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Climate Modelers Meet in Switzerland

The ability to model climate at high spatial resolution is a relatively new scientific initiative. While significant progress has been made in climate modeling, in part as a result of increased spatial resolution, much is still unknown about these models. Climate modelers met in Wengen, Switzerland, last year to assess their progress and difficulties. The difficulties include deficiencies in physical parameterization schemes, inadequate simulations of feedback mechanisms between different elements of the climate system, and problems with the quality, representation, and spatial distribution of observational data for verification purposes.

Climate modelers focused on the advantages and limitations of today's high-resolution models in simulating current climate as well as future climate under conditions of enhanced atmospheric greenhouse gas concentrations. They also discussed estimating regional-scale climate and the sensitivity of different regions to global climate change through variable-mesh general circulation models (GCMs), nested regional climate models (RCMs), and statistical-dynamical methods.

Many of the discussions focused on common problems. The presentations showed that even state-of-the-art GCMs operating at resolutions as high as T-106 (that is, 1 x 1 degree latitude/longitude) have inadequate spatial resolution to provide detailed regional representations of climate. This resolution also leads to difficulties in generating climatologically observed frequencies and locations of blocking. GCM results are sensitive to the physical parameterizations used. A new radiation scheme in the German GCM at the Max-Planck Institute in Hamburg, for example, was shown to be superior to an earlier version.

Many independently derived GCMs exhibit common problems, such as inadequate soil moisture/temperature and precipitation feedback mechanisms in sensitive regions such as the Mediterranean basin. The Hamburg group found that a higher resolution improves the modeling of orographic effects, as expected, and cyclone development.

Higher resolution allowed large-scale, systematic changes to be recognized. The jets shifted poleward in relation to a similar shift in the mean sea level pressure, which is strongest in the Summer Hemisphere. A warming of the troposphere is also noticeable. At 200 mbar this increase of resolution from T30 to T106 is 2 K from pole to pole. At 850 mb the increase is mainly seen in the Northern Hemisphere summer and is reaching in some areas values of more than 4 K compared to the T42 model. Higher resolution also leads to the detection of an Azores anticyclone. There is too little precipitation over Europe in June, July, and August, and this error increases with resolution, and a feature which is very similar to that observed in the United Kingdom (Hadley Centre) climate model.

RCMs are increasingly used as "intelligent interpolators" to downscale coarse-mesh GCM simulations. Owing to their limited computational domain, RCMs employ grid size anywhere from a factor of 3 to 10 finer than those of GCMs. Current trends in improvin the resolution of GCMs indicates that, to st ahead of GCMs, RCMs will enter the nonhy drostatic regime within the next decade. In the process of downscaling, an RCM will ge erate a set of coherent high-resolution climate fields with structures at scales finer th those in the driving model.

GCM-derived lateral boundary condition are generally used to provide input to regional models. The accuracy of regional cl mate model simulations is limited by the accuracy of these boundary conditions. Op erational analyses, such as from the European Center for Medium-Range Weather Forecasts, provide lateral boundary conditions for regional climate simulations that a superior to those provided by GCM climate model runs. Part of this deficiency is due to the poorer spatial resolution in the GCMs. The regional climate model results are, how ever, better for winter simulations because the information passed into the model from the larger-scale analyses. Summer regional climate simulations, particularly for such fields as precipitation, suffer because of inadequate soil moisture information, including accurate representation of soil and vegetation physics in the model.

Swiss attempts at modeling climate processes and change over the Alpine regio at very high resolution have been undertaken using the German GCM at T-106 resolu tion and a 20-km grid version of the NCAR/Penn State RCM centered over the Alps. This high resolution has enhanced the structural patterns of temperature and precipitation in the presence of an improved orographic representation; the coupled model system has also allowed an assessment of the shifts in temperature extremes in relation to possible changes in mean future climate.

The uncertainties remain high, however, and the possibilities for accurate intercomparisons between models and observations remain hampered by model grid mesh size, heterogeneous distributions of climatic records, and local characteristics that are often not well captured even at high resolution.

German groups have also carried out simulations of present-day climate for January and July through monthly runs with a German mesoscale climate model (MCGaP) driven by the German T106 GCM. This method is well suited for analyzing regional climate processes and their interactions. Present-day climate for near-surface temperature and precipitation can be reproduced by this method if the initialization by the large-scale fields is adequate. The simulated precipitation pattern for January over the Alpine region compares especially well with the precipitation climatology provided by the Swiss Federal Institute of Technology in Zurich for that area. The splitting of the surface energy balance between sensible and latent heat fluxes, which strongly depends on available soil moisture, dominates the near-surface temperature pattern.

