3C.4 INFLUENCE OF LARGE-SCALE ATMOSPHERIC MOISTURE FLUXES ON THE INTERANNUAL TO MULTIDECADAL RAINFALL VARIABILITY OF THE WEST AFRICAN MONSOON

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1. INTRODUCTION

In the West African region food security depends, apart from non-climatic factors, on several climatic factors, such as the intensity of dry spells within the growing period, the onset of the rainy season, or the long term rainfall variability. The latter depends, amongst other factors, on the water vapour supply, the activity of African Easterly Waves (AEW) and of Mesoscale Convective Systems (MCS), and the stability of the atmosphere, which can be assessed by various parameters, e.g. convective available potential energy (CAPE).

The objective of this study is to improve the comprehension of the influence of continental-scale atmospheric moisture on the long term rainfall variations on interannual to multidecadal time scale. Therefore various components of the atmospheric water budget are assessed via moisture fluxes and moisture flux divergences.

2. DATA

In this study temperature, specific humidity, and u and v component of the horizontal wind vector at 1000, 925, 850, 700, 500, 400, 300 hPa of the ERA-40 re-analyses (for 1979-2001) and the ECMWF operational analyses (for 2002-2007) are applied. By means of the surface pressure these parameters are extrapolated from the pressure level. Since the operational analyses of the ECMWF are inhomogeneous and therefore not ideal for climatologic investigations, first attempts have been made with the NCAR-2 re-analyses, but will not be presented here. Besides, the ECMWF data have the advantage of a higher horizontal resolution of 1.125° x 1.125°. The full time resolution of 4 times daily (00, 06, 12, 18 UTC) was utilized in this study, because the largest amount of moisture in the atmosphere is to be expected around the time of the precipitation events which, due to the large extent of the investigation area, are spread over 24 h.

The AMMA EOP years are compared to the long-term mean 1979-2001 and to particularly interesting earlier years, which were chosen for their interesting rainfall characteristics. According to the Landsea statistic of precipitation indices (Fink et al. (2007)), the selected years exhibit the following characteristics: 1987: Guinea Coast (GC) wet, Central Sahel (CS) and West Sahel (WS) dry, 1988: wet, 1990: dry, 1998: GC and WS dry, CS wet, 1999: GC dry, WS and CS wet, 2002: dry, 2005: GC dry, WS and CS wet, 2006: dry, and 2007: WS dry, CS and GC wet.

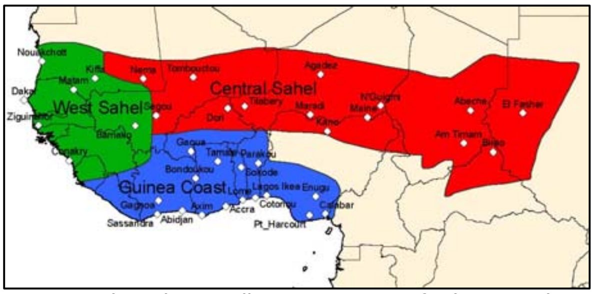

FIG. 1: The three climate zones of the Landsea precipitation indices.

For our investigations the troposphere is split up into three distinct layers, the entire troposphere (surface to 300 hPa), the monsoon layer (surface to 850 hPa) and the layer of the African Easterly Jet (AEJ) (700 to 500 hPa). Seasonal as well as monthly means were computed, but only the latter are presented in this study.

3. THEORY

The atmospheric water vapour budgets and fluxes are discussed by means of the aerial runoff vector $\vec{Q}$ and the columnar moisture divergence $\vec{\nabla}\vec{Q}$ (Eq. 1 & 2) after Peixoto and Oort (1992):

$$\vec{Q} = \frac{1}{g}\sum_{p_{sfc}}^{p_{top}} q \cdot \vec{v} \cdot \Delta p \qquad \text{in kg/m*s} \qquad (1)$$

$$\vec{\nabla} \cdot \vec{Q} = \frac{1}{a}\left[\frac{1}{2\cdot\Delta\lambda\cdot\cos\varphi}\left(\vec{Q}_{i+1,j} - \vec{Q}_{i-i,j}\right) + \frac{1}{2\cdot\Delta\lambda}\left(\vec{Q}_{i,j+1} - \vec{Q}_{i,j-1}\right) - \tan\varphi \cdot \vec{Q}_{i,j}\right]$$

in kg/m²*s, converted to mm/period (2)

With specific humidity q in kg/kg, horizontal wind

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vector $\vec{v}$ in m/s, pressure difference Δp, horizontal resolution $\Delta\lambda$, latitude φ, and indices i, j for latitude, longitude.

