



High Performance Computing / Le Calcul Intensif

Seamless MESO-NH modeling over very large grids

Simulations MESO-NH sans couture sur de très grandes grilles

Florian Pantillon^a, Patrick Mascart^{a,*}, Jean-Pierre Chaboureau^a, Christine Lac^b,
Juan Escobar^a, Jacqueline Duron^a

^a Laboratoire d'Aérodynamique, University of Toulouse and CNRS, Observatoire Midi Pyrénées, 14, avenue Edouard-Belin, 31400 Toulouse, France

^b CNRM/GAME, Météo-France and CNRS, 42, avenue Gaspard-Coriolis, 31057 Toulouse cedex 01, France

ARTICLE INFO

Article history:

Available online 30 December 2010

Keywords:

Computer science
Meteorological model
Seamless MESO-NH modeling

Mots-clés:

Informatique, algorithmique
Modèle de recherche météorologique
Simulations MESO-NH sans couture

ABSTRACT

With the computing power it brings, the new generation of massively parallel computers allows one to perform a “seamless” modeling of weather on large grids, but it requires a large parallel computing capability for the models. Due to improvements in this direction in the meteorological model of the French research community MESO-NH, a computing performance of over 4 Teraflop/s was obtained with 130 000 cores on the machine of the European computer center PRACE. This is a first in France for a weather code. A high resolution simulation, covering the Atlantic and Europe, of the tropical cyclone Helene and its interaction with a planetary wave was also conducted, for which the excellent result gives hope to an improved weather forecasting in Europe.

© 2010 Académie des sciences. Published by Elsevier Masson SAS. All rights reserved.

RÉSUMÉ

Grâce à la puissance de calcul qu'elle apporte, la nouvelle génération de calculateurs massivement parallèles permet de réaliser sur de grandes grilles une modélisation « sans couture » des phénomènes météorologiques, mais elle demande aux modèles une grande capacité de calcul parallèle. Suite à des améliorations apportées dans ce sens au modèle MESO-NH de recherche météorologique mésoéchelle communautaire français, une performance de calcul dépassant 4 Téraflop/s a été obtenue avec 130 000 coeurs sur la machine du centre de calcul européen PRACE. Il s'agit d'une première en France pour un code météorologique. Une simulation haute résolution, couvrant l'Atlantique et l'Europe, du cyclone tropical Hélène et de son interaction avec une onde planétaire de moyenne latitude a également été réalisée, dont l'excellent résultat laisse espérer à terme une amélioration de la prévision du temps en Europe.

© 2010 Académie des sciences. Published by Elsevier Masson SAS. All rights reserved.

1. Introduction

Further to the workshop on high performance computation held on 29 June 2010 in Paris which has surveyed an exceptionally wide multidisciplinary spectrum of computational topics, the present article is restricted to presenting some recent work made in the field of atmospheric physics. The scope addresses both very large (synoptic) scales and very small

* Corresponding author.

E-mail address: patrick.mascart@aero.obs-mip.fr (P. Mascart).

(hectometric) ones, and so, to some extent, provides an overall view of the promising new possibilities offered by parallel high performance supercomputers for improving both meteorological weather forecasting and climate modeling.

Numerical weather prediction (NWP) models deal with a huge range of scales, from planetary waves to near-convective scales down to turbulence. So far, the computing power of these machines have led researchers to focus either on small-scale weather phenomena over a limited area or weather systems of larger size, the smaller scale processes then being coarsely represented and their impact on the dynamics of larger scale poorly studied. In particular, the current global NWP models represent the convection crudely through a parameterization while only a few regional NWP models permit the convection to be explicitly resolved. This “cloud drawback” was identified as a major uncertainty altering the predictability of weather systems.

