Atmospheric circulation associated with recent Sahelian hydrologic anomalies

WASSILA M. THIAW, JAMIE V. KOUSKY & VADLAMANI KUMAR
NOAA/NWS/NCEP, Climate Prediction Center, Washington DC 20233, USA
e-mail: wd53wt@sgi43.wwb.noaa.gov

Abstract Atmospheric circulation over the tropics during recent wet and dry periods over the Sahel has been studied using the NCEP/NCAR re-analysis data set. The results show that the mid and upper level easterly jets play an important role in modulating rainfall variations over the Sahel. In particular, the lower tropospheric easterly jet is stronger during dry years whereas the upper level easterly jet is weaker. Moisture fluxes over West Africa during dry and wetter periods have also been studied, indicating that an important source of moisture for West Africa, is the southern Atlantic. The magnitude of the moisture flux in this region is greater during the wet episodes than during periods of droughts.

INTRODUCTION

It has been established that drought is a recurrent feature of the Sahelian climate. Long-term rainfall variability in the Sahel is dominated by multidecadal trends, with periods of droughts alternating with periods of wetter episodes (Lamb, 1985; Nicholson *et al.*, 1988). However, even during wet or dry periods, interannual rainfall variability is still large. In this paper, our definition of the Sahel is the region between 10°–20°N and 20°E–15°W. We examine the period 1968–1997, which is more representative of the recent climate fluctuations in this region. The rainfall data used are monthly totals of rainfall retrieved from the Climate Prediction Center's Climate Anomaly Monitoring System (CAMS) data base. Time series of seasonal (July–September) percentiles (Fig. 1) show evidence of interannual variability in the 1968–1997 period. The longest stretch of drought was 5 years in the early 1980s, and the longest stretch of wet episodes was 3 years from 1969 to 1971. In this paper, the wet period consists of the years when rainfall variability was close to the 75th percentile, including 1974, 1988, and 1994. The dry period corresponds to 1972, and 1982–1984, when the variation in rainfall was near the 25th percentile. The atmospheric circulation data used in examining these rainfall episodes are retrieved from the NCEP/NCAR re-analysis data set. Composites of wet and dry years relative to the 1968–1997 period were constructed and the circulation associated with those episodes examined. The analyses of winds and specific humidity were used to construct anomaly wind fields at 700 hPa, 200 hPa stream function, and integrated water vapour fluxes from the surface to 850 hPa. After a description of the characteristics of the atmospheric circulation, some aspects of water vapour transport are presented.

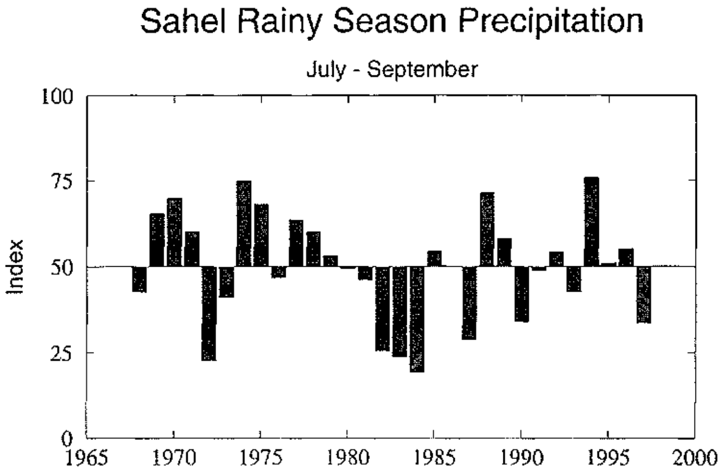

Fig. 1 Sahelian (July–September) rainfall index for the period 1968–1997. Index is based on 20 raingauges.

