The competitive impacts of global SST warming and CO2 increase on Sahelian rainfall: results from CMIP5 idealized simulations

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Background

West Africa is affected by large climate variability at different timescales, from interannual to multidecadal, with consequent strong environmental and socio-economic impacts, especially in the Sahelian countries, where the economy is mainly sustained by rainfed agriculture. The annual precipitation in the Sahel is limited to the boreal summer season, from July to September (JAS), and it is strongly linked to the **West African monsoon (WAM)** dynamics. After a wet period during the 50s-60s, **Sahel** has undergone a severe (large scale and long-lasting) **drought in the 70s-80s**, and a partial **recovery of precipitation is observed at the turn of the 21st century**.

Objective

- To study the effects of CO2 concentration increase and global SST warming on the WAM variability in July-September (JAS);
- focusing on the regional-versus-global aspects of the WAM dynamics and drivers.

Motivation

A number of studies tackled the problem of the simulation and interpretation of the climate variability and change in the Sahel, pointing out the importance of the global SST variability and GHG concentrations, which produce opposite effects on the monsoonal precipitation. A consensus exists on the drying effect of the global SST, and the positive effect of the increasing GHG concentration, which appear therefore in competition. In this context, **state-of-the-art coupled climate models still show poor ability in correctly simulating the WAM historical variability and also a large spread is observed in future climate projections.**

Experiment	Forcing	
	SST	CO2
CTL	Observed 1979-2008	Observed 1979-2008
4K	Observed 1979-2008 + uniform 4 K increase	Observed 1979-2008
4xCO2	Observed 1979-2008	4x increased concentration

