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Laboratoire de Météorologie Dynamique du CNRS, Ecole Polytechnique, Palaiseau, France

Comparison of the African and the 6–9 day Wave-like Disturbance Patterns over West-Africa and the Tropical Atlantic During Summer 1985

A. Viltard, P. de Felice, and **J. Oubuih**

With 9 Figures

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Summary

Using the ECMWF and NMC analyses, this study documents the composite structures of the African and of the 6–9 day waves. In spite of the fact that the two types of disturbances develop over almost the same area, i.e. Central and West Africa and the tropical Atlantic, during the same season, i.e. summer, in spite of the fact that they have almost the same East-West velocity, i.e. 7–8 degree longitude per day, the structures of the two waves are very different.

At 12.5° N, the African wave has an amplitude maximum in the meridional wind component whilst the zonal wind component is almost unperturbed. On the contrary, in the 6–9 day wave, at 12.5° N and also at 12.5° S, the zonal wind component has an amplitude maximum whilst the meridional wind component is very small and there is an amplitude maximum for the meridional wind component at the equator and 20° N.

1. Introduction

Synoptic-scale wave-like disturbances have long been known to exist in the tropical belt. Westward propagating African disturbances have been described by Piersig (1936) and Regula (1936). The Easterly wave has been mentioned by Riehl (1948). The most detailed and recent studies of the African wave disturbances have been made by Carlson (1969a, b), Burpee (1972, 1974, 1975) and by Reed et al. (1977, 1988a, b). The waves have been most extensively studied over the west coast of Africa and the tropical Atlantic between 5° N–20° N, mostly during the second half of the monsoon seasons (August–September). Typically, African waves have a wavelength of about 2500–3000 km, a period of 3–5 days and a westward phase velocity of about 7–8 degree longitude per day. They are better detected in the meridional than in the zonal wind component at the 850 and 700 hPa levels.

Yanai and Murakami (1970) have shown that a second type of disturbances, apparently not related to the African waves is situated close to the equator and has a longer wavelength (about 6000 km). De Felice et al. (1990, 1992) using the European Centre for Medium-Range Weather Forecasts (ECMWF) analyses have shown that synoptic-scale wave disturbances moved westward over West Africa and the tropical Atlantic during summer 1981. They had a 6–9 day period and a velocity of about 8.5 degree longitude per day. The wave structure had features similar to a mixed Rossby-gravity wave, like the disturbances of Yanai and Murakami.

Now the 6–9 day disturbances have a zonal velocity almost equal to that of the African waves. They are observed during the same season, over the same area, with a period almost double. For these reasons the 6–9 day disturbances are often considered merely as the result of the strengthening of the African waves one time out of two. In this paper we try to show that the African wave and the 6–9 day wave are two very different types of disturbances. The African wave is most easily identified in the meridional wind component at about 12° N and does not much affect the zonal wind component. On the contrary, at this latitude the 6–9 day wave is most easily identified in the zonal wind component. At 12° N, which is the mean latitude of the Intertropical Convergence Zone (ITCZ) during summer over West Africa, the mean zonal wind component at 700 hPa is about 8–12 ms^{-1}, thus the 6–9 day does not change the zonal wind direction since its amplitude is about 3 ms^{-1}. This is why this wave is not readily seen on the synoptic charts. On the contrary the mean meridional wind component is very small at this level and this latitude; the African wave changes its direction periodically and this is easily detected on the synoptic charts.

In the next section we describe the data used. We describe the composing methods in Section 3 and make a few comments on the African and 6–9 day waves composite structures in Section 4. In Section 5 we add further evidence of the existence of the 6–9 day wave on several parameters using observational data.

2. Data

Most of our results were obtained from two (1981 and 1985) summers (1 July–30 September) with twice daily (00 00 and 12 00 UTC) analysed wind fields of the ECMWF and NMC systems (four daily, 00 00, 06 00, 12 00 and 18 00 UTC) at the 700 hPa level on a 2.5° × 2.5° grid, between the latitude circles 30° N and 30° S and the longitudes 60° W–20° E.

Reed et al. (1988a, b) assessed the performance of the ECMWF system in analysing Easterly wave disturbances over Africa and the tropical Atlantic during summer 1985. We also include the radiosonde data from Dakar (14.75° N, 17.5° W), for the summers of 1960 and 1974, as well as the sea level pressure observations for 26 stations of West Africa during summer 1974.

The 6–9 day wave disturbances do not appear clearly each summer. The summers of 1981 and 1985, were chosen because the 6–9 day waves were better organized and developed during these summers than during the other summers for which we have data. De Felice et al. (1992) have suggested an explanation for the 6–9 day wave intermittency which might be linked to the zonal wind component vertical meridional profile. A nearly uniform zonal wind profile would be suitable for the 6–9 day wave development and a zonal wind profile with large shears would not be.

