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Linearity, climate sensitivity and climate changes in the surface temperature field

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The relationship between equilibrium global mean temperature, T_e, and applied radiative forcing, R_f, is commonly expressed by the linear equation (Gregory et al., Roe and Baker):

$\Delta T_e = \lambda R_f$

where λ is a constant known as the feedback parameter. Here we address the question of whether the relationship between T_e and R_f is, in fact, well quantified by such a linear equation. Our analysis is based on the output of a global climate model. If the relationship breaks down when moving from a single equation model to a complicated global circulation model it is unlikely to reassert itself in the real world with all its additional complexity. Thus nonlinearity in the model can be taken as a strong indication of nonlinearity in reality, while linearity in a model might only be taken as a weak indication of linearity in reality.

Thanks to the support of the climate*prediction*.net team and participants, we were able to run large (>500 members) initial condition ensembles with a global climate model (HadSM3) at seven values of R_f. Results will be presented demonstrating the nonlinear nature of the T_e, R_f relationship.

The term "linear" is used with a number of different meanings, leading to confusion in discussions between the many disciplines involved in climate science research. Furthermore, in the high-dimensional space of climate model output, linearity with R_f can be achieved in a variety of ways: for instance, linearity in magnitude of change (as in the equation above), linearity in degree of rotation within the high-dimensional model state space, linear change in variance in each dimension. These will be illustrated. Analysis of the above ensembles will be used to show that not only is the model nonlinear in the scalar global mean temperature, but also in the pattern of change.

These results imply key messages for ensemble design. Most crucial is consideration of larger initial condition ensembles than is typical in climate model experiments. Such ensembles allow the reduction of sampling errors to levels sufficient to identify nonlinear responses within the model. The ensembles used in this research can provide guidance on the minimum ensemble size necessary to answer a variety of policy relevant questions. This will be illustrated in terms of the minimum ensemble size necessary to identify the nonlinear response in equilibrium global mean temperature.

References:

- Roe, G.H. and M.B. Baker, Why is climate sensitivity so unpredictable? Science, 2007. 318 629-632

- Gregory, J.M. et al. A new method for diagnosing radiative forcing and climate sensitivity, Geophysical Research Letters, VOL. 31, L03205, 2004.