Simulating global climate in historical times using a coupled atmosphere-ocean general circulation model with all relevant forcings

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A meaningful simulation of the climate of past centuries has to take into account all relevant forcings. We have undertaken such a simulation of the climate of the last five centuries with the state of the art coupled atmosphere-ocean general circulation model ECHAM4-OPYC (Stendel et al., 2006). The model has been driven with natural (solar variability, volcanic aerosol) and anthropogenic (greenhouse gases, sulfate aerosol, land-use changes) forcings. In contrast to previous studies, we have taken into account the latitudinal dependence of volcanic aerosol (Robertson et al., 2001) and the changing land cover for a period covering several centuries (Klein Goldewijk, 2001). The experiment has been conducted with the relatively high horizontal resolution of T42. The concentrations of greenhouse gases and CFCs has also been taken from Robertson et al., while solar irradiance variability is based on the updated data set of Lean et al. (1995). Compared to the much-discussed large volcanic forcing of Zorita et al. (2004), the volcanic aerosol load in our simulation is considerably smaller, with the exception of the unknown volcano of 1809 and of Tambora 1815. Changes in land use affect the solar part of the volcanic forcing, and we have made an attempt to calculate the long wave part for historical eruptions as well by estimating the increase of stratospheric temperature due to the aerosol (Andronova et al., 1999). However, there is no feedback to model dynamics.

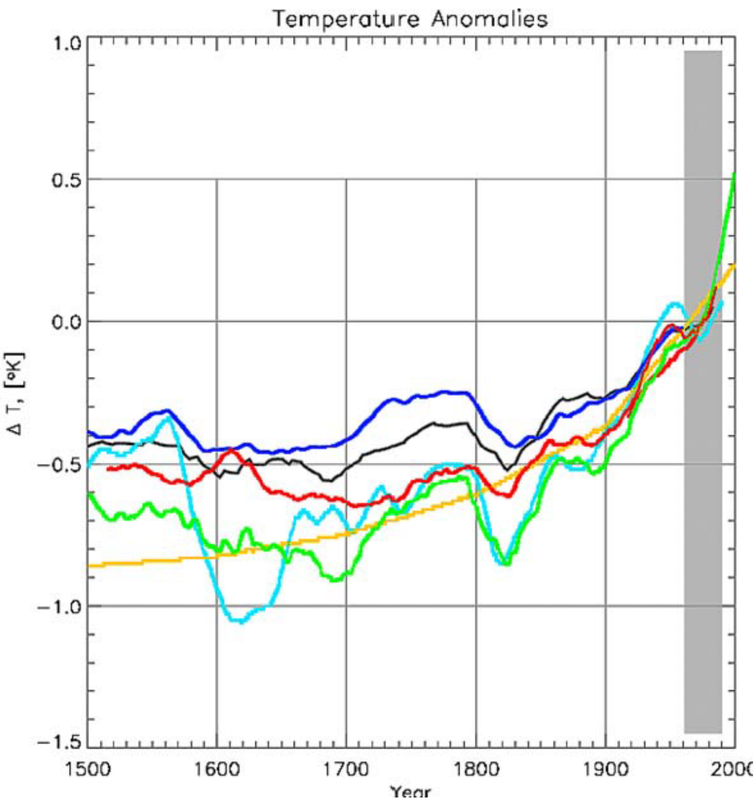

Fig. 1: Thirty-year running averages of near surface temperature anomalies 1500–2000 for the instrumental record (brown curve), the reconstructions of Huang et al. (2000, yellow curve), Esper et al. (2002, light blue) and Mann and Jones (2003, dark blue), the model simulations of Crowley (2000, black) and Zorita et al. (2004, green) and Stendel et al. (2006, red curve).

Fig. 1 shows that we, nevertheless, find a clear signature of large volcanic eruptions in the simulated temperature record. The model is able to simulate individual extreme events such as the "year without a summer" 1816. Strong warming is simulated after 1850, in particular over land, going along with an increase of the positive NAO phase. Consistent circulation anomalies are simulated in multidecadal means with similarity to observed and reconstructed anomalies, for example during the late 17th and early 18th century. The model is able to reproduce some of the observed or reconstructed regional patterns. Cooling during the Late Maunder Minimum is smaller than in other studies, due to the relatively small variations in solar activity and the relatively modest volcanic forcing applied here.

Colder than average conditions, for example during the late 17th and early 18th centuries, go along with a decrease in pressure difference between low and high latitudes and a decrease of the North Atlantic Oscillation. This favours positive sea ice anomalies east of Greenland and around Iceland, leading to widespread negative temperature anomalies over Europe. We also find characteristic blocking patterns over Western Europe, in particular during autumn which contribute to the advection of cold air (Fig. 2).

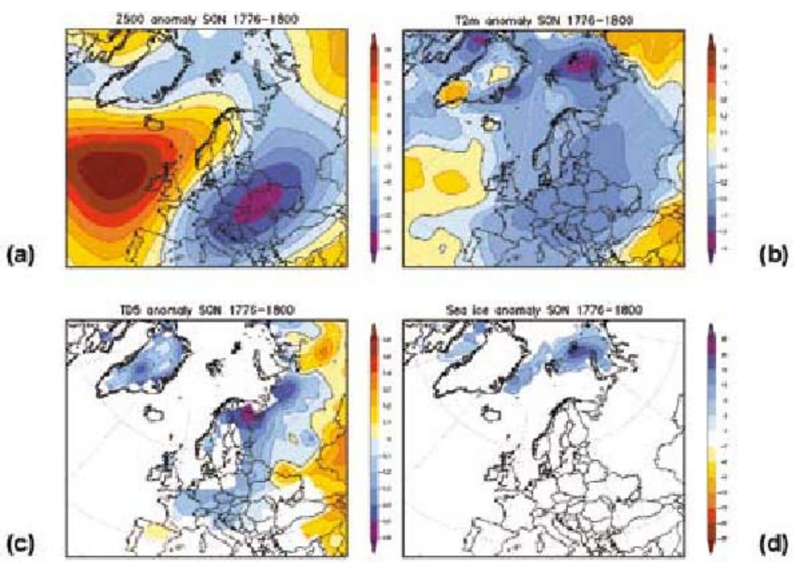

Fig. 2: Twenty-five-year (1776–1800) autumn (SON) anomalies from the 200 year mean 1500–1700 for (a) 500 hPa geopotential (gpm), (b) 2m temperature (K), (c) deep-soil temperature (K) and (d) sea ice cover (%).

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