Potential future changes in the Indian summer monsoon associated with a global warming of 2 °C with respect to pre-industrial times

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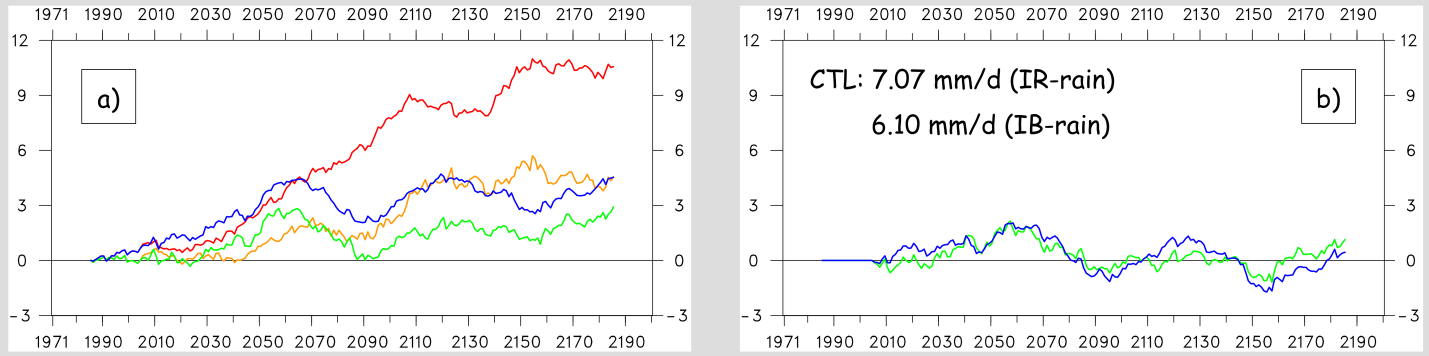
Purpose of the study

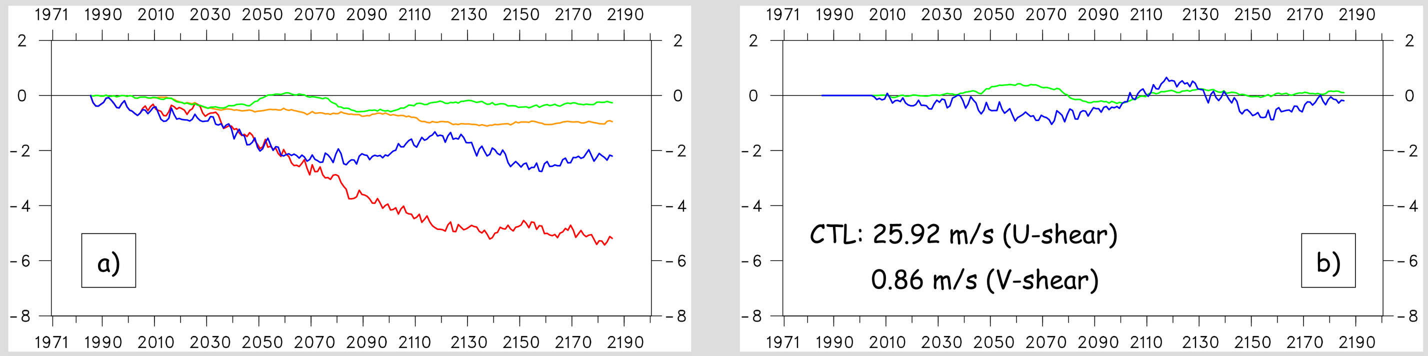
In accordance with the objective of Article 2 of the UNFCCC, the Copenhagen Accord (2009) aims at **limiting the global warming at 2 °C with respect to pre-industrial times**, in order to **avoid dangerous anthropogenic interference with the climate system**. In this study, the potential **future changes in different aspects of the Indian summer monsoon associated with a global warming of 2 °C with respect to pre-industrial times** are assessed, focussing on the role of the different mechanisms leading to these changes. In addition, these changes as well as the underlying mechanisms are **compared to the corresponding changes associated with a markedly stronger global warming exceeding 4.5 °C**, associated with the widely used SRES A1B scenario.

Change monsoon rainfall indices



Changes in the 30-year averages of the rainfall indices for the Indian summer monsoon with respect to the period 1971-2000 for 2GL (blue and green) and A1B (red and orange, a). Also the non-linear components of the change for 2GL with respect to the global annual mean temperature changes in 2GL and A1B (b). The blue and red lines indicate the rainfall in the Indian region and the green and orange ones the rainfall over India and Bangladesh. Units are 1/10 mm/d; the years indicate the centres of the 30-year periods.

