

A study of large-scale vertical motion over West Africa

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सार — 1979 के पश्चिम अफ्रीका मानसून परीक्षण (वामैक्स) के संचालन के दौरान घटित पश्चिम अफ्रीका में गर्जनात्मक मौसम के तीन अलग-अलग अभिलेखित मामलों का शुद्धगतिक उर्ध्वाधर पी-वेग क्षेत्र के साथ अन्वेषण किया गया। यहाँ पर प्रयुक्त योजना न्यूनतम बर्ग-समतल तकनीक पर आधारित है जिसकी व्याख्या जगेडे और बालोगुन (1991) में की गई है और यह कुंग (1972, 1973), और पेडर (1981) द्वारा प्रयुक्त समान विधियों से भिन्न है।

इस अध्ययन में हमारा उद्देश्य प्रेक्षित सतह को प्रस्तुत करने के लिए शुद्धगतिक विधि की उपयोगिता को व्यक्त करना है। सभी तीनों मामलों में यह देखा गया है कि वर्षा पैटर्न और उपक्षेत्र में आकलित उर्ध्वाधर वेग क्षेत्रों के मध्य कुछ सामंजस्य है।

ABSTRACT. Three separately recorded cases of thundery weather over West Africa that occurred during the conduct of the West African Monsoon Experiment (WAMEX) of 1979, are investigated with the kinematic vertical *p*-velocity field. The scheme employed here is based on a least-squares-plane technique which has been described in Jegede and Balogun (1991), as a variant to the similar methods used by Kung (1972, 1973), and Pedder (1981).

The aim in this study is to demonstrate the practicability of the kinematic method for interpreting observed surface weather. In all the three cases, there was some consistency noted between the precipitation patterns and the computed vertical velocity fields within the sub-region.

Key words — WAMEX, Vertical velocity, Inter-tropical discontinuity.

1. Introduction

Due to the intense radiative heating that is usually received in the tropical areas during the monsoons, vigorous local convection occurs which often matures to form cumulonimbus complexes that are embedded in the synoptic scale weather systems within the area. In such convective areas, the field of the vertical motion is seen to be largely indicative of the pattern of precipitation (Bannon 1948, Riehl *et al.* 1952, Miller and Panofsky 1958).

Routine measurements of the large-scale vertical velocity are not made since the typical magnitudes involved are so small for a reliable record of this quantity to be made. Therefore, it is then necessary to indirectly estimate this quantity using a computational procedure. There are several of such techniques available and in use for evaluating the large-scale vertical motion field, and these are mainly: precipitation (Bannon 1948), adiabatic (Miller 1948), vorticity (Riehl *et al.* 1952), numerical (Sawyer and Bushby 1953) and kinematic (O'Brien 1970, Smith 1971). A survey of some of these techniques and their inherent limitations is discussed in Panofsky (1951), Miller and Panofsky (1958), and Lateef (1967). However, it should be commented here that the choice of a particular method is dependent on the density and the type of available data, and also on the kind of analysis required.

The kinematic method used in this study, is derived from the continuity equation. In the scheme, no previous assumption about the nature of the original

atmospheric circulation is required except for the hydrostatic balance. Smith (1971) and Kung (1972, 1973) have to a remarkable degree of success, used the kinematic method to obtain "realistic" profiles of the vertical velocity to describe synoptic scale features over North America for some specific case studies. Also in a recent study of the synoptic scale features over West Africa by Jegede and Balogun (1991), the kinematic approach has been utilised to compute the large-scale motion fields using data collected during the FGGE's West African Monsoon Experiment (WAMEX). Their kinematic fields obtained showed some consistency with recognised synoptic features over the sub-region. The kinematic method by Jegede and Balogun (1991) is used in this study to estimate the vertical velocity field from the sparse upper-air data available within the area. This field is then used to study the weather (precipitation) patterns on the three days: 19 and 29 July, and 10 August, all of which fall within the special observation period (SOP) of the WAMEX in 1979.

2. Data

Over West Africa, dearth of data from a dense network of upper-air stations has posed to be a major difficulty to producing accurate analyses of the meteorological fields. It is within this limitation that this present effort is directed.

