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

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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 decreased El Niño variability in response to increasing GHGs. 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.

A 10,000-year pre-industrial control simulation is conducted, in which the CO_2 concentration is held constant at 280 ppm. The El Niño variability is realistic, with the sea surface temperature (SST) variability in the Niño 3 and 3.4 regions being only slightly weaker than in observations. The power spectrum of the Niño 3.4 SST anomalies exhibits peak variability at a period of 4 years. The model also exhibits a hybrid mode, shifting between S-mode and T-mode on decadal timescales in a manner which is entirely consistent with 20th century observations.

Three further simulations are conducted, in which the CO_2 concentration is increased at 1% pa until it reaches two, three and four times the pre-industrial level (560, 840 and 1120 ppm respectively). The CO_2 concentration is held constant thereafter. Each simulation is integrated for a total of 6,000 years, ensuring that the climate system has reached thermal equilibrium.

The transient response of the model to increasing CO_2 is an increase in El Niño variability. However, once the CO_2 concentration is stabilised, El Niño variability begins to decrease. The dynamics of El Niño events change, with S-mode being entirely absent in all the enhanced CO_2 simulations. The location of greatest SST variability also shifts eastwards, with El Niño events becoming increasingly confined to the eastern Pacific as the CO_2 concentration is increased. The equilibrium response of the ocean is one with enhanced warming in the eastern tropical Pacific. The thermocline is therefore much flatter than in the control simulation, representing a background state in which the development of El Niño events is suppressed.

Because of the change in the spatial structure and extent of El Niño events, it is essential to choose the metric used to measure El Niño variability carefully. Based on SST variability in the Niño 3.4 region, El Niño is similar in strength to the control simulation for $2xCO_2$, but much weaker for $3xCO_2$ and $4xCO_2$. Based on the Niño 3 region, however, El Niño is enhanced relative to the control simulation for $2xCO_2$, but weaker for $3xCO_2$ and much weaker for $4xCO_2$.

These simulations show that the transient and equilibrium responses of El Niño to enhanced GHGs can be fundamentally different. As different components of the climate system separately reach equilibrium, the amount of El Niño variability can either increase or decrease. This suggests the intriguing possibility that the inter-model differences seen 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.