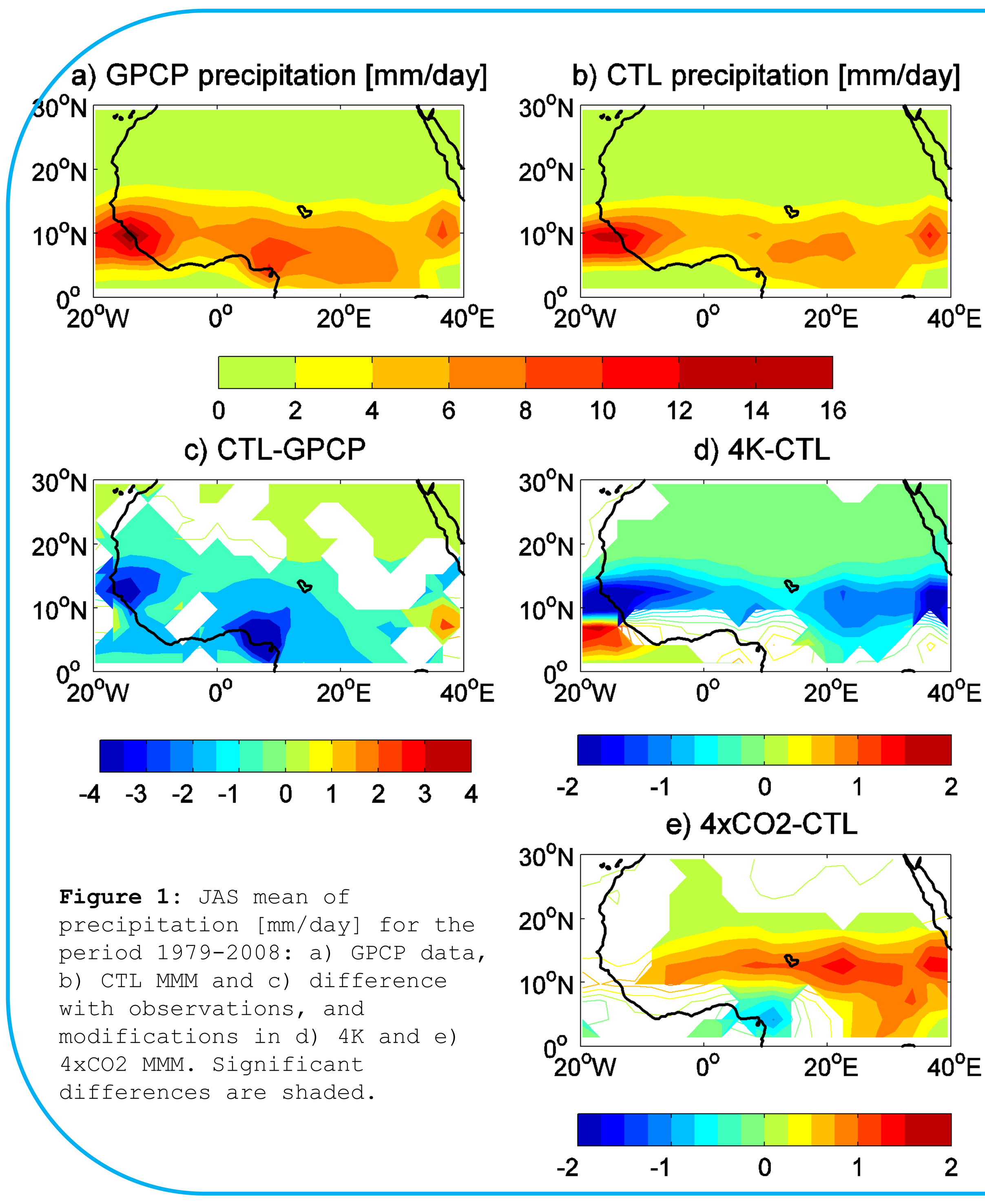

Figure 1: JAS mean of precipitation [mm/day] for the period 1979-2008: a) GPCP data, b) CTL MMM and c) difference with observations, and modifications in d) 4K and e) 4xCO2 MMM. Significant differences are shaded.

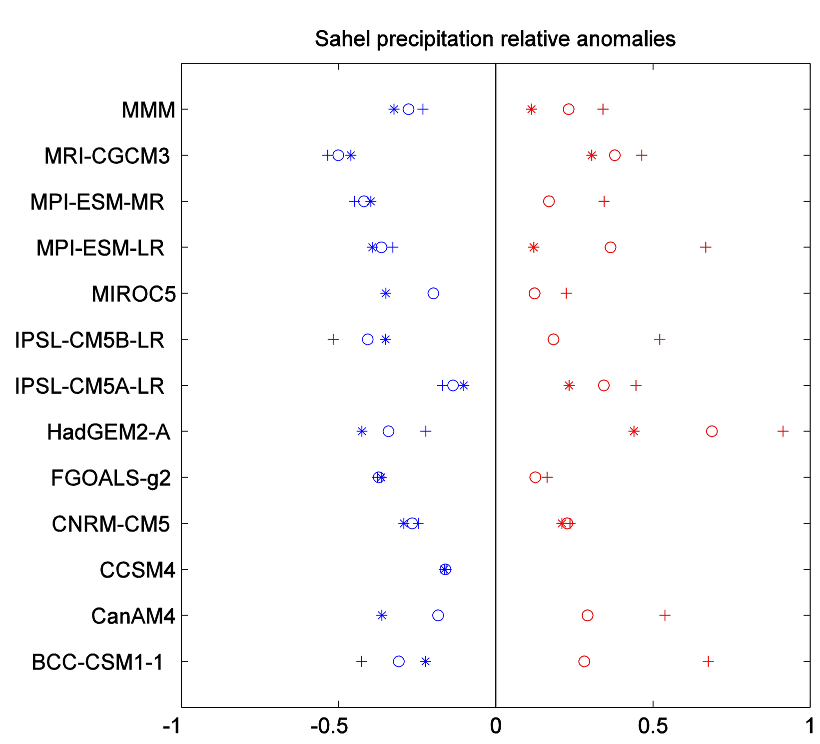

Figure 3: Significant relative differences between 4K (blue) and 4xCO2 (red) simulations and CTL for JAS climatological precipitation, in Sahel (10°-20oN, 20°W-30°E, circles), western (west of 0°E, stars) and eastern Sahel (east of 0°E, crosses).