The moisture enrichment of the West African continent is determined via net moisture budgets Q_{net} and trans-boundary fluxes Q_{tb} (Eq. 3 & 4) over the borders of a box centred around the mean position of the maximum rainfall belt, identified with the mean zonal minimum of outgoing long-wave radiation (OLR) (Fig. 2).

$$Q_{tb} = \sum Q_{u,v} \quad (3)$$

$$Q_{net} = Q_{tb}^{17°W} - Q_{tb}^{5°E} + Q_{tb}^{5°N} - Q_{tb}^{15°N} \quad (4)$$

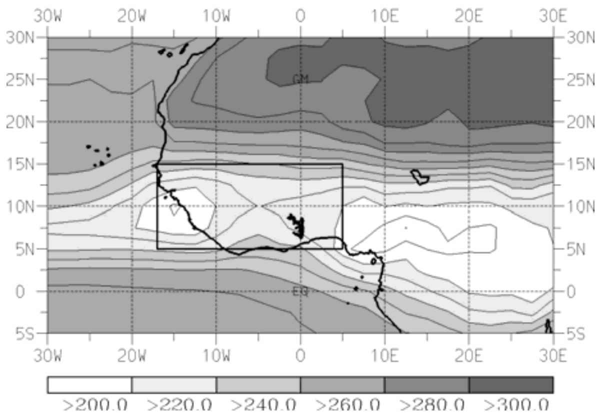

FIG. 2: NOAA mean June-September (JJAS) OLR in W/m² (averaging period: 1979-2001) with position of the box over West Africa (5-15°N, 17°W-5°E).

4. RESULTS

In this study the results of three selected years, chosen as to give examples of a wet, dry and a dipole year, will be presented.

4.1 1988 - wet

According to the Landsea statistic, all three climate zones exhibit an equally high positive precipitation anomaly in 1988.

The net moisture budget anomalies for the whole troposphere are positive for all months (Fig. 3), with exception of May. This surplus of moisture is mainly due to (a) an enhanced meridional moisture transport northward from the Gulf of Guinea over the southern boundary and (b) less outflow of moisture over the western boundary. Split up into the monsoon layer (ML) and the layer of the AEJ (JL) it can be seen that (a) is the result of a stronger moisture transport northward in the ML, whereas (b) is a result of the combination of a stronger moisture influx in the ML and a smaller outflow in the JL for June-September (JAS). The question is: Is the enhanced transport of moisture due to more moisture in the atmosphere or due to stronger winds?

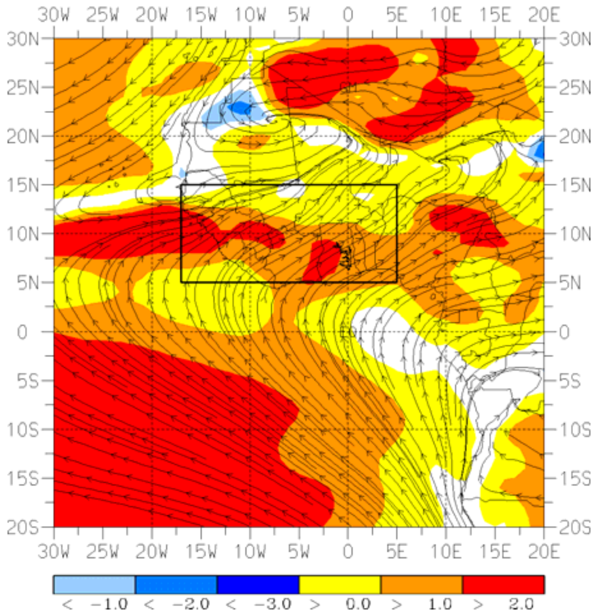

FIG. 4: Streamlines: Mean SFC to 850 hPa wind for August 1988. Colouring: Wind force anomalies 08/1988 minus 08/1979-2001 in m/s.

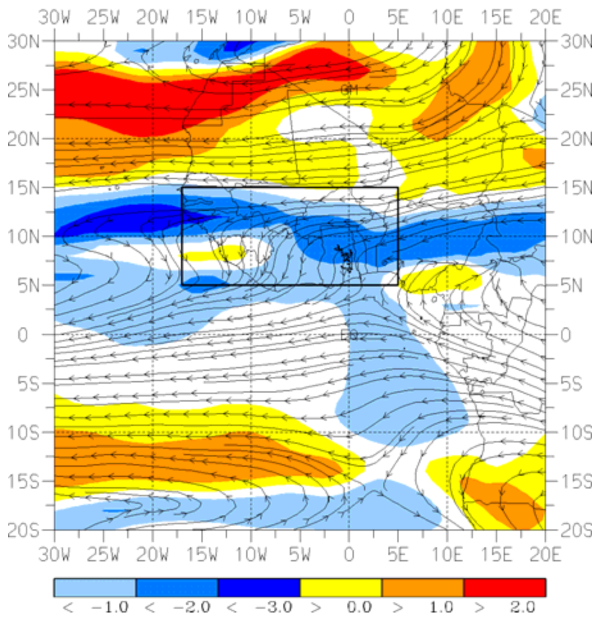

FIG. 5: Streamlines: Mean 700 to 500 hPa wind for August 1988. Colouring: Wind force anomalies 08/1988 minus 08/1979-2001 in m/s.