3. Composite Analysis

We have applied the same composite method to study the African and the 6–9 day wave structures. The method has been described in some detail by de Felice et al. (1990). It is close to the method used by Reed and Recker (1971) and by Burpee (1975). We chose the level and latitude where the African and the 6–9 day waves had large amplitudes: 700 hPa and 12.5° N. The period is 1 July–30 September, the area 30° N–30° S, 60° W–20° E, for both disturbances. The compositing is accomplished by dividing each wave into eight categories determined (i) for the African wave, from the filtered meridional wind component series and (ii) for the 6–9 day wave, from the filtered zonal wind component series. Category 1 dates are associated with maximum southerly (westerly) wind and category 5 dates with maximum northerly (easterly) wind. The dates of categories 2, 3 and 4 are at a quarter, half and three quarter respectively, of the interval between category 1 and the following category 5. The dates of categories 6, 7 and 8 are at a quarter, half and three quarter, respectively, of the interval between category 5 and category 1 of the following wave. We should emphasize here that only the dates of the categories are determined with the filtered series, using a bandpass first-order Butterworth filter (Krishnamurti et al., 1990).

After estimating the value of each parameter (e.g., zonal and meridional wind components) for each category at each longitude, the mean values are computed for each latitude over all the waves of the interval 1 July–30 September. As there is about twenty five African waves and about thirteen 6–9 day waves in the time interval, and 33 grid points on each latitude, between 60° W and 20° E, each composite value is a mean of about 825 values for the African wave and 430 values for the 6–9 day wave. The values which were composited were the anomalies computed on each grid point by substracting the mean of the period

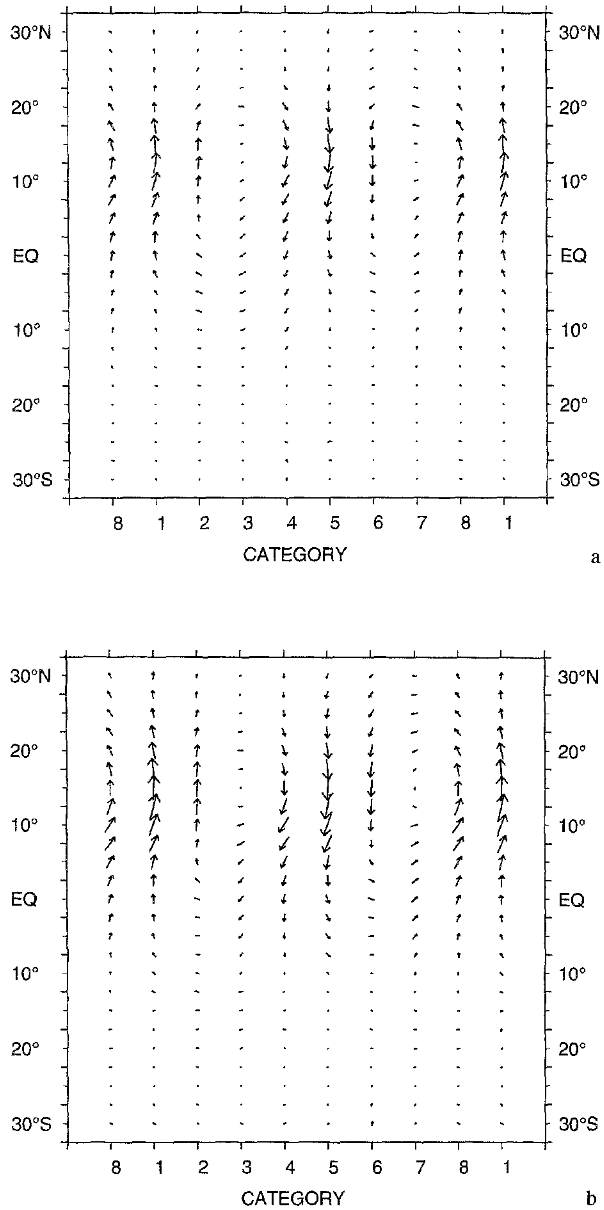


Fig. 1. The African composite wave of the wind vector anomalies at the 700 hPa level, computed with unfiltered data. a) Summer 1981; wind vector maximum is 2.80 ms^{-1}; b) Summer 1985; wind vector maximum is 2.85 ms^{-1}

