Mecanismos de los cambios climáticos; herramientas matemáticas aplicables e incertidumbres en los resultados ***Mechanisms of climate change; applicable mathematical tools, strengths and uncertainties***

J.M. Baldasano

U. Politécnica de Cataluña, Barcelona Barcelona Supercomputing Center-Centro Nacional de Supercomputación (BSC-CNS)

The reality of present climate change (CC) has been accepted. Thanks to the sustained, comprehensive and objective assessments by the Intergovernmental Panel on Climate Change (IPCC), a consensus, with a high degree of confidence, has emerged in the scientific community that human activities are the essential factor contributing to CC. The numerical experimentation with climate models during the past 40 years has played a crucial role in creating this scientific consensus, and in its acceptance by the world.

The climate modelling community is therefore faced with a major new challenge: is the current generation of climate models adequate to provide societies with accurate and reliable predictions of regional climate change, including the statistics of extreme events and high impact weather, which are required for global and local adaptation strategies?

A major conclusion is that regional projections from the current generation of climate models were sufficiently uncertain to compromise this goal of providing society with reliable predictions of regional climate change. This is necessary because adaptation strategies require more accurate and reliable predictions of regional weather, air quality and climate extreme events than are possible with the current generation of climate models. It is possible firstly because of major advances in scientific understanding, secondly because of the development of seamless prediction systems which unify weather, air quality and climate prediction, thus bringing the insights and constraints of weather and air quality prediction into the climate change arena, and thirdly because of the ever-expanding power of computers.

Climate models are also useful tools for analyzing observations in a consistent physical framework. Analysis and prediction from past observations helps in interpreting the observed historical changes in the climate system and develop confidence in projections of future change.

The following important scientific and organizational questions will be examined:

- Current generation climate models have serious limitations in simulating regional features, for example, rainfall, mid-latitude storms, organized tropical convection, ocean mixing, and ecosystem dynamics. What is the scientific strategy to improve the fidelity of climate models?
- Is the low resolution of current climate models due to limitations of scientific understanding or lack of powerful computers and scientific staff?
- Several current operational Numerical Weather Prediction (NWP) centres are using global models with resolutions of 25-50 km. During the next years, it is expected that several global NWP models will have spatial resolution of about 10 km. Should the next IPCC assessment include at least a few climate models at about 10 km resolution for oceans and atmosphere?
- What is the strategy to ensure enhanced and sustained modelling efforts and computing power at the existing modelling centres of the world? Or, is the scale of the challenge so large that in addition to the current national efforts, a far more comprehensive and internationally coordinated approach is needed?
- A large body of evidence based on modelling experiments suggests that as models improve their parameterizations and increase their spatial resolution, the model's ability to simulate the current climate as well as the model's skill in predicting daily and seasonal fluctuations improves. What is the likelihood that if the spatial

resolution of climate models is sufficiently increased so that deep convective cloud systems, ocean overflows and mesoscale eddies, and heterogeneous land surface processes can be explicitly resolved, and therefore, do not need to be parameterized, the fidelity of climate models in simulating the current climate will improve?

- Will a major enhancement in computing power and dedicated scientific staff to develop data assimilation systems for very high resolution models enhance the value of space observations that are being made at a significant cost?
- It is well recognized that if the global models, from which lateral boundary conditions for regional models are prescribed, do not have reliable simulation of planetary waves and the statistics of tropical and extratropical storms, blocking and other regional phenomena, the use of high resolution regional models to downscale regional climate change is questionable. Is there a less questionable alternative? Is time-slice experiments using very high resolution (as high as regional models) global atmospheric models with surface boundary conditions from global change experiments, less questionable than regional downscaling? How important is coupling with the ocean and land at time and space scales commensurate with those of the atmosphere model? Are there more effective techniques available, perhaps in other disciplines, which could be employed to resolve the relevant features of the climate system?
- How accurate must simulations of the physical climate system are to justify the extension of climate models to include additional complexity due to chemical and biological processes? What time and space scales of coupling are fundamental to the system? What are the appropriate metrics to evaluate climate models?
- What are the current trends in computing? What is the best strategy to foster collaboration and interaction among the weather and modelling community, computational fluid dynamics community and computer (and chip) manufacturers to achieve a million fold increase in the effective computing power for climate and weather modelling and prediction?

Refs.

IPCC (2007) Fourth Assessment Report (AR4)-Working Group I Report: **The Physical Science Basis**, Chap. 1. Intergovernmental Panel on Climate Change

Wehner M., L. Oliker, J. Shalf and A. Mirin, 2008 **Towards Ultra-High Resolution Models of Climate and Weather.** *International Journal of High Performance Computing Applications* (submitted)

National Research Council 1998 **Capacity of U.S. Climate Modeling to Support Climate Change Assessment Activities**. *Climate Research Committee. Board on Atmospheric Sciences and Climate. Commission on Geosciences, Environment, and Resources*. National Academy Press

(disponible en: www.nap.edu/books/0309063752/html/index.html)

Hansen *et al.,* 2005**, Earth's Energy Imbalance: Confirmation and Implications**. *Science, 308*: 1431-1435

Hansen et al., 2007, **Dangerous human-made interference with climate: a GISS modelE study**. *Atmos. Chem. Phys., 7*, 2287–2312

Baldasano J.M., E. Valera y P. Jiménez, 2003, **Air Quality Data from Large Cities**. *The Science of the Total Environment, 307, 1-3:* 141-165

Jiménez P., J. Lelieveld y J.M. Baldasano ,2006, **Multi-scale Modeling of air pollutants Dynamics in the North-Western Mediterranean Basin during a typical summertime episode.** Journal of *Geophysical Research 111*, D18306, doi:10.1029/2005 JD006516

Baldasano, J.M., P. Jiménez P., O. Jorba, E. López, R. Parra y C. Pérez ,2006, **Dynamics of air pollution in the North-Western Mediterranean Basin (Catalonia) in summer by using high-resolution air quality modeling**. *Contribution to Science 3 (2):*167-180

Baldasano J.M. (2007) **The Need of High Performance Computing for Enhancing Climate Change and Air Quality Forecasting Systems.** International *Supercomputing Conference ISC'07*, Dresden (Germany) 26-28 June

Jiménez-Guerrero P., C. Pérez, O. Jorba and J.M. Baldasano 2008 **Contribution of Saharan Dust in an Integrated Air Quality System and its On-Line Assessment**. *Geophysical Research Letters, 35*, L03814, doi:10.1029/2007 GL031580.