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Some aspects of the West African monsoon circulation as deduced from a geostationary satellite

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सार–इस शोध पत्र में 15 जुलाई से 10 अगस्त 1979 के एफ. जी. जी. ई. अभियान के दौरान अभिलक्षित और उपग्रह से लिये गए मेघ पवनों के सदिश मे ज्ञात किये गए पश्चिमी अफ्रीका के मानसूनी परिसंचरण के कुछ लक्षणों पर चर्चा की गई है। परिकलित पवनों के सामयिक औसत मानों से ज्ञात हुआ है कि निम्न तलों पर पवनों का प्रवाह दक्षिणी (मानसूनी) है तथा महाद्वीपीय उत्तरपूर्वी पवनों के साथ इस प्रवाह की विच्छेद रेखा लगभग 16°–18° उ० पर, मान्य माध्य स्थिति के दक्षिण में लगभग 300 किमी० की दूरी पर स्थित है। मध्य और उच्च क्षोभमंडल के दोनों क्षेत्रों में पवनों का प्रवाह पूर्वी है जिसका अक्ष लगभग क्रमश: 12°–14° उ० और 8° उ० अक्षांशों पर स्थित है। अक्ष दक्षिण की ओर चक्रवाती और उत्तर की ओर प्रतिचक्रवाती परिसंचरण है। उप-क्षेत्र पर जुलाई/अगस्त माह की मौसम की प्रतीकात्मक एवं अत्यक्ष परिघटनाओं के संदर्भ में, उपग्रह से प्राप्त प्रेक्षणों पर आधारित क्षोभमंडलीय परिसंचरण पर चर्चा की गई है।

उपग्रह से प्राप्त प्रेक्षणों पर आधारित ग्रिड-पवनों से ज्ञात किये गए वायुराशि क्षेत्र दर्शाते हैं कि स्थल क्षेत्र पर पवनों का अंतर्वाह मुख्यत: निम्नतम तल 1000–850 हे० पा० पर होता है, जबकि उच्चतर तलों (850 हे० पा० के ऊपर) पर पवनों का बहिर्वाह अधिक महत्वपूर्ण है। क्षोभमंडलीय पवनों के औसत मानों से ज्ञात होता है कि इस क्षेत्र से वायुराशि का अपसरण होता है। मानसून की चरम अवस्था के आस-पास, मानसूनी वर्षा के अस्थायी रूप से रुकने की मौसम परिघटना के संदर्भ में इस निष्कर्ष के महत्व पर भी चर्चा की गई है।

