# Observation of a Variable Northerly Wind Component in the African Monsoon Layer

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ABSTRACT

This note describes low-level observations obtained during WAMEX from an instrumented DC 7 aircraft. These data give a detailed description of the dynamical and thermodynamical structure of the layer 0.5–3 km over a zonal and a meridional cross section. The results indicate that a large and variable northerly wind occurs down to the Equator in the monsoon layer.

## 1. Introduction

The 1974 GARP Atlantic Tropical Experiment (GATE) was primarily concerned with the investigation of the marine tropical atmosphere; in a complementary goal, the 1979 West African Monsoon Experiment (WAMEX) was designed to supply observations of the continental tropical atmosphere over western Africa. An overview of the scientific objectives of WAMEX has been given by Mbele–Mbong (1981). In order to obtain data between the meteorological observational stations and over the Gulf of Guinea, low-level flights of a DC 7 aircraft were planned. The purpose of this note is to describe the dynamical and thermodynamical features of low tropical layers observed during two flights flown during undisturbed conditions.

## 2. The aircraft experiment

During WAMEX, the instrumented DC 7 aircraft operated by the C.E.V. (Centre d'Essais en Vol) was based in Abidjan, Ivory Coast. Data were recorded on magnetic tape at different rates; they include thermodynamic, radiation and microphysical data and aerodynamic and navigation parameters. The data used in this study were obtained from temperature and humidity sensors and from a Doppler radar and an inertial navigation system. The characteristics of the corresponding sensors are listed in Table 1. The two components of the horizontal wind (positive toward the east and the north) were calculated and corrected using the method proposed by Guillemet *et al.* (1977). After elimination of the erroneous data, 15 s averages of temperature, humidity, horizontal winds, pressure, latitude and longitude were computed.

The tracks and corresponding times of the two flights are given in Table 2, and shown in Fig. 1. During these flights, the aircraft made successive ascents and descents in order to measure the meteorological parameters listed in Table 1 at altitudes ranging from 0.5 to 3 km. In this way we obtained a zonal cross section (flight 7) and a meridional cross section (flight 9) of the low layers in the tropical atmosphere.

The cross sections of temperature and humidity discussed in the following sections were produced by a kriging[1] technique (Olea, 1974); however, because of the complexity of the fields, the cross sections of wind were subjectively interpolated. However, it can be seen that, due to the lack of data, the cross sections shown in Fig. 3 are rather hypothetical below 2 km.

## 3. Synoptic-scale conditions during the aircraft experiment: Oscillation of the meridional wind above the 900 mb level consistent with the easterly waves

An important and long recognized feature of the large-scale circulation over West Africa is the presence of westward traveling disturbances with periods of ~3–5 days, and mean wavelengths of ~2500 km (Carlson, 1969; Burpee, 1972; Reed *et al.*, 1977). Extensive analysis using spectral and composite methods have shown that the large-scale thermodynamical structure of the air masses are related to these disturbances (Burpee, 1974; Reed *et al.*, 1977).

In order to study the aerial observations with respect to the large-scale circulation, the occurrence of westward traveling disturbances has been examined during WAMEX. With this in view, height–time cross sections of the meridional wind at Bobo Dioulasso (11°10′N, 4°18′W) and Abidjan (5°18′N, 4°01′W) are shown in Figs. 2a and 2b, respectively. These cross sections used twice a day radiosonde data from 1 to 15 August 1979. At the two stations, the layers located below the

[1] Technique of optimal objective analysis of observed fields.

