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Uncertainties in climate change prediction: El Niño-Southern Oscillation and monsoons

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Abstract

The sensitivity of climate phenomena in the low latitudes to enhanced greenhouse conditions is a scientific issue of high relevance to billions of people in the poorest countries of the globe. So far, most studies dealt with individual model results. In the present analysis, we refer to 79 coupled ocean–atmosphere simulations from 12 different climate models under 6 different IPCC scenarios. The basic question is as to what extent various state-of-the-art climate models agree in predicting changes in the main features of El Niño-Southern Oscillation (ENSO) and the monsoon climates in South Asia and West Africa. The individual model runs are compared with observational data in order to judge whether the spatio-temporal characteristics of ENSO are well reproduced. The model experiments can be grouped into multi-model ensembles. Thus, climate change signals in the classical index time series, in the principal components and in the time series of interannual variability can be evaluated against the background of internal variability and model uncertainty.

There are large differences between the individual model predictions until the end of the 21st century, especially in terms of monsoon rainfall and the Southern Oscillation index (SOI). The majority of the models tends to project La Niña-like anomalies in the SOI and an intensification of the summer monsoon precipitation in India and West Africa. However, the response barely exceeds the level of natural variability and the systematic intermodel variations are larger than the impact of different IPCC scenarios. Nonetheless, there is one prominent climate change signal, which stands out from model variations and internal noise: All forced model experiments agree in predicting a substantial warming in the eastern tropical Pacific. This oceanic heating does not necessarily lead to a modification of ENSO towards more frequent El Niño and/or La Niña events. It simply represents a change in the background state of ENSO. Indeed, we did not find convincing multi-model evidence for a modification of the wavelet spectra in terms of ENSO or the monsoons. Some models suggest an intensification of the annual cycle but this signal is fairly model-dependent. Thus, large model uncertainty still exists with respect to the future behaviour of climate in the low latitudes. This has to be taken into account when addressing climate change signals in individual model experiments and ensembles.

Keywords: ENSO; monsoon; climate change; model intercomparison

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1. Introduction

The Indian and West African monsoons as well as the El Niño-Southern Oscillation (ENSO) phenomenon represent the most prominent climate features in the low latitudes and directly affect life conditions and human welfare of more than one third of the Earth's population (Fein and Stephens, 1987; Allan et al., 1996; Saha and Saha, 2001). These phenomena are partly linked to each other via tropical teleconnections and exhibit large variability at different time scales (Webster et al., 1998; Klein et al., 1999). In recent years, floods and droughts may have occurred with enhanced frequency and duration (Diaz et al., 2001; Houghton et al., 2001; Anderson et al., 2002). In particular, subsaharan West Africa has experienced a striking drought series during the second half of the 20th century (Nicholson, 2001), albeit not unprecedented (Gasse, 2001), with large implications for the socio-economic systems (Findley, 1994; Benson and Clay, 1998). There is also some indication that the monsoons and ENSO may be highly sensitive to enhanced greenhouse conditions (Fedorov and Philander, 2000; Stephenson et al., 2001; Hulme et al., 2001). Thus, gaining insight into the future behaviour of tropical climate is a key challenge for climate research (Desanker and Justice, 2001; Jenkins et al., 2002).

Many studies have addressed the response of the Indian monsoon climate to radiative heating using climate model simulations for the 21st century. Most authors agree that the South Asian summer monsoon rainfall may become more abundant due to oceanic heating and changes in the Hadley circulation (Bachiochi et al., 2001; May, 2002) or enhanced warming and snow cover reduction over the Eurasian continent (Robock et al., 2003). For the same reason, the winter monsoon dynamics may weaken (Hu et al., 2000). Besides total precipitation amount, rainfall intensity and extreme events may also be modified under enhanced greenhouse conditions but with a spatially more heterogeneous fingerprint (May, 2004). Douville et al. (2000) point to an increase in summer monsoon rainfall despite a weakening of the overall monsoon circulation due to local feedbacks with an intensified hydrological cycle. Some studies highlight the counterbalancing role of greenhouse gases (G) and sulphate aerosols (S), the inclusion of the latter leading to a reduction in precipitation over South Asia (Bhaskaran and Mitchell, 1998; Kumar and Ashrit, 2001; Lal and Singh, 2001). Meehl and Arblaster (2003) have suggested a mechanism, which relates global radiative heating to regional climate change in the Indian sector: While increasing rainfall amount is associated with a warmer Indian Ocean, heating in the tropical Pacific is responsible for an enhanced interannual monsoon variability through teleconnections via the Walker circulation.

Less scientific attention has been paid to the sensitivity of the West African monsoon. Hulme et al. (2001) point to a weak trend towards more humid conditions in tropical West Africa in a number of climate model experiments, but this signal is partly blurred out by model uncertainty. Similar results are presented by Houghton et al. (2001) as well as Paeth and Hense (2004). Experiments with a regional climate model draw a more differentiated picture of future monsoon changes in West Africa, describing a dipole response with dryer climate in the Sahel and more abundant summer monsoon rainfall over the Guinean Coast region (Paeth and Stuck, 2004). This may further strengthen the meridional gradient in freshwater availability and cause large-scale migration processes (Findley, 1994).

In terms of ENSO, the question of future changes is quite complex: On the one hand, state-of-the-art climate models still meet difficulties in simulating the observed characteristics of ENSO (Latif et al., 2001). On the other hand, ENSO changes may primarily occur in higher-order moments than in the form of a shift in the mean state (Timmermann, 1999; Fedorov and Philander, 2000; Houghton et al., 2001). Moreover, it is unclear whether the present-day indicators of the coupled phenomenon like the Southern Oscillation index (SOI) or the Niño3 index (NI3) will adequately represent the ENSO features in a warmer climate. While Boer et al. (2004) have described an El Niño-like warming in the tropical Pacific, several studies indicate a tendency towards La Niña-like events (Timmermann, 1999; Doherty and Hulme, 2002). The frequency of strong ENSO events may be increasing in the 21st century (Timmermann et al., 1999). However, Collins (2000) has not found any sensitivity of ENSO in the Hadley Centre model. A modification of the ENSO–monsoon teleconnection is reported by Ashrit et al. (2003), leading to more abundant rainfall in South Asia.

Many of these studies have one technical aspect in common: They rely on one single climate model or even one single model simulation. As such a single model experiment may not be representative of the climate response to anthropogenic forcing, it is urgently required to quantify the signal-to-noise ratio with respect to internal variability and model uncertainty. The former factor is related to the non-linearity of the model equations and the latter arises from uncertainty in model physics and parameterizations. The way out of the dilemma is to analyse ensemble simulation, where internal variability is assessed by prescribing different initial conditions but identical forcings in the long-term runs (Li, 1999). A practical way to account for model