Fig. 4 gives the mean August wind for SFC to 850 hPa as streamlines, and the wind force anomaly for 1988 minus 1979-2001. The hot colours at the southern and western boundaries of the box indicate that the wind force in the ML was stronger in 1988 than in the long term mean. Besides, A. Reiner found in previous investigations positive monsoon layer height anomalies of 500-1000 m south of 12.5°N for August 1988, with a maximum at 7.5°N.

Fig. 5 exhibits the same as Fig. 4, but for 700 to 500 hPa. At the western boundary the cool colours indicate a stronger than average wind force of the AEJ in August 1988.

4.2 2005 - dipole

2005 can be classified as a dipole year. The Guinea Coast exhibited a negative precipitation anomaly, whereas West Sahel and Central Sahel both had more precipitation than average.

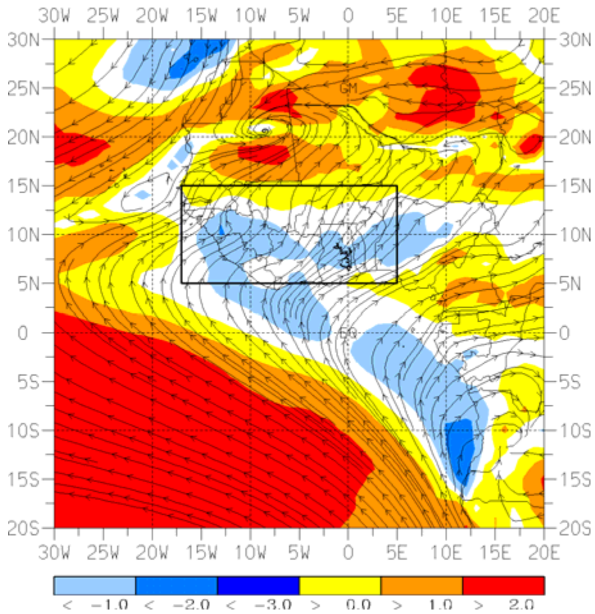

FIG. 7: Streamlines: Mean SFC to 850 hPa wind for August 2005. Colouring: Wind force anomalies 08/2005 minus 08/1979-2001 in m/s.

The net moisture budget anomalies for the whole troposphere of the West African continent are distinctly negative for all months (often not even reaching half of the long term mean), sometimes even revealing a negative moisture budget (April, October, November) (Fig. 6). This is caused by (a) a weakened moisture inflow in SFC to 300 hPa from the South and West (the latter especially in October) and (b) a stronger outflow of moisture over the northern boundary. Looking at the individual layers it is clear that for both (a) and (b) the anomalous moisture transport in the monsoon layer is responsible.

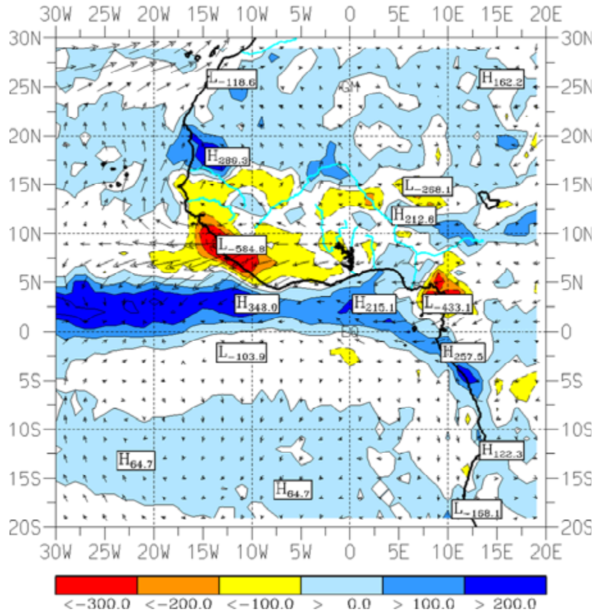

FIG. 8: Vectors: SFC to 850 hPa anomaly of the aerial runoff vector Q in kg/m*s. Colouring: anomalies of moisture flux divergence 08/2005 minus 08/1979-2001 in mm/month. Sign convention: Positive indicates stronger moisture flux convergence than average.