TABLE 1. List of the parameters measured on the DC 7 aircraft during WAMEX.

| Parameters | Probe | Accuracy |
|---|---|---|
| | *Thermodynamic parameters* | |
| Total temperature | Rosemount 50 Ω, 102 E | 0. 1°C outside cloud |
| Total temperature | T 4113 | 0. 2°C outside cloud |
| Dew point | Cambridge ECG 137 C-3 | 1°C |
| Dynamic pressure | H 1810 | 0. 1 mb |
| Static pressure | G 1300 | 1 mb |
| | *Dynamic and attitude parameters* | |
| Magnetic heat | C11 Sperry Compass system | 2° |
| Roll angle | radar system | * |
| Pitch angle | radar system | * |
| Attack angle | sideslip | * |
| Yawl angle | sideslip | * |
| *X* acceleration | accelerometer | * |
| *Y* acceleration | accelerometer | * |
| *Z* acceleration | accelerometer | * |
| Ground speed | Doppler radar | 0.5 m s$^{-1}$ |
| Drift angle | Doppler radar | 0. 2° |
| Roll angle | LTN51 Inertial platform | * |
| Pitch angle | " | * |
| True head | " | * |
| Heart angle | " | * |
| *X* axis speed increment | " | * |
| *Y* axis speed increment | " | * |
| Vertical acceleration | " | * |
| Longitude | " | * |
| Latitude | " | * |
| East speed | " | * |
| North speed | " | * |
| Azimuth platform | " | * |
| Drift angle | " | * |
| Ground speed | " | * |
| True head | " | * |

* Values to be determined.

900 mb level are under a well-marked southerly flow during the whole period. In the upper layers, the meridional wind clearly exhibits an alternation between a southerly and a northerly component with periodicity of ~3–5 days. In the layer located between 850 and 700 mb, maxima in the northerly component, reaching up to 4 m s$^{-1}$, appear approximately on the same days at the two stations. Taking into account the results of previous and more extensive studies, this analysis confirms that the easterly waves were present over the WAMEX area. The 700 mb trough crossed over Bobo Dioulasso and Abidjan in the afternoon of 5 August for the first wave, around midnight on 8 August for the second wave, and on 11 August for the third wave. At the 850 and 700 mb levels, and between latitudes 5 and 10°N, no large horizontal tilt of the wave troughs

TABLE 2. Flight descriptions.

| Flight number | Date | Track* | Time GMT** |
|---|---|---|---|
| 7 | 8 August 1979 | A | 1240–1630 |
| 9 | 10 August 1979 | B | 1200–1530 |

* From Fig. 1.
** Time at which the aircraft is located at the extremities of the track shown in Fig. 1.

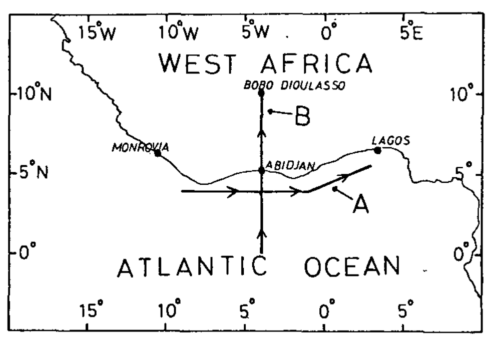


FIG. 1. Flight tracks (see Table 2).

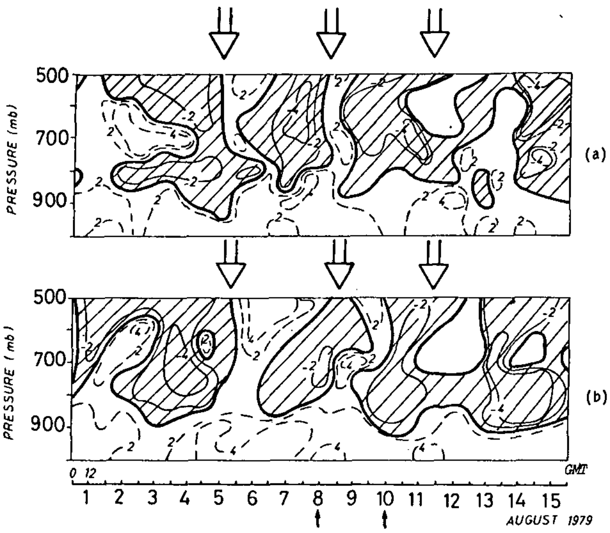


FIG. 2. Height–time cross section of the meridional wind at (a) Bobo Dioulasso from 1 to 15 August 1979 and at (b) Abidjan from 1 to 15 August 1979. Clear areas represent southerly wind, hatched areas northerly winds. The black arrows on the abscissa indicate times of research flights.

is apparent from Figs. 2a and 2b. On 5 and 8 August, the wave troughs clearly exhibit a vertical tilt at the two stations. In these cases, the phase of the wave at the 850 mb level is in advance of that at 700 mb by ~1 day.