The recent advent in France and Europe of massively parallel computers, using hundreds of thousands of cores, opens new perspectives. In France, the GENCI (Grand équipement national de calcul intensif, Ministère de la recherche et l'enseignement supérieur, CEA, CNRS, Universités et INRIA) consortium now offers a few machines with a high standard. In Europe, the PRACE consortium gives the opportunity to run codes with performance of Pflop/s. These new computers will be sufficient to carry out, on large spatial domains (large grids), a “seamless” modeling of weather events and to study their scale interaction.

In this short article we present the recent development made for the MESO-NH model system, the French research meteorological model at mesoscale. Two examples taken from recent advances made by Toulouse University and Météo-France research groups are highlighted: (i) modeling of a meteorological weather system made over a single very large size grid stencil covering a whole continental scale domain; and (ii) extreme high resolution eddy resolving modeling of a tropical convective cloud providing further insights into the turbulent variability of a cloud. Section 2 presents the MESO-NH model and the development made to achieve a performance of a sustained 4 Tflop/s. Section 3 shows the two meteorological applications of the use of the model on large grid. Section 4 concludes with some perspectives.

2. MESO-NH system

The research model MESO-NH [1] is the mesoscale meteorological French community, jointly developed by the Laboratoire d'Aérodynamique (UPS/CNRS) and the GAME/CNRM (CNRS/Météo-France). It is a gridpoint limited area model based on a non-hydrostatic system of equations, to deal with the same tool for a wide range of atmospheric phenomena, from planetary waves (a few thousand kilometers) to the turbulent vortices (a few meters). It also has a complete set of equations for a physical representation of clouds and precipitation. It allows for the transport of passive tracers. Finally, the whole is coupled to models of chemistry, aerosols and atmospheric electricity. This model offers a perfect setting for any simulation of physicochemical processes in which the atmosphere is the seat.

All MESO-NH software represents about one million lines of code. Since several years, the system works on the parallel scalar machines of GENCI and Météo-France, and recently on the first PRACE petaflop computer. However, high performance computation on these new computers has required an extension of the model parallel capabilities. Although much of the MESO-NH model is parallel since 1999 [2], it was nevertheless necessary to adapt to new computers (on issues concerning the I/O and the pressure solver). In doing so, an excellent scalability of MESO-NH has been obtained and the sustained Teraflop/s has achieved on all machines where the code has been tested (Fig. 1), showing that it can adapt to most type of machines. It has also been successfully run on the PRACE machine with grids of $2048 \times 2048 \times 128$ points (500 million points) and exceed the sustained 4 Teraflop/s using 130 000 of the 300 000 available cores. This is the first time that such computing power is reached for a meteorological research code on a supercomputer in Europe.

3. Applications

3.1. Transition of a tropical cyclone

The first scientific application using the modified MESO-NH focused on the case of the extratropical transition of the tropical cyclone Helene in the North Atlantic in September 2006 [3]. The interaction of a tropical cyclone with a planetary wave (a midlatitude Rossby wave) is poorly addressed by current NWP models, in part because of the relatively coarse horizontal mesh (20 km). The relative low resolution allows only an approximate representation of cloud processes, a so-called convective parameterization, which can lead to poor weather forecasts in Europe.

Instead, we run MESO-NH with a much finer spatial resolution (4 km) on a grid of $3072 \times 1920 \times 72$ points (425 million points). At that resolution the vertical velocity of air masses and thus clouds is explicitly calculated resulting in well resolved cloud systems. This is shown in Fig. 2 with values of upper tropospheric humidity larger than 80% associated with clouds (see [6] for more details on upper tropospheric humidity). A good match was obtained between observation and simulation, both over the full domain and in the vicinity of the cyclone. The deepening of the cyclone Helene (minimum of the mean sea level pressure) was also correctly predicted when compared with analysis from a global model (weather analysis of in situ and satellite observations).

