DEVELOPING KNOW-HOW ON REGIONAL CLIMATE CHANGE RESEARCH

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Appropriate responses to climate change require a worldwide capability to assess and properly interpret scientific findings. The declaration of the Intergovernmental Panel on Climate Change (IPCC) that global warming is "unequivocal" has shifted emphasis from research to action. Choosing priorities for mitigation and determining the best options for adaptation are most likely to succeed if the assessments of impacts and consequences are performed in the regions affected and by people from these regions. Accordingly, the World Climate Research Program (WCRP) and the Abdus Salam International Centre for Theoretical Physics (ICTP) organized a training workshop to teach participants around the world how to use WCRP's Third Coupled Model Intercomparison Project (CMIP3) database to gain regional climate understanding in the context of state-of-the-art simulations of climate change.

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DOI:10.1175/2008BAMS2665.1

In final form 8 July 2008

INTERPRETING CLIMATE CHANGE SIMULATIONS

WHAT: Eight lecturers trained 21 university and government scientists from 20 developing nations to use climate model output to investigate regional climate change.
WHEN: 26–30 November 2007
WHERE: Trieste, Italy

The CMIP3 database[1] contains more than 35 terabytes of output from 23 climate models examined in the Fourth Assessment Report (AR4) of the IPCC. Availability of these data to all interested researchers introduces a new era in climate change science—see "The WCRP CMIP3 Multimodel Dataset: A New Era in Climate Change Research," *Bulletin of the American Meteorological Society*, September 2007, 1383–1394. However, the learning curve can be steep because the user base grows to include investigators of climate impacts on human society and natural ecosystems. During the workshop, lecture sessions were therefore combined with hands-on laboratory training in which participants devised and executed projects using the CMIP3 data. With a thorough understanding of the uncertainties and limitations

[1] The CMIP3 database is maintained by the Lawrence Livermore National Laboratory's (LLNL's) Program for Climate Model Diagnosis and Intercomparison (PCMDI), under sponsorship of the U.S. Department of Energy Office of Science.

of the data, combined with practice experience, the participating scientists can now instruct colleagues in their own nations on the use of the database for regional climate change research. (A Web site containing the details of the workshop program and lecture notes is available at http://cdsagenda5.ictp.trieste.it/full_display.php?smr=0&ida=a07125.) Daytime lectures in the workshop discussed radiative forcing and observations and the attribution of climate change; the use of climate models to study climate change, with an emphasis on understanding uncertainties in future climate projections; an overview of the CMIP3 output in terms of present-day climate and future climate projections; and the role of scientists acting as advocates on climate change issues. Evening seminars emphasized regionalizing the multimodel outputs and alerting students to the strengths and weaknesses of the IPCC-assessed database of future climate projections. These highly interactive sessions covered the following: i) selecting a project, ii) creating regional teams, iii) accessing the CMIP3 data, iv) giving a "behind the scenes" glimpse of what it is to be an IPCC lead author; v) describing what can be researched with CMIP3, for example, tropical cyclones, vi) publishing results from the CMIP3 archive, and vii) assessing regional predictions: can we make them, should we use them?

On the first day of the workshop, the focus was on climate models and the WCRP's CMIP3 database. Its history and the present status of the CMIP3 archive, including how to register and download data, the types of variables and time frequencies of data available, and the data format (netCDF), were described. One issue facing users from developing nations is the time required to download the data via slow Internet connections. While connectivity remains a concern, workshop participants were able to access part of the CMIP3 database that has been archived at ICTP. The general topic of climate modeling was further expanded through an outline of the development of climate models, which emphasized that many share a similar "family lineage" and noted the milestones of computer advancements that have aided computer modeling progress.

After a day of lectures on the radiative forcing of climate change and an overview of the AR4 findings, the workshop focused on understanding and assessing uncertainties in climate change prediction. For example, the long time scales involved make climate change prediction essentially a boundary value problem of determining the response of the climate system to external forcings, although the initial ocean and land conditions might play a role. Sources of uncertainty include how natural and anthropogenic greenhouse gases (GHGs) and aerosols may change in the future, nonlinear responses (such as threshold behavior and feedbacks) of the climate system, and the presence of quasi-stationary regimes and natural variability. The use of climate models to assess climate change (the "prediction process") adds uncertainty because the models do not perfectly represent the climate system and they respond differently to the same forcing. Because of these uncertainties, climate change prediction needs to be approached in a probabilistic way, with large numbers of model simulations to produce meaningful probability density functions (PDFs).

The uncertainties associated with the CMIP3 archive were detailed so that the workshop participants would understand its limitations. It was pointed out that the archive constitutes an ensemble of opportunity and represents a "collection of best guesses" that does not span the full uncertainty range. The ability of climate models to reproduce historical and past climates and the intermodel agreement in the simulated response do not guarantee reliable projections, because models share biases and are not independent of one another or distributed around the truth. In addition, on continental scales the CMIP3 models simulate temperature best, followed by sea level pressure and precipitation, although there are substantial differences between models on finer scales that complicate the regional climate change question. The accuracy of other output fields varies, so that different models have different sets of best-simulated fields, and the multimodel mean typically outperforms the best individual models. Thus, a simple ranking of overall model performance is difficult.