The zonal and meridional flights began about noon on 8 and 10 August 1979, respectively. As the zonal flight was made from 9°W to 3°E, Fig. 2 shows that the track was flown on both sides of the second wave trough (the approximate wave displacement is 8° per day). From the same figure, it appears that the meridional flight was made between the ridge and trough axes of the third wave.

## 4. Zonal cross section on 8 August (flight 7)

Fig. 3 shows the vertical cross sections of temperature (Fig. 3a), relative humidity (Fig. 3b), zonal wind (Fig. 3c) and meridional wind (Fig. 3d). The track flown in the vertical plane is shown in Fig. 3a. The zone of transition which is indicated in Fig. 3b marks the boundary between the dry air region and the region with large relative humidity values (i.e., the monsoon layer). For this zone located between 1.5 and 2.5 km, the equivalent potential temperature exhibits a mean value and a vertical gradient of 332 K and 1.1 K (100 m)$^{-1}$, respectively. The zonal wind shows negative values (easterlies) of ~5 m s$^{-1}$ above 1.5 km. Below 1.5 km over the eastern part, the zonal wind has a positive component (westerlies) reaching 4 m s$^{-1}$. West of 2°E, the meridional wind shows a southerly component between 0.5 and 1.5 km, a northerly component between 1.5 and 2.5 km, and a southerly component in the overlying layer.