3.2. Deep convection

The second scientific application addresses the modeling of stratospheric water vapor, an important driver of decadal global surface climate change. The main source of water vapor is provided by troposphere–stratosphere exchanges in the

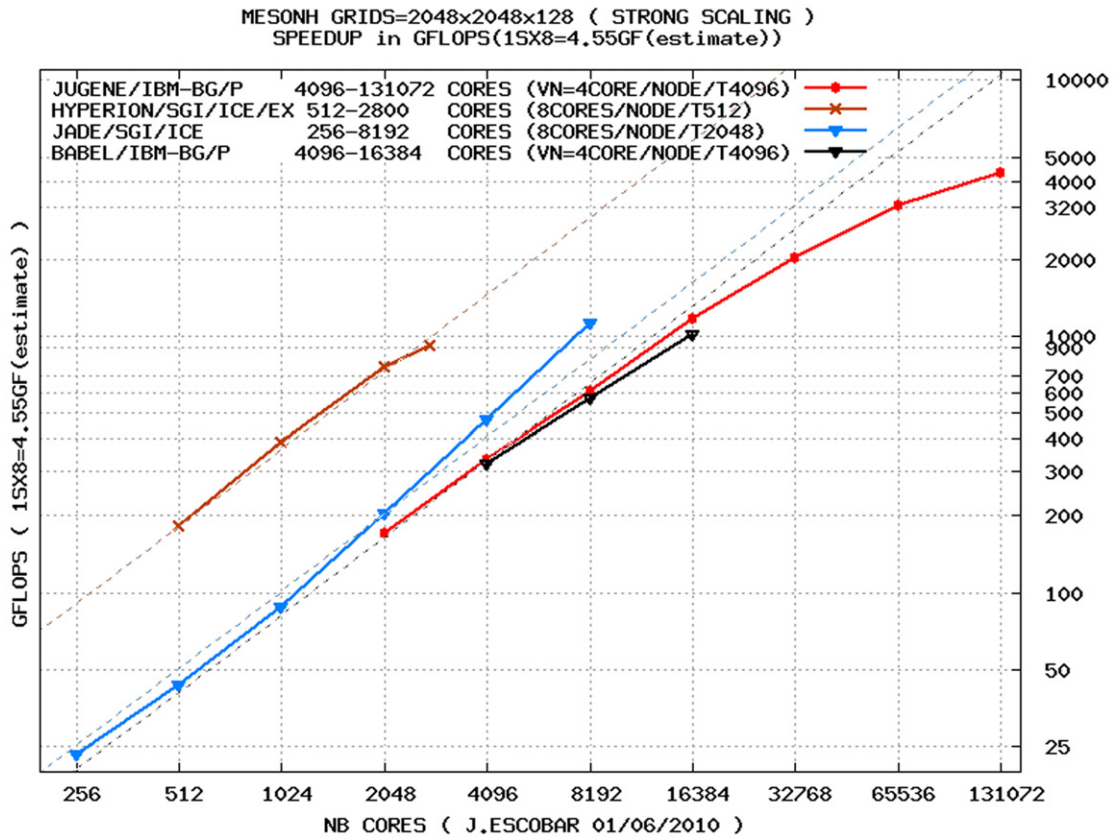


Fig. 1. Performance of MESO-NH in scalability: average sustained power (expressed in gigaflops) depending on the number of cores obtained by MESO-NH on different machines and for a grid of $2048 \times 2048 \times 128$ points (500 million points). The types of machines on which MESO-NH was run: IBM Blue Gene/P (Babel at IDRIS and Jugene at PRACE), SGI-Ice Xeon (Jade at CINES) and SGI-Ice Nehalem (Hyperion at CALMIP).

Fig. 1. Performance de MESO-NH en scalabilité : puissance soutenue moyenne (exprimée en Gigaflops) en fonction du nombre de coeurs obtenue par MESO-NH sur différentes machines et pour une grille de $2048 \times 2048 \times 128$ points (500 millions de points). Les types de machines sur lesquelles MESO-NH a tourné sont : IBM Blue Gene/P (Babel à l'IDRIS et Jugene à PRACE), SGI-Ice Xeon (Jade au CINES) et SGI-Ice Nehalem (Hyperion au CALMIP).