Change monsoon wind-shear indices

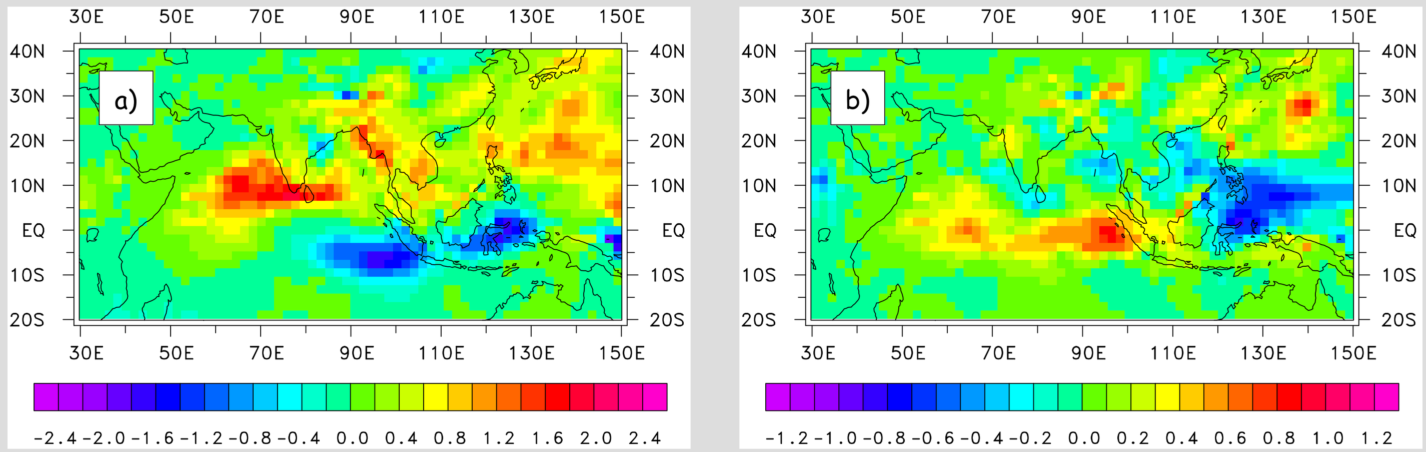


Changes in the 30-year averages of the wind-shear indices for the Indian summer monsoon with respect to the period 1971-2000 for 2GL (blue and green) and A1B (red and orange; a). Also the non-linear components of the change for 2GL with respect to the global annual mean temperature changes in 2GL and A1B (b). The blue and red lines indicate the vertical shear of the zonal wind component and the green and orange ones the vertical shear of the meridional wind component. Units are m/s; the years indicate the centres of the 30-year periods.

Scenario simulations

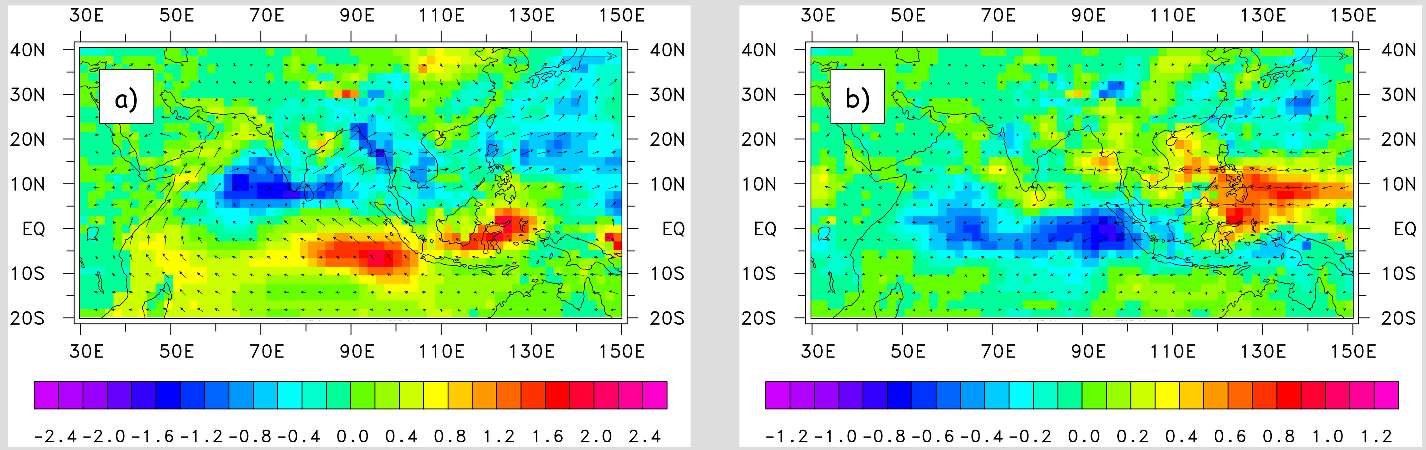
The study is based on **two sets of four ensemble simulations with the ECHAM5/MPI-OM coupled climate model**, each starting from different initial conditions. In one set of simulations (**2020-2200; 2GL**), greenhouse gas concentrations and sulphate aerosol load have been prescribed in such a way that the simulated global warming does not exceed 2 °C with respect to pre-industrial times. In this scenario the atmospheric concentrations of the **well-mixed greenhouse gases are prescribed according to the SRES A1B-scenario for 2020**, while the **global anthropogenic sulphate aerosol load is prescribed according to the SRES A1B scenario for 2100**. In the other set of simulations (**1860-2200; A1B**), greenhouse gas concentrations and sulphate aerosol load have been prescribed according to observations until 2000 and according to the SRES A1B scenario after 2000.