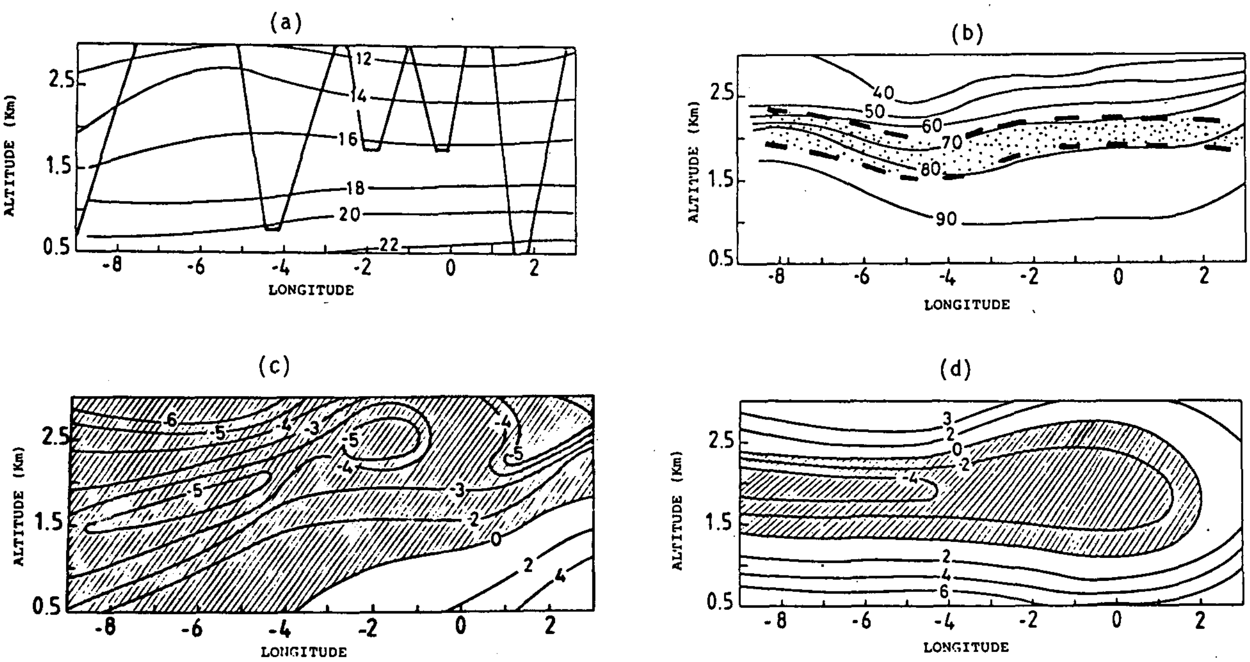


FIG. 3. Cross sections obtained from the zonal flight 7 on 8 August 1979 (track A): (a) temperature (°C), (b) relative humidity (percent), (c) zonal wind (m s$^{-1}$) positive toward the east (striped area), and (d) meridional wind (m s$^{-1}$) negative toward the south (striped area). In Fig. 3a, the straight lines show the track flown in the vertical plane. The heavy dashed lines in 3b indicate the zone of transition.

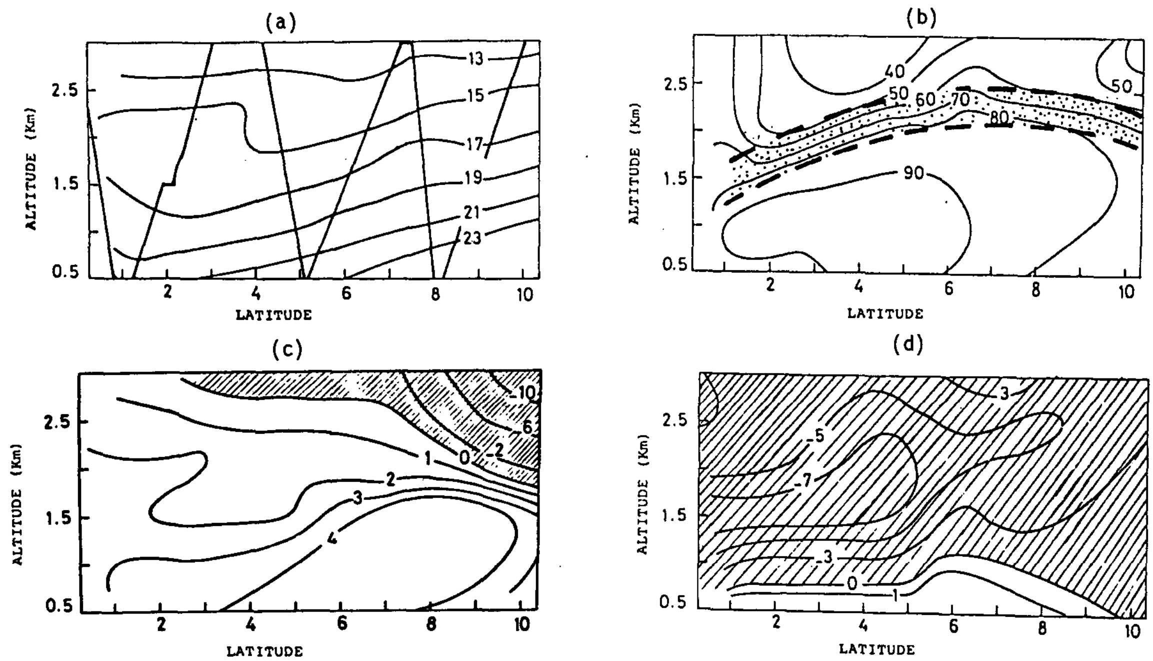


FIG. 4. As in Fig. 3 except for the meridional flight 9 on 10 August 1979 (track B).