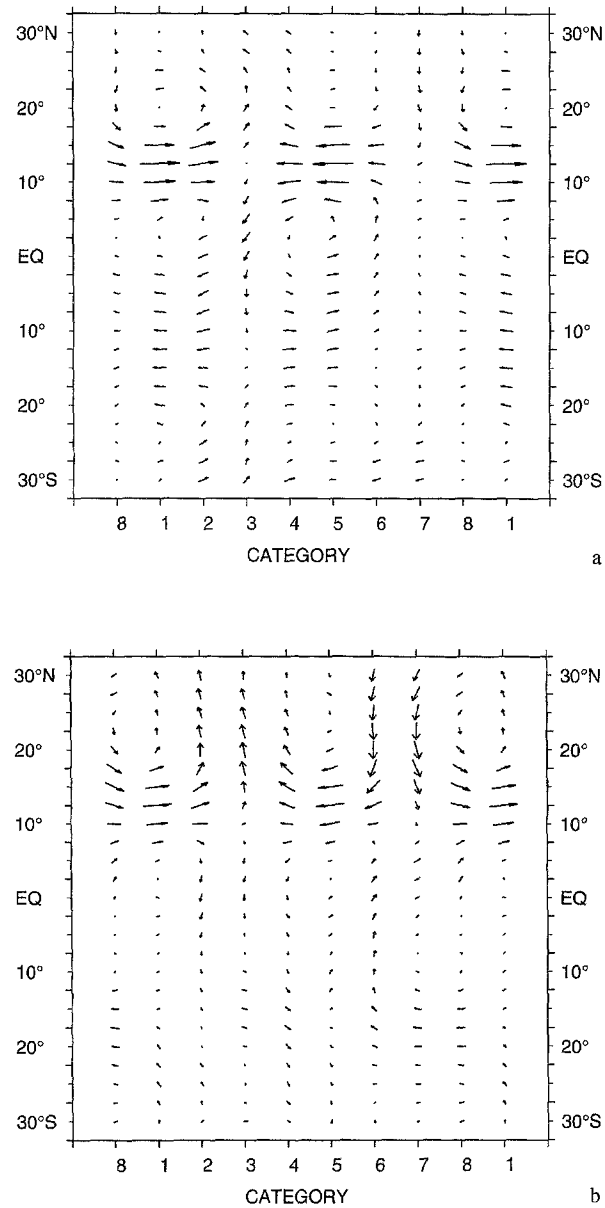


Fig. 2. Same as Fig. 1 but for the 6–9 day wave. a) Summer 1981; wind vector maximum is 3.10 ms^{-1}; b) Summer 1985; wind vector maximum is 3.15 ms^{-1}

1 July–30 September. The results are displayed in Fig. 1a and b for the African wave and in Fig. 2a and b for the 6–9 day wave.

In the method described above, the dates of the categories were determined at each longitude for all latitudes (30° N–30° S) from a particular latitude (12.5° N), on which the wave had a amplitude maximum. However, if the wave feature at other latitudes do not maintain a constant phase difference relative to those at 12.5° N, the amplitude of the wave composite at these latitudes will be too small (Duvel, 1990). This effect is not very important when the latitude considered is not too far from the reference latitude. For example, the meridional wind component amplitude in the African wave, computed by Duvel at 10° N, 15° W, was 1.5 ms^{-1} when the latitude used for compositing was 20° N, and 2 ms^{-1} when the

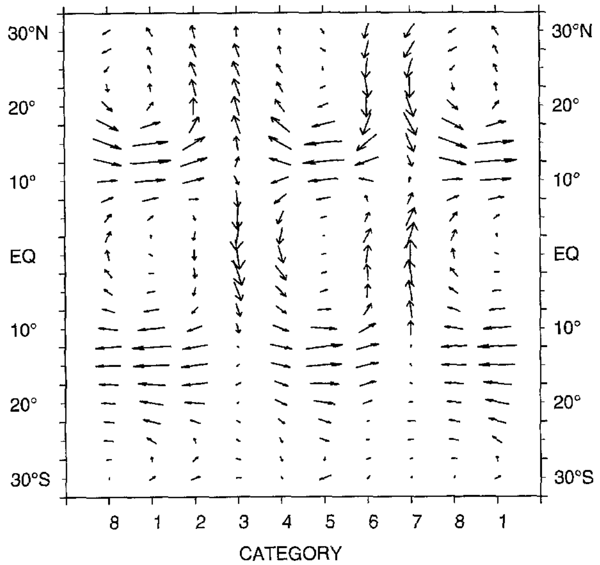


Fig. 3. Same as Fig. 2b, but with (i) the reference latitude 12.5° N for the zonal wind component in the northern hemisphere, (ii) the reference latitude 0° for the meridional wind component in the vicinity of the equator and (iii) the reference latitude 12.5° S for the zonal wind component in the southern hemisphere; wind vector maximum is 3.2 ms^{-1}

reference latitude was 10° N. Our reference latitude is 12.5° N, hence we think that in the interval 7.5° N–17.5° N which, according to Reed et al. (1977) is the area where the African wave develops, the effect mentioned by Duvel should not be very large.