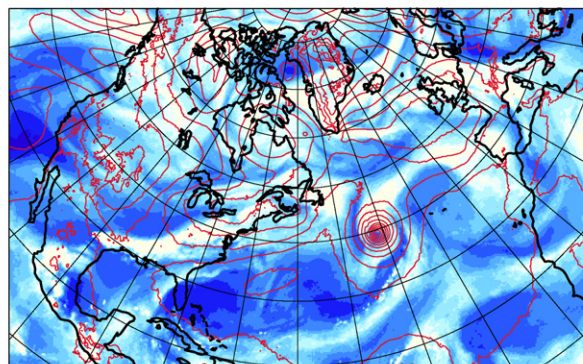
tropics. The mechanisms of exchange remain debated, between slow transport at large scale through the maritime continent and fast convective transport above the continents. A difficulty to estimate the contribution of deep convection to the stratospheric water vapor budget comes from the sensitivity of the representation of deep convective clouds with the horizontal grid spacing. At least a few hundred meters are required to simulate direct intrusions of convective plumes into the stratosphere [4]. However, the results become more robust using a higher resolution, with a grid spacing of 100 to 200 m.

The impact of a higher resolution on the representation of deep convection is illustrated for the Hector thunderstorm [5], located almost every day over the Tiwi Islands, north of Darwin, Australia during the pre-wet season. Fig. 3 shows 3-dimensional views of Hector photographed from Darwin and obtained from two MESO-NH simulations. These simulations share the same vertical resolution of 150 m with 200 gridpoints over the vertical. On the upper right panel the simulation uses a 2.5 km resolution over 288×256 gridpoints, on the lower right panel the other is performed with a 208 m grid spacing over 862×430 gridpoints. The latter offers a qualitatively more realistic view of the Hector cloud as compared with the photographic observation.

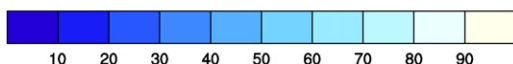
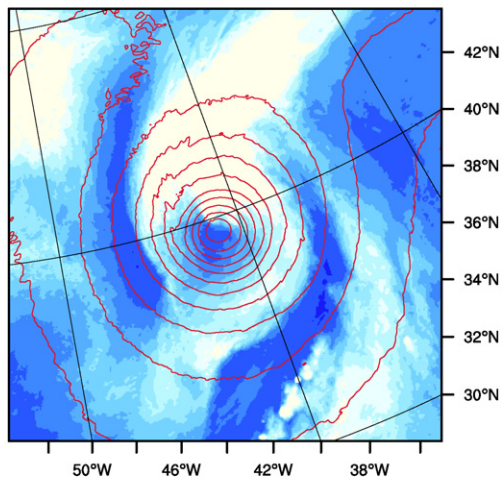
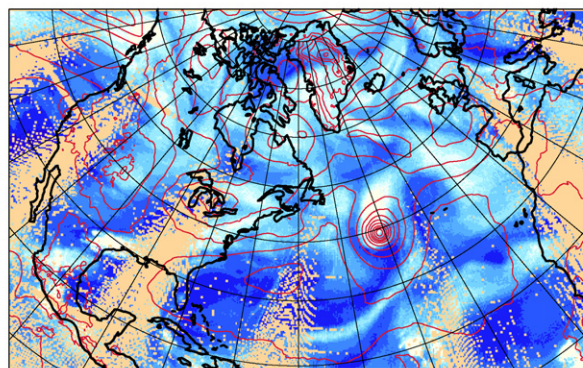
In particular, a potentially significant difference between the two runs is found in the small scale structure at the cloud top. The 2.5 km resolution simulation displays a smooth upper interface separating the saturated cloud and the overlying stratospheric dry air. By contrast, the 208 m resolution simulation shows a more corrugated cloud top, increasing the surface offered to exchange water vapor between the cloud and the lower stratosphere. A quantitative study of the relevance of this difference for the cloud top detrainment is under way.

