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Impact of small-scale fluctuations on climate sensitivity and its stochastic analysis

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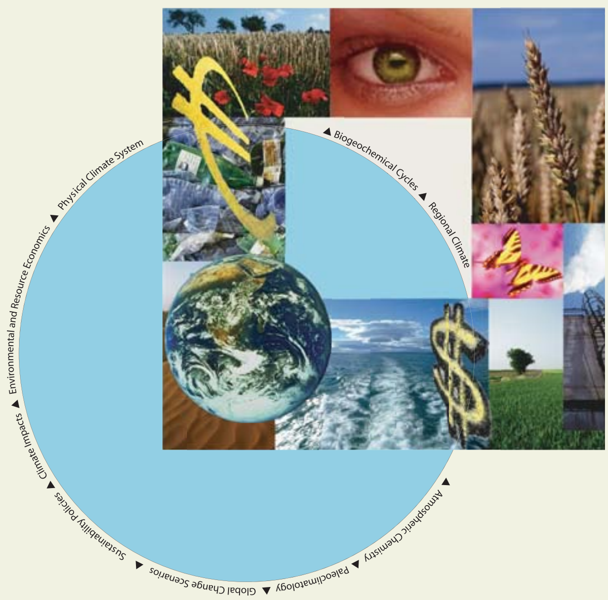

Abstract

One of the main challenges in climate research is the estimation of the climate response to increasing greenhouse gas concentrations. Such an estimation is often made with the aid of a climate model. Although climate models are forced in the same way, they simulate different climate sensitivities. Model errors caused by the representations of feedback processes related to water vapour, clouds, temperature lapse rate and surface albedo are known to account for the high uncertainty of the modelled climate sensitivity. But also the representation of dynamical small-scale processes could affect the modelled climate sensitivity. All climate models have finite spatial and temporal resolutions. The impact of unresolved processes is often parameterised without taking the variability induced by subgrid-scale processes into account.

The aim of this study is to investigate the impact of enhanced small-scale atmospheric fluctuations on the modelled climate response to increased CO_2 concentration. Using a coupled atmosphere-ocean-sea ice general circulation model (ECHAM5/MPI-OM) we carried out experiments with enhanced small-scale fluctuations. To enhance small-scale fluctuations we reduced the horizontal diffusion or added white noise to spectral coefficients with high total wavenumbers.

Whereas the reduction of the horizontal diffusion hardly affects the mean state of the pre-industrial climate, the additional noise alters the climate considerably. The climate response to a doubling of the CO_2 concentration is influenced by both methods used to enhance the small-scale fluctuations. Reducing the horizontal diffusion by a factor of 3 leads to an increase of the equilibrium climate sensitivity at the surface by 13%. If white noise is added to the small scales, the surface climate sensitivity tends to weaken. In general, the largest changes in responses occur in the upper troposphere.

To better understand how small-scale fluctuations alter the climate sensitivity we used a simple stochastic model. We fitted a Langevin equation to the global mean temperature time series at 300 hPa. The analysis based on the stochastic model enables us to distinguish between two mechanisms influencing the climate sensitivity. Enhanced small-scale fluctuations can influence the climate sensitivity via altering feedback and interaction processes which are present in the unperturbed system and/or via altering processes which are only occurring in response to the CO_2 increase. Whereas reducing the horizontal diffusion changes the climate sensitivity via the second mechanism, the additional noise initiates both mechanisms.

Although the impact of the enhanced small-scale fluctuations on the modelled climate sensitivity is not as large as, e.g., the impact of different cloud parameterisations, it is not a negligible source of uncertainty for the determination of the future climate change.