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Climate Intervention as an Optimization Problem

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Typically, climate models simulations of intentional intervention in the climate system have taken the approach of imposing a change (eg, in solar flux, aerosol concentrations, aerosol emissions) and then predicting how that imposed change might affect Earth's climate or chemistry. Computations proceed from cause to effect. However, humans often proceed from "What do I want?" to "How do I get it?"

One approach to thinking about intentional intervention in the climate system ("geoengineering") is to ask "What kind of climate do we want?" and then ask "What pattern of radiative forcing would come closest to achieving that desired climate state?" This involves defining climate goals and a cost function that measures how closely those goals are attained. (An important next step is to ask "How would we go about producing these desired patterns of radiative forcing?" However, this question is beyond the scope of our present study.)

We performed a variety of climate simulations in NCAR's CAM3.1 atmospheric general circulation model with a slab ocean model and thermodynamic sea ice model. We then evaluated, for a specific set of climate forcing basis functions (ie, aerosol concentration distributions), the extent to which the climate response to a linear combination of those basis functions was similar to a linear combination of the climate response to each basis function taken individually. We then developed several cost functions (eg, relative to the 1xCO2 climate, minimize rms difference in zonal and annual mean land temperature, minimize rms difference in zonal and annual mean runoff, minimize rms difference in a combination of these temperature and runoff indices) and then predicted optimal combinations of our basis functions that would minimize these cost functions. Lastly, we produced forward simulations of the predicted optimal radiative forcing patterns and compared these with our expected results.

Obviously, our climate model is much simpler than reality and predictions from individual models do not provide a sound basis for action; nevertheless, our model results indicate that the general approach outlined here can lead to patterns of radiative forcing that make the zonal annual mean climate of a high CO2 world markedly more similar to that of a low CO2 world simultaneously for both temperature and hydrological indices, where degree of similarity is measured using our explicit cost functions.

We restricted ourselves to zonally uniform aerosol concentrations distributions that can be defined in terms of a positive-definite quadratic equation on the sine of latitude. Under this constraint, applying an aerosol distribution in a 2xCO2 climate that minimized a combination of rms difference in zonal and annual mean land temperature and runoff relative to the 1xCO2 climate, the rms difference in zonal and annual mean temperatures was reduced by $\sim$90% and the rms difference in zonal and annual mean runoff was reduced by $\sim$80%. This indicates that there may be potential for stratospheric aerosols to diminish simultaneously both temperature and hydrological cycle changes caused by excess CO2 in the atmosphere.

Clearly, our model does not include many factors (eg, socio-political consequences, chemical consequences, ocean circulation changes, aerosol transport and microphysics) so we do not argue strongly for our specific climate model results, however, we do argue strongly in favor of our methodological approach.

The proposed approach is general, in the sense that cost functions can be developed that represent different valuations. While the choice of appropriate cost functions is inherently a value judgment, evaluating those

functions for a specific climate simulation is a quantitative exercise. Thus, the use of explicit cost functions in evaluating model results for climate intervention scenarios is a clear way of separating value judgments from purely scientific and technical issues.