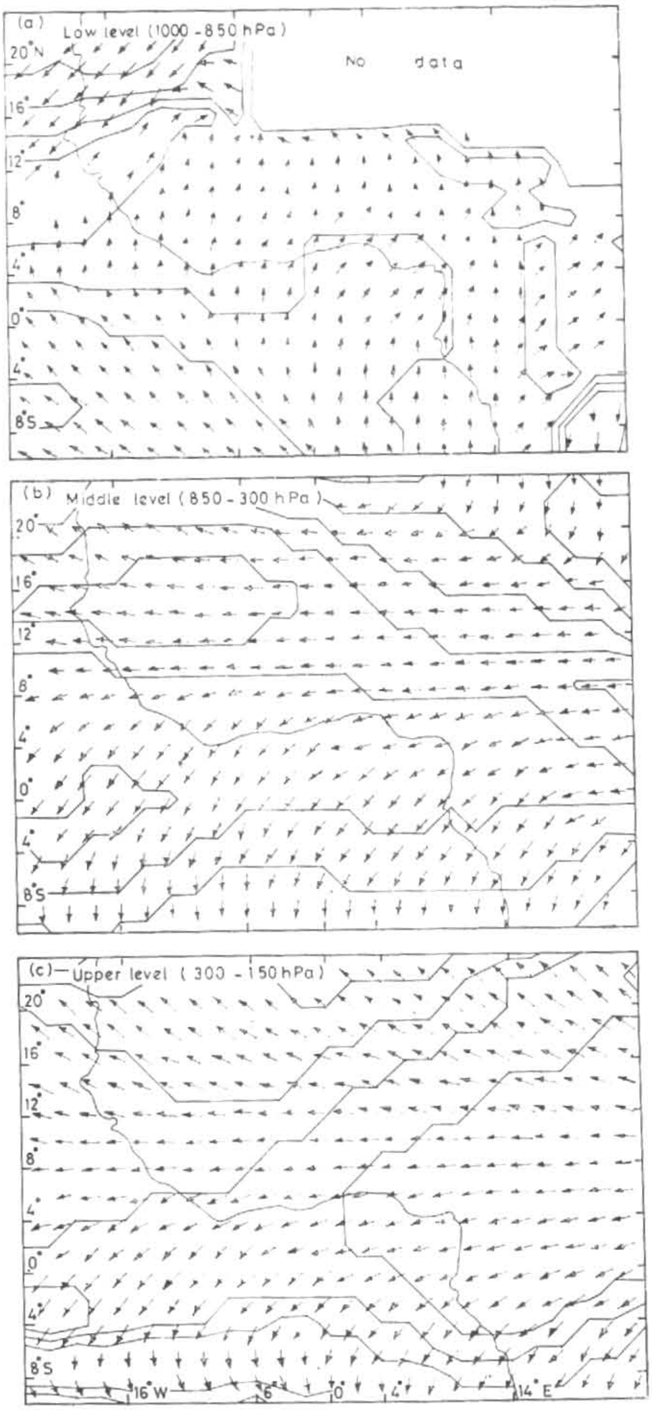
ABSTRACT. This paper focusses on some aspects of the West African monsoonal circulation observed during the period : 15 July-10 August 1979 of the FGGE, as derived from the satellite cloud windvectors. Temporal averages of the computed windfields reveal that the flow at the low level is southerly (monsoonal), and its line of discontinuity with the continental northeasterly was found at approximately 16°-18°N, lying about 300 km south of the accepted mean position. At both the middle and upper troposphere, the flow is easterly with an axis about 12°-14°N and latitude 8° N respectively, such that it is a cyclonic circulation south of the axis and northwards, it is anticyclonic. The satellite-observed tropospheric circulation is then discussed in relation to the weather manifestations over the sub-region typical of the July/August period.

The mass fields obtained from our gridded satellite-winds indicate that inflow into the land area occur mainly at the lowest layer (1000-850 hPa), whereas at the upper levels (that is, above 850 hPa) it is predominantly an outflow. The tropospheric average gives a net mass for divergence from within the area. The significance of this result in relation to the observed weather phenomenology of a temporary cessation of the monsoon precipitations occurring about the peak of the season is also discussed.

Key words — West Africa, Satellite-derived windfields, Monsoon circulation, Mass-budget.

1. Introduction

It is well known that the mean near surface flow over the West African area exhibits a seasonal reversal such that during the northern summer, it is predominantly southwesterly. This current originates from the south Atlantic due to the pressure gradient that exists between the south hemispheric high and the low pressure situated over North Africa. The air close to the surface is heavily moisture laden and from the condensation of water vapour through latent heat release, it is the primary source for most of the precipitation that is received during the monsoon period. The southwesterly flow forms a wedge underneath the relatively drier continental northeasterlies (blowing over the Sahara desert) with the transition between the two air-masses at the surface identified as the Inter-Tropical Discontinuity (ITD) line over West Africa(Hamilton and Archbold 1945, Adejokun 1966). At the peak of the monsoons in July/August, the most northward extent of the southwesterly flow as marked by the position of the ITD line is reached which is approximately 22°-25° N. Associated with the northward (latitudinal) migration of the ITD over the area (the surface position at the beginning of the season in April is 6°-8°N), are the identified zones of different convective patterns that partitions the entire area into latitudinal bands of distinct weather characteristics (Hamilton and Archbold 1945, Walker 1960). Contrary to the well recognised flow features at or near surface over West Africa, the circulation at the upper levels of the troposphere is not as well studied particularly in