Figure 2 shows that the zonal wind component is affected by the 6–9 day wave in the latitude interval 25° S-25° N. There is a zonal wind maximum on categories 1 and 5 clearly visible at 12.5° S with signs opposite to those at 12.5° N on the same categories. So, following Duvel, we composited the zonal wind component in the southern hemisphere with the dates of the categories determined by the filtered zonal wind series at 12.5° S, instead of 12.5° N. Figure 2 also shows an amplitude maximum of the meridional wind component at the equator, hence we composited the meridional wind component between 10° N–10° S with the dates of the categories determined on the filtered series of the meridional wind component at the equator. Figure 3 displays the result of this composition for 1985. We got the same pattern (not shown) with the NMC analyses. The pattern obtained for 1981 (not shown) is almost identical, though the noise is a bit larger in 1985 than in 1981. The pattern looks very much like the schematic illustration of pressure and streamline patterns for the mixed Rossby-gravity wave displayed by Wallace (1973). Figure 3 is very close to Fig. 6 in de Felice et al. (1992) which was obtained on a time interval of 51 days (7 July–26 August) of summer 1981, on the longitude interval 60° W–10° W, with filtered wind components. In the present paper, filtering was used only to determine the dates of the zonal wind component maximums. The composited data were the anomalies of the velocity which have not been filtered. We think that if the 6–9 day oscillation did not exist, it would be difficult to explain how, by compositing 430 values one could have an amplitude of the wave zonal component as large as 3 ms^{-1} when the wind mean velocity was about 8 ms^{-1} at 12.5° N. This suggests the 6–9 day wave-like disturbance pattern is rather robust.

4. Comparison of the African and 6–9 Day Wavelike Disturbances

Figure 1a displays the wind perturbation caused by the African wave. It mainly affects the meridional wind component with a perturbation maximum at 12.5° N, which reduces northward and southward. The zonal wind component is not very much influenced by the African wave. There are two vortices centered about 12.5° N, anticyclonic on category 3 and cyclonic on category 7. When we composited the anomalies, we have extracted from the initial data the wave mean effect on the wind field. The patterns obtained by this method are very different from what is observed on a synoptic chart where the African wave, easily detectable, moves East-West in a wind field with zonal wind component meridional gradients. For this reason we composited the African wave with the initial data instead of their anomalies computed on each grid point as described in Section 3. After compositing we substracted the zonal wind component mean velocity computed on the whole area and the whole summer. We did not substracted the meridional wind component mean velocity because it was very small. The pattern displayed in Fig. 4 is what would be seen by an observer moving westward at this mean velocity (5.6 ms^{-1}). We only considered the northern part of our area since the charts of the African wave

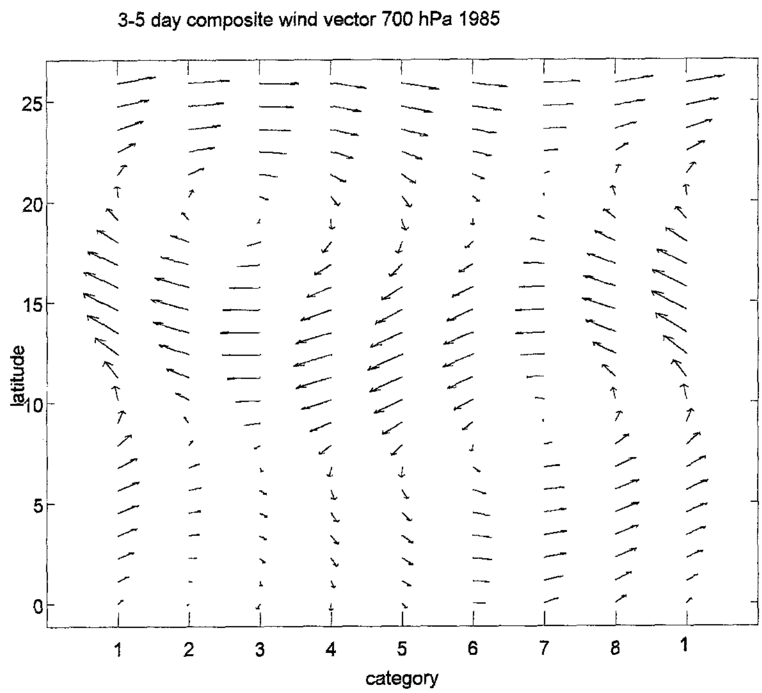


Fig. 4. The African composite wave at the 700 hPa level for summer 1985. The spatial and temporal mean of the zonal wind component ($-5.06\,ms^{-1}$) has been substracted from the composite values. Wind vector maximum is $4.69\,ms^{-1}$

published in the literature do not display the south of the equator where the African wave is not visible during the northern hemisphere summer. We used the ECMWF analyses on a $1.125° \times 1.125°$ grid with 4 data per day. Figure 4 looks very much like the figures displayed for example by Reed et al. (1977). The wave-like pattern is clearly visible between 10°–15° N with a ridge on category 3 and a trough on category 7. Whatever the compositing method, the two wave patterns are very different.

