Application of climate models within supercomputing frameworks

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The atmospheric physical and chemical processes are tightly coupled and nonlinear (Carmichael et al., 2007), and occur over a wide range of spatial and temporal scales that make global-scale numerical modeling of the troposphere a challenging venture. Computational speed of the coupled climate-chemistry models becomes a critical factor as long simulation periods, from several model months to a few years, are necessary to obtain reliable model statistics (Lee et al., 1999).

Therefore, there is a vital need for High Performance Computing in order to be able to predict the future evolution of our climate, and answer the key questions for society about the impact of increased greenhouse gases on global warming. Even though there is small doubt that climate is vulnerable to mankind's activity (IPCC, 2007; Rahmstorf et al., 2007), many questions remain unsolved at the quantitative level (extreme events and regional impacts on air quality, feedbacks between climate and biogeochemical cycles, impacts of climate change on marine and terrestrial ecosystems and on societies). All these questions are strongly linked to the amount of computing power available since they ask for increased model resolution, large number of experiments, an increased complexity of Earth System Models, and longer simulation periods compared to the current state of climate models.

The structure and intensity of an extreme climate event depends on complex non-linear interactions between large scales (several 100 km) and smaller scales (down to a few km). Model simulations are required that are able to represent both modification of the larger-scale, global, state (inside which extreme events are developing) and the fine-scale temporal and spatial structure of such events (storms, cyclones, intense precipitation, etc). Current global climate models (GCMs) have typical grid cell of hundred km; contain most of the processes that are believed to be important in determining climate (Schmidt et al., 2006); and are limited in their capacity to represent processes such as clouds, orography effects, small-scale hydrology, etc. High-resolution global models are therefore needed to improve our predictions and understanding of the effect of climate on seasonal, decadal and century timescales (Figure 1). A rising interest comes in the following decade, which represents a key planning horizon for infrastructure upgrades, insurance, energy policy, and business development (Smith et al., 2007).

Another issue is related to the simulation of regional-scale climate features, for which improved regional climate models (RCMs) are needed. Due to the relatively coarse horizontal grid, the GCMs are not suitable for climate studies on a regional scale domain. Variables such as surface temperature, surface wind, precipitations and cloudiness are highly dependent on the topography of a region (Giorgi et al., 1994), and the synoptic scale of several hundreds of kilometers that characterizes the grid of a GCM is not fine enough to correctly resolve such events at a regional scale (10-20 km). Furthermore, the parameterization of the physical events and quantities that appear in a global model may result extremely different from those implemented in a regional model.

The current implementation of the finite-volume atmospheric models is limited in terms of scalability by the choice of computational grids and numerical methods. Development of new models are required focusing in new numerical techniques to break through these scalability limitations. Therefore, a challenge for future developments is based on new-generation codes.

Despite the Earth System Modeling codes are currently implemented in high-performance computing infrastructures, a major challenge lies in the efficient use of a large number of processors for applications at high spatial resolution; therefore an important work is needed in the improvement of parallel performance of the codes. Over the next decade global models will require scalability beyond hundreds of thousands processors. Increasing model resolution down to 1 km for regional models or 20 kms for global climate models require increases by factors of 100 to 1,000 computing power compared to the current state.

The requirements of a good parallel performance for Atmospheric Earth System Modeling is supported by the "European Network for Earth System Modelling" (*http://www.enes.org*) which has emphasized a need for at least 60 Tflops sustained as soon as 2008 with a need for a renewal of investment at every 4 to 5 years at least during 10 to 15 years. Increase of computing power by a factor of 2 to 10 is required to better account for the complexity of the system. This complexity will need to be included in medium to high resolution models and therefore require a factor of 100 to 10,000 times the current power.

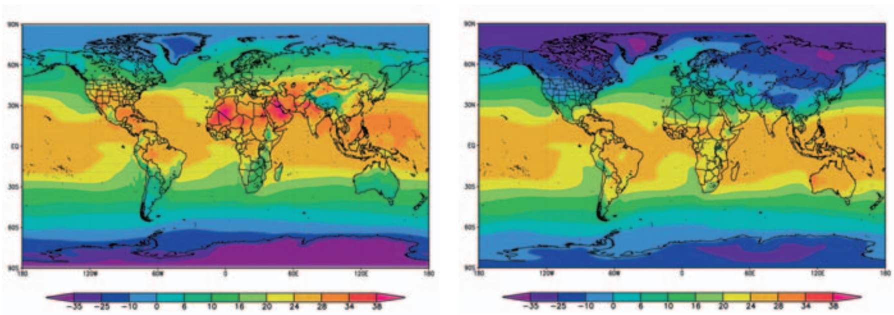

Figure 1. Climate simulations for 2m temperature during summertime months (JJA) with GISS ModelE by NASA (left) and wintertime (DFJ) with WACCM model (right), both implemented in MareNostrum supercomputer at BSC-CNS.