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Date: 30 April 2009

Technical Briefing Paper (3): Climate Models and Scenarios

Synopsis Climate models are used to project changes in global temperature, rainfall, sea level and other earth system properties to changed concentrations of anthropogenic greenhouse gases and aerosols. Although there is strong consensus amongst models about future warming, patterns of rainfall and runoff are much less certain. This reflects different approaches to land and atmosphere process representation in models at regional scales. Nonetheless, climate models do show coherent signals of seasonal runoff change in regions dominated by snowpack accumulation and melt.

Explanation Climate models are numerical representations of the climate system based on its physical, chemical, and biological properties, component interactions and feedback mechanisms. The three-dimensional climate system is represented by primary equations describing the movement of energy (first law of thermodynamics) and momentum (Newton's second law of motion), conservation of mass (continuity equation), and water vapor behavior (ideal gas law). These equations are solved at discrete grid-points across the surface of the Earth, and between coupled layers in the atmosphere and ocean, at time-steps of 10-30 minutes (Figure 1).

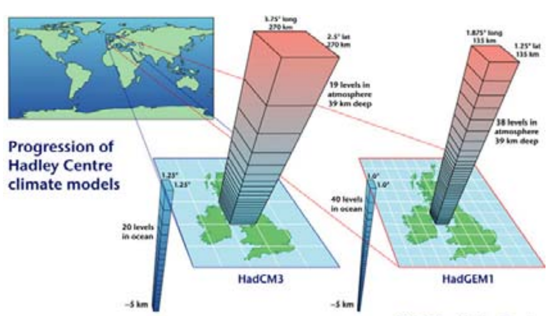

Figure 1 The UK Met Office Hadley Centre third generation ocean-atmosphere climate model (HadCM3) has an atmospheric model with a horizontal resolution of 2.5 x 3.75 degrees and 19 vertical levels, and an ocean model with a horizontal resolution of 1.25 x 1.25 degrees and 20 vertical levels (left panel). HadGEM1 has double the spatial resolution of HadCM3 in all three dimensions (right panel), implying an eight-fold rise in the computational effort needed to produce scenarios. Source: Met Office Hadley Centre.

Solving equations for thousands of grid-points is typically undertaken by supercomputers. To make the task manageable, the horizontal resolution of climate models is coarse, typically 50-400km. This means that many important components of the climate system that have scales much finer than this (e.g., convective clouds, coastal breezes, etc.) must be simplified (or parameterized) using statistical representations for the effects of small-scale processes on large scale climate behavior. The parameterization of clouds, for example, is particularly challenging, not least because of their role in the energy balance and feedbacks arising from increased atmospheric moisture content with global warming. As well as simplifying key processes through parameterization, climate models also average conditions between grid-points. For example, rainfall is assumed to occur uniformly over large areas, neglecting the influence of topography, and underestimating peak intensities.

Climate models compute energy transfers through the atmosphere (involving water vapor and cloud interactions), the direct and indirect effects of aerosols (on radiation and precipitation), changes in snow cover and sea ice, the storage of heat in soils and oceans, surface fluxes of heat and moisture, and finally, the large-scale transport of heat and water by the atmosphere and ocean. Some climate models incorporate land-surface schemes including the freezing and melting of soil moisture, and the regulation of evaporation by plant stomata (due to variations in temperature, vapor pressure and CO_2 concentration). More sophisticated models include carbon cycling and atmospheric chemistry for trace gases (such as CH_4, N_2O, CFC_{11}, CFC_{12}, and $HCFC_{22}$).

Application Climate models are the primary tool for calculating Earth system responses to past and projected concentrations of greenhouse gases and aerosols, as well as to natural variations in the planetary energy balance arising from changes in solar output and cooling by volcanic eruptions.

Despite different parameterization and process representation, there is now remarkable agreement amongst climate models about projected temperatures for the next two or three decades. The agreement stems from the fact that much of the additional warming is due to the climate's response to past emissions and the thermal inertia of the oceans. The consensus is also largely independent of the assumed emission scenario. Regardless of the climate model or emission scenarios, the change in global mean temperature is projected to be ~0.2ºC/decade, compared with ~0.1ºC/decade if concentrations are held constant at year 2000 levels.

