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Non-equilibrium metrics for palaeo climate sensitivity in the presence of rapid transitions

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Equilibrium climate sensitivity is one measure that is frequently used to predict long-term climate change in GCMs. Despite much research over the last decades, little progress has been made in constraining the uncertainty on climate sensitivity. One reason for this is the fact that the climate has a strong internal variability on many time scales, is subject to a non-stationary forcing and mostly out of equilibrium with the changes in the radiative forcing.

Palaeo records of past climate variations can give insight into how the the climate system responds to various forcings although care must be taken of the *slow* feedback processes at comparing palaeo climate sensitivity estimates with estimates from (short time scale) model simulations. In addition, for the late Pleistocene ice age cycles it has been shown from both proxy data and a conceptual climate model that climate sensitivity varies considerably between the cold and warm phases because the *fast* feedback processes change their relative strength over one cycle.

Here we use a conceptual model with known dynamics modelling the late Pleistocene ice ages to explore how climate sensitivity can be estimated from the model time series. Extracting the climate sensitivity from the relation between radiative forcing and global mean temperature leads to strongly state dependent behaviour and even negative values for climate sensitivity at rapid transitions into the deep glacial states. The degree to which the system is out of equilibrium and its relation to the equilibrium assumption of climate sensitivity needs therefore to be taken into account. Furthermore, Milankovitch forcing is generally not considered in palaeo climate sensitivity estimates. In the model time series we show how the sensitivity to Milankovitch forcing can be accounted for in an estimate of the climate sensitivity. We also investigate how the climate sensitivity in this non-equilibrium system varies with the averaging time, dependent on the phase of the forcing and the phase of the ice age cycle.