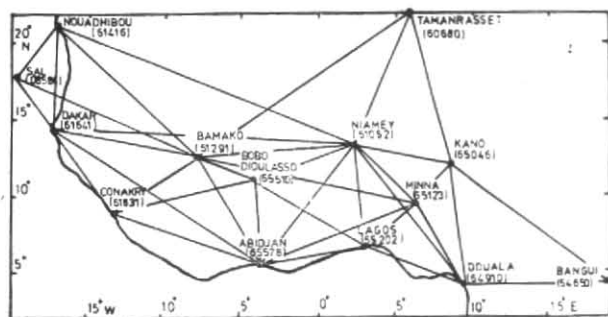


Fig. 1. Area of this study showing the layout of upper air stations used for least-squares-plane estimations (In the brackets the WMO station identification number are indicated)

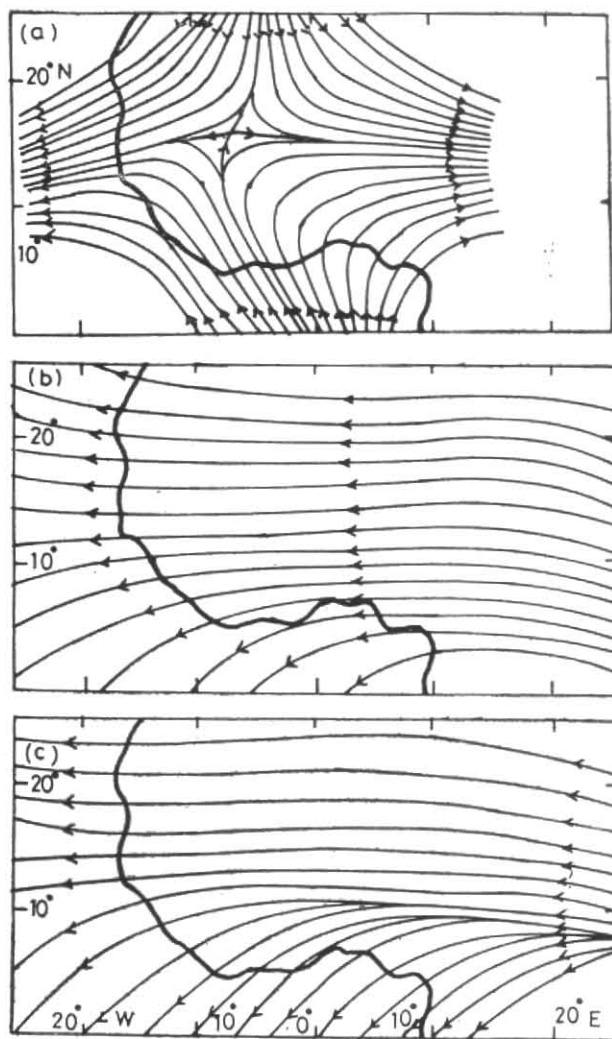


Fig. 2. 1200 GMT streamlines plotted at : (a) low level [1000-850 hPa], (b) middle level [850-300 hPa], and (c) upper level [300-100 hPa] for 19 July 1979