Initialization of soil moisture is a major problem in global and regional climate modeling, as is sufficiently high resolution (10 to 100 km) data for the evaluation of regional climate simulations, which either do not exist or are not generally available. Simulations for the Arctic have been conducted elsewhere in Germany with an RCM developed in Hamburg. This RCM is a very useful tool for understanding the physical processes that determine Arctic climate on monthly-mean timescales. Using the model, it was found that the changes due to different parameterizations are of the same order as the model error itself.

Research at Colorado State University has focused on surface-atmosphere feedback mechanisms which, on regional to subcontinental scales, are likely to have a significant impact on the climate system. In particular, changes in vegetation patterns—for example shifts from natural grasslands to agricultural lands to the east of the Rocky Mountains—exert a large influence on convective activity. Simulations with the RAMS mesoscale model developed at Colorado State illustrate the extreme differences in convective activity over areas with natural pre-European settlement vegetation, which leads to shallow convective activity, and the same regions with current 1990s vegetation, which leads to large cumulus clusters and regions of heavy precipitation. These biosphere-atmosphere feedback effects are often at least as large, in terms of human-induced perturbations to regional temperature and precipitation, as hypothesized from greenhouse gas-induced warming.

An RCM developed in Canada is based on the fully elastic nonhydrostatic equations for atmospheric flow. This RCM is solved with semi-implicit and semi-Lagrangian solution algorithms and permits a 15-minute time step for simulations at a horizontal grid-spacing of 45 km, which results in substantial computational savings. To evaluate the potential of RCMs as "intelligent interpolators," a series of simulations were performed to infer the influence of initial and lateral boundary conditions on fine-scale structures that develop in the course of an RCM simulation. These GCM simulations were of various lengths but all ended at the same time on a given day in January. Initial conditions have very little influence on the simulation after 24 to 36 hours and time-dependent lateral boundary conditions strongly control the evolution of the fine-scale details in RCM-simulated fields.

Eigenvector reconstruction methods are being applied to instrumental data to calibrate the large-scale temperature signal represented by multiproxy data networks at the University of Massachusetts. Calibration and verification exercises were used to demonstrate the skill with which diverse proxy data can capture large-scale patterns of surface temperature from several centuries ago. The calibrations were used to reconstruct large-scale temperature patterns back to 1650 including long-term time series of Northern Hemisphere average temperature and the NINO3 SST (sea surface temperature) index. These large-scale reconstructions now provide a means for estimating the faithfulness of the century-scale variability produced in coupled climate models.

Finally, climate data sets were presented that can provide input and validation information for both GCM and regional models. These data, compiled at the Hadley Center, are also valuable for documenting variability and changes in climate. Global radiosonde temperature data can be used to compare with climate model results. At Hadley Centre, adjustments are only made to radiosonde temperatures if changes in radiosonde instrumentation require it, which minimizes the risk of introducing biases from any spurious change in advanced technology instruments such as Microwave Sounding Units, which are used as a reference. Adjustments are of the order of 2°C at 50 hPa over Australia, which reduces apparent cooling in the stratosphere.

Model simulations, whether they depend on observed SST or couple the atmosphere and ocean, yield the best profiles of zonal-mean temperature change if changes in greenhouse gases, sulphate aerosols, and stratospheric ozone are included. The mean of four simulations with the UK climate model forced with the global sea-ice and sea surface temperature data set gave a Southern Oscillation Index (SOI) that correlated at 0.60 with the observed index for 1871–1940, when SST observations were sparser, after smoothing to pass variations longer than 9 months. The gridded global sea level pressure data set reproduces the smoothed SOI very closely: $r = 0.91$ for 1871-1994. The Hadley Centre plans to use the U.S. National Center for Enviromental Prediction Reanalysis [*Kalnay et al.*, 1996] to improve the structure of the sea level pessure in data-sparse areas, but biases in this reanalysis over high, cold terrain will need to be circumvented. In the context of ongoing international research and intergovernmental negotiations for the Framework Convention on Climate Change, climate model results will play a central role in highlighting a selection of potential climatic trends, and in providing climatological data sets for studies of the possible impacts of climate change on a number of environmental and socio-economic sectors. It is clear that to progress further in the field of climate modeling, however, many of the points addressed above will need to be exhaustively considered in the near future. In addition, uncertainties in the high-resolution simulations need to be quantitatively communicated to the users of these data.—*Martin Beniston, Institute of Geography, University of Fribourg, Switzerland; Roger A. Pielke, Sr., Dept. of Atmospheric Science, Colorado State University, Fort Collins; Klaus Arpe, Max-Planck Institute for Meteorology, Hamburg, Germany; Klaus Keuler, Fraunhofer Institute for Environmental Research, Garmisch-Partenkirchen, Germany; Rene Laprise, University of Quebec at Montreal, Canada; Michael E. Mann, University of Massachusetts, Amherst; Annette Rinke, Alfred-Wegener Institute for Polar Research, Potsdam, Germany; and David E. Parker, Hadley Centre, United Kingdom Meteorological Office, Bracknell*

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Reference

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