The wind force anomaly SFC to 850 hPa for August in Fig. 7, as an example of the monsoonal months for the northern boundary, indicates that the wind force in the ML at the northern boundary was stronger than in the long term mean. The anomaly of the moisture flux convergence given in Fig. 8 confirms the impression of an enlarged moisture supply in the northern part of the box.

Looking closer at the enhanced moisture transport out onto the Atlantic Ocean westward in October, the mean streamlines in the ML in 2005 (Fig. 9) reveal a completely different pattern than in the long term mean (Fig. 10). The typical bend to the North-East is not visible. Instead, the streamlines cross the western boundary in zonal direction to the West. In Fig. 11 the moisture flux divergence anomalies reveal an Innertropical Convergence Zone (ITCZ) positioned far further South than average, indicating an earlier than normal transition southward.

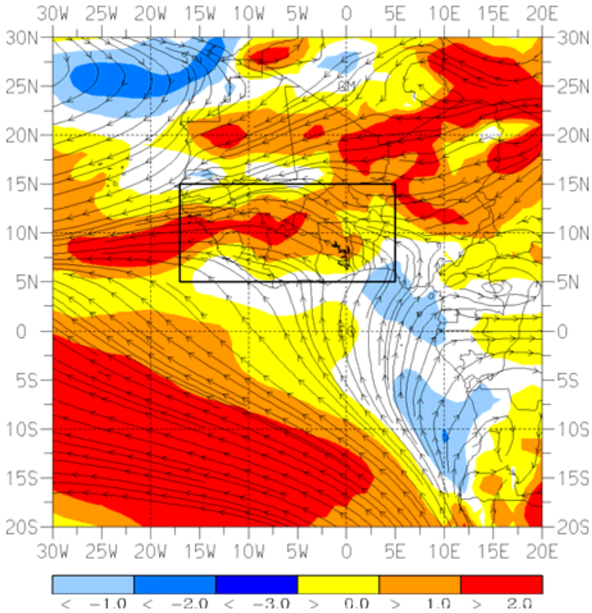

FIG. 9: Streamlines: Mean SFC to 850 hPa wind for October 2005. Colouring: Wind force anomalies 10/2005 minus 10/1979-2001 in m/s.

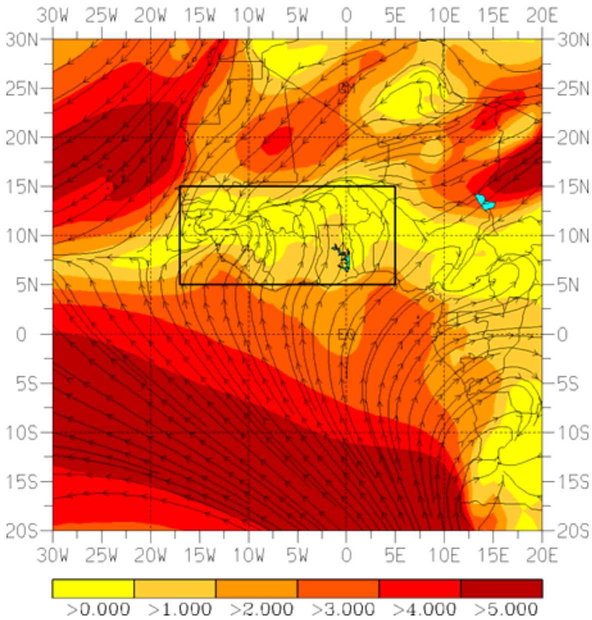

FIG. 10: Streamlines: Mean SFC to 850 hPa wind for October 1979-2001. Colouring: Wind force 10/1979-2001 in m/s.

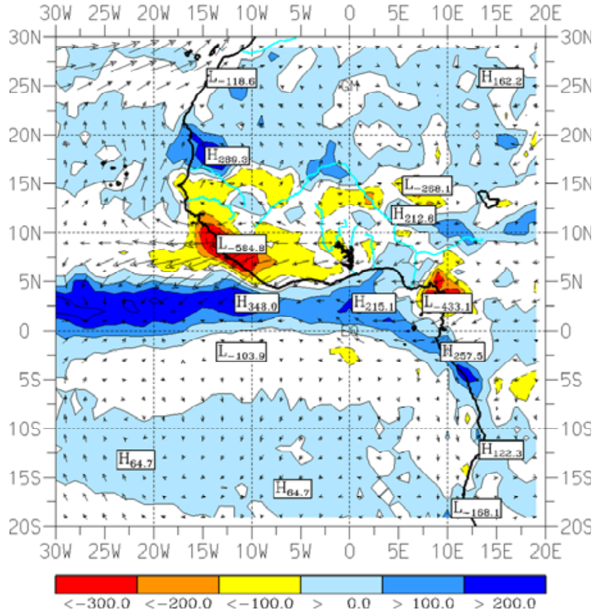

FIG. 11: Vectors: SFC to 850 hPa anomaly of the aerial runoff vector Q in kg/m*s. Colouring: anomalies of moisture flux divergence 10/2005 minus 10/1979-2001 in mm/month. Sign convention: Positive indicates stronger moisture flux convergence than average.