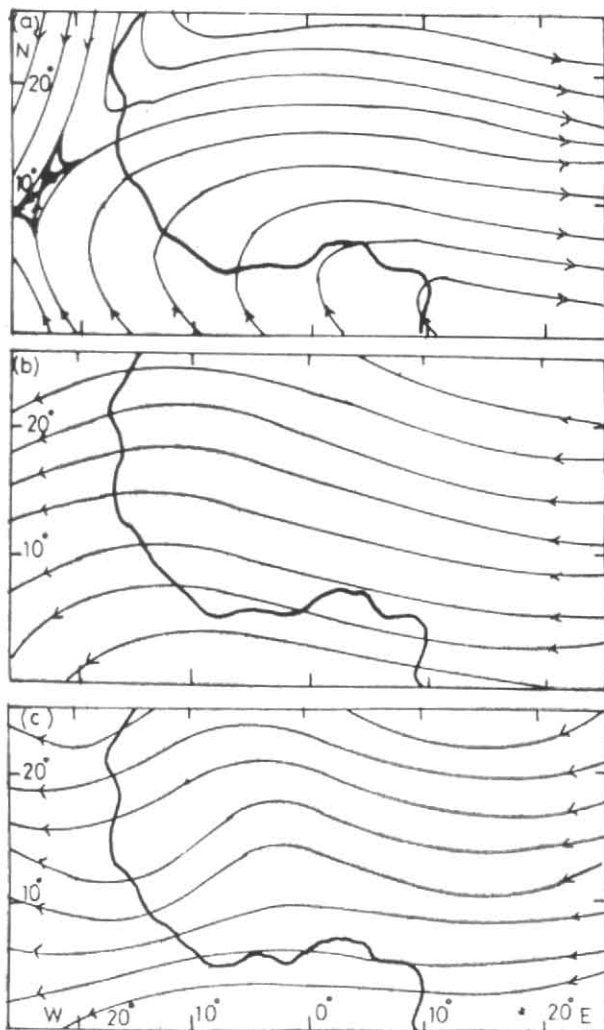


Fig. 3. Same as for Fig 2, except on 29 July 1979

To compute the kinematic vertical velocity fields for these cases (19 and 29 July and 10 August), use has been made of the 1200 GMT upper-air data collated from the rawinsonde stations that are identified in Fig. 1. The computed fields are then compared with the convective patterns recorded on the respective dates, utilizing a composited database. These include the 1200 GMT METEOSAT wind vectors from Balogun (1982) and cloud pictures (ESA 1979) and the surface weather charts and records for the respective dates that have been studied. All these various data sets form part of the contributions to the field data gathered over the sub-region during the conduct of the WAMEX.

3. The least-squares-plane method

In the rectangular coordinate system, a plane surface fitted to the horizontal wind data can be represented as:

$$u(x, y) = u_0 + a_1x + a_2y$$

$$v(x, y) = v_0 + b_1x + b_2y$$

where, $a_1 = \partial u / \partial x$, $a_2 = \partial u / \partial y$, $b_1 = \partial v / \partial x$, $b_2 = \partial v / \partial y$.

The plane approximation to the actual windfield stated in Eqns. (1) and (2), has been remarked by Pedder