Climate projections over longer time-scales are less certain because they depend upon assumptions about the future emissions of greenhouse gases and aerosols. In March 2000, the Intergovernmental Panel on Climate Change (IPCC) approved a set of emission scenarios to replace the IS92 scenarios used in the 1996 IPCC Second Assessment Report. The new scenarios, were presented in the IPCC Special Report on Emission Scenarios (SRES), and have much lower emissions of sulphur dioxide than the IS92 scenarios. Four SRES "marker" scenarios A1, A2, B1 and B2 cover a range of future demographic, economic and technological "storylines" and hence divergent climate responses.

Case Study Global patterns of runoff under a changing climate

Rainfall and temperature projections under future greenhouse gas emissions yield changes in global patterns of water balance components such as evaporation, soil moisture and river flow. Figure 2 shows projected changes in annual runoff by the end of the 21st century under the SRES A1B emissions scenario, based on results from 12 climate models. The white and hatched areas denote where there is either little or strong consensus about the sign of the change respectively.

Even where the models agree, there is insufficient detail for water resource planning at the river basin scale. The information is better at highlighting broad trends in hydrological behavior. For example, higher air temperatures mean that more winter precipitation falls as rainfall rather than snow, and that the onset of spring snowmelt is earlier (and sometimes more rapid). Hence large parts of North America, Scandinavia and the European Alps are expected to see increased seasonality of flows with higher spring peaks and lower summer flows. Other robust signals include higher flows in rivers fed by melting glaciers over the next few decades, followed by reductions once the ice stores have been depleted. Likewise, warmer temperatures will favor more evaporation and drying of soils, increasing the risk of drought and depleted runoff as is anticipated for the Mediterranean basin.

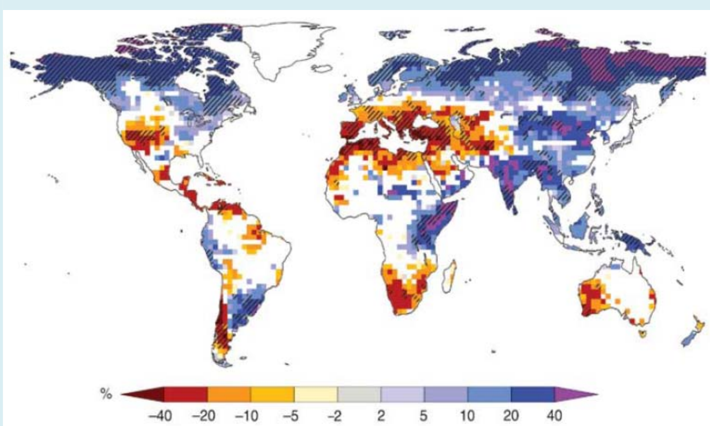

Figure 2 Percent changes in annual runoff for the period 2090-2099, relative to 1980-1999. White areas are where <66% of the climate model ensemble agree on the sign of change, and hatched areas are where >90% of models agree on the sign of change. Source: IPCC, 2007: Climate Change 2007 Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.

Figure 3.5, page 49.

Supporting materials and links

Meehl, G.A., Stocker, T.F., Collins, W.D., et al. 2007. Global Climate Projections. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Solomon, S., Quin, D., Manning, M., et al. (eds.), Cambridge University Press, UK.

Milly, P.C.D., Dunne, K.A. and Vecchia, A.V. 2005: Global pattern of trends in streamflow and water availability in a changing climate. *Nature*, **438**, 347–350.

Smith, D.G., Cusack, S., Colman, A.W., Folland et al. 2007. Improved surface temperature prediction for the coming decade from a global climate model. *Science*, **317**, 796-799.

See Water Research Foundation Technical Briefing Paper 4 (*Rationale and applications of regional climate downscaling*)