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Uncertainty quantification of climate sensitivity: State-dependence, extreme values and the probability of tipping

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The Equilibrium Climate Sensitivity (ECS) remains not very well constrained, either by climate models, observational, historical or palaeoclimate data. In addition to the classical notion of uncertainty (of measurement or model), the spread in ECS values finds its origin in various dynamical aspects:
(i) The climate system exhibits strong internal (and forced) variability on many timescales meaning that the 'equilibrium' will only be relative to fixing the slow feedback processes. The implicit assumption here is that time scale separation (fast and slow) exists and ECS values from palaeoclimate (model or data) time series can be compared to short model simulations. Palaeoclimate records instead can also give insight into the so-called Earth System Sensitivity (ESS), which includes the integrated effect of slow processes and boundary conditions (e.g. geography, vegetation and land ice). (ii) The background state dependence of the fast feedback processes: Information from the late Pleistocene ice age cycles indicates that the ECS varies considerably between regime because of fast feedback processes changing their relative strength over one cycle. (iii) Tipping elements in the climate system: Extreme values of palaeo-derived ECS suggest that the climate response is in a region where there is a breakdown of the assumption of a linear response to perturbations. Here we show that for models of the climate system with more than one regime and occasional switches between these regimes, we can empirically determine probability of change in regime and confirm that extremes of climate sensitivity are associated with very high probabilities of tipping.