Figs. 1(a-c). (a) Low level (1000-850 hPa), (b) middle level (850-300 hPa), and (c) upper level (300-150 hPa) flow field over the West African area during the priod 15 July-10 August 1979 at 0000 UTC and 1200 UTC

close connection to the observed surface weather (specifically in relation to the precipitation characteristics). This has been attributed mainly to the paucity of the upper-air data existing within the region. It is in this regard that the availability of the satellite cloud winds which is made use of in this study proves to be of an advantage in obtaining a three dimensional structure of the regional circulation.

It is the purpose of this paper to detail out some of the prominent features of the regional monsoon circulation for the entire troposphere that was derived from the METEOSAT cloud winds observed during the peak of the monsoon period in July/August of 1979. This is explained in relation to the surface weather phenomena typical of the period within the West African area. The study is based only on the satellite-derived winds data collated for the Special Observation Period (SOP), 15th July-10th August, which falls within conduct of the West African Monsoon Experiment (WAMEX) of 1979 and served as part of the monsoon sub-programme of the FGGE (WMO 1988). The satellite winds selected encompass an area defined by latitude 10° S and 24° N, and by longitude 25°W and 25°E which in essence covers the entire continental West Africa. The year 1979 that has been chosen in this study is reported to be a typical monsoon year in West African considering the patterns of occurrence of the onset and cessation of the monsoon rains during the year (Adefolalu *et al.* 1985, WMO 1990).

Estimates for the mass distribution along the lateral boundary of the domain have also been obtained from the same data set and which is discussed for the entire tropospheric depth.

2. Data

As part of the monsoon sub-programme of the Global Atmospheric Research Programme (GARP), the WAMEX was initiated to produce for analyses, an extensive database specifically for the West African area comprising of both conventional meteorological instrumentation and satellite-derived data for the required variables (WMO 1978, 1988). It is in support of this experiment that the satellite derived gridded winds (from the METEOSAT) used in this study have been produced. These satellite wind vectors have been obtained by the tracking of cloud and water vapour elements from successive images produced every 30 min in three spectral bands : one band in the visible spectrum and two in the infrared spectrum to generate the windfields at three main levels : low (1000-850 hPa), middle (850-300 hPa) and upper (300-150 hPa). The digitizing and quality control for the satellite winds have been processed using the Man-computer Interactive Data Access System (McIDAS) based at the Space Science and Engineering Centre (SSEC) of the University of Wisconsin, Madison, USA. Details about the technicalities involved in the extraction and processing of the WAMEX windsets are contained in a special report published by the SSEC and is available on request [Balogun 1982(a)]. The satellite-derived wind data analysed for this study was made accessible to the author by Professor E.E. Balogun (personal communications). These are windsets retrieved from the (0000 UTC and 1200 UTC) data stored on a $2° \times 2°$ grid format covering an area which is essentially the whole of the West African sub-region on a magnetic tape for the period : 15th July-10th August and at the three afore-mentioned levels above.

3. Circulation patterns obsereved during the period : 15th July-10th August

The main circulation features observed within the troposphere over West Africa during the period are presented in the Figs. 1 (a-c). These represent the layer averaged flow conditions for the low, middle and upper levels respectively. The windvector plots analysed have been computed from the zonal and meriodional wind components digitized at every $2° \times 2°$ grid.