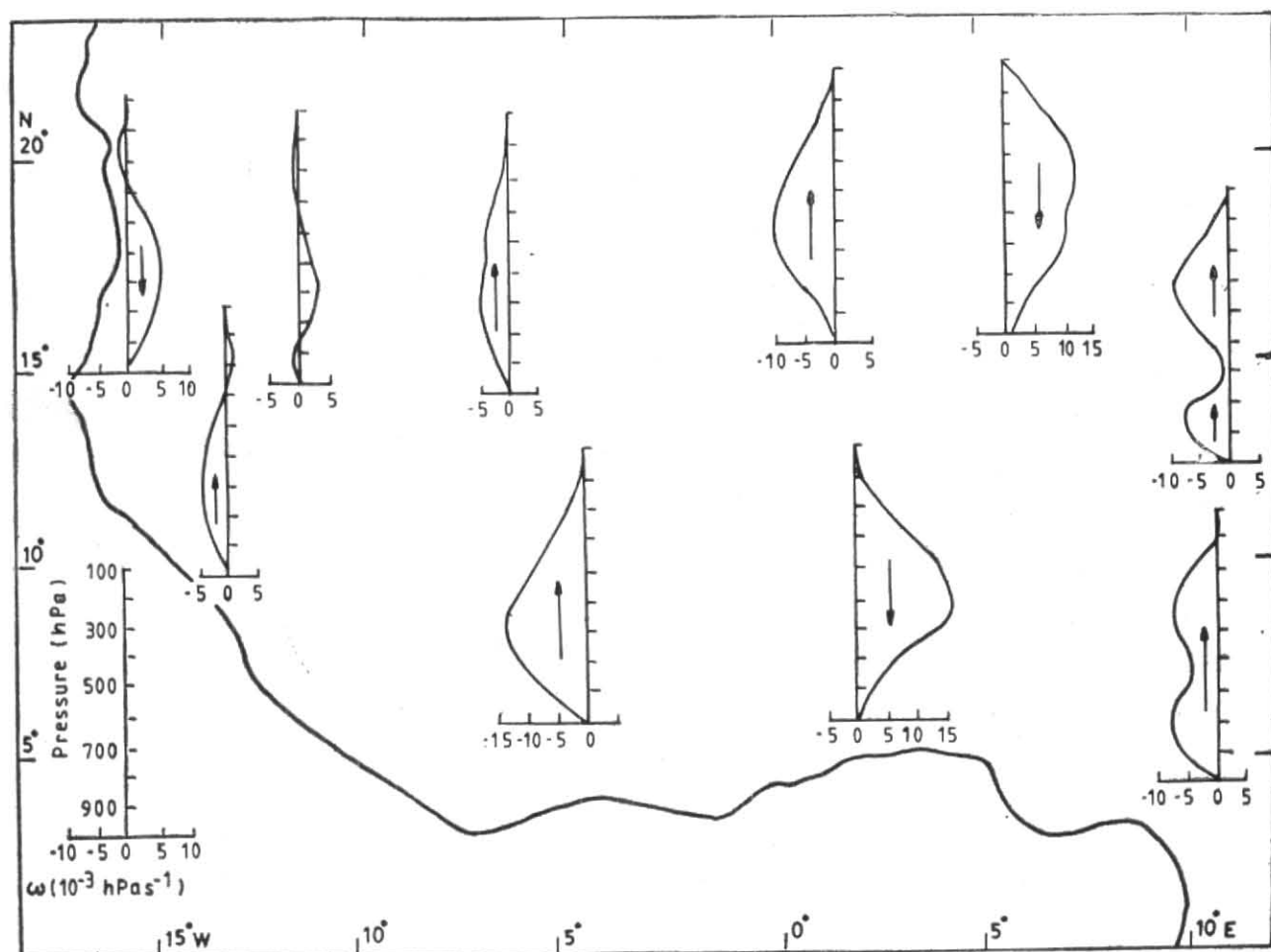


Fig. 4. Vertical p -velocity (ω) distribution over West Africa at 1200 GMT for 19 July 1979

(1981) to be sufficiently reliable over a limited area (order of about 700 km).

In order to solve for the least-square plane coefficients a_1 , a_2 , b_1 and b_2 , we require at least three wind observations from three different upper-air stations located within the map space which are to be solved simultaneously (see Pedder 1981) to obtain:

$$a_1 = \sum \beta_{i,1} u_i ; \quad a_2 = \sum \beta_{i,2} u_i \quad (3)$$

$$b_1 = \sum \beta_{i,1} v_i ; \quad b_2 = \sum \beta_{i,2} v_i \quad (4)$$

Note that in Eqns. (3) and (4) above, u_i and v_i represent the actual (or observed) wind components at each station. Also that,

$$\beta_{i,1} = \frac{x_i \sum_{j=1}^m y_j - y_i \sum_{j=1}^m x_j y_j}{\sum_{j=1}^m x_j^2 \sum_{j=1}^m y_j^2 - \left(\sum_{j=1}^m x_j y_j \right)^2} \quad (5)$$

and

$$\beta_{i,2} = \frac{y_i \sum_{j=1}^m x_j - x_i \sum_{j=1}^m x_j y_j}{\sum_{j=1}^m x_j^2 \sum_{j=1}^m y_j^2 - \left(\sum_{j=1}^m x_j y_j \right)^2} \quad (6)$$

In Eqns. (5) and (6) above, the individual station's natural coordinates (that is, latitude ϕ_i , and longitude λ_i) have been transformed into spherical curvilinear coordinates by the following relationships:

$$x_i = \lambda_i R \cos \phi_i \quad (7)$$

and

$$y_i = R \phi_i \quad (8)$$

In the least-squares plane method employed in this study, different combinations of three or more neighbouring stations located within the West African area (see Fig. 1), were made over the large area to produce an array of representative data points. These points represent the geometric centres for the different stations' arrays selected in the estimation. In grouping of these stations together, a length scale of approximately