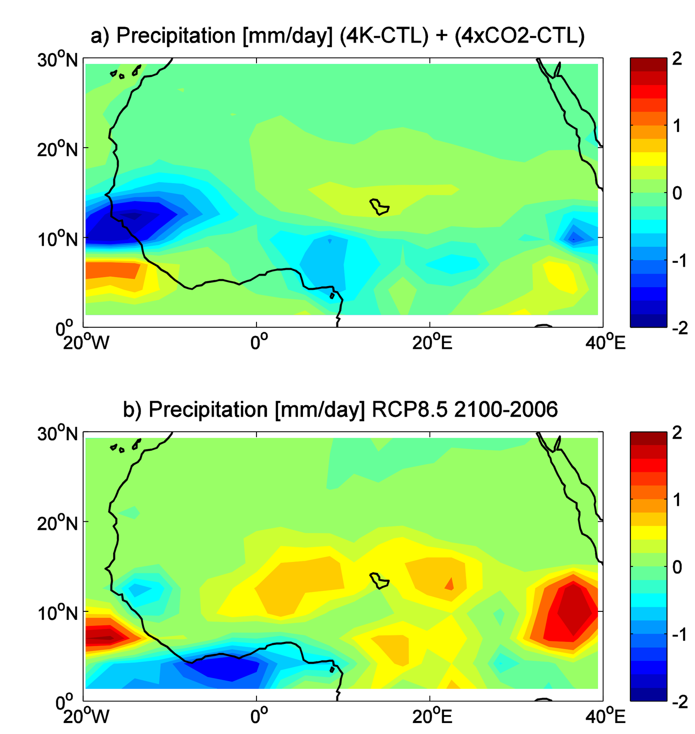

Figure 2: JAS MMM of precipitation [mm/day]: a) combination of the 4K and 4xCO2 differences with CTL (displayed in Figure 1d, e) and b) 21st century trend in the RCP8.5 scenario, presented as the difference between the end point of the linear trend over the period 2006-2100.

Country	Model
China	BCC-CSM1-1
Canada	CanAM4
USA	CCSM4
France	CNRM-CM5
China	FGOALS-g2
UK	HadGEM2-A
France	IPSL-CM5A-LR
	IPSL-CM5B-LR
Japan	MIROC5
Germany	MPI-ESM-LR
	MPI-ESM-MR
Japan	MRI-CGCM3

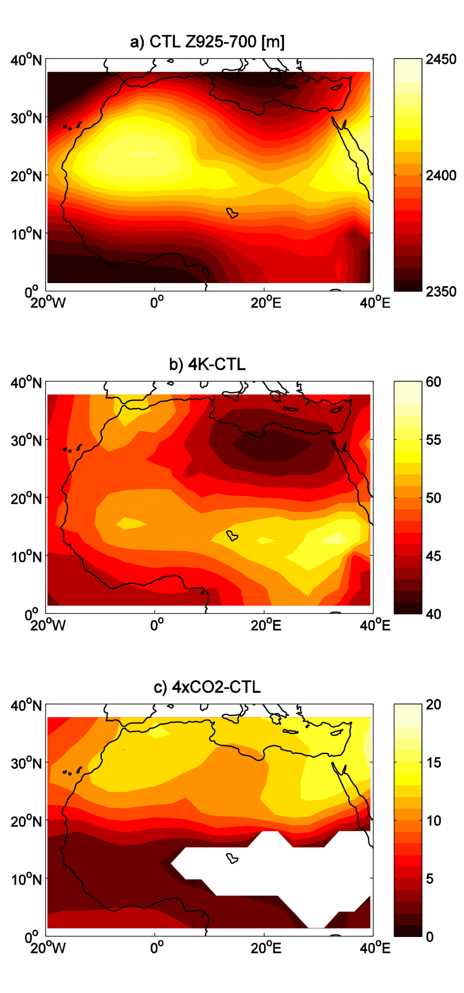

Figure 4: JAS mean of the 925-700 hPa thickness [m] for the period 1979-2008: a) CTL MMM and modifications in b) 4K and c) 4xCO2 MMM. Significant differences are displayed. Note the differences in the colour bars.