From Fig. 1(a), it is observed that at the lowest levels, there was a southerly flow coming into the area from the over south Atlantic and penetrates into inland areas reaching as far as 16°-18°N where it meets the continental northeasterly winds. It should be mentioned here that it is the monsoon current which brings over the area moisture from its transport over the Atlantic into the continent. This is responsible for almost 80% of the annual rainfall totals received (Balogun 1981, Omotosho 1984, 1985). In Fig. 1(a), our identified latitudinal position of intersection for the two currents falls well behind the generally accepted position of the northward tip of the monsoon flow at the peak period about July/August. The position that is often quoted for the monsoon peak period in the literature is approximately 22°-25° N (Hamilton and Archbold 1945, Walker 1960 Adejokun 1966). From separate data collated during the WAMEX (WMO 1990) the spatial mean for the surface position of the ITD line was established to range from 17.9° N in July to 19.6° N in August of 1979. The disparity in our results may be attributed to the fact that in our case the satellite wind data represents an average for a layer (1000-850 hPa) and the confluence of the two currents which is located at about 16°-18° N as shown in Fig. 1(a), might not actually be a true position of the wedge at the surface (that is, the ITD line) but rather at a relatively higher level (which is behind) since the wedge slants heavily in a north-south direction. However, it is clear that the position of the ITD line for the July/August period in 1979 lags well behind the mean. In a related study of the climatology of the annual precipitation trends over the West African area, Lamb (1977, 1978) has associated the years with pronounced drought in the Sudan sahelian areas as those having poor northward penetration of the south-westerlies during the course of the monsoon season (that is, the flow not reaching as far as 20°N). Therefore, it is stressed here that this feature of the ITD line not quite advancing up to its long-time mean latitudinal position for the period July/August is a reflection of a weakness in the intensity of the monsoon season during the particular year over the entire area. In another study reported by the WMO (1990), the monsoon year of 1979 was partby likened to those of the other years (*e. g.*, 1972) with drought manifesting in the sahelian area of the sub-region as a consequence of the shallow penetration, by the monsoonal flow during the season.

In Fig. 1(b), the flow at the middle levels (850-300 hPa) is easterly having an axis positioned along 12°-14°N where a separation of the flow is noticed to occur such that south of the latitude, the flow is cyclonic, whereas it is observed as anticyclonic north of the latitude. The synoptic observation that there littal is or no convective activity in the areas beyond 20° N [which is north of the axis in Fig. 1(b)] is supported here because of the mid-level anticyclone that is found to exist in those parts, unlike in the areas south of the axis where convective activity is manifest which is indicated by the cyclonic circulation noticed in these parts. The middle level flow characteristics mapped out in Fig. 1(b) is supportive of the previous classical studies in which the land areas over West Africa has been partitioned into different weather zones or latitudinal bands from the coastal line up to about 20°N (Hamilton and Archbold 1945, Schove 1947). According to a study by Shinoda (1986) which is based on an analysis of the 1979 FGGE data over West Africa, he showed that the precipitating areas (over 10 mm rainfall) to be located south of the ITD line which he has defined as the steep gradient zone of specific humidity as 922 hPa which crosses 15°-20°N. Also the author has

