Local Feedbacks and Global Climate Sensitivity

How much the global surface temperature will rise with increasing atmospheric CO_2 concentrations is still uncertain. The Intergovernmental Panel on Climate Change (IPCC 2001) has reviewed the predictions in response to a CO_2 doubling in 20 state-of-the-art coupled atmosphere-ocean climate models and found increases ranging from 2.0 to 5.1°C. The reasons for the large differences among the model simulations of global warming are not well understood. Conventional wisdom would suggest that the differences reflect the various ways in which the models parameterize convective and cloud processes, but a detailed understanding of how these parameterized processes affect climate sensitivity is lacking. The models may also differ significantly in their resolved atmospheric dynamics, water vapor transport schemes, and ocean dynamics.

As a first step to understanding these differences, **Kevin Hamilton**, leader of the IPRC Impacts of Global Environmental Change Team, is collaborating with **George Boer** of the Canadian Center for Climate Modelling and Analysis (CCCMA) on diagnosing local and global climate feedbacks in different climate models. They have begun with analyzing simulations obtained with the NCAR Climate System Model (CSM) under control conditions and under increased solar constant conditions (*IPRC Climate*, vol. 2, no. 2).

Hamilton and Boer define local feedback in terms of the changes in the radiative fluxes with the increased solar constant. For any column $dh'/dt = A' + R' = A' + R^* + F$. Here h is the total heat stored in the atmosphere-ocean column, A is the convergence of the dynamical heat flux in the atmosphere and ocean, R is the net radiative flux (downward minus upward) at the top of the atmosphere, and the prime denotes the change in these quantities in a perturbed experiment relative to the control. The change in radiative fluxes can then be written in terms of the climate forcing, F, and the response, R^*. The climate feedback parameter is defined as R^* divided by the surface temperature change in the warm experiment: $\lambda=-R^*/T'$. The global climate sensitivity is s, where $s=\langle T'\rangle/\langle F\rangle= -\langle T'\rangle/\langle\lambda T'\rangle$, and $\langle\ \rangle$ denotes a global average.

Global sensitivity, therefore, depends on the reciprocal of the global integral of an appropriately weighted local feedback parameter: Regions of positive feedback parameter increase the overall climate sensitivity, and regions of negative feedback decrease climate sensitivity. It turns out that the feedbacks in the NCAR model vary greatly with region, supporting the idea that the differences among models in the predicted increase in global surface temperature could be at least partly connected to differences in local feedbacks.

Figure 6 shows the feedback parameters for various components of the atmosphere as determined from a comparison of simulations with the NCAR CSM under control conditions and under a solar constant increase of 2.5%. Panel (a) shows the total feedback in adjusting to the warming. The most striking geographical variation in sensitivity is in the tropical Pacific, where the only major region of net positive feedback occurs in the central Pacific. Panel (b) shows the contribution to the feedback that can be attributed to cloud changes, while panel (c) shows the contribution that can be attributed to changes in the cloud free atmosphere, and panel (d) shows the contribution from changes in surface albedo. Not shown is the remaining contribution to the total feedback, namely, the infrared surface feedback, which is strongly negative everywhere.

Most of the geographical variation in the tropics seems to arise from the cloud feedbacks. The cloud response may be connected with a modest maximum in the surface warming that occurs near 160ºW. Interestingly, the structure of the feedback parameter in the tropical Pacific has similarities to that diagnosed in a global warming simulation performed by George Boer with the CCCMA global model (*IPRC Climate*, vol 3., no. 1), supporting the idea that local climate feedbacks are important in determining overall climate sensitivity.

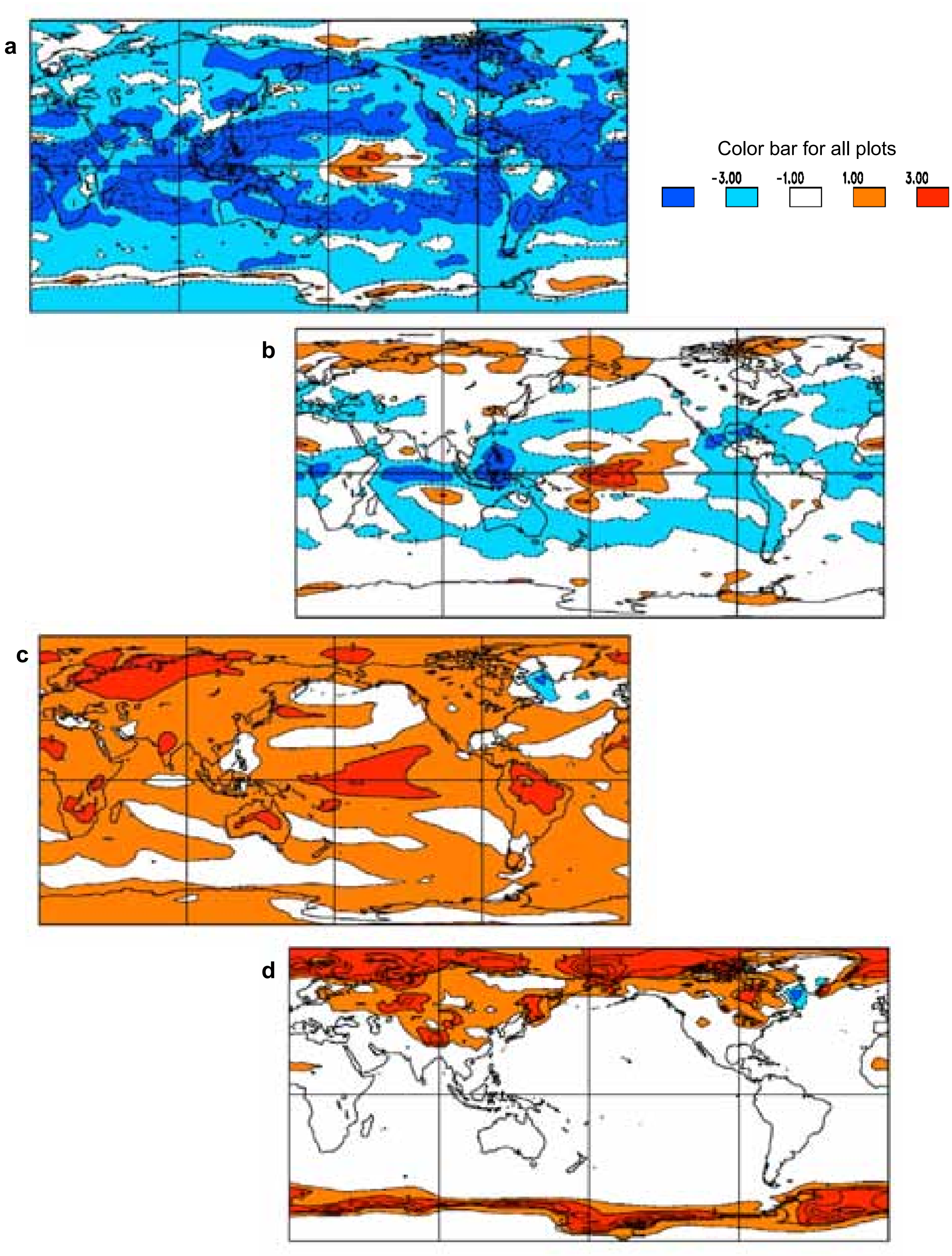

Figure 6. *Diagnosis of the geographical distribution of local radiative climate feedback, λ, in the NCAR climate System Model. The shading key is labelled in* W^{-2} K^{-1}*. Results diagnosed from a control run and a warmed earth experiment with an increased solar constant: (a) total feedback, (b) feedback from cloud processes, (c) feedback from changes in the clear sky atmosphere, and (d) feedback from surface albedo changes.*