Toward Reducing Uncertainties in Arctic Climate Simulations

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The coincidence of rapid change in Arctic climate (the extreme 2007 decline in sea ice and recent unprecedented warming) and enhanced observational activities during the International Polar Year (IPY; 2007–2008) offers hope that these changes will be documented in great detail. However, in order to explain changes in the Arctic and predict its future dynamics, models of the Arctic climatic system are needed to reproduce past and present states and to predict future transformations. Results from existing models are not always satisfactory [e.g., *Stroeve et al.*, 2007] because there are significant uncertainties in model forcing, parameterization of physical processes, and internal model parameters.

How to reduce uncertainties in model results and how to provide the best linkages among model and observational needs were the major themes of a SEARCH for DAMOCLES (S4D) meeting held 29–31 October 2007 in Paris with representatives from Canada, Denmark, Finland, France, Germany, Norway, Poland, Russia, Sweden, United Kingdom, and United States attending.

The goal of the international S4D project is to coordinate major European and U.S. Arctic research activities during the IPY that are aimed at understanding the nature, extent, and future development of Arctic change. The European component of the project is DAMOCLES (Developing Arctic Modeling and Observing Capabilities for Long-term Environmental Studies), and the U.S. interagency component is SEARCH (Study of Environmental Arctic Change).

Synchronization of these programs will enhance the acquisition of Arctic data and their distribution, storage, and analysis by eliminating gaps and redundancies. SEARCH for DAMOCLES participants aim to make the best use of modeling and observations by reducing uncertainties in model results and by providing the best linkages between model and observational needs across disciplines. S4D recommendations include the facilitation of information exchange among Arctic model intercomparison projects; the establishment of a comprehensive Arctic observational network; thorough validation of atmospheric reanalysis data; the extension of reanalysis efforts to sea ice, ocean, hydrology, and permafrost data; the implementation of rapid data exchange among data centers; the exploration of model classification based on objective characteristics that demonstrate levels of model error and uncertainty; and the training of young scientists in Arctic research and modeling.

The major S4D project recommendations are outlined below.

Model Intercomparison Projects

Three model intercomparison projects (MIPs) are working to improve Arctic models: the Arctic Climate MIP (ARCMIP), the Arctic Ocean MIP (AOMIP), and the Coupled ARCMIP (CARCMIP, which tests truly coupled atmo-sphere-ice-ocean-land models). The MIPs are optimal tools for system integration, especially when they are carefully and diligently validated against observations. MIPs provide the community with an opportunity for testing models against one another and against observations in a coordinated manner that accelerates model improvement and evolution. One outcome of MIPs activity is a better understanding of the strengths and weaknesses of different models, information that can then be used to assess future predictions and to guide fully coupled climate model development. The S4D program recommends facilitating interactions among Arctic MIPs and continuing their support and promotion via deeper collaboration between SEARCH and DAMOCLES.

Model-Observation Connections

It is difficult to construct, understand, and explain a global picture based on observations without including modeling. It is also problematic to use models for prediction of climate without knowing and understanding model errors and their uncertainties. For example, small errors in ice parameters stemming from errors in atmospheric forcing can translate into serious errors in ocean variables. That is why the MIPs are in demand—the major challenge for them is to improve regional and global models based on results of model validations against observations. This work is expensive and requires significant financial and labor resources.

To develop a comprehensive Arctic model, it is necessary to involve the entire community of modelers and observers representing atmospheric, terrestrial, ice, and ocean disciplines. Discussions at the S4D meeting concluded that there are insufficient observational data available for model initialization, forcing, validation, and assimilation and that a comprehensive Arctic observational network is urgently needed to satisfy the needs of both observational and modeling communities. Modeling must play a substantial role in Arctic observational network design and provide a scientifically effective system for the temporal and spatial distribution of observational sites. This is especially important during times of rapid sea ice change, when planning for traditional fieldwork is at risk.

Model Validation

Model validation is the first step in model improvement. Data coverage for model validation must be relatively dense in order to reproduce four-dimensional system variability. For the Arctic, where the observational network is based on coastal stations and central Arctic data are sparse, this condition is difficult to satisfy. However, considering model validation and model improvement as an iterative process, it is possible to enhance model accuracy via (1) data assimilation that provides gridded data sets that are physically consistent and constrained to match available observations and that can be used as first-order data for model validation and (2) model improvement based on the analysis of errors in these gridded data sets and the introduction of better model physics and parameterization.

The S4D program recommends (1) thorough validation of atmospheric reanalysis data used to force coupled ice-ocean and terrestrial models, (2) revealing terrestrial, ice, and ocean model errors that are due to forcing uncertainties, and (3) improving the atmospheric reanalysis models. The program also recommends the extension of reanalysis efforts to sea ice, ocean, hydrology, permafrost, and other disciplines; the continuation of coupled-model data assimilation technique development; and the facilitation of immediate data exchange among data holders.

Model Improvements

The largest biases in all global models occur in the Arctic. Regional Arctic models exhibiting high spatial resolution and improved physics are more accurate but frequently show striking differences in MIP studies. The S4D program has identified a set of urgent improvements needed for Arctic models. Some of these recommendations are common for all Arctic models and may be termed trivial, but they nevertheless need serious attention, namely, increasing model resolution, improving initial and boundary conditions, establishing initialization techniques for seasonal and decadal prediction systems, and enhancing forcing. These recommendations—except for the one to increase model resolution—could be implemented by increasing the quantity and quality of observations and improving data assimilation methods.

The atmospheric models can be improved by better description and parameterization of cloud properties, surface turbulent fluxes, and convective plumes associated with sea ice openings.