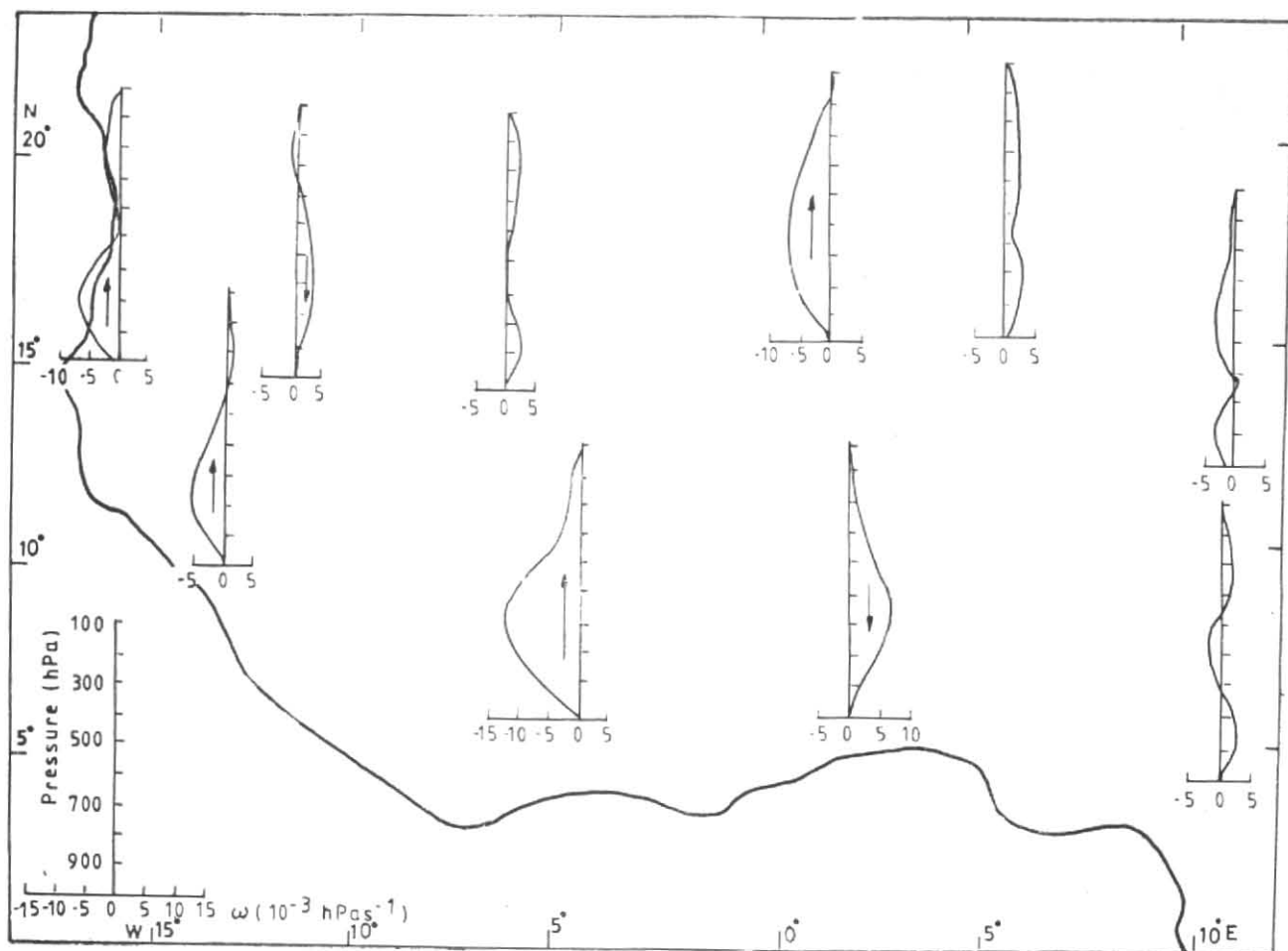


Fig. 5. Same as for Fig. 4 except on 29 July 1979

1000 km was considered as the limit within any particular array so as not to smooth out features that could be characteristic of synoptic scale disturbances over the area.

An advantage with this technique is that the positions of these points (mean latitude and longitude coordinates obtained from each array) is only needed to be evaluated for a once and for all estimations over the sub-region. From the scheme, the additional data points generated improves the quality of the derived field over the study area considerably.