Future climate projections were examined through changes in variability and extremes as well as regional patterns of climate change in the CMIP3 models. These discussions gave the workshop participants a picture of the changes projected for their regions. Changes in extremes are particularly important because the greatest risk comes from high-cost, low-probability events. In global warming projections, temperature variability decreases in high latitudes because of the reduction in snow and ice cover, while it increases at lower latitudes because of decreases in soil moisture. Models also indicate a decrease in the number of precipitation days and an increase in precipitation intensity, although these changes vary regionally. Here resolution may play a factor because models cannot resolve tropical cyclones and other mesoscale convective systems. That stated, subcontinental-scale regions in which the CMIP3 models agreed on the sign of both temperature and precipitation changes were able to be identified. Indeed, it was noted that the patterns of change are scalable (i.e., one can infer regional changes from global changes) and that understanding the temporal path to regional change is important for assessing impacts.

On the final day the workshop attendees presented the results of the projects they had been working on with the guidance of the lecturers. They were as follows:

- Precipitation variability and change over central and eastern Europe (R. Bojariu, T. Csaba, T. Halenka, J. Raisanen, and L. Srnec): The analysis of precipitation over central and eastern Europe revealed that many of the CMIP3 models overestimate annual precipitation compared to observations for the late twentieth century and indicate an increase of winter precipitation amounts and summer precipitation variability in the future scenario simulations. Additionally, principal component analysis techniques were tested as a basis for model selection.
- Anthropogenic forcing and tropical–temperature cloud bands over southern Africa (F. Engelbrecht, M. Hansingo, and P. Hunstman-Mapila): Future changes in summer [January–March (JFM)] precipitation and associated circulation mechanisms (such as tropical–temperate trough formation) were examined for southern Africa; this analysis will be used to create scenarios for future change over the Okavanga Delta in Botswana, a major wetland region and methane producer.
- Precipitation and temperature changes in North Africa using CMIP3 data (B. Abiodun, A. Sarr, and M. Umer): The analysis revealed there is considerable spread among models in both the characterization of present-day climate over the Sahel region and the projected future changes in precipitation. Nonetheless, several models indicate future decreases in precipitation over the western Sahel and increases in precipitation over the eastern Sahel. Future work will include analysis of extremes using daily data.
- Precipitation and temperature changes in South, Southeast, and East Asia using CMIP3 data (Y. Bao, A. Remedio, I. P. Sharma, and F. Syed): An examination of 13 models for the present-day and the AR4 A1B scenario simulations (monthly temperature and precipitation) emphasized how the topography of Asia poses a challenge for coarse-resolution global models, giving this group the impetus to perform dynamical downscaling experiments with GCM output in the future. The strongest annual response in both temperature and precipitation was found over Tibet.
- South American monsoon onset changes (S. Rauscher and M. Rojas): Using daily precipitation data from two models, a decrease in precipitation intensity and a shorter rainy season were noted for central South America in the A2 scenario of AR4 compared to the twentieth-century simulations. The opposite, that is, an early onset of the rainy season and higher precipitation intensities, were found for southeastern South America.
- Characterizing uncertainties in precipitation changes in South America (R. Da Rocha, M. Rojas, Y. Silva, S. Solman, and R. Terra): After dividing South America into climatically homogeneous subregions, the skill of each model in representing the precipitation annual cycle was used to create a model subset. A comparison of the full ensemble with this higher-skill subset revealed that model choice does not greatly affect the ensemble mean signal. An analysis of precipitation changes per unit temperature change was also performed in order to determine the scalability of the climate change signal in order to assess the near-future (20 yr) climate change.
- Precipitation–ENSO relation in present and future climate in South America (R. Da Rocha, M. Rojas, Y. Silva, S. Solman, and R. Terra): Using monthly sea level pressure data, the Southern Oscillation Index for the twentieth-century simulations was calculated for 18 models in order to evaluate how well the models simulate ENSO events and their variability, with the goal of exploring future changes in ENSO-related teleconnection patterns over South America.
- Impacts of climate change on Atlantic tropical cyclones (A. Babatunde and T. Stephenson): Changes found in hurricane indices in several models could suggest a method of projecting future changes in hurricane activity over the tropical North Atlantic.

Selecting a single outstanding project for one award was challenging because all students had accomplished much in a very short time. A vote of the course lecturers awarded to Tannecia Stephenson and Abiodun Babatunde copies of McGuffie and Henderson-Sellers' *A Climate Modeling Primer* for their exemplary project.

As the workshop closed, the need for improved regional projections of climate change for decision making was highlighted. A first step toward this goal is to ascertain if increasing model resolution improves climate projections. Because climate change will remain a risk management issue for the foreseeable future, scientists must do climate research well while also becoming advocates for preventing climate change. Participants were asked to explain impacts and deliver appropriate warnings, and to participate in the global debate on climate change in order to actively combat a climate security threat.

A special issue of *Global and Planetary Change* is currently in preparation featuring research developed from projects initiated during the workshop. The success of this first joint WCRP–ICTP workshop led to a commitment by both organizations to host further joint senior training opportunities. [For more information contact Filippo Giorgi (giorgi@ictp.it).]