The African wave is mainly observed in the ITCZ, e.g. in a latitude belt approximately centered at 12.5° N. The 6–9 day wave affects a latitudinal zone extending approximately from 25° N to 25° S. In the African wave the meridional wind component is strongly affected at 12.5° N whilst the zonal wind component is only slightly affected. In the 6–9 day wave the zonal wind component is largely modulated by the wave at 12.5° N and 12.5° S whilst the meridional wind component is very small at these latitudes. Figure 5 displays the wind perturbation as a function of latitude on category 5, for the two disturbances. They display a meridional wind maximum (i) at 12.5° N for the African wave ($2.85\,ms^{-1}$) and (ii) at the equator for the 6–9 day wave ($2.6\,ms^{-1}$). The zonal wind perturbation maximum is $0.9\,ms^{-1}$ for the African wave and there are two maxima, one at 12.5° N ($3.15\,ms^{-1}$), the second at 12.5° S ($2.95\,ms^{-1}$) for the 6–9 day wave.

5. Further Evidence of the 6–9 Day Oscillation and Conclusion

We have used the ECMWF analyses to study the African and the 6–9 day disturbances because Reed et al. (1988a and b) have shown that it was possible to follow the African wave over Africa and the Atlantic ocean with these analyses. We applied a compositing method to view the two disturbances, for the summers of 1981 and 1985, at the 700 hPa level. We found the African wave pattern as described by Reed et al. (1977), for example. The African and 6–9 day disturbance patterns are very different from one another, as displayed by Fig. 1b and 3.

Figure 5 displays the latitudinal structure of the two disturbances on category 5. In Section 4 we have emphasized on the 12.5 ° N latitude, where the meridional wind component has a maximum in the African wave, and the zonal wind component a maximum in the 6–9 day wave.