4.3 2006 - dry

The AMMA SOP year 2006 was a dry year for all three climate zones of the Landsea statistic.

The net moisture budget anomalies for the whole troposphere were negative for all months, but not as negative as in 2005 (Fig. 12). This is due to (a) a weaker moisture transport into the box from the Gulf of Guinea and (b) an enhanced outflow over the western and northern boundary of the box. Both (a) and (b) are due to an anomalous moisture transport in the monsoon layer. Especially June jumps to the eye, when only 7 % of the moisture of the long term mean were transported into the box from the West. Comparing Fig. 13 and 14, the streamlines of the mean wind in SFC to 850 hPa for June exhibit a completely different pattern. In 2006 the bend of the monsoonal flow to the North-East has not yet taken place. This is confirmed by the anomaly of the moisture flux divergence in Fig. 15, which indicates a more southerly position of the ITCZ than in the long term mean.

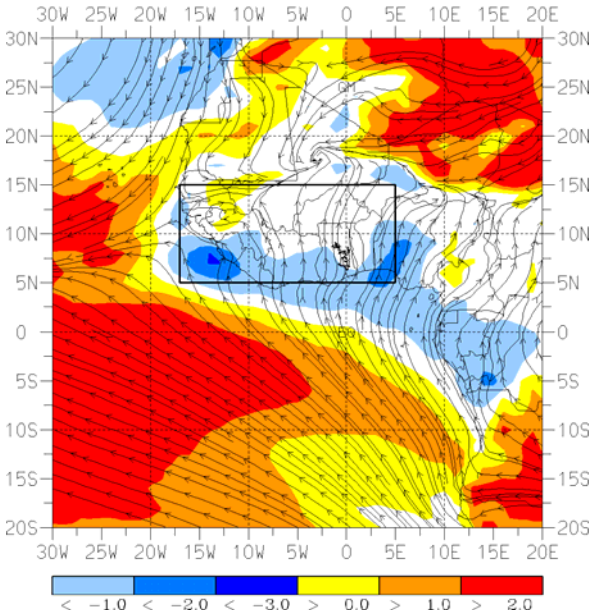

FIG. 13: Streamlines: Mean SFC to 850 hPa wind for June 2006. Colouring: Wind force anomalies 06/2006 minus 06/1979-2001 in m/s.

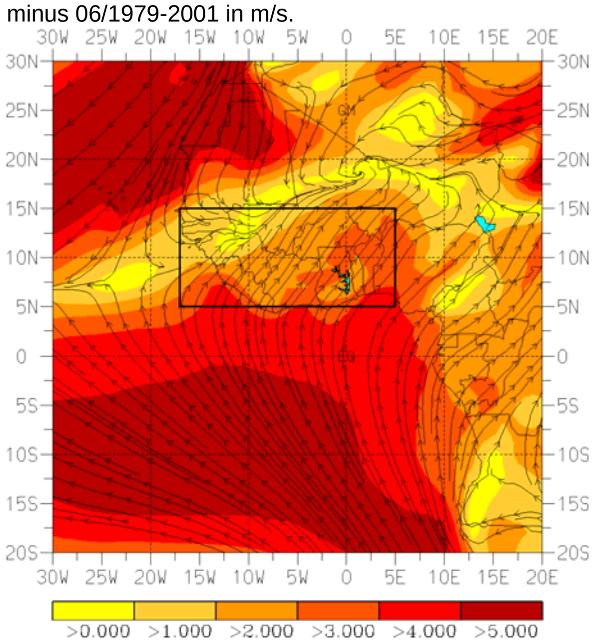

FIG. 14: Streamlines: Mean SFC to 850 hPa wind for June 1979-2001. Colouring: Wind force 06/1979-2001 in m/s.

5. SUMMARY

In the wet year of 1988, increased southerly and westerly low-level moisture inflow, and easterly reduced mid-level outflow onto the Atlantic Ocean are the major causes for the surplus in total water vapour convergence. In the dipole year of 2005 the low-level moisture flow anomalies appear to be of greater importance than those in the mid-level. The stronger meridional moisture transport over the northern boundary might be connected to the more abundant rainfalls in the Central Sahel region. In the dry AMMA SOP year 2006 a later transition of the ITCZ is the cause of the late onset of the typical monsoonal flow, and therefore of the smaller than average net moisture at the monsoon onset.