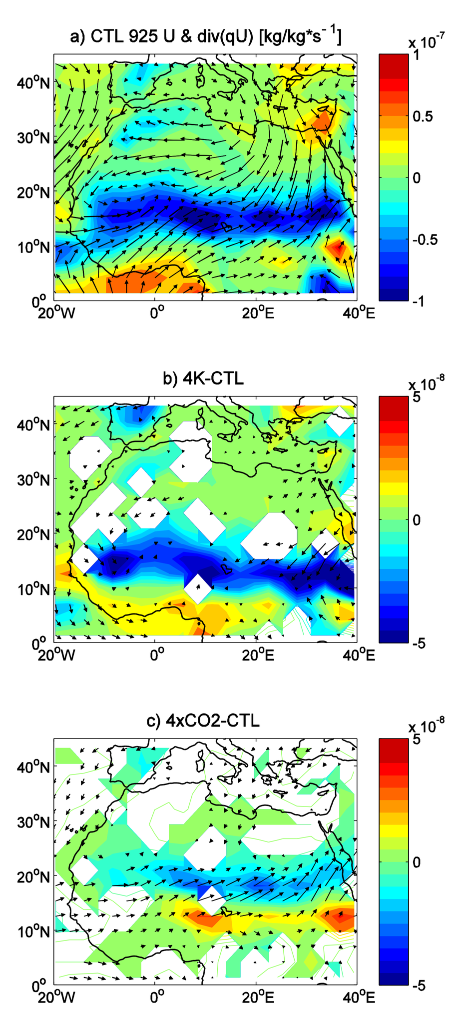

Figure 5: JAS mean of wind and moisture transport divergence at 925 hPa [kg/kg*s-1] for the period 1979-2008: a) CTL and c) difference with b) 4K and c) 4xCO2. Significant differences are displayed

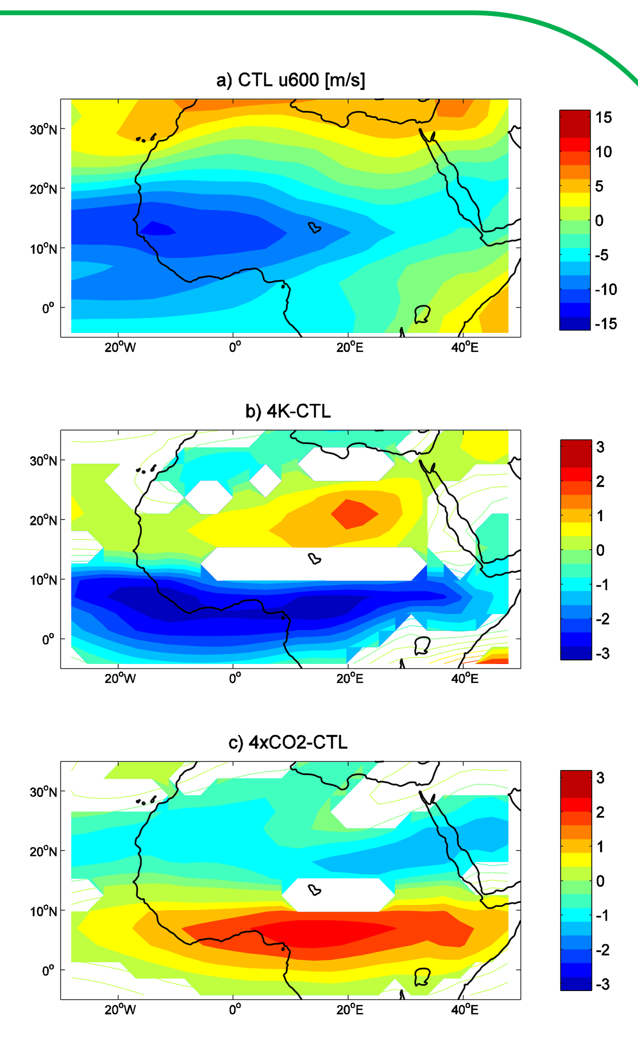

Figure 6: JAS mean of the zonal wind at 600 hPa [m/s] for the period 1979-2008: a) CTL MMM, and modifications in b) 4K and c) 4xCO2 MMM. Significant differences are displayed.

