Effects of CO_2 Forcing Magnitude on Climate Feedbacks

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Abstract Radiative feedbacks in the climate system are a major source of uncertainty in estimates of climate sensitivity. These feedbacks are associated with effects of changes in water vapor, clouds, lapse rate and surface albedo on the Earth's radiation budget.

We use the radiative kernel technique [Soden et al., 2008] to quantify feedbacks to examine the effect of increasing CO_2 forcing. We compare feedbacks resulting from the climate response to instantaneous doubling, quadrupling and octupling of CO_2 levels in the fully coupled National Center for Atmospheric Research (NCAR) Community Climate System Model (CCSM).

We find a significant decrease in albedo feedback, and increase in lapse rate feedback with increasing CO_2 forcing. The differences in water vapor feedback, however, are smaller than the feedback's variability.

Radiative Kernel Technique

Individual feedbacks are computed according to the linear decomposition of the feedback parameter γ

$$\gamma = \frac{\Delta(F-Q)}{\Delta T_s} = \frac{\partial(F-Q)}{\partial T_s} + \sum_{i=1}^{N} \frac{\partial(F-Q)}{\partial X_i}\frac{dX_i}{dT_s} + Re$$

where X_i represents feedback variables (albedo, water vapor, lapse rate and clouds). Each individual feedback can be decomposed into a radiative kernel $\frac{\partial(F-Q)}{\partial X_i}$, representing the response of top-of-atmosphere radiative fluxes to incremental changes in X_i and a climate response of X_i, $\frac{dX_i}{dT_s}$.

The kernel is calculated using the model's radiative transfer algorithm. The climate response is obtained from the difference in X_i and T_s between a control and experiment model simulation.

Because cloud radiative forcing is nonlinear with respect to cloud variables, feedbacks cannot be evaluated directly using a cloud kernel. We have not included the cloud feedback in the present study.

Reference

Soden, Brian J., Isaac M. Held, Robert Colman, Karen M. Shell, Jeffrey T. Kiehl, Christine A. Shields, 2008: Quantifying Climate Feedbacks using Radiative Kernels, *J. Clim.*, **21**, 3504-3520.

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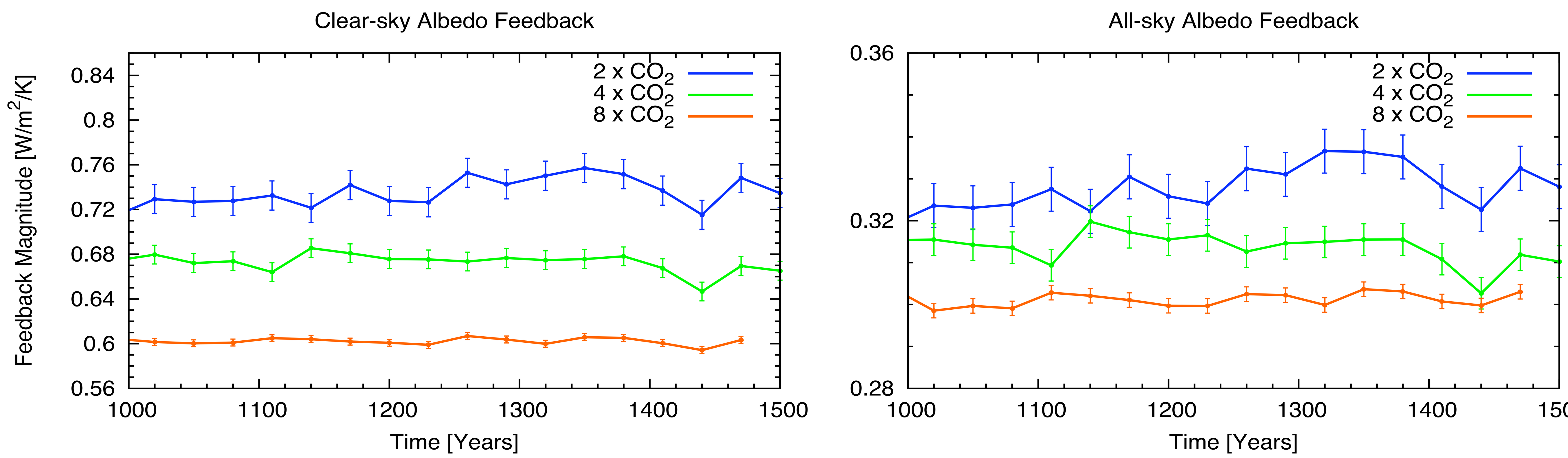

Figure 1 Clear-sky and all-sky Albedo Feedback in W/m²/K, calculated for 2 x CO_2, 4 x CO_2 and 8 x CO_2 using 30 year averages. In the clear-sky case, the feedback decreases significantly with increasing CO_2 concentrations. This decrease is dampened in the all-sky case, likely as cloud albedo increases and compensates for decreasing sea-ice albedo.