Concluding, investigations of the net moisture budget can further our understanding of how more abundant moisture over West Africa is converted into rainfall. However, the studies have to be extended onto the investigations of monsoon layer height anomalies and perhaps precipitable water content, in order to complement the investigations.

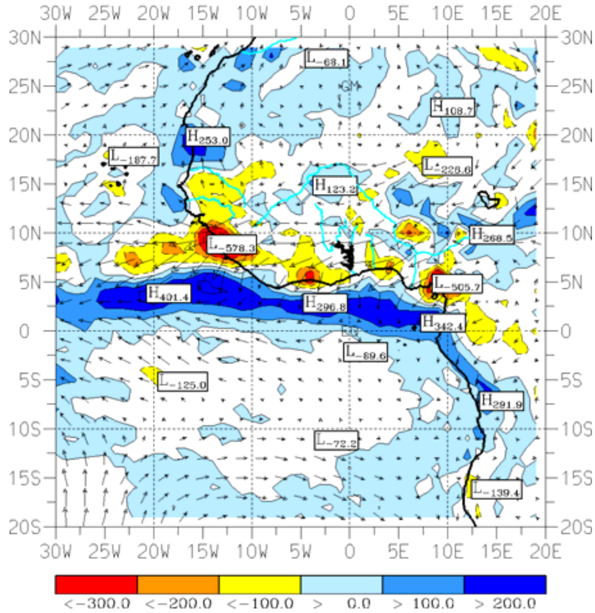

FIG. 15: Vectors: SFC to 850 hPa anomaly of the aerial runoff vector Q in kg/m*s. Colouring: anomalies of moisture flux divergence 06/2006 minus 06/1979-2001 in mm/month. Sign convention: Positive indicates stronger moisture flux convergence than average.

7. REFERENZES

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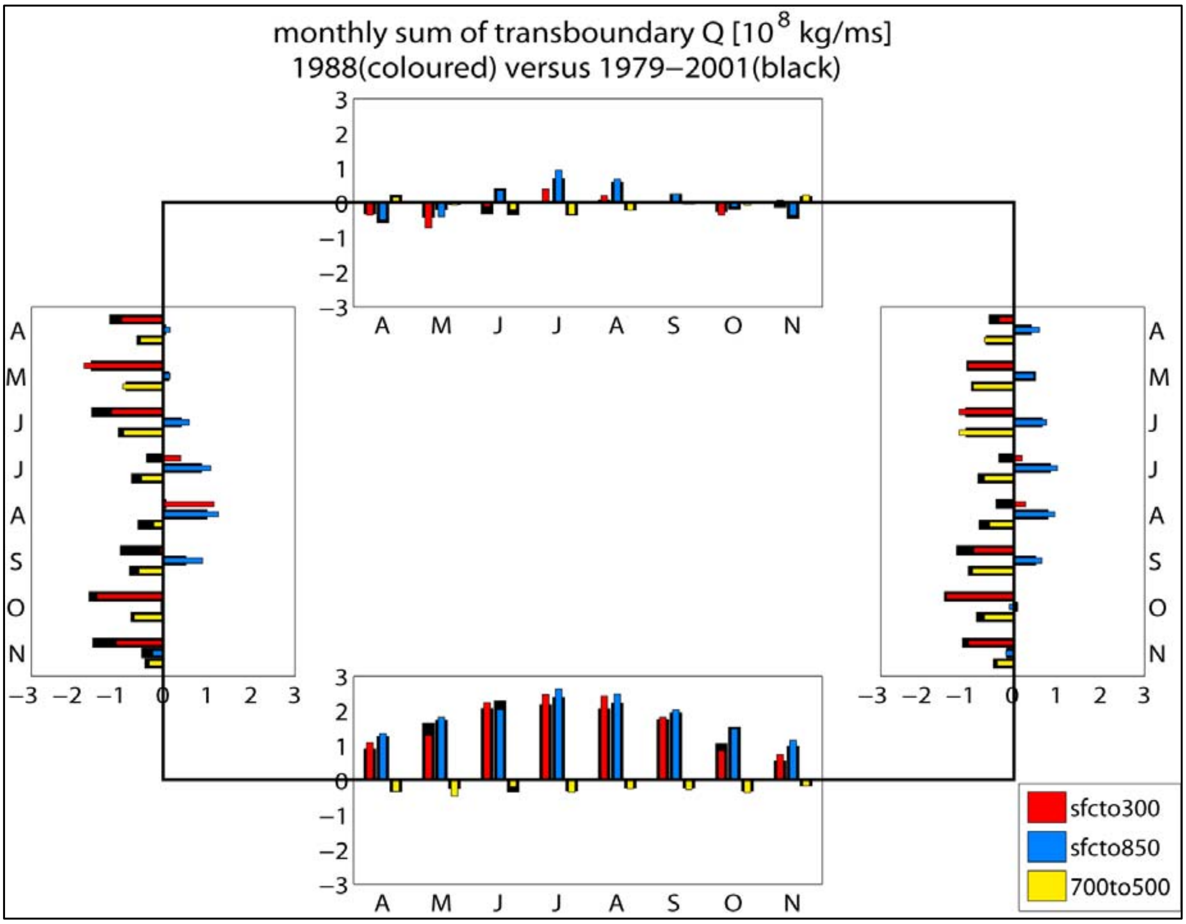