ATMOSPHERIC CIRCULATION

Over West Africa, rainfall is dependent upon the northward displacement of the Intertropical Convergence Zone (ITCZ), which reaches its northernmost position during the northern hemisphere summer in August. During this period, the large scale flow is characterized by the low-level southwesterly winds and an upper-level easterly flow. There are two easterly wind maxima between 10° and 15°N. The maxima in the upper troposphere near 200 hPa is referred to as the tropical easterly jet (TEJ), and the other in the mid-troposphere at 700–600 hPa is called African easterly jet (AEJ). Another important feature of the Sahelian climate is the evidence of easterly waves in the wind field during the summer with an average period of 3.5 days and an average wavelength of 2500 km (Burpee, 1974). The African waves are often associated with squall lines that form, develop and dissipate within the waves. However, the influence of the African waves on the re-analysis dataset is not discussed in this paper. Composites of the 700 hPa zonal wind anomaly for wet and dry periods are shown in Figs 2(a) and (b). The 700 hPa wind anomaly fields reveal that during the wet periods, westerly anomalies south of the Sahel between 10°S and 15°N and easterly anomalies over northwestern Africa are dominant. These westerly anomalies exhibit a clear axis centred around 8°N and are consistent with a weakening of the AEJ and increased cyclonic vorticity. During the dry years, a dipole is evident, with easterly anomalies between 5°S and 15°N and westerly anomalies north of 15°N. This is associated with increased anticyclonic vorticity in this region, creating favourable conditions for an acceleration of the easterlies and enhanced AEJ.

In the upper troposphere, the 200 hPa stream function anomaly field features an anomalous anticyclonic circulation over both hemispheres, with enhanced easterlies across West Africa during the wet periods (Fig. 2(c)). This pattern is consistent with a strengthening of the upper level easterlies and therefore a re-enforcement of the TEJ. During the dry years (Fig. 2(d)), a reversal in the circulation pattern is evident, with reduced anomalous anticyclonic circulations over both hemispheres, which contribute to suppressed upper level easterlies and a weakening of the TEJ across West Africa. These results are consistent with the findings by Newell & Kidson (1984) that the 700 hPa easterly jet near 15°N is stronger in dry years, while the tropical easterly jet is weaker.

HORIZONTAL MOISTURE FLUX FIELDS

To study moisture flux across West Africa during wet and dry years, bi-weekly fields of meridional and zonal fluxes of specific humidity for the surface-850 hPa and 700–500 hPa were computed. Here, only meridional moisture fluxes for the first halves of May and July are shown. Fluctuations of moisture fluxes at time scales shorter than two weeks are also computed but are not discussed here. During the wet years, the meridional flux field over West Africa during the first half of May (Fig. 3(a)), reveals a strong southerly flux centred just north of 10°S near the 0° longitude and a strong northerly flux along the coast of West Africa. The zero line located near the equator over the Atlantic Ocean, tilting northward over Africa is close to the location of the intertropical discontinuity. A strong southerly flux is also present over the Bay of Bengal corresponding to the pre-onset phase of the Indian monsoon. The zonal flux field reveals a westerly flux over northern Indian Ocean. A weak westerly flux