The vertical p -velocity for a given layer of thickness Δp , can then be easily evaluated using the relationship below:

$$\omega_p = \omega_0 - (\nabla_H \cdot \mathbf{V}) dp, \quad p < p_0 \quad (9)$$

where, $\nabla_H \cdot \mathbf{V} = \partial u / \partial x + \partial v / \partial y - [(\bar{v}/R) \tan \bar{\phi}]$

and where, R and $\bar{\phi}$ represent the earth's mean radius and the mean latitude respectively.

In order to produce a realistic profile of the vertical p -velocity, that is, a pre-condition that this quantity

is zero both at the surface and at the tropopause (O'Brien 1970, Pedder 1981), we have applied a correction factor of the form:

$$(\nabla_H \cdot \mathbf{V})_c = \frac{\omega_t}{(p_0 - p_t)}$$

to the original estimates of ω_p obtained in Eqn. (9). The subscripts zero and t represent values at the surface and at the tropopause respectively. From the author's experience, the scheme outlined above can be implemented conveniently on a microcomputer.

4. Case studies

Over West Africa, the changing synoptic flow patterns noticed from the beginning of the summer monsoon about May to its peak around July/August gives an indication to the variable nature of the weather during the period. The characteristics of the West African monsoon and the surface weather have been described elsewhere in Hamilton and Archbold (1945), Obasi (1965) and Adefolalu (1972).

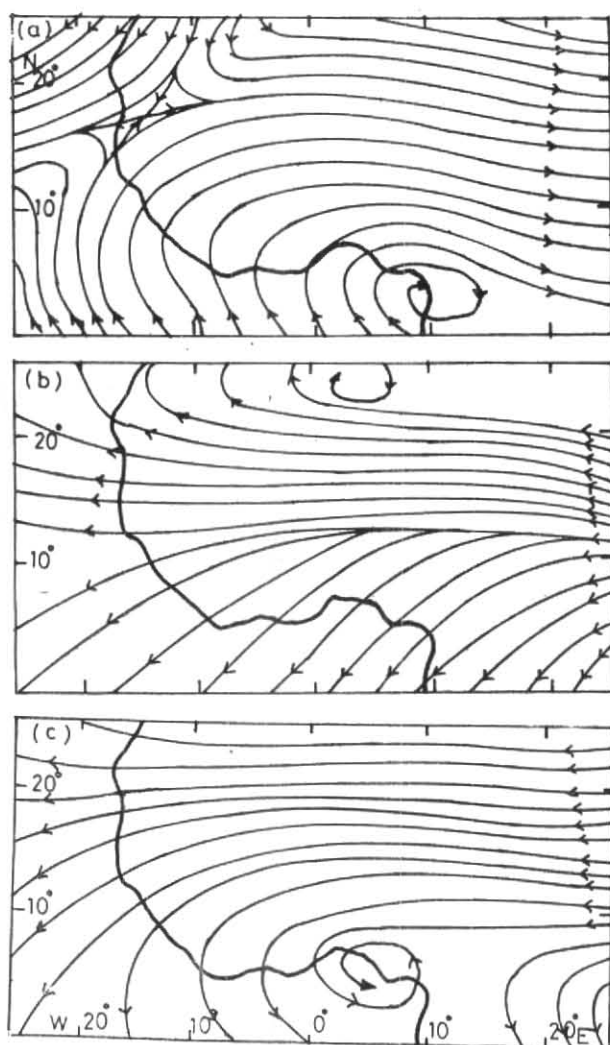


Fig. 6. Same as for Fig. 2 except on 10 August 1979

Typically the flow at the lower levels is characterized by the moist southwesterly monsoon which forms a wedge underneath the dry and hot northeasterly winds blowing from the Azores sub-tropical high-pressure system. The surface of transition between the two wind regimes of contrasting thermodynamic properties within the continental West Africa is referred to as the Inter-Tropical Discontinuity (ITD) surface (WMO 1978). The intersection of this surface with the ground (which is referred to the ITD line in the literature), has a migrating position which is between the latitudinal belt 4° - 6° N in January, and latitude 22° - 25° N in August. The ITD line in West Africa is drawn on surface charts by the location of the 15° C dewpoint isotherm, and by using the discontinuities in temperature and windfields.