Change monsoon rainfall



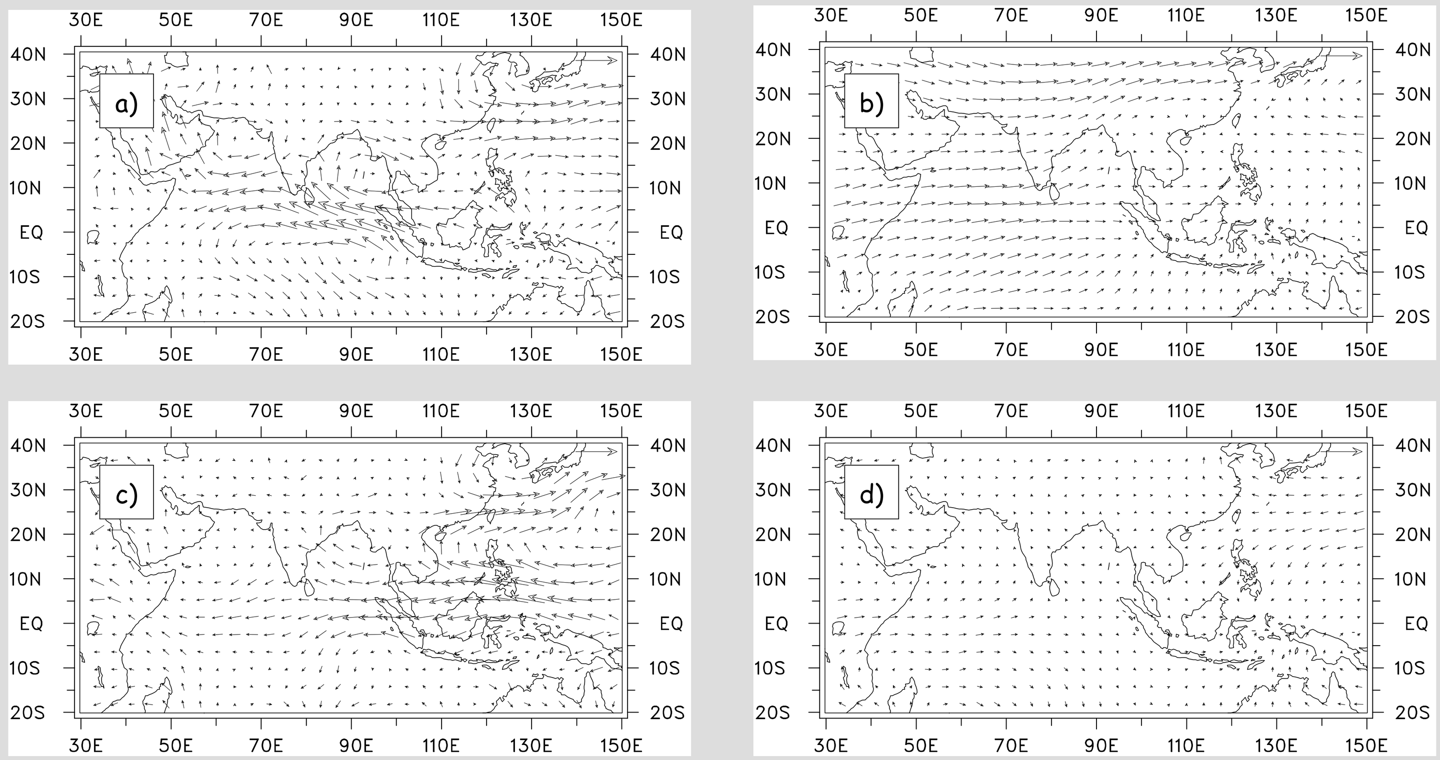
Change in the seasonal mean (JJAS) daily precipitation for the period 2171-2100 with respect to the period 1971-2000 for 2GL (a) as well as the non-linear component of the change for 2GL with respect to the global annual mean temperature changes in 2GL and A1B (b). Units are mm/d; the contour interval is 0.1 mm/d (b) and 0.2 mm/d (a).