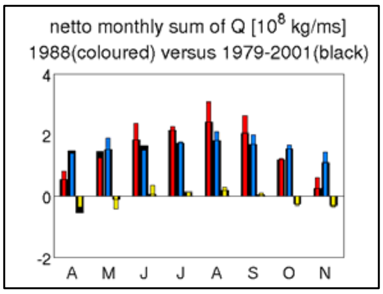
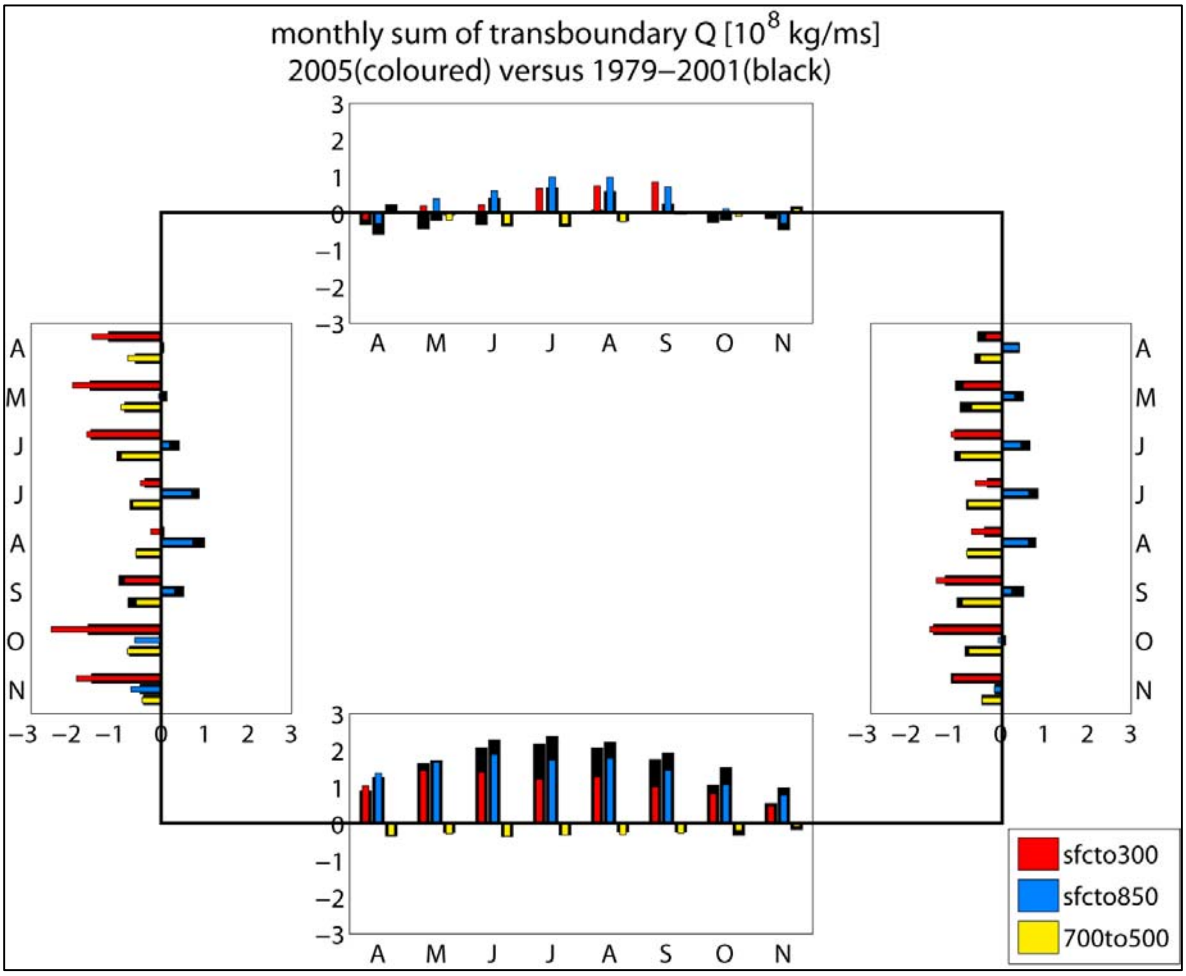


FIG. 3: Monthly sum of the trans-boundary fluxes in 10^8 kg/m*s for 1988.