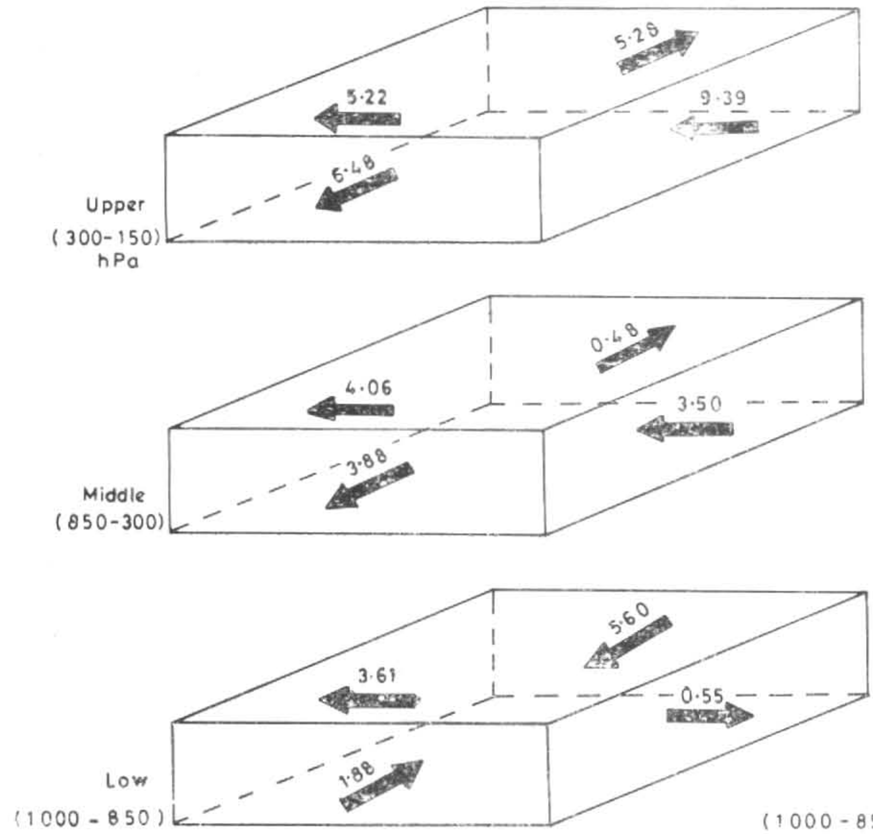


Fig. 2. Layer by layer normal wind components, Cn around the lateral boundary of the domain : 10°S, 25°E, 24°N and 25°W (unit : ms^{-1})

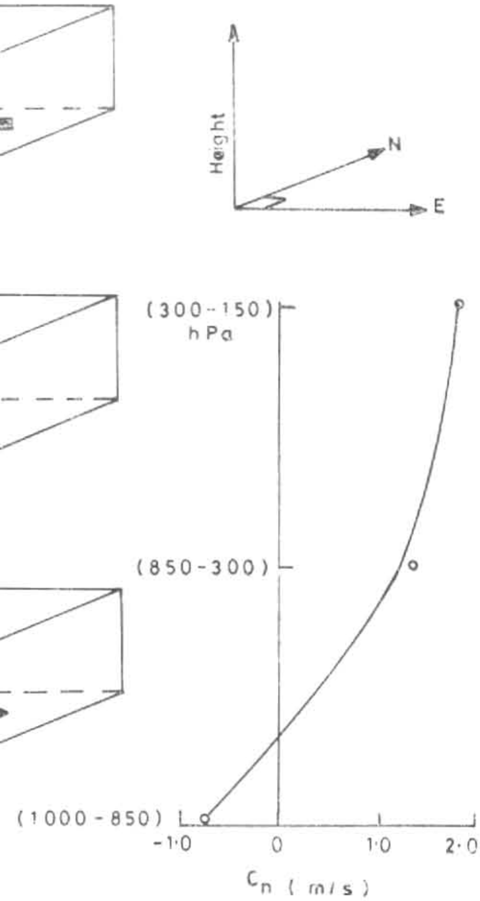


Fig. 3. Vertical profile of the layer averaged normal wind Cn components over West Africa for the same period

identified that the zone of maximum rainfall over the area is located between the latitudinal band 10°-15°N for the same period. It should be remarked that the axis of the easterly current in Fig. 1(b), found as approximately 12°-14°N is in a close agreement to the acknowledged position of the middle-level African Easterly Jet (AEJ) which is at about 700 hPa over West Africa.

The flow patterns at the upper levels (300-150 hPa) shown in Fig. 1(c), are very similar to the middle level flow. But the position of the axis of the easterly flow has shifted southwards to about 8°N. This latitudinal position for the axis of the easterly flow in the figure for the upper levels is noted to be coincident to that of Tropical Easterly Jet (TEJ) at 200 hPa located over West Africa for the period of observation. When compared with the middle level circulation, the curvature of the upper level flow is not as prominent which suggests that the influence of the jet steam on the flow at the upper level is more intense during the period.