Change monsoon moisture flux



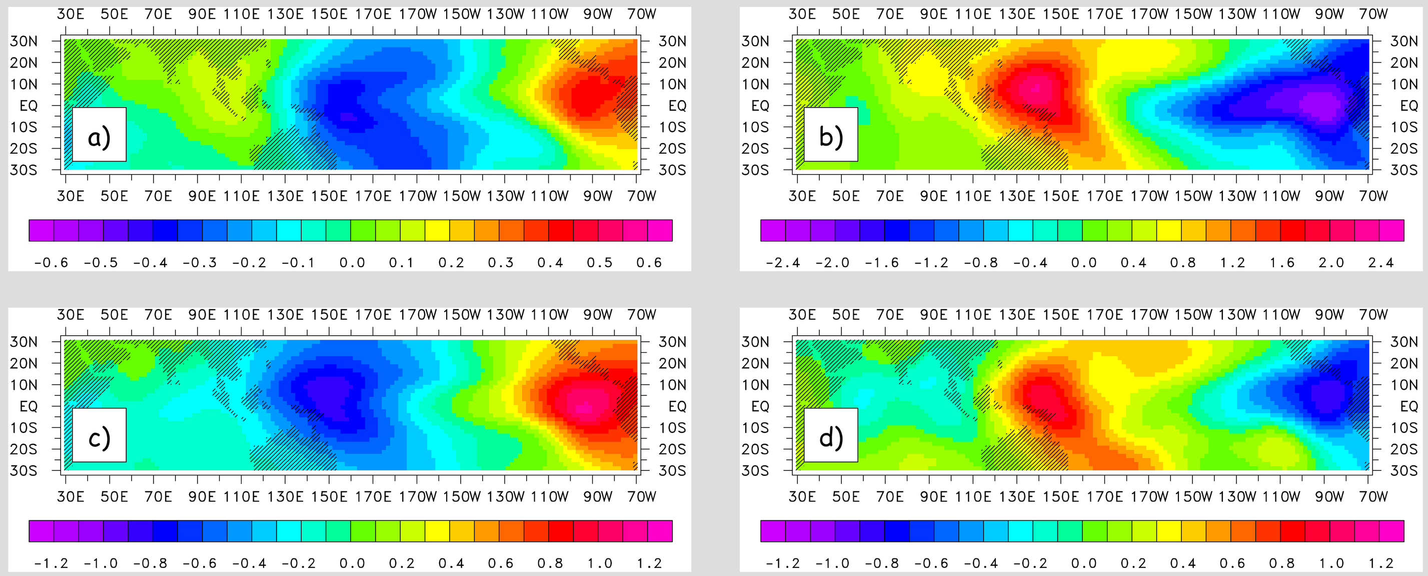
Change in the seasonal mean (JJAS) vertically integrated moisture flux (arrows) and in the seasonal mean difference between evaporation and precipitation (colours) for the period 2171-2100 with respect to the period 1971-2000 for 2GL (a) as well as the non-linear component of the change for 2GL with respect to the global annual mean temperature changes in 2GL and A1B (b). Units are kg/(ms) for the moisture flux and mm/d for the difference between evaporation and precipitation; the contour interval is 0.1 mm/d (b) and 0.2 mm/d (a), and the arrows in the upper right corner represent 75 kg/(ms) (b) and 150 kg/(ms) (a).

Change monsoon flow



Change in the seasonal mean (JJAS) horizontal winds for the period 2171-2100 with respect to the period 1971-2000 for 2GL at 850 hPa (a) and at 200 hPa (b) as well as the non-linear component of the change for 2GL with respect to the global annual mean temperature changes in 2GL and A1B at 850 hPa (c) and at 200 hPa (d). Units are m/s; the arrows in the upper right corner represent 1.5 m/s (c), 3 m/s (a, d) and 6 m/s (b).

Change pre-monsoon velocity potential



Change in the seasonal mean (MAM) velocity potential for the period 2171-2100 with respect to the period 1971-2000 for 2GL at 850 hPa (a) and at 200 hPa (b) as well as the non-linear component of the change for 2GL with respect to the global annual mean temperature changes in 2GL and A1B at 850 hPa (c) and at 200 hPa (d). Units are 10^6 m^2/s; the contour interval is 0.05 × 10^6 m^2/s (c), 0.1 × 10^6 m^2/s (a, d) and 0.2 × 10^6 m^2/s (b).

Conclusions

The study reveals **marked changes in the Indian summer monsoon associated with a global warming of 2 °C** with respect to pre-industrial times, namely an **intensification of the monsoon rainfall** and a **weakening of the monsoon flow**, mainly due to an **intensification of the atmospheric moisture flux** into the region and by **changes in the Walker circulation**, respectively. The **magnitude of the global warming primarily has local effects** on the relative strength of the projected changes.

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