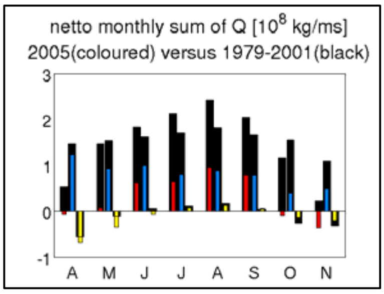


FIG. 6: Monthly sum of the trans-boundary fluxes in 10^8 kg/m*s for 2005.

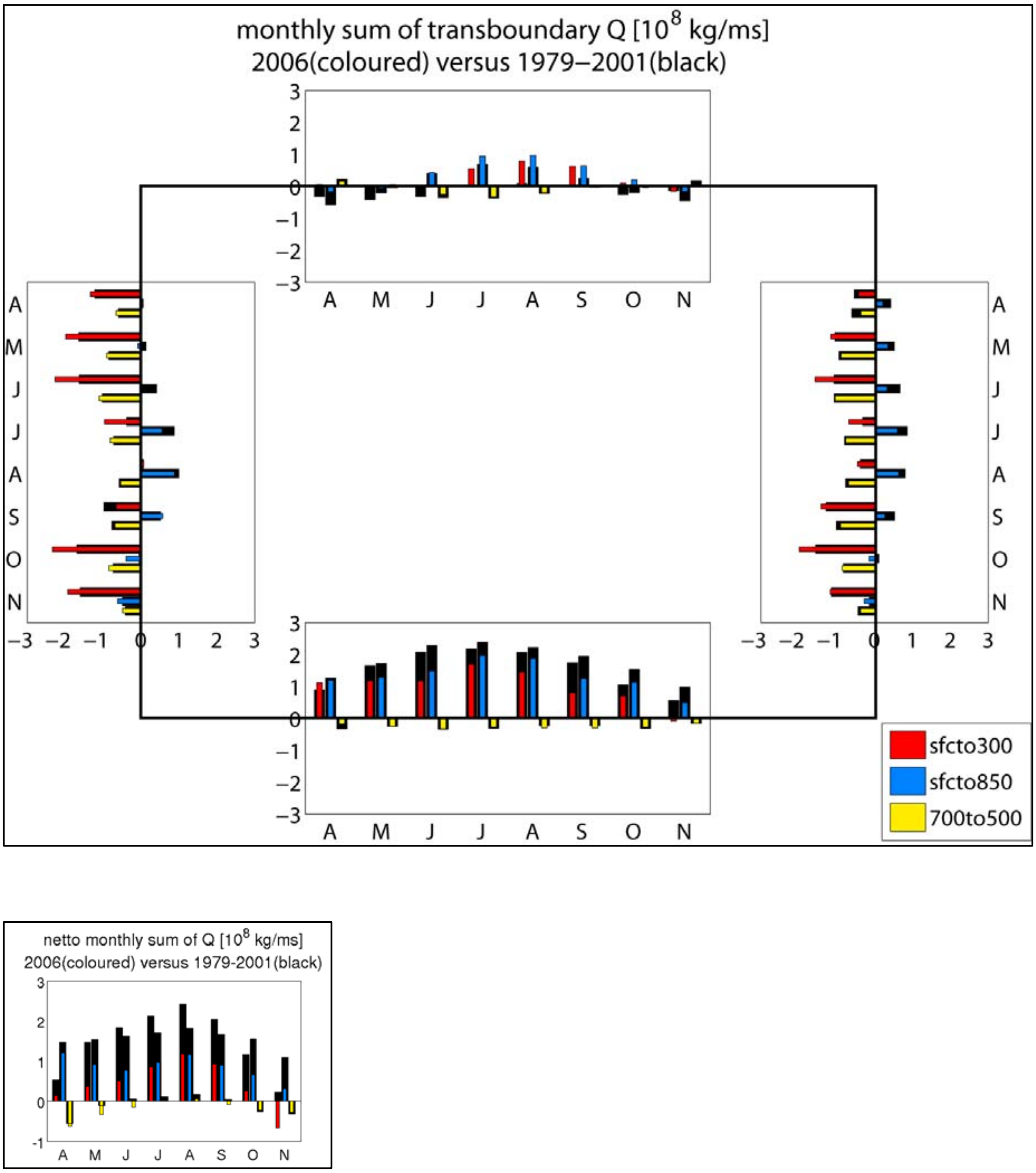


FIG. 12: Monthly sum of the trans-boundary fluxes in 10^8 kg/m*s for 2006.