The appearance of the two jet streams (AEJ and TEJ) during the monsoons is seen on the surface weather by the presence of a zone of bad weather formation in between the relative latitudinal positions of the jets (WMO 1990). This band which is about 200 km wide corresponds to a region of maximum rainfall, and it moves northward with the jets such that its poleward displacement is observed to be about half that of the jets. As the distance between jets widens the band becomes narrower. The position of this band of bad weather is in agreement with the identified weather zone C for West Africa (Hamilton and Archbold 1945) which is typified by intense convective activity. It should be noted here that the formations of both the AEJ and the TEJ stipulate different conditions (strength of the jet and its position) for an active precipitation to be sustained during the monsoons.

4. Mass distribution around the lateral boundary

The mass fields within the West African area obtained for the period is as represented in Fig. 2 showing the layer by layer averages for the low (1000-850 hPa), middle (850-300 hPa) and upper (300-150 hPa) levels. These averages have been determined from the normal wind components taken at 2° grid locations around the lateral boundary of the domain prescribed by 10°S, 25°E, 24°N and 25°W. At the low levels, the mass inflow into the area occurs both at the southern and northern boundaries, reflecting the influences of the monsoonal current (southwesterlies) and the continental northeasterlies. Also at the low levels, there is outflow from both the eastern and western flanks. Above, at both the middle and upper levels, the patterns are quite similar with an inflow into the area occurring only at the eastern boundary which in some sense justifies the expectation of the influence of the easterly and the two main jet streams moving over the sub-region. At these levels, outflow is noted to occur from the western, southern and northern boundaries.

The mass fields at each layer are shown by the profile in Fig. 3. This summary indicates that the mass inflow into the area takes place at the lowest levels while outflow occurs at both the middle and upper troposphere. The inflow at the lowest levels by the southwesterlies is responsible suggesting that for the moisture flux into the area. This feature of the low-level flow field, suggesting that it is predominantly an inflow of moisture at the lower levels from the transport over the Atlantic is discussed by Balogun [1982(b)]. The water vapour flux budget obtained over the West African area during the 1979 monsoon season by Cadet and Nnoli (1987) also brings out the same conclusion for the low level flow. This influx at the lowest levels is overcompensated for by the flow at the upper level which accounts for a larger outflow (of moisture) from within the area at these levels. This feature is probably a consequence of the two easterly jets—AEJ and TEJ, acting as a major artery for the moisture. The tropospheric average indicates mass divergence from the area during the period. The picture of mass divergence that we have obtained is probably a reason why there is the usual occurrence of a break in precipitations in areas lying below latitude 15°N during the monsoon peak period (from mid-July to mid-August) despite the thickness of the monsoon layer. Such a circulation pattern is probably responsible for the noticeable period of a temporary cessation of the monsoon rains which is well described as the "Little Dry Season" or the LDS in West Africa (Hamilton and Archbold 1945, Omotosho 1988, Jegede and Balogun 1991).

5. Conclusions

From the gridded satellite windsets used in this study, we have been able to obtain quantitatively, a three dimensional picture of the flow characteristics in West Africa typifying the monsoon peak period (July/August). At the low levels, the southwesterly (monsoon) winds plotted did not penetrate beyond 18°N (which falls behind the long-time mean position, 20°N for the monsoon peak). Consequently, we have been able to assert that the monsoonal activity in 1979 was weak. The axes of the easterly currents, was about 12°-14°N at the middle layer (850-300 hPa) and at the upper layer (300-150 hPa) it was 8°N, which are coincident with positions of the AEJ and the TEJ respectively, over the area. The mass flux estimations around the lateral boundary of the domain indicate that mass (and moisture) inflow into the area occur at the lowest levels, which is overcompensated by the outflow at the upper levels. From the tropospheric volume, the net mass divergence within the area was associated with the feature of a temporary break in monsoon rains during the period. This phenomenon is described in the literature as the "Little Dry Season" or the LDS .

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