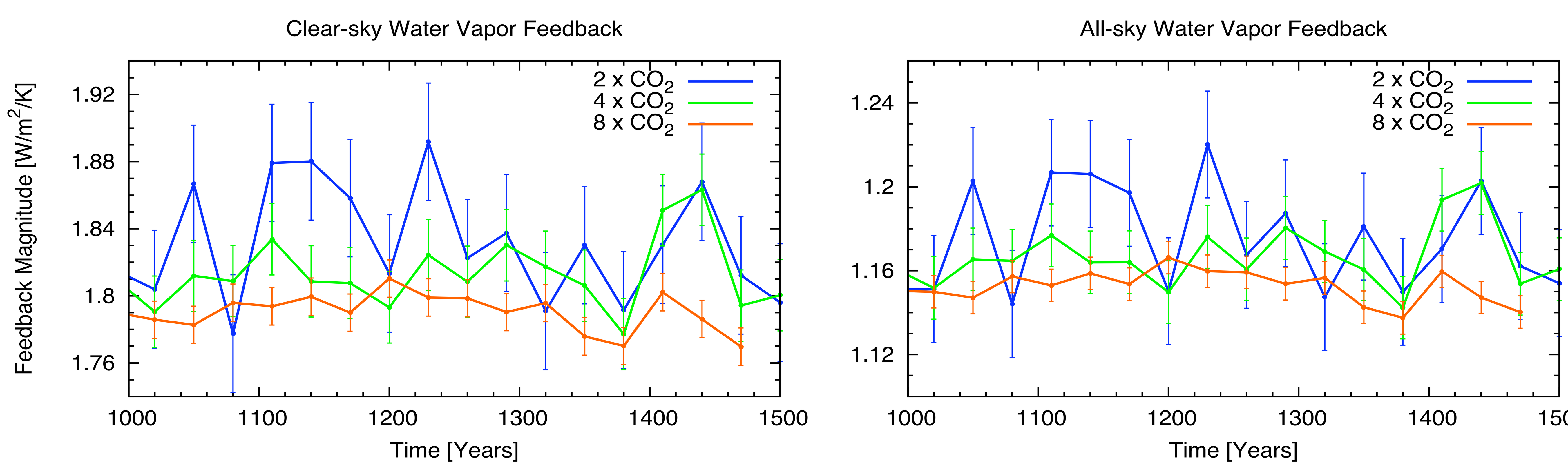

Figure 2 Water Vapor Feedback, as Figure 1.
The feedback magnitude decreases somewhat. However, variability is too large for the change to be significant.

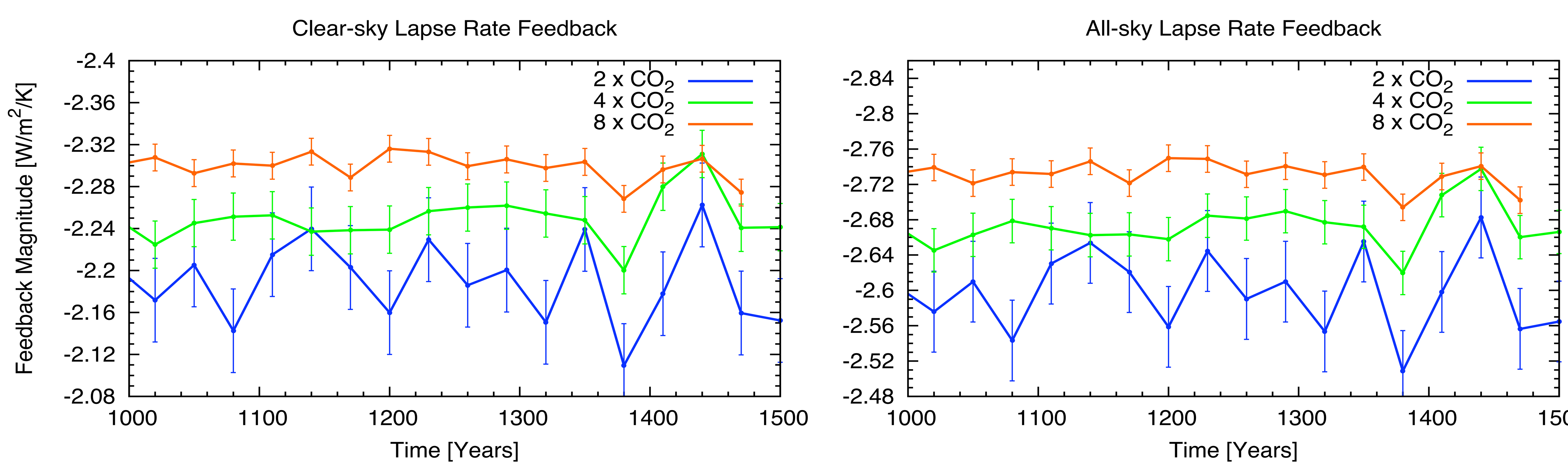

Figure 3 Lapse Rate Feedback, as Figure 1. The feedback magnitude increases with increased CO_2 concentrations. The larger variability of all three feedbacks for lower CO_2 concentrations is likely due to the division by a smaller value of temperature change, dT_s.