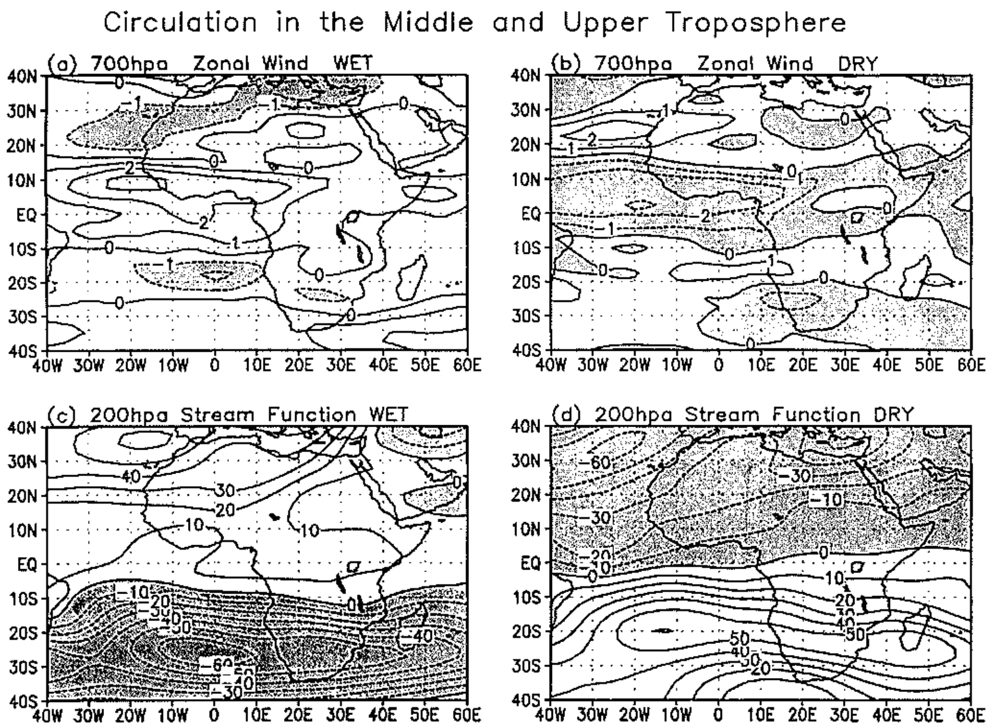

Fig. 2 700 hPa zonal wind anomaly field for wet (a) and dry periods (b); and 200 hPa stream function anomaly field for wet (c) and dry periods (d), derived from the NCEP/NCAR re-analysis data set. Anomalies are departures from the 1968–1996 base period.

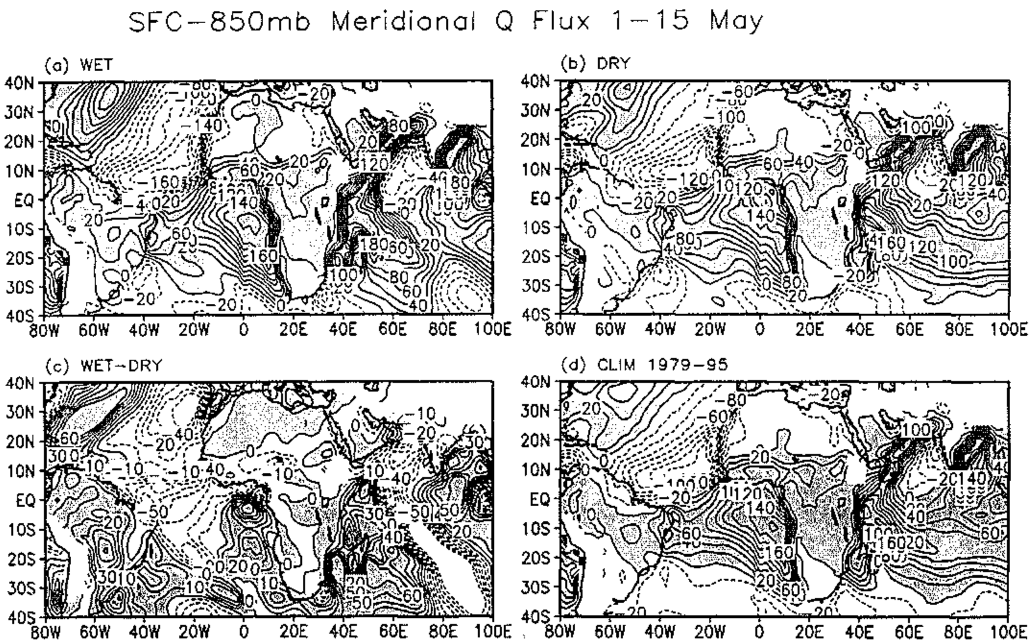

Fig. 3 Vertically integrated mean meridional flux of water vapour for the surface to 850 hPa for 1–15 May for the wet (a), and dry period (b), wet–dry (c), and climatology (d). Units are kg $m^{-1} s^{-1}$.

over the Gulf of Guinea is also present and indicates that the West African monsoon flow is penetrating inland. During this period, for the dry years (Fig. 3(b)), the moisture flux field presents a pattern similar to that of the wet years. However, the magnitude of the flux over the southern Atlantic Ocean is smaller during the dry years than during the wet years (Fig. 3(c)). As the season progresses from May to June, the monsoon over West Africa penetrates further inland. The magnitude of the northerly flux over the north Atlantic just off the coast of northern Africa and off the coast of northern South America, and the magnitude of the area of southerly flux over the eastern Indian Ocean have increased. Easterly fluxes in the south and north Atlantic have increased indicating an enhancement of the trade winds. However, the penetration of the West African monsoon inland is only slightly less pronounced in the drier years than in the wetter years. During July and August, for the wet years, the southerly flow extends further inland compared with earlier periods (Fig. 4(a)). The 20 line over the Atlantic Ocean has moved northward and the westerly flux over West Africa extends up to 20°N, where it has intensified. The easterly flux corresponding to the strong trade winds of the southern hemisphere has increased. During this period for the dry years (Fig. 4(b)), the inland penetration of the West African monsoon is less pronounced and the 20 line across West Africa is located 1° further south. It can also be noticed (Fig. 4(c)) that the magnitude of the moisture flux over the southern Atlantic and over West Africa is greater during the wet periods than during the dry periods. In September, the monsoon is beginning to decrease in intensity for both wet and dry years. However, the meridional flux still penetrates in land, indicating a persistence of West African monsoon activity.

