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Challenges in Earth System Modelling: Approaches and Applications

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W14 Challenges in Earth System Modelling: Approaches and Applications

Position Paper

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Workshop Focus

Earth system modeling has taken on increasing importance over the past several years. These models are being used to address an increasing number of environmental and global change problems of societal concern. Perhaps most commonly known is the application to possible greenhouse-gas induced warming. Other compelling problems include the climatic effects of land use changes, aerosols (including sulfate emissions, and smoke from biomass burning), changing trace gas fluxes, interactions and feedbacks with the global carbon cycle and the impacts of changing nutrient fluxes to Earths ecosystems. While originally based on general circulation models of the atmospheric component of climate, over the years the models have expanded to include oceanic circulation, land and sea ice, the full biosphere, atmospheric chemistry, and biogeochemical cycles (such as carbon, sulfur, oxygen and iron).

These models attempt to simulate the full complexity of natural systems, which includes the rendering of many interconnected physical processes that range across orders of magnitude in temporal and spatial scale. This poses a massive challenge in how to incorporate all the relevant processes, in developing a computer code that has appropriate numerical capabilities, and in obtaining computational resources sufficient to make the many required model runs at the necessary resolution in time and space. Satisfactory solutions for all of these remain to be found. But these are hardly all the challenges. These models produce voluminous output, which if nothing else tax data storage and processing systems. But since the models also try to capture the full complexity of natural systems, interpreting the many feedbacks and interplays is essentially as difficult as understanding them in the real earth system using real observations. Indeed, among other tasks, these models are used to fill in massive gaps in our observational network, as well as understanding of the key physics involved. The above are primarily scientific and numerical engineering issues. Perhaps the most important problem, however, is how to use the model results to understand and help to solve real issues; that is, how to apply the results in a manner that will help stakeholders address their problems. This can be posed as how to employ the model results, both direct, quantitative output, and the qualitative understandings obtained from them, into Decision Support Systems (DSS).

In this workshop we aim to bring together model developers, experienced users of earth system models, along interested potential users, and especially persons interested in the application or implication of model results, especially, but not restricted to, integration of these models within DSS frameworks. Our hope is to move beyond mere presentation of individual projects and results, and have a truly interactive dialog between all of these interested parties.

Some specific topics of interest (more can be brought up at the workshop):

1. Model development, including making and refining simulation of key physical processes and numerical developments needed to run the models on current and planned future computer systems. Listed below by model component are some key areas that need to be addressed:

Atmosphere modeling

(i) Convection is one of the hardest atmospheric phenomena to model. This is both because of the very small spatial scale over which it occurs and because of limited physical knowledge on how and when it occurs. Yet convection is a key way by which vertical motions, and associated mass and energy fluxes, occurs in the atmosphere.

(ii) Clouds and radiation, along with convection, are the most poorly simulated phenomena in the atmosphere. We are not even sure if clouds have a negative of a positive feedback overall on atmospheric temperatures. While clear-sky radiation is fairly well-known, cloudy sky radiation is much less so. Clouds also share with convection the problem of spatial scale.

(iii) The boundary layer is the region of the atmosphere probably the most poorly simulated overall, and yet it is the key by which fluxes are transferred from the free atmosphere to land and water surfaces and vice-versa.

(iv) The ability to conduct specific tracer transport in atmospheric models is a critical component of simulations that use inverse techniques to assess surface source-sink relationships. As the number of tracers reach several hundred and interact with both gas phase and particulate species the challenges of atmospheric chemistry and biogeochemistry increase.

Land modeling

(i) Inclusion of dynamic vegetation scheme. Progress is being made in this direction but more is needed, both to understand how vegetation will change as climate changes, and because these changes in vegetation can in turn have feedbacks that affect climate.

(ii) Energy and moisture fluxes with higher resolution and greater physical precision. These fluxes are the key way in which the land surface interacts with the atmosphere;

they have very small spatial scales, are in many instances poorly measured, and usually simulated with simplistic routines most appropriate for smooth surfaces.

(iii) Mixed vegetation types in a single grid box. Given the fairly coarse resolution of even present-day models (the latest IPCC model runs are at a resolution of approximately 140 km by 140 km in latitude and longitude), how best to describe the small-scale structure in vegetation and other land surface types contained within a single model grid.

(iv) Vertical structure of the vegetation. This will allow a better simulation of vertical transport of fluxes, and is related to both items (ii) and (iii). Better simulation of forest canopies is a particular need.

Ocean modeling

(i) Eddy resolving ocean models. The spatial scales of ocean eddies is much smaller than that of atmospheric eddies, making it much more difficult to properly resolve and simulate. Yet these eddies are a major source of mass, energy and constituent transport in the oceans.

(ii) Explicit treatment of ocean convection. Convection in the ocean is even more poorly understood and modeled than that in the atmosphere, furthermore because the ocean is largely barotropic, convection is restricted to just a few key geographic regions. Yet this convection is responsible for most of the deep water in the ocean, hence changes in the nature of this convection are likely to have dramatic consequences on climate.

(iii) Oceanic ecosystem model with the carbon cycle and several other biogeochemical tracers. The ocean is an often overlooked portion of climate when ecosystems are considered. Yet it is a key part of the carbon cycle, and other tracers such as DMS are increasingly known to be important yet poorly understood and modeled.

(iv) Sea ice modeling is a critical component of the ocean modeling frameworks and have a significant impact on the thermodynamics of earth system science.

2. Application of earth system models to any relevant scientific question of global change including feedbacks in the integrated biogeochemical-physical climate system

Several new climate, carbon and biogeochemical modeling results that require multi-Tera flop computational resources will be discussed within the context of climate science and high performance computing. Fully coupled Earth system models, in both the biogeochemical and physical sense, that specifically tracks CO_2 and dimethyl sulfide exchange between the ocean, land and atmosphere systems can be described. As an example of the utility of next generation Earth system models, a series of specific biogeochemical processes and feedbacks in the climate system are examined.

Biogeochemical modeling needs

(i) Inclusion of a fully interactive carbon cycle with the physical climate system. This will allow the complex feedbacks between the carbon cycle and climate to be investigated.

(ii) Full biogeochemistry in land and ocean models. This approach will allow feedbacks and interactions between the myriad of chemical cycles in the terrestrial and oceanic systems to be evaluated.

(iii) Terrestrial biosphere response to nutrient tracer deposition. This will allow the impact of the deposition of nutrients, such as nitrogen, to be examined in the fully coupled biogeochemical physical climate system.

3. Methodologies for employing output from earth system models into DSS

Consistent with the theme of fully coupled, comprehensive Earth system model creation, a highly detailed numerical model of energy usage is grafted to a GCM. This energy use and resource allocation model is driven with GCM simulated climate variables from 2000-2025 so as to predict the financial impacts and feedbacks of global warming.

Energy/financial modeling

The output from the global climate simulations are used to computed heating and cooling days for the time period 2000-2025. The heating and cooling days evolve over time as the climate essentially warms and this impact is assessed by the use of a detailed economic/energy model.

The relative energy usage between natural gas, coal, hydro in a changing climate is evaluated as a function of climate change and resource availability.

4. Integrated earth system model for Decision Support Systems DSS (or other) application to problems of societal interest

We evaluate several Earth system model prediction within the context of guiding policy and decision making. As example is a modeling project in Central America whereby we simulate future climate as a function of greenhouse gas increases and land use change. This allows the climate to be predicted and assessments made with regard to precipitation and temperature on agriculture.