Based on the meridional extent of the ITD line, the sub-region is partitioned into zones (latitudinal bands) of different weather regimes with conditions ranging from the areas completely devoid of any significant convective activity to areas of high frequency of thunderstorm occurrence (see for example,

Hamilton and Archbold 1945, and Balogun 1981). During the peak of the monsoon period in August, when the ITD line reaches its most northernmost limits, the rainbands extends from about 10° N to 15° N across the sub-region.

Case I—19 July

The synoptic report at 1200 GMT on 19 July indicated significant precipitation recorded over the entire West African area with rainfall amounts ranging between 10 and 100 mm (Adedolalu 1989).

The large-scale flow over the area in Fig. 2 is plotted as stream lines taken from the satellite derived (METEOSAT) wind vectors of Balogun (1982) for 1200 GMT on the 19 July at the low level (1000-850 hPa), middle level (850-300 hPa), and at the upper level (300-100 hPa). From the [Fig.2(a)], the low level circulation indicates an inflow of the southwesterly monsoon into the area. This stream converges with the continental air mass, to form into a col centrally

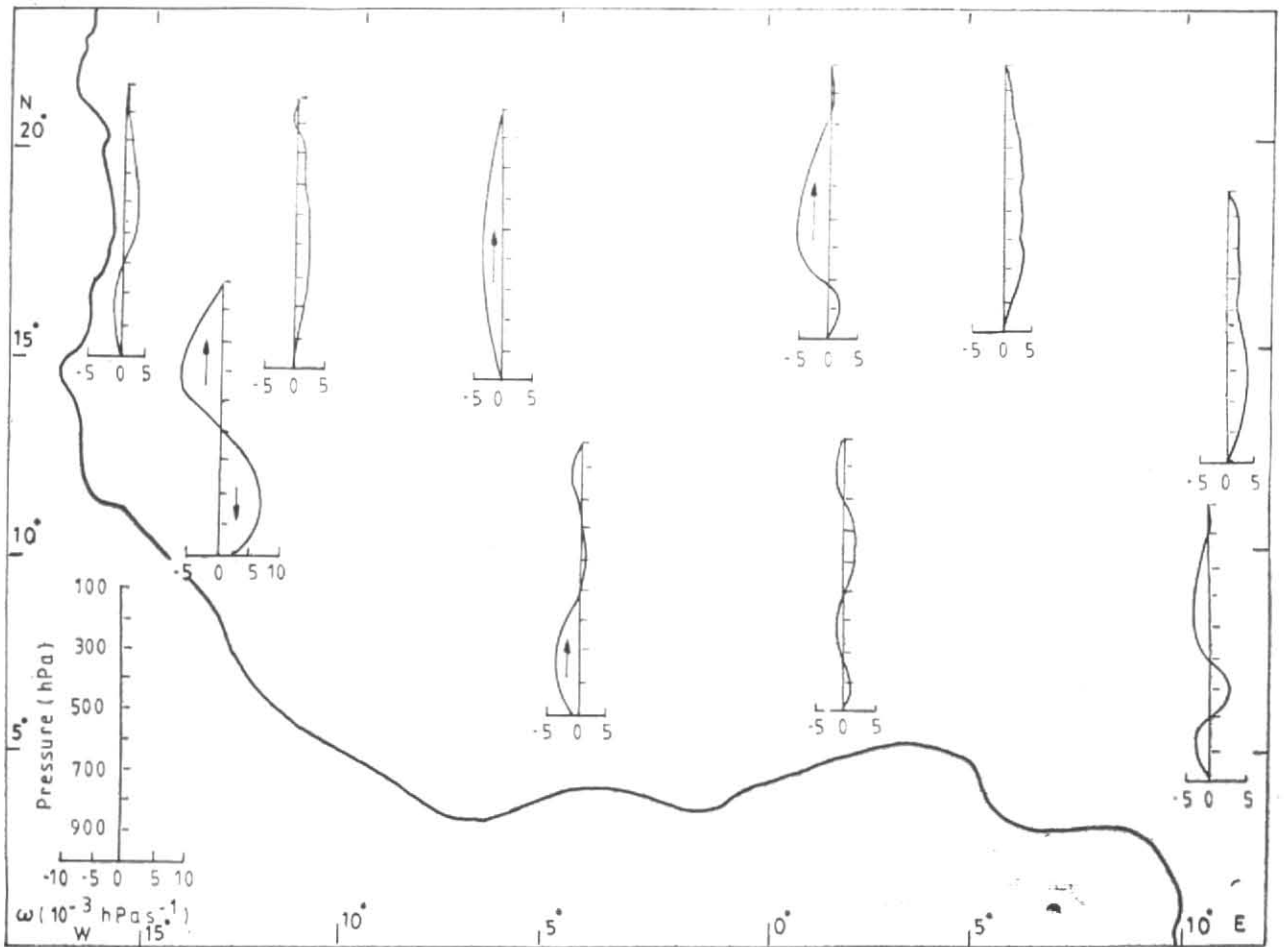


Fig. 7. Same as for Fig. 4 except on 10 August 1979

located over the sub-region. The middle level flow in Fig. 2(b) is easterly, and shows a weak diverging flow but which is more pronounced at the upper level [Fig. 2(c)]. The flow fields in Fig. 2 support the report of a widespread bad weather occurrence over the entire area during the period.

The field of vertical p -velocity over West Africa computed from radiosonde data for 1200 GMT on 19 July is shown in Fig. 4. The procedure described in section 2 above has been used to evaluate the quantity. It is evident from the stations' vertical velocity profiles shown in Fig. 4 that there was a considerable upward (vertical) motion common to most of them during the same period. This supports the widespread and considerable convective activity mentioned on this date. However, it is to be noticed that the intensity of the convection (vertical motion) reduces by an order of magnitude in the areas west of longitude 10° W. The reason for this feature is not sufficiently understood at present. Due to good data resolution from the scheme, pockets of subsident motion are observed to be well-distributed as such to compensate the upward motion for a mass balance

condition to be obeyed. Generally, the vertical p -velocity field obtained in Fig. 4 is indicative of the widespread thundery weather over the area.

Case II — 29 July

