Synoptic flow perturbations over West Africa

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ABSTRACT

Utilising wind data for the significant levels: 2 000 feet, 850, 700, 500, and 300 mbs, detailed analyses of West African upper-air charts reveal distinct features of the atmospheric flow, especially in connection with mid-tropospheric easterly wave activity over the area.

The history of a semi-vortical perturbation whose motion was in rhythm with the propagation of a 700 mb easterly wave is described.

It is concluded that an easterly wave model incorporating the 700 mb trough (and ridge) as integral feature(s) of the flow describes best the majority of significant weather zones and puts on a firmer basis the existence of westwards moving semi-vortical lines of thunderstorms frequently traversing the heart of West Africa during the rainy seasons.

1. General statement and method of work

Efforts to relate weather of West Africa with the flow over the area was brought to a focal milestone by Regula (1936), especially in connection with what used to be known as "tornadoes". (The term "tornado" is gradually losing popularity among West African Meteorologists, to be replaced by "squalls".)

Further attempts to investigate and document the meteorology of the area was then made by Hubert (1938). In 1946 Schove presented "stability isopleths" which showed their troughs and wedges moving consistently from East to West and advecting with them characteristic weather tendencies. In addition, he showed that well-defined lines of squalls were associated with troughs in the easterly flow.

Gilchrist & Matthews' (1961) topography analysis of 850 mb synoptic charts showed that lows and ridges can be found and that definite squall lines or disturbance lines, as they were called (ibid.), propagated ahead of and in close association with the lows. We note, unfortunately, that their effort was plauged by a high degree of subjectivity.

The isogon-isovel technique, first described by Bjerknes & Sandstrom (1910) and later developed by Palmer and others (1955) affords description with the winds, better than topography analysis, of the propagation of definite flow perturbations. Although, it might be possible to achieve the best analysis, especially in temperate latitudes, by supplementing the former method with the latter, or vice versa, in the tropics, however, the relatively great frequency of rawin observations and the paucity of radio-sonde data recommend the relatively objective streamline technique of analysis.

In the Nigerian Meteorological Service forecast offices, simple free-hand streamline analysis of the winds has been in use for over half a decade. The results obtained therefrom, though encouraging, have not been very satisfactory due to weaknesses inherent in free-hand streamline analysis. Such a weakness is evidenced by too often inappropriate designation of "Low" to an area which would normally be a "Col" if quantitative method is used.

Since the aim here is to observe as accurately as possible the variation of the instantaneous flow in time and in depth, especially through the lower middle troposphere with the type of circulation changes which might occur, and to see if there are any clear-cut relationships between the flow aloft and significant surface weather, the former method has been used entirely on its own merit to provide insight into the instantaneous flow-structure and the local consequences.

Attention has been focussed on 26–28 July, 1960 and Fig. 1 shows the present locations of rawin and radio-sonde network used. Data derived from upper air measurements made before or after periods of strong convection at every one of the stations were the ones considered acceptable because they afforded clear

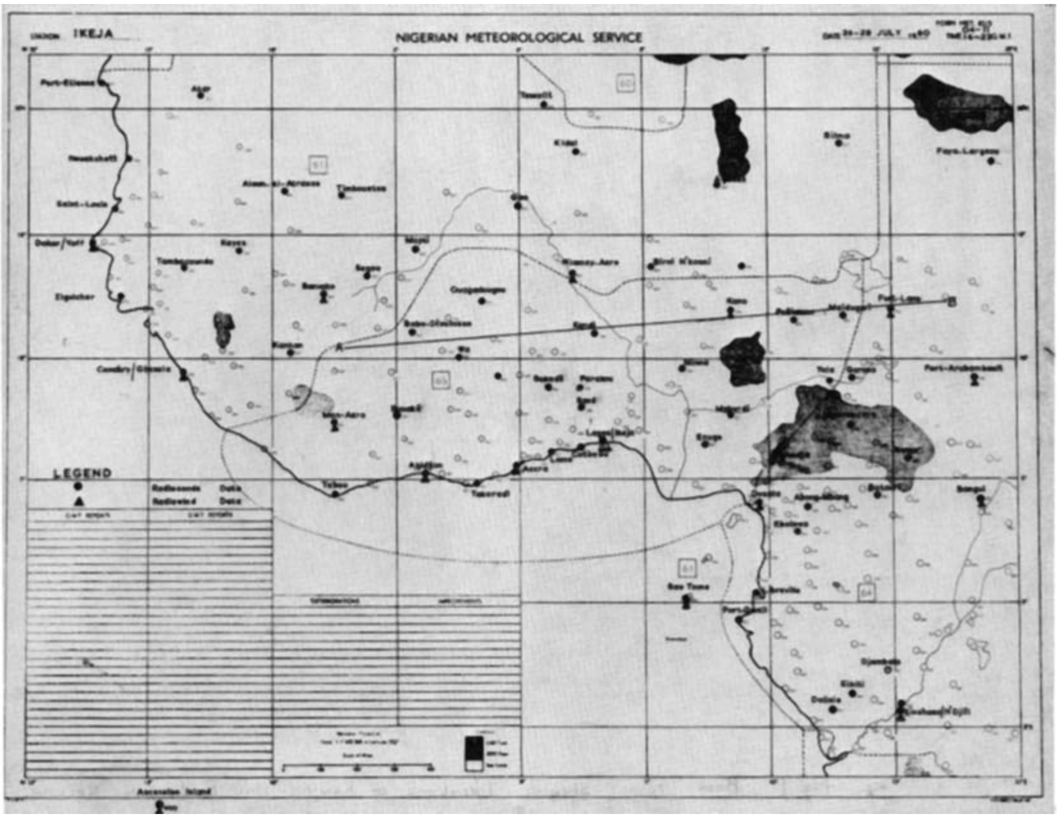

Fig. 1. Base map showing locations of rawin and radiosonde network used.

observation of only those activities associated with the systems delineated. Hence, only the morning (0400–1100 GMT) and the evening (1500–2300 GMT) charts have been analysed; these periods are centered on 0600 GMT and 1800 GMT respectively, during either or both of which times ascents are made at the stations. Where observations were lacking for any map-time there were usually ascents for the previous or later periods. These additional data, shown in parenthesis on the charts, were considered in filling gaps but with little weight put on them.

From the analyses emerged classical examples of travelling cyclonic vortices mainly at 850 mb, and of easterly waves at 700 mb level. The well defined semi-vortical lines-of-squalls, or of bad weather, have been identified with the easterly waves in the basic flow. These linear systems form the subject of a forthcoming report. Also, because of its continuing importance the lower low latitude Easterly Jet has been discussed very briefly.

2. Activity in the low troposphere

During the period of analysis the major part of the West African troposphere played host to a basic easterly current. Wind speeds at low levels were low (usually less than 30–40 kt) but are significant in view of generally low wind speeds. They increased with height, reaching a relative maximum between 10 000 and 25 000 feet.

Daily variation in wind speeds and directions, due to changes of the flow structure in those latitudes north of West Africa, showed prominently on the analysed upper air charts.

Generally, an easterly field from 700 mb level upwards existed within 10°–15° N overlying a south to south-westerly current.

Gilchrist & Matthews (1961) have contour-analysed the same situation, and it may be interesting to compare Fig. 3*a* with Fig. 3*d*, one of the charts presented.