4. Conclusion and outlooks

The high performance of the MESO-NH code demonstrates its capability of being employed using several thousand processors on the existing parallel machines. This allows us to address new issues on meteorology. Two particular applications were shown, one concerning the interaction between convective and synoptic scales, and the other focusing on the sensi-

4-km Meso-NH run at t+54 on 24 Sep 2006 06UTC

Upper Tropospheric Humidity [%]

**Zoom on Hurricane Helene****Observation and Analysis on 24 Sep 2006 06UTC**

Upper Tropospheric Humidity [%]

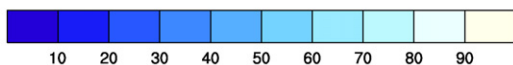
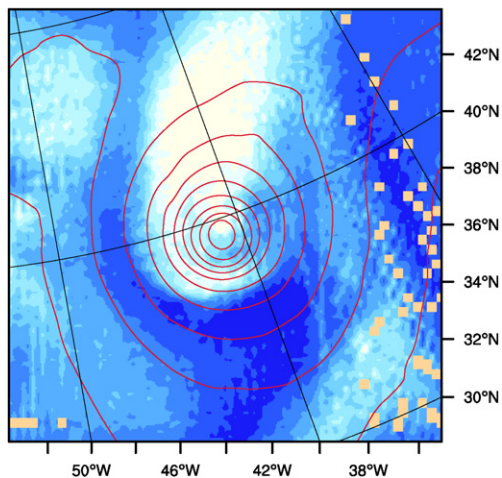
**Zoom on Hurricane Helene**

Fig. 2. MESO-NH simulation (top) and meteorological analysis of satellite observations (bottom) on the entire domain of simulation (left) and zoomed in on Hurricane Helene (right) on September 24, 2006 at 0600 UTC. The colors represent the moisture of the upper troposphere, high humidity (in white) indicating the presence of cloud cover. The lines are isobars (mean pressure at sea level). MESO-NH simulation run with 4096 cores on a grid of 413 million points and has generated 134 GB of files per output on the Jade machine of GENCI.

Fig. 2. Simulation MESO-NH (en haut) et analyse météorologique des observations satellitaires (en bas) sur le domaine entier de simulation (à gauche) et zoomé sur le cyclone Héléne (à droite) pour le 24 septembre 2006 à 0600 UTC. Les couleurs représentent l'humidité de la haute troposphère, la très forte humidité (en blanc) indiquant la présence d'une couverture nuageuse. Les lignes sont des isobares (pression au niveau de la mer). La simulation MESO-NH a tourné avec 4096 coeurs sur une grille de 413 millions de points et a généré 134 Go de fichiers par échéance sur la machine Jade du GENCI.

tivity of deep convection representation to the grid spacing. The up-coming petaflop computer capabilities will enlarge the current perspectives. For example, the interaction of convection with synoptic scales will be studied over large domains, like a hemisphere for limited-area models or at global scale. The weather predictability at convective scales will be easily achieved in a probabilistic perspective by running large ensembles of simulations starting from perturbed initial conditions. Running the model with a large number of variables (bin cloud model, chemistry) will be also more common. Further work is however needed to prepare the code to petaflop machines.

Acknowledgements

This study was sponsored by the French Ministry of Research through the project ANR-VMC2007 "Forecast and projection in climate scenario of Mediterranean intense events: Uncertainties and Propagation on environment" (MedUP) and by the Institut National des Sciences de l'Univers through the EPIGONE project. Florian Pantillon was supported by a CNRS and Météo-France PhD grant. Satellite data was obtained through the French Mixed Service Unit ICARE. Computer resources were