The surface weather report for 29 July indicates a different pattern of rainfall from that recorded earlier on the 19th. On this date, heavy precipitation fell only in the western areas, but little or no rainfall was recorded in the sections lying east of the Greenwich meridian.

The large-scale flow in the lower layers at 1200 GMT [Fig. 3(a)] for 29 July shows that the position of the strong convergence originally in the central part of the region [Fig. 2(a)] has now been shifted to around the west coast. Apart from this, the strength of the convergence of these currents at the low level is observed to be weaker and showing drastic reduction in magnitude further eastwards into the continental areas. Both the middle and upper level easterly flows in Figs. 3(b) and 3(c) respectively are divergent compensating for the lower level convergence. The observed westward shift of area of convergence agree with the weather report.

The profiles for the vertical motion field over West Africa at 1200 GMT for 29 July is shown in Fig. 5. The vertical velocity distribution indicated that there was appreciable upward motion (*vis-a-vis* convective activity) only within the western half of the sub-region. Specifically, the southwestern and the central parts show profiles which seem to portray these areas as highly convective during the period. The intensity of convection (that is upward velocity) is not so pronounced in the eastern parts (beyond longitude 5° E), which is also in agreement with the weather report.

Case III — 10 August

The surface weather recorded on 10 August is similar to that for 29 July. Little or no convective activity took place in the areas lying eastwards of the Greenwich meridian.

The flow pattern at the low level [Fig. 6 (a)] shows a convergence around the western areas, which is similar to the low level circulation on 29 July [Fig. 3 (a)].

Here again, the vertical motion field in Fig. 7 over West Africa for 1200 GMT on 10 August displays a remarkable similarity to the weather report with mainly the western areas to be convective, though not as prominent as for the 29 July case shown in Fig. 5.

6. Conclusion

From the profiles of the vertical *p*-velocity analysed over West Africa for the three selected days: 19 and 29 July and 10 August all taken from the 1979 WAMEX data, we have been able to show using a kinematic scheme that there is a good correlation between the computed fields and the precipitation patterns. It is then the present opinion that the derived fields of vertical velocity is valid to apply to large-scale studies of intensity convection and its distribution over the area.

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