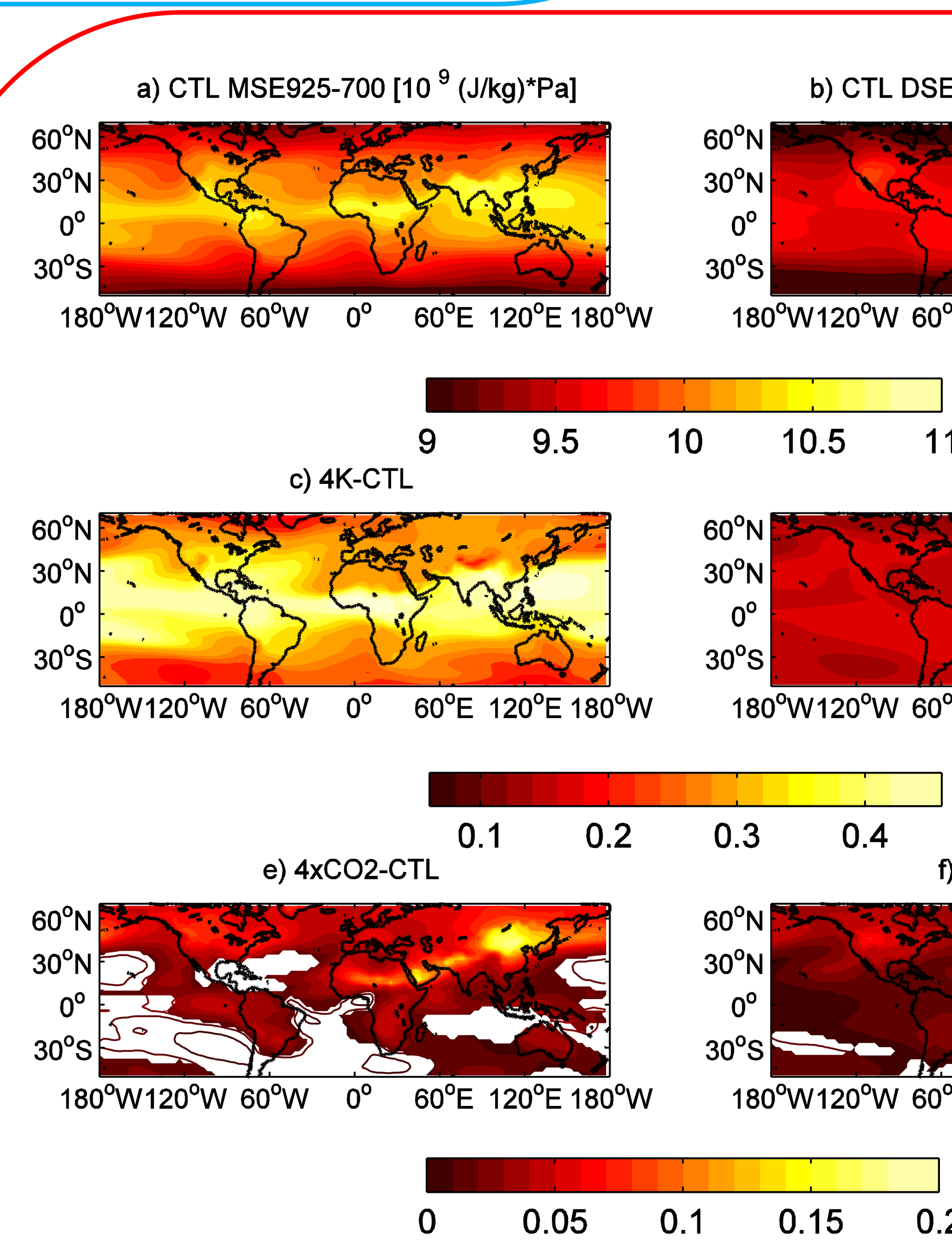

Figure 7: Moist and Dry Static Energy (MSE and DSE) in CTL and differences with 4K and 4xCO2 [(J / kg) * Pa]. Significant differences are displayed.

