Should we expect climate models to converge when we increase resolution?

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One of the questions that climate modellers should address is whether their models have sufficient spatial resolution to represent the physical processes affecting climate. We have addressed this issue using the Hadley Centre climate model, HadAM3 (the climate version of the Met Office's Unified Model) and report the results in Pope and Stratton (2002). The model is run in AMIP II mode with 4 horizontal resolutions ranging from N48 (2.5 x 3.75 deg) to N144 (0.833 x 1.25 deg). An inherent assumption in this approach, and in numerical modelling of the atmosphere generally, is that models will converge towards an ideal solution as resolution is increased - provided we stay within the range for which the parametrizations are valid. We have shown that this assumption is not always justified. For example, the plot of zonal mean temperatures and differences shows that the warming in the troposphere when resolution is increased is largely converged at N96 (1.25 x 1.875 deg) whereas the cooling around the tropopause at the north pole is only apparent at N144. In principle, undesirable resolution dependencies in physical parametrizations can be removed. However, many processes, and in particular intermittent processes such as convection, are inherently non-linear making resolution dependency inevitable.

We used a range of techniques to identify the processes that affect convergence. For example, dynamical core tests with a smooth uniform land surface everywhere, were used to isolate dynamical processes. 'Spin-up' tendencies were used to diagnose the contribution of individual physical parametrizations and the dynamics scheme. The tendencies are produced by running a series of 1 day integrations starting from operational analyses scattered evenly through the period 1/12/98 to 21/2/99. The analyses use an assimilation system based on the forecast version of HadAM3. Spin-up tendencies are produced by taking the accumulated increments for each of the basic model fields from the dynamics and physical parametrization schemes and averaging them for all the runs. The dependency of the results on particular details of the model were also investigated to see how general the results are.

We showed that non-linearity in both the hydrological cycle and the dynamics play an important role in the lack of convergence. Non-linearity in convection and the response of vertical motion to increased resolution affected the convergence of the tropical circulation, assocated precipitation and the Madden Julian oscillation. They also affected mid-latitude storms. Non-linear dynamics affected the convergence of the tropopause temperature in the full model and the surface pressure in the dynamical core. The general resolution dependency of the results and the particular lack of convergence of some fields mean that it is important to explore the ability of the global model to simulate climate and the signals of climate change at a range of resolutions.

Pope V D and R A Stratton, 2002: The processes governing resolution sensitivity in a climate model. Climate Dynamics, to appear.

Impact of resolution changes on zonal mean temperatures (K)