REPLY TO RASOOL

Rasool raises both technical questions and a philosophical/moral issue.

Average global temperature. We obtain temperature trends with a method which minimizes error due to incomplete spatial coverage of observing stations and varying record lengths (Hansen *et al.*, 1981). By using a global temperature history generated by a long run of a general circulation model with realistic spatial and temporal variability, we have obtained an 'error bar' for each observational network. A meaningful global trend begins when the network reaches the extent which existed near the end of the 1800's.

Solar variability. We stated that "Solar variability is highly conjectural, so we first study CO_2 and volcanic aerosol forcings and then add solar variations" and also stated that the solar variation tested "serves as an example of solar variability of a plausible magnitude". Omitting any test of solar effects would have avoided predictable criticism for this controversial area, but it also would have ignored our own sensitivity test (Hansen *et al.*, 1981; Fig. 2) which indicated that solar variations, as well as CO_2 and aerosols, are potentially important forcings on the 100 year time scale. Thus we studied the effect of plausible solar variability, which allowed us to state that our conclusions were not affected by likely variations of solar irradiance.

Cloud feedback. We did not ignore cloud feedback. We included it in our discussion of climate sensitivity, and for our standard model we chose a sensitivity between those for the common 'fixed cloud altitude' and 'fixed cloud temperature' assumptions. In recognition of the uncertainty clouds and other factors introduce to global climate sensitivity, we also tested the effect of letting model sensitivity be a free parameter. We found that with an exchange rate between the ocean mixed layer and thermocline based on passive tracers ($k \sim 1-2$ cm^2 s^{-1}), a climate sensitivity of 2.5–5 °C is needed to provide best fit to the observed global temperature trend. The consistency of this empirical sensitivity with the *a priori* sensitivity from climate models provides some evidence that the net feedbacks in the models are of the right order.

Rasool argues that our caveats are understated, offering three specific examples:

CO_2 airborne fraction. Assumption that 50% of released CO_2 will remain airborne in the future seems conservative, on the basis of both observed CO_2 trends and geochemical models (Broecker and Peng, 1982).

Ocean circulation. We included ocean circulation effects in a simple way, assuming that heat perturbations behave as a passive tracer. We believe that this is a conservative approach for projections of future CO_2 warming of surface air. When ocean surface layers warm, the vertical stability should increase over most of the ocean, thus decreasing the effect of ocean thermal inertia in damping surface temperature response.

Polar ice. The melting time of polar ice does not affect our projection of global temperature, except to the extent that latent heat of melting reduces air temperature. This effect is negligible on global mean (Hansen *et al.*, 1983).

Rasool asks how we can make precise predictions, when there are so many caveats. But we did not make precise predictions. We used a range of energy growth rates from

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no growth (0%/yr) to fast growth (3%/yr), and climate sensitivities from 1.4 to 5.6 °C for doubled CO_2. Despite this, we showed that large climate effects are projected for next century, and that plausible variations of other climate forcings such as volcanic aerosols and solar irradiance cannot counteract the CO_2 warming on that time scale.

Rasool's suggestion that we emphasized the worst case to get attention of decision makers who control funding is puzzling, because funding agencies (and scientists) could not be expected to react favorably to such tactics, and disappointing, because it questions our scientific integrity. In fact, the 'impending calamities' Rasool refers to are discussed in a rational tone in our paper with reference to model results, historical analogs and research by others, with appropriate caveats.

As scientists we did our best to present an unbiased projection of likely climatic effects of CO_2. We also fulfilled what we believe is a responsibility of scientists: to point out clearly the consequences of their findings. We are confident that careful examination of our paper, our testimony to 'decision makers who control funding' (Hansen, 1982) and the science that forms the basis for our article will bear out that we presented our results in an unbiased professional fashion, in the spirit of good science.

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