Changes in climate sensitivity and polar amplification over the last 500 million years

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During the Phanerozoic (the last ~0.5 billion years), the Earth has experienced massive changes in climate, spanning the extensive glaciations of the Permo-Carboniferous (~300 million years ago), to the mid-Cretaceous super-greenhouse (~100 million years ago). Recently, several studies have used geological data to reconstruct global mean temperatures through this period, as a way of characterising the zeroth-order response of the Earth system to its primary forcings.

Here we use two new ensembles of model simulations covering the entire Phanerozoic, consisting of 2× >100 simulations at a 5 million year resolution, to explore the key metrics of climate sensitivity and polar amplification using the HadCM3 climate model. The model version we use has undergone a substantial development process and can simulate the climate of the Eocene, where extensive observations exist, at least as well as much more recent (CMIP5) models, but at a fraction of the computational cost.

The two ensembles explore uncertainty in the CO_2 forcing during the Phanerozoic, being forced by (a) a published CO_2 curve based on proxy reconstructions, and (b) a derived CO_2 curve that results in global mean temperatures in agreement with temperature reconstructions. Comparison of the ensembles indicates that the climate sensitivity is both temperature and paleogeography dependent, increasing with increasing temperatures, and varying as a function of the supercontinent configuration. We also explore polar amplification, and again find that this is dependent on background climate and paleogeography. We apply energy balance methods to explore the reasons for the varying polar amplification, and also find a key role for the ocean circulation state.