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The influence of aerosols on North Atlantic cyclones

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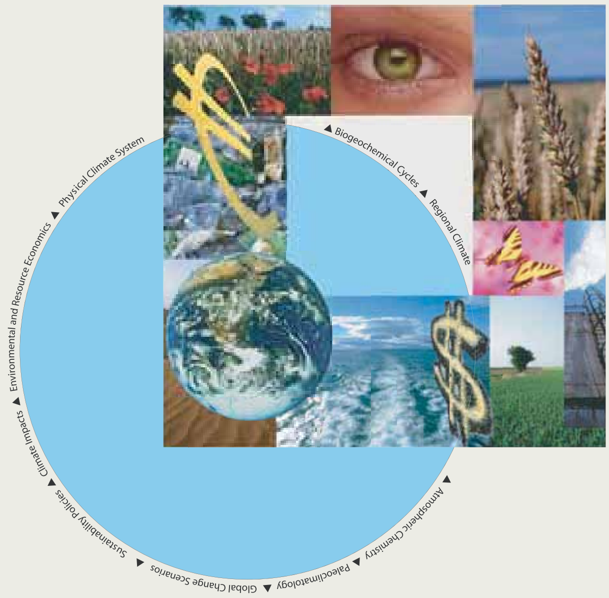

Abstract

Extratropical low-pressure systems or cyclones, which mainly originate over the North Atlantic, characterise the everyday weather in Europe. Severe cyclones can cause large amounts of damage due to high wind speeds and heavy precipitation. The question arises if and how cyclones will change due to future anthropogenic impacts. Previous studies of the response of cyclonic activity to global climate change have primarily focussed on the effect caused by increasing greenhouse gas concentrations and the associated global warming. It is uncertain, though, how this warming will influence the number, intensity and locations of cyclones in the North Atlantic/European region. This uncertainty is caused by two competing energetic effects that occur simultaneously: the meridional temperature gradient decreases because of the differential warming of polar and tropical regions and the latent heat content of the atmosphere increases. In addition to the anthropogenic greenhouse forcing, radiatively active aerosol particles modify the earth's energy budget. Therefore, they should also be taken into account when studying cyclonic activity.

In this study, the influence of the direct sulphate aerosol effect on North Atlantic cyclones is investigated in simulations of the ECHAM4/OPYC3 coupled climate model with respect to temperature, baroclinicity and cyclone tracks. The simulations include a control experiment (CTL) and two transient experiments from 1860 to 2050, one with increasing concentrations of greenhouse gases (GHG) and the other additionally allowing for the direct radiative effect of anthropogenic sulphate aerosol (GSD). Different cyclone characteristics in CTL agree well with those in the ECMWF Re-Analysis ERA40 which gives confidence in the performance of the climate model and in its use to address the uncertainty mentioned above.

The comparison of a present to a future simulation period leads to the following results: The greenhouse gas effect causes a warming in both winter and summer whereas the aerosol effect causes a cooling, but of smaller magnitude. Considering the effects together, the sulphate aerosol present in GSD attenuates the warming projected in the GHG simulation. Regarding the atmospheric baroclinicity, greenhouse gases tend to increase it while the sulphate aerosol effect tends to decrease it. The cyclone track density shifts northward in both winter and summer in GHG. In GSD, this shift is distinctly dampened and almost negligible. The number of all cyclones detected in the North Atlantic/European region does not change significantly in either experiment. Deep cyclones with core pressures below 970 hPa occur more often in the future in GHG, but not in GSD. The direct radiative effect of sulphate aerosol thus strongly moderates the response of the climate system to the increase in greenhouse gas concentrations, but does not reverse it.

In another part of this study, the influence of aerosols on the cyclone *Grace*, which developed over the North Atlantic in March 2000, is investigated in a case study setup with respect to the change in certain meteorological parameters along the cyclone track. For this case study, which covers a 10-day period, two ensembles of 13 simulations each are produced. For one ensemble, ECHAM5-HAM is used considering the full AeroCom emission inventory. For the other, the anthropogenic contributions to the emissions are neglected. The two ensembles exhibit differences in the sulphate burden along the track. However, these differences have no impact on the track of *Grace* itself or on the along-track aerosol optical depth, net surface solar radiation and precipitation. While the current setup proves to be an inappropriate tool for the case study analysis, the simulations do reveal an interesting phenomenon south of the actual region of interest in this study: they indicate long-distance transport of sulphur dioxide and sulphate from Europe towards northern Africa where both species accumulate due to inefficient sink processes. The prevailing winds during the case study period suggest that the accumulated sulphur species are transported across the Sahara towards the North Atlantic where they are partly transported toward the north again. This possible transport mechanism has not yet been validated, though, since the observational data are not sufficient.