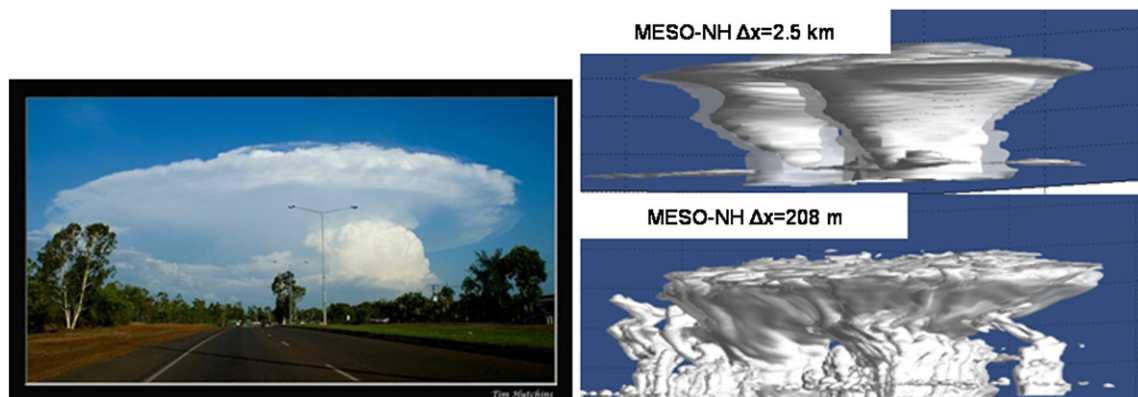


Fig. 3. 3-dimensional view of Hector (left) photographed from Darwin and (right) simulated by MESO-NH using a horizontal grid spacing of (above) 2.5 km and (bottom) 208 m.

Fig. 3. Vue en trois dimensions de Hector, (à gauche) photographié depuis Darwin et (à droite) simulé par MESO-NH avec une maille horizontale de (en haut) 2,5 km et (en bas) de 208 m.

allocated by CALMIP, GENCI (IDRIS, CINES, and CCRT; projects 0569, 1065, and 1076) and on the first petaflops component of the PRACE infrastructure (project 3656).

References

- [1] J.P. Lafore, J. Stein, N. Asencio, P. Bougeault, V. Ducrocq, J. Duron, C. Fischer, P. Hérelil, P. Mascart, V. Masson, J.P. Pinty, J.L. Redelsperger, E. Richard, J. Vilà-Guerau de Arellano, The Meso-NH Atmospheric Simulation System. Part I: Adiabatic formulation and control simulations. Scientific objectives and experimental design, *Ann. Geophys.* 16 (1998) 90–109.
- [2] P. Jabouille, R. Guivarch, P. Kloos, D. Gazen, N. Gicquel, L. Giraud, N. Asencio, V. Ducrocq, J. Escobar, J.L. Redelsperger, J. Stein, J.P. Pinty, Parallelization of the French meteorological mesoscale model MesoNH, in: *Lecture Notes in Comput. Sci.*, vol. 1685, 1999, pp. 1417–1422.
- [3] D.P. Brown, Hurricane HELENE, 12–24 September 2006, Tropical cyclone report, available online at http://www.nhc.noaa.gov/pdf/TCR-AL082006_Helene.pdf, 2006.
- [4] J.-P. Chaboureau, J.-P. Cammas, J. Duron, P.J. Mascart, N.M. Sitnikov, H.-J. Voessing, A numerical study of tropical cross-tropopause transport by convective overshoots, *Atmos. Chem. Phys.* 7 (2007) 1731–1740.
- [5] D. Brunner, P. Siegmund, P.T. May, L. Chappel, C. Schiller, R. Muller, T. Peter, S. Fueglistaler, A.R. MacKenzie, A. Fix, H. Schlager, G. Allen, A.M. Fjaeraa, M. Streibel, N.R.P. Harris, The SCOUT-O3 Darwin Aircraft Campaign: rationale and meteorology, *Atmos. Chem. Phys.* 7 (2009) 93–117.
- [6] H. Clark, J.P. Chaboureau, Uncertainties in short-term forecasts of a Mediterranean heavy precipitation event: Assessment with satellite observations, *J. Geophys. Res.* 115 (2010) D22213, doi:10.1029/2010JD014388.