.I.R.A.とCMCC、ESCとの協力関係を強化し、ESCモデルとCMCCモデルの比較検討を通して、両コミュニティのモデル構築と予測精度向上に貢献する予定である。

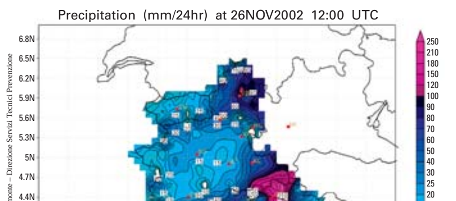

図1　シミュレーション再現および予測対象事例。

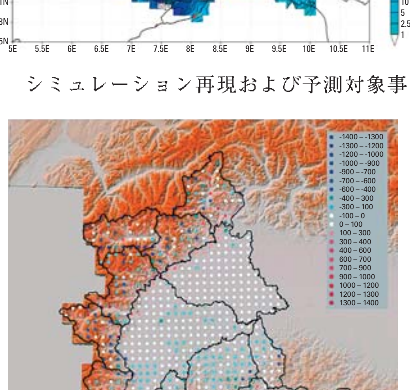

図2　LAMモデルの地形と衛星観測データと標高差。