Climate effects representing tropospheric aerosols and clouds, stratospheric ozone, and Arctic haze require more studies. Significant improvements are needed in the description of precipitation, humidity fluxes, surface radiative fluxes, and spatial and temporal variability of snow and ice albedo. Thorough studies of inversions and the stable boundary layer are also important for model enhancement.

Coupled ice-ocean models have problems with restoring and flux correction procedures, and this limits the models' "natural" variability caused by forcing, the models' physics, and the models' errors due to the problems with numerical representation of model equations. It is important to overcome these problems by improving model forcing and internal model parameters based on observations. Processes of vertical and lateral mixing and the parameterization of eddies, plumes, freshwater and heat fluxes, the cold shallow halocline, and brine formation also require refinement and validation. With the increase in model horizontal resolution, sea ice dynamics and thermodynamics must be improved toward (1) a better description of small-scale processes and deformations and (2) the introduction of forcing at inertial and tidal frequencies. Frazil ice (initial stage of sea ice) formation and land-fast ice (which forms and remains fast along the coast) development and decay have to be taken into account as well.

The reduction of uncertainties in terrestrial model results can be achieved via the improvement in information about evapotranspiration, soil characteristics, precipitation and moisture fluxes, permafrost characteristics, and processes in wetlands and peatlands.

The use of a multiensemble approach based on different model realizations with standardized forcing can be valuable for the analysis of model uncertainties.

S4D Coordination

A coordinated community approach to the investigation of Arctic climate variability is the only way to assess the degree of uncertainty in the results and conclusions of different modelers, scientific groups, or institutions. Coordinated S4D activities will contribute to this assessment by establishing a set of benchmarks characterizing state-of-the-art Arctic climate modeling and the most up-to-date analysis of the Arctic climate and its variability. The benchmarks will constitute basic characteristics of polar processes that each model should reproduce with a given accuracy. These include, for example, patterns of atmosphere, ice, and ocean circulation and other parameters that characterize major climate states. A model that cannot meet these benchmarks will be recommended for improvement before its application in Arctic studies.

One of the major impacts of S4D activity will be the engagement of young scientists in Arctic studies. The program provides guidelines for a new generation of Arctic modelers on how to critically analyze and improve Arctic modeling. S4D will pay special attention to educational outreach to young scientists through publications, Web sites, and workshops, to encourage them to learn about and participate in Arctic research and modeling.

For more information about DAMOCLES and SEARCH, visit the following Web sites: http://www.damocles-eu.org/index.shtml and http://www.arcus.org/search/index.php.

Reference

Stroeve, J., M. M. Holland, W. Meier, T. Scambos, and M. Serreze (2007), Arctic sea ice decline: Faster than forecast, *Geophys. Res. Lett.*, *34*, L09501, doi:10.1029/2007GL029703.

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MEETINGS

The Science of Global Soil Change: Networking for Our Future

Global Soil Change Workshop; Duke University and Center for Environmental Farming Systems, Durham and Goldsboro, North Carolina, 10–13 December 2007

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Some of the most important scientific questions today concern the future of Earth's soil. Understanding the biological, ecological, chemical, and physical processes governing soil functions is directly related to most if not all of the grand challenges in environmental science outlined by the National Academies (*Grand Challenges in Environmental Sciences*, National Research Council, 2001). Because of the inherently long-term nature of soil change, addressing these questions requires research over decadal timescales. This feature of soil science presents significant challenges to those designing and implementing research programs, and yet is critical to the understanding of soil systems and the improvement of land management.

To promote and expand long-term soil research, a workshop was convened in December 2007 where participants from Africa, Asia, Australia, Europe, and the Americas formally established a global network of long-term, soil research studies. The workshop highlighted the proposition that soil studies spanning decades are critical to answering some of the most significant questions faced by humanity: (1) Can soils more than double food production in the next few decades? (2) How does soil interact with the global carbon cycle? (3) How can land management improve soil's processing of carbon, nutrients, wastes, toxins, and water?

The long-term soil research network is supported by an advanced-format Web site that showcases more than 150 long-term studies and encourages scientists from around the world to collaborate in new ways (http://ltse.env.duke.edu). At the workshop, researchers presented results from long-term studies of soil fertility and contamination, crop production, greenhouse gas emissions, and water quality. All researchers emphasized the efficacy of long-term soil experiments to quantify fundamental ecosystem changes over timescales of decades to centuries, changes that may be entirely undetectable without long-term monitoring and analysis.

Participants were challenged to engage in cross-site studies to advance the science of sustainability and to promote new, long-term studies to learn how to best meet growing demands placed on soils. Henry Janzen (Agriculture and Agri-Food Canada, Lethbridge, Alberta) made an impassioned plea for a new generation of Earth scientists to expand the vision of those who initiated long-term soil experiments, some in the nineteenth century. Participants expressed concerns about funding levels for long-term soil studies, many of which suffer from lack of stable institutional support. Many remain productive only through the dedication of individual scientists. According to workshop organizer Daniel Richter, professor of soils and ecology at Duke, "Long-term soil observatories need explicit and much greater support not only to improve our rapidly intensifying management of land and water, but also to better manage environmental change."

At the conclusion of the workshop, Ishaku Amapu (Ahmadu Bello University, Zaria, Nigeria) emphasized that "we need to make our long-term experiments work harder." Such long-term research requires long-range planning coordinated across many disciplines, and workshop organizers invite interested scientists, students, and the public to join this international effort. Organizers have funding support from the U.S. National Science Foundation's Research Coordination Network Program and Critical Zone Exploratory Network, the U.S. Department of Agriculture, and Duke University for five yearly meetings.

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