## 5. Meridional cross section on 10 August (flight 9)

The measurements obtained during flight 9 clearly exhibit thermodynamical change related to the land–sea discontinuity on both sides of latitude 5°N. Indeed, on the one hand the temperature (Fig. 4a) shows a positive south-to-north gradient through the layer located below 2 km, and on the other hand, the altitude of the zone of transition (Fig. 4b) varies from 1.2 km over 1°N to 2 km over the continental region. The zonal wind (Fig. 4c) below 1.5 km shows positive values (westerlies) reaching 4 m $s^{-1}$ from 4 to 9°N. The large negative values (easterlies) which appear above 2 km and north of 8°N are related to the near proximity of the African low-level jet. With respect to these three parameters, the observed cross sections are qualitatively in agreement with the meridional structure of West African monsoons resulting from the numerical study by Krishnamurti *et al.* (1979). For the meridional wind (Fig. 4d), the southerly component occurs only for altitudes <0.7 km. The strongest northerlies, reaching 7 m $s^{-1}$, are observed from 5°N south to the Equator. From the zonal and meridional cross sections, it can be noticed that the vertical wind shear is not obviously related to the vertical profiles in temperature and humidity.

## 6. Comments about the aerial observations

### *a. Variable northerlies through the layer 0.5–3 km*

Above 1–1.5 km, the observed northerly wind component is in agreement with the synoptic conditions prevailing during the flights (Fig. 2). For the zonal flight, the presence of a southerly component above 2.5 km can be explained by a large phase lag of the wave between this level and lower levels. This feature is consistent with the analysis of Fig. 2 and with the results of Burpee (1974) who has shown that the phase lag between the 700 and 900 mb levels is about ⅕ to ¼ of the total wavelength. According to Fig. 2, in the case of the meridional flight, no large horizontal tilt is apparent through the layer 0.5–3 km to the north of 5°N; at southern latitudes, the increase in the northerlies near 1.5 km can be related to an increasing tilt of the wave near this level above the Gulf of Guinea. This feature is somewhat different from previous studies based on the compositing method (Burpee, 1975; Reed *et al.*, 1977) which reported a well-marked southwest-to-northeast tilt at 700 mb between 0 and 20°N. However, the difference can easily be accounted for by the variations of wave structure that result from selecting different periods for study.

### *b. Water vapor flux associated with the meridional wind: Flight 7*

The occurrence of a northerly wind component through the monsoon layer has important implications for the transport of water vapor between the Atlantic Ocean and the African continent. In order to estimate this transport in the case of flight 7, the respective contribution of each layer 500 m thick has been computed and the values are given in Table 3.

TABLE 3. Water vapor flux in layers 500 m thick for the horizontal sector 9°W–3°E (from flight 7).

| Layer (m) | Flux ($10^{-2}$ kg $m^{-2}$ $s^{-1}$) |
|---|---|
| 3000–2500 | 0.91 |
| 2500–2000 | −1.06 |
| 2000–1500 | −2.27 |
| 1500–1000 | 0 |
| 1000–500 | 6.51 |

This computation results from an integration of the mean flux across elemental surfaces defined by a length of 1° longitude and a height of 500 m. The major positive contribution appears in the layer between 500 and 1000 m, with a value of $6.51 \times 10^{-2}$ kg $m^{-2}$ $s^{-1}$, whereas the major negative contribution of about $2.27 \times 10^{-2}$ kg $m^{-2}$ $s^{-1}$ is found between 1500 and 2000 m. Because of its northerly component, the meridional wind leads to a transport of water vapor toward the lowest latitudes through the middle layers; in the studied case, this flux is roughly half that carried over the continent through the layer 500–1000 meters.

## 7. Conclusions

The results of two aerial observations made through the layer 0.5–3 km in the tropical atmosphere have been shown. These measurements have revealed that a large northerly wind component may occur in the monsoon layer down to the Equator. Although the wind fields are in agreement with the synoptic flow related to the easterly waves, it is also possible that smaller scale circulations are present and act to modify the wind fields in the monsoon layer. This problem will be examined at a future date using satellite data from Meteosat.

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Mrs. C. Baraduc skillfully typed the manuscript.

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