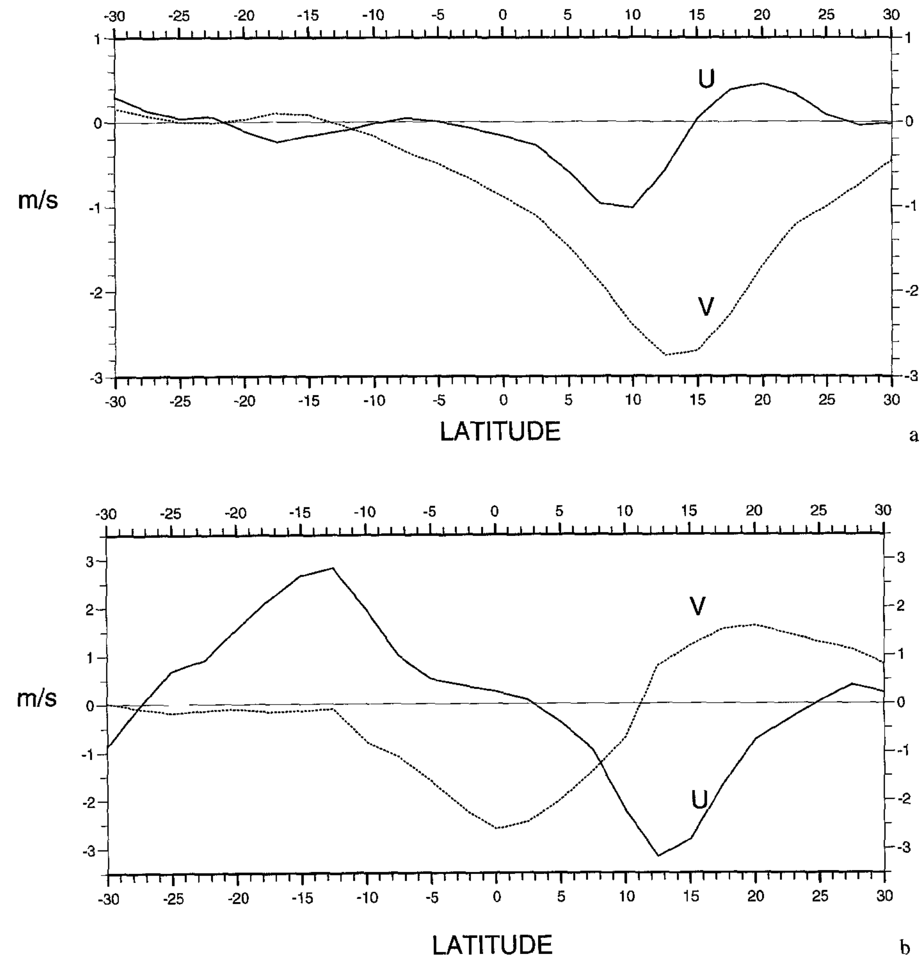
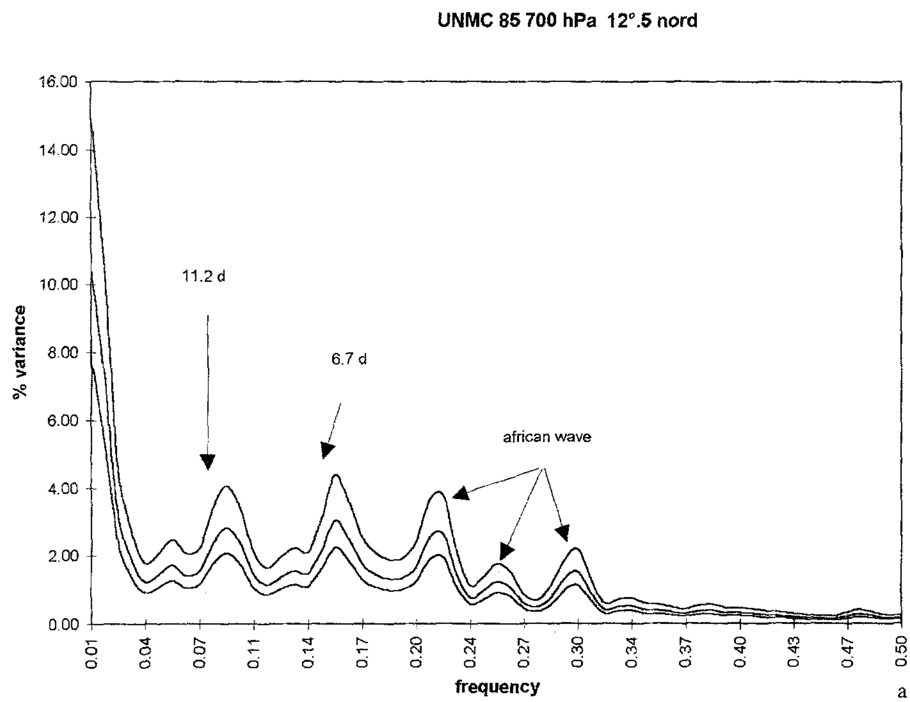


Fig. 5. Wind perturbation on category 5 as a function of latitude, at the 700 hPa level, for summer 1985. Continuous line, zonal wind component; interrupted line, meridional wind component: a) for the African wave; b) for the 6–9 day wave. Note the scale of (a) is twice that (b)

At the equator, the meridional wind has a maximum in the 6–9 day wave and we suggest it may explain the rather large modulation of about 6–7 day period Cadet and Houston (1984) found in the precipitable tropospheric water content over Africa and the Atlantic ocean.

We have computed the mean spectra for the meridional and zonal wind components (Fig. 6) along the 12.5° N latitudinal circle, between 60° W and 20° E with NMC analyses, for the whole summer 1985, at the 700 hPa level. For the zonal wind component, the largest peak (significant at the 90% confidence level, with 50 d.o.f) is at the 6.7 day period. The 4.5 day peak slightly smaller is also significant. There are also two small peaks at 4. and 3.3 days. The peak at the 14–15 day period may display the period detected by Krishnamurti and Bhalme (1976) in the Indian monsoon. For the meridional wind component the largest peak is for the African wave but the 6–9 day peak is also significant. For the vertical wind component power spectrum (not shown) there is much energy in the diurnal and semi-diurnal periods. The African wave is clearly visible and the 6–9 day oscillation is also displayed. There is again a small peak at the 14–15 day period.

The 6–9 day oscillation was observed on the wind component of several summers before 1981. Adefolalu (1974) found a large peak in the 6–9 day band period in the zonal wind component at N'djamena (12° 08′ N, 15° 02′ E) between the 950 and 600 hPa levels during summer 1958. The power spectrum of the zonal wind component for summer 1960 in Dakar (Fig. 7) shows a large peak for the frequency 0.13 day^{-1}, i.e. for the period 7.7 days. Viltard and de Felice (1979) have computed the power spectrum of the meridional wind component in Dakar for all tropospheric levels for the