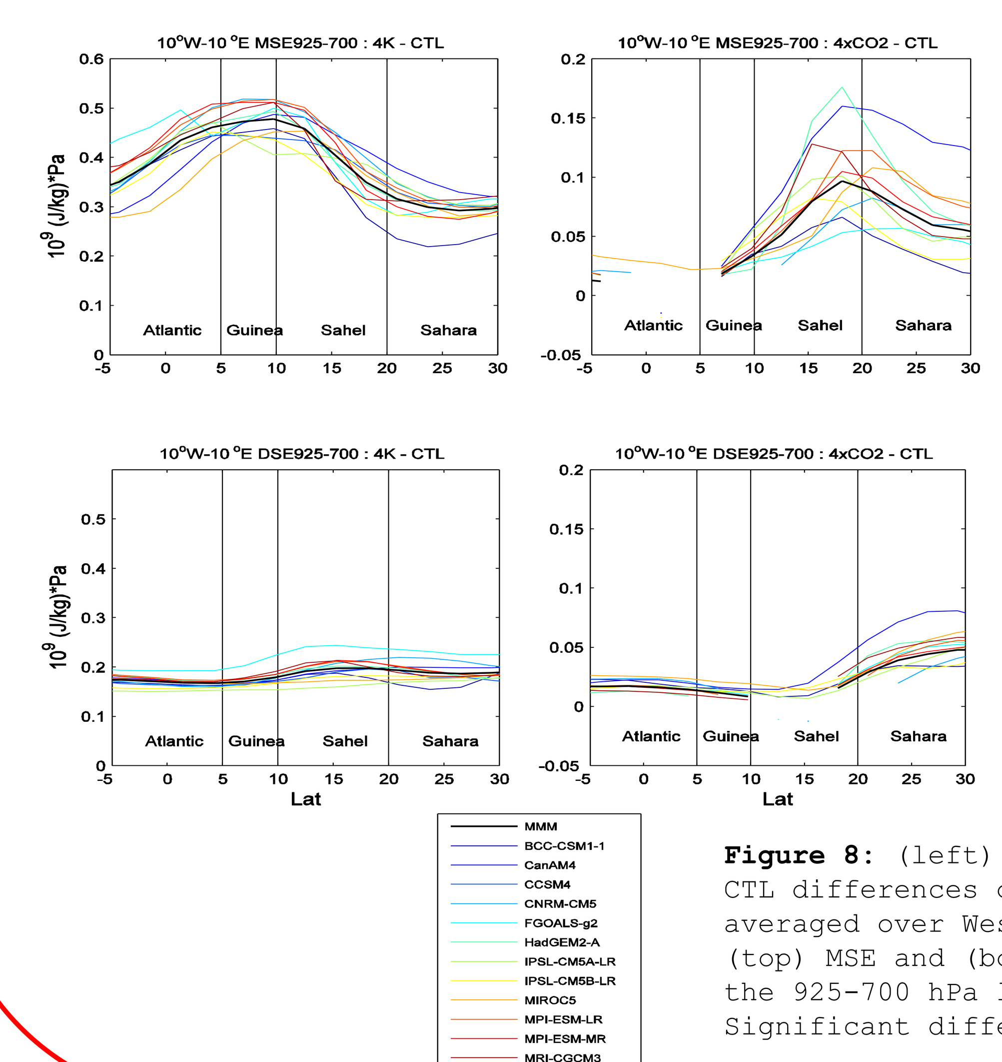

Figure 8: (left) 4k-CTL and (right) 4xCO2-CTL differences of the meridional profile, averaged over West Africa (10°W-10°E), of (top) MSE and (bottom) DSE, integrated in the 925-700 hPa layer [(J / kg) * Pa]. Significant differences are displayed.

Conclusions

Competition between the global SST warming and the CO2 increase in driving the WAM variability:

SST warming -> Dry Sahel
(reinforced evaporation in the global Tropics -> reduced MSE meridional gradient over West Africa - > inhibition of the monsoonal flow and the ITCZ northward migration);

CO2 increase -> Wet Sahel
(atmospheric radiative warming -> enhanced evaporation over the Sahel and warmer Sahara -> reinforced MSE meridional gradient -> more intense monsoonal circulation and precipitation).

! Comprehension of the mechanisms linking the WAM variability to SST and CO2 forcings;

! Ability of the climate models in reproducing these mechanisms, for reliable simulations of the past, present and future variability.

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