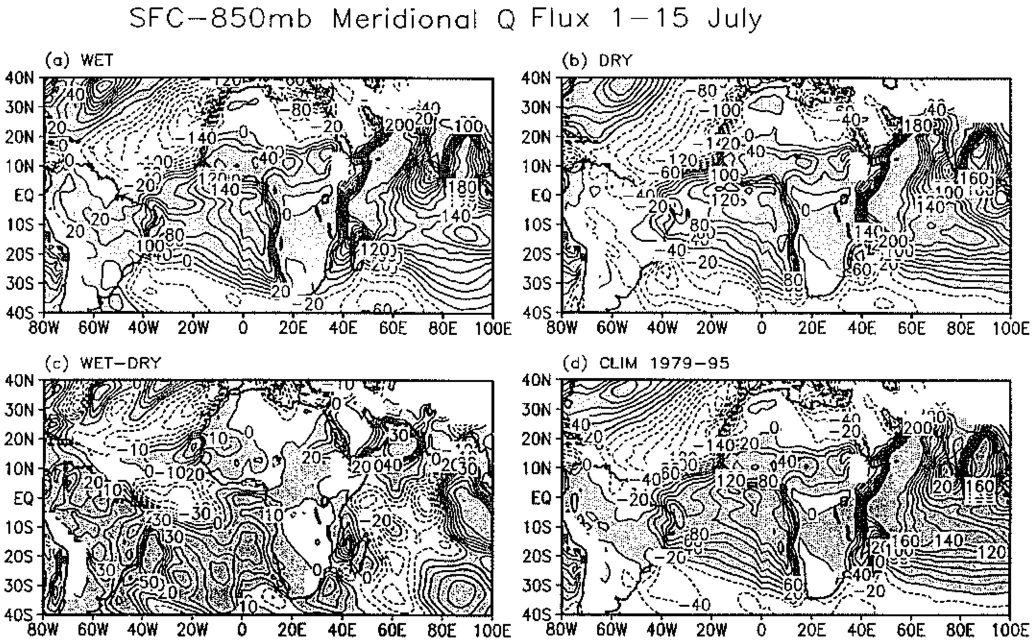

Fig. 4 Vertically integrated mean meridional flux of water vapour for the surface to 850 hPa for 1–15 July for the wet (a), and dry period (b), wet–dry (c), and climatology (d). Units are kg m^{-1} s^{-1}.

Acknowledgements The authors would like to thank Wayne Higgins and the anonymous reviewers for their constructive criticism of the manuscript. Appreciation is also expressed to Julian Wang for providing some of the re-analysis data.

REFERENCES

Burpee, R. W. (1974) Characteristics of north African easterly waves during the summers of 1968 and 1969. *J. Atmos. Sci.* **31**, 1556–1570.

Cadet, D. L. & Nnoli, N. O. (1987) Water vapour transport over Africa and the Atlantic ocean during summer 1979. *Quart. J. Roy. Met. Soc.* **113**, 581–602.

Lamb, P. J. (1985) Rainfall in sub-Saharan West Africa during 1941–83. *Gletscherk. Glazialgeol.* **21**, 131–139.

Newell, R. E. & Kidson, J. W. (1984) African mean wind changes between Sahelian wet and dry periods. *J. Climatol.* **4**, 27–33.

Nicholson, S. E. *et al.* (1988) *Atlas of African Rainfall and its Interannual Variability*. Dept of Meteorology, Florida State University, Tallahassee, Florida 32306, USA.