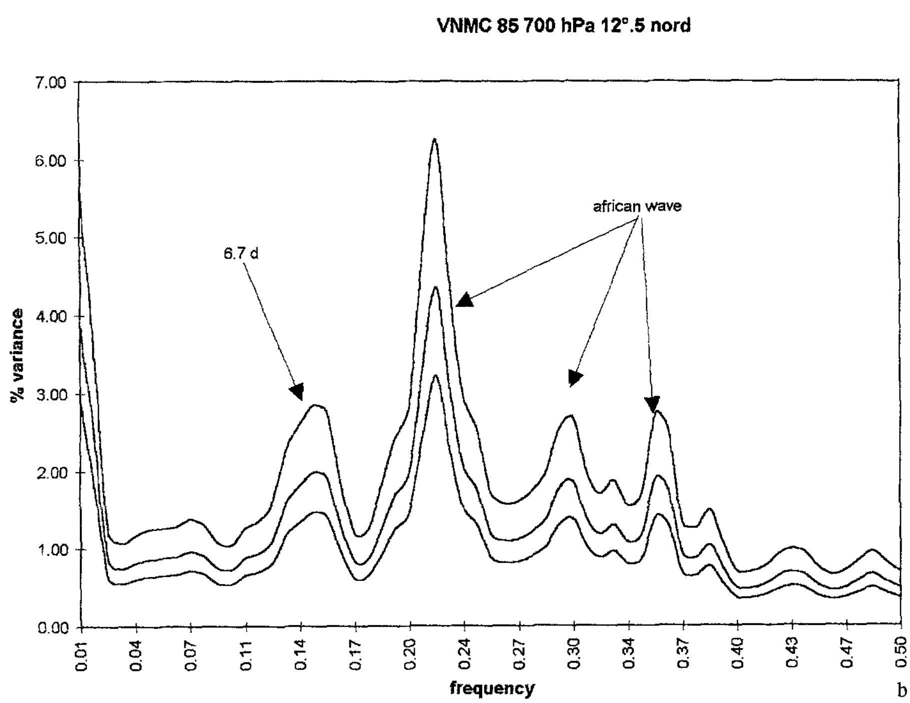


Fig. 6. Zonal (a) and meridional (b) wind component mean power spectra at 12.5° N, between 60° W–20° E, 700 hPa, summer 1985, with 90% confidence interval

period 24 June–20 September 1974 (GARP Atlantic Tropical Experiment), with four daily soundings. There were two intervals with large spectral energy: the 3.2–4. day interval from 950 to 200 hPa and the 6–9 day interval from 900 to 450 hPa.

The 6–9 day oscillation appears also on pressure. Figure 8 displays the mean power spectrum of the surface pressure (8 data per day) of 26 stations of West Africa, rather evenly distributed south of 21° N and west of 5° E, for summer 1974. There are clearly two large peaks at 7.4 and 4.6

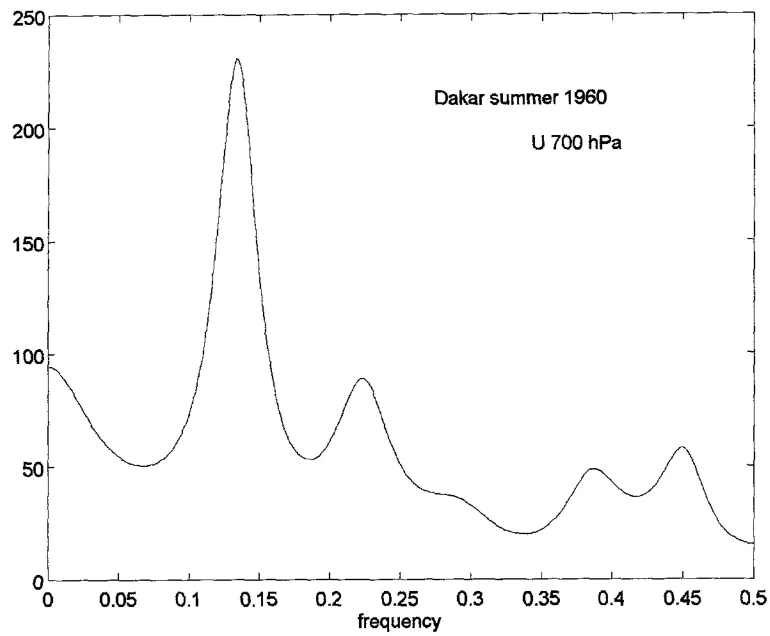


Fig. 7. Spectrum (MEM) of the zonal wind component in Dakar, 700 hPa, summer 1960; energy per frequency interval versus frequency (day^{-1})

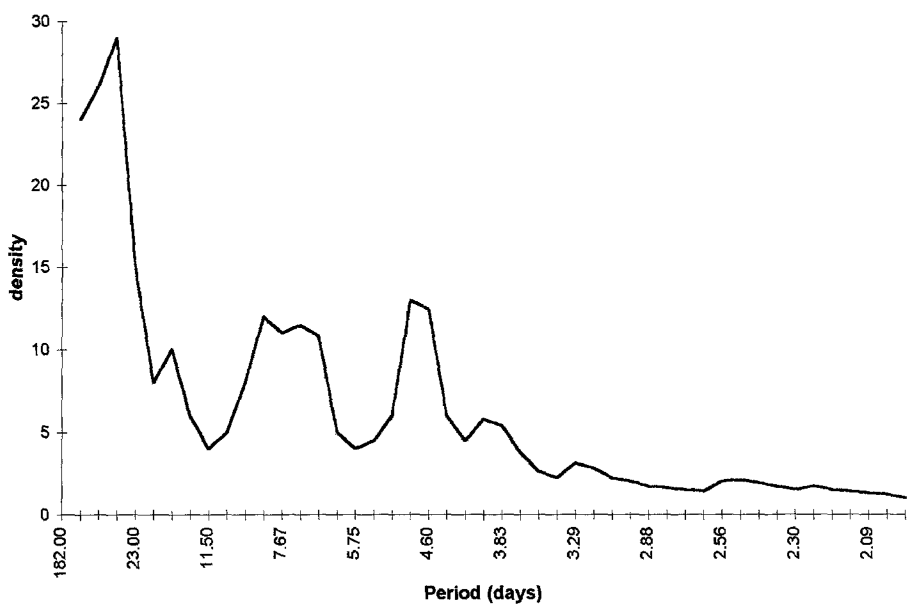


Fig. 8. Surface pressure mean power spectrum for 26 stations of Western Africa, summer 1974

days and two small peaks at 3.87 and 3 days. There again we find a small peak in the 13–15 day period interval.

The 6–9 day oscillation appeared on cloudiness in 1985. Figure 9 displays the power spectrum of the daily relative cloud covered pixel number on a 2.5° × 2.5° square centered at 15° N, 10° W for summer 1985. The data are extracted from the ISCCP-C1 catalogue (Sèze and Rossow, 1991a, b).

We have shown that the 6–9 day oscillation was detected on several atmospheric parameters: wind components, surface pressure, cloud cover, during the summers of several years in Western Africa and the Tropical Atlantic in the low and middle troposphere. We don't think it is an artefact of the ECMWF or NMC systems since the oscillation is displayed by stations' observations of wind and pressure and satellites' cloud cover measurements. The 6–9 day oscillation looks like a mixed Rossby-gravity wave. It is quite different from the African wave pattern. We propose to study the possible influence of the 6–9 day oscillation on other parameters such as water vapor content and rain.

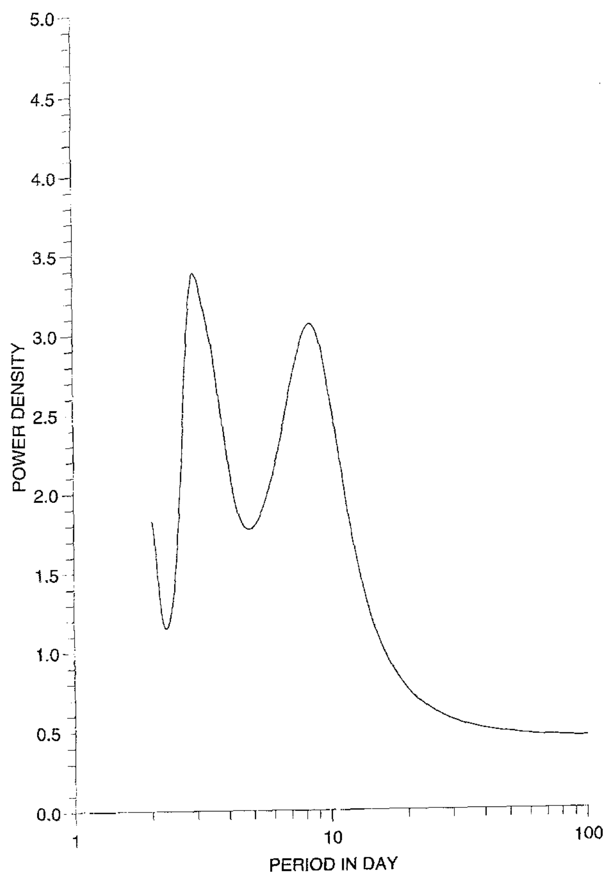


Fig. 9. Power spectrum of the relative cloud pixel number on a 2.5 × 2.5 degree square centered at 15° N, 10° W, summer 1985

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Authors' address: A. Viltard, P. de Felice and J. Oubuih, Laboratoire de Météorologie Dynamique du CNRS, Ecole Polytechnique, F-91128 Palaiseau Cedex, France.