El Niño in a warming world: Transient and equilibrium responses to enhanced atmospheric greenhouse gases

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1. Introduction

The response of El Niño to increased atmospheric greenhouse gas (GHG) concentrations is uncertain. There is a considerable spread in El Niño behaviour between the IPCC AR4 models, with models simulating either increased or reduced El Niño variability in response to increasing GHGs (Guilyardi, 2006). However, the AR4 models were not integrated for sufficient duration to allow the equilibrium response of El Niño to enhanced GHGs to be investigated. To explore both the transient (short-term) and equilibrium (long-term) changes in El Niño characteristics, this study integrates a low-resolution coupled atmosphere-sea ice-ocean general circulation model to equilibrium for scenarios in which the atmospheric CO$_2$ concentration is increased to two, three and four times the pre-industrial level.

2. Climate model simulations

This study uses the CSIRO Mk3L climate system model v1.1 (Phipps, 2006). It comprises an atmospheric general circulation model with a resolution of 5.6' × 3.2' and 18 vertical levels, an oceanic general circulation model with a resolution of 2.8' × 0.8' and 21 vertical levels, a dynamic-thermodynamic sea ice model, and a land surface scheme with static vegetation. A 10,000-year pre-industrial control simulation is conducted, in which the CO$_2$ concentration is held constant at 280 ppm. Three further transient simulations are conducted. Starting from year 100 of the control simulation, the CO$_2$ concentration is increased at 1% pa until it reaches 2, 3, and 4 times the pre-industrial level (560, 840 and 1120 ppm respectively). The CO$_2$ concentration reaches these values in years 170, 240 and respectively, and is held constant thereafter. Each simulation is integrated for a total of 6,500 years, ensuring that the climate system has reached thermal equilibrium.

3. Changes in El Niño variability

The changes in the amplitude of El Niño variability are shown in Figure 1. As the CO$_2$ concentration increases, the initial response of the model is an increase in El Niño variability. However, once the CO$_2$ concentration is stabilised, there is a rapid decrease in variability within the 3 × and 4 × CO$_2$ simulations, particularly in the Niño 3.4 region. There is a further, slow decline in variability as the simulations progress towards thermal equilibrium, which is also experienced by the 2 × CO$_2$ simulation.

4. Changes in ENSO dynamics

The leading principal components of sea surface temperature (SST) for each simulation are shown as Figure 2. As the CO$_2$ concentration is increased, the location of greatest SST variability shifts eastwards and El Niño events become increasingly confined to the eastern Pacific. This shift explains why variability in the Niño 3.4 region decreases by more than that in the Niño 3 region. Also apparent from Figure 2 is the increase in El Niño variability in the 2 × CO$_2$ simulation, in contrast to the reduction at higher CO$_2$ concentrations. The El Niño mode is almost completely absent in the 4 × CO$_2$ simulation.

5. Conclusions

Using a low-resolution coupled atmosphere-sea ice-ocean general circulation model, it has been shown that the transient and equilibrium responses of El Niño to enhanced atmospheric greenhouse gases can be fundamentally different. As different components of the climate system separately reach equilibrium, the magnitude of El Niño variability can either increase or decrease. This suggests the intriguing possibility that the inter-model differences in ensembles such as AR4 may be due, in part, to differences between the magnitudes of the short- and long-term responses within the models.

6. References


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