

# Climate Response to Strong Global Perturbations

Researchers interested in modeling the sensitivity of climate to changes in atmospheric composition have overwhelmingly focused on predicting the response to relatively modest external forcing—typically the kind of changes in concentration of long-lived greenhouse gases that are likely to be seen in the next 50 to 100 years. The likelihood that atmospheric carbon dioxide (CO<sub>2</sub>) concentrations will reach twice pre-industrial levels sometime in the 21st century has led to the "double CO<sub>2</sub>" scenario as a standard case that many modeling groups have simulated.

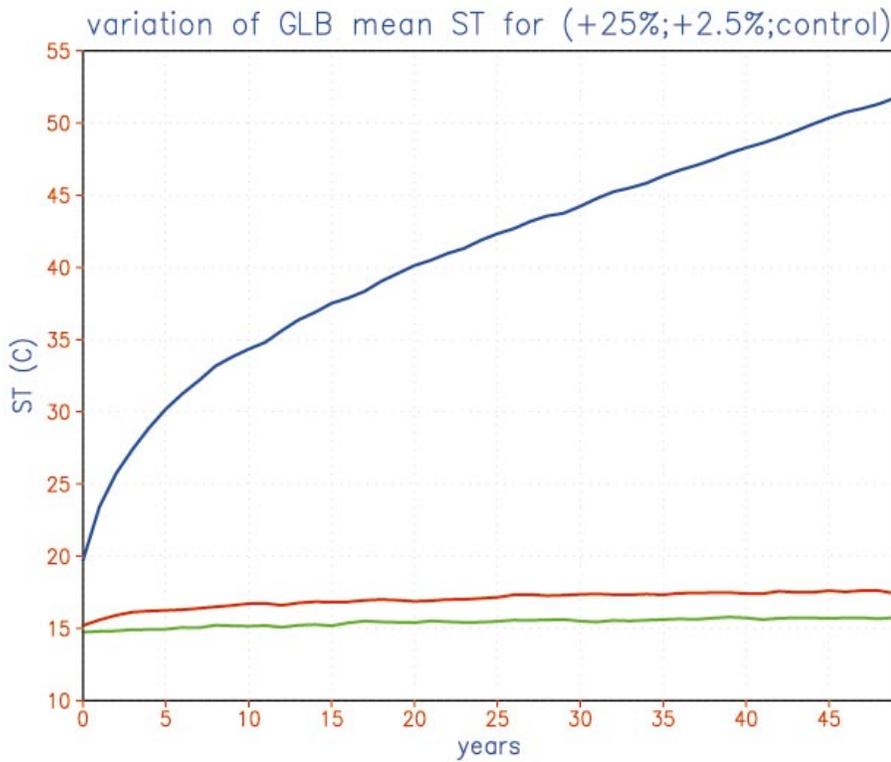
The doubling of CO<sub>2</sub> concentration leads to a net direct forcing of the troposphere of about 5 W/m<sup>2</sup>, and the effects are thought to be similar to those that would be caused by about a 2% increase in the solar constant. The various current state-of-the-art models predict that the increase in global mean surface temperature due to a doubling of CO<sub>2</sub> concentration will reach equilibrium between 2°C to 5°C.

Unfortunately for mankind, it is very likely that in the next few centuries the climate forcing from human activities will reach at least 10 W/m<sup>2</sup> (corresponding to a four-fold increase in CO<sub>2</sub> levels), quite possibly 15 W/m<sup>2</sup> (an eight-fold increase in CO<sub>2</sub> levels), and conceivably even much higher, given the human capability to influence the atmospheric concentrations of other important greenhouse gases such as nitrous oxide, methane, hydrofluorocarbons, hydrochlorofluorocarbons and chlorofluorocarbons. The question of whether the surface climate response to such forcings saturates with increasing forcing or grows nonlinearly will determine how serious such perturbations could be for future generations. This is also an issue of interest to planetary scientists, since the very high temperature observed in the Venusian atmosphere has been attributed to the so-called "runaway greenhouse (RG) effect." The RG effect is the strongly nonlinear response of surface temperature on an earth-like planet when radiative forcing exceeds a hypothesized threshold. The RG effect has been studied in very simple climate models, but the existence of the RG instability threshold has not yet been demonstrated in a comprehensive general circulation model.

At the IPRC, **Weijun Zhu** and **Kevin Hamilton** (Theme 4 Leader and Professor of Meteorology) are examining the nature of the response to large climate perturbations using the NCAR Climate System Model (CSM). To keep matters as simple as possible, the climate perturbations were introduced by changing the solar constant while the concentrations of long-lived atmospheric constituents were kept constant at near present-day values. Figure 6 shows the evolution of the annual-mean global surface temperature in a control version, and in versions in which the solar constant was instantaneously increased by 2.5% and 25%. The temperature in the +2.5% run appears to reach equilibrium at about 2°C above the control run. This is roughly the same warming that has been found by other investigators when the CO<sub>2</sub> in this model is doubled. The CSM is thus one of the least sensitive of the current comprehensive climate models.

The +25% solar constant run shows a continuously rising temperature through the full 50 years of integration. It is not clear if the climate in this case will reach equilibrium, but the temperature increase over the control by year 65 already exceeds 40°C, suggesting that the response has become extremely nonlinear. It is possible that the continued warming in this experiment indicates that the model with +25% is close to the RG instability boundary. Figure 7 shows the annual-mean surface temperature change (relative to control) averaged over years 41 to 50 of the +2.5% and +25% runs. The extreme warming in the +25% experiment is evident, and is almost everywhere much more than 10 times the warming in the +2.5% run. It should be emphasized that this model includes only water vapor and cloud feedback processes, since concentrations of long-lived greenhouse gases are held fixed.

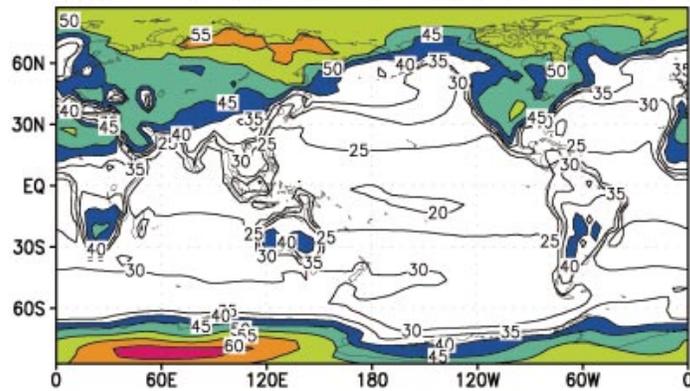
Hamilton and Zhu are now conducting experiments to characterize the sensitivity of the model climate to changes in the solar constant of +5%, +10% and +15%, and to determine at what temperature the nonlinearity in the equilibrium climate response to radiative forcing perturbations becomes significant. They are analyzing the results of these model experiments to see how transient eddies in both the tropics and extratropics respond to very large changes in the mean climate.



**Figure 6:** Annual-mean global surface temperature in integrations of the NCAR coupled atmosphere-ocean general circulation model in the control run (green), and in runs with the solar constant increased over the standard value by 2.5% (red) and by 25% (blue).

**Figure 7:** Surface temperature in °C averaged over years 41–50 in the +25% solar constant run minus that in the control run (top panel). Surface temperature averaged over years 41–50 in the +2.5% solar constant run minus that in the control run (bottom panel). Contours labeled in °C.

Surface Temperature (+25%–Control)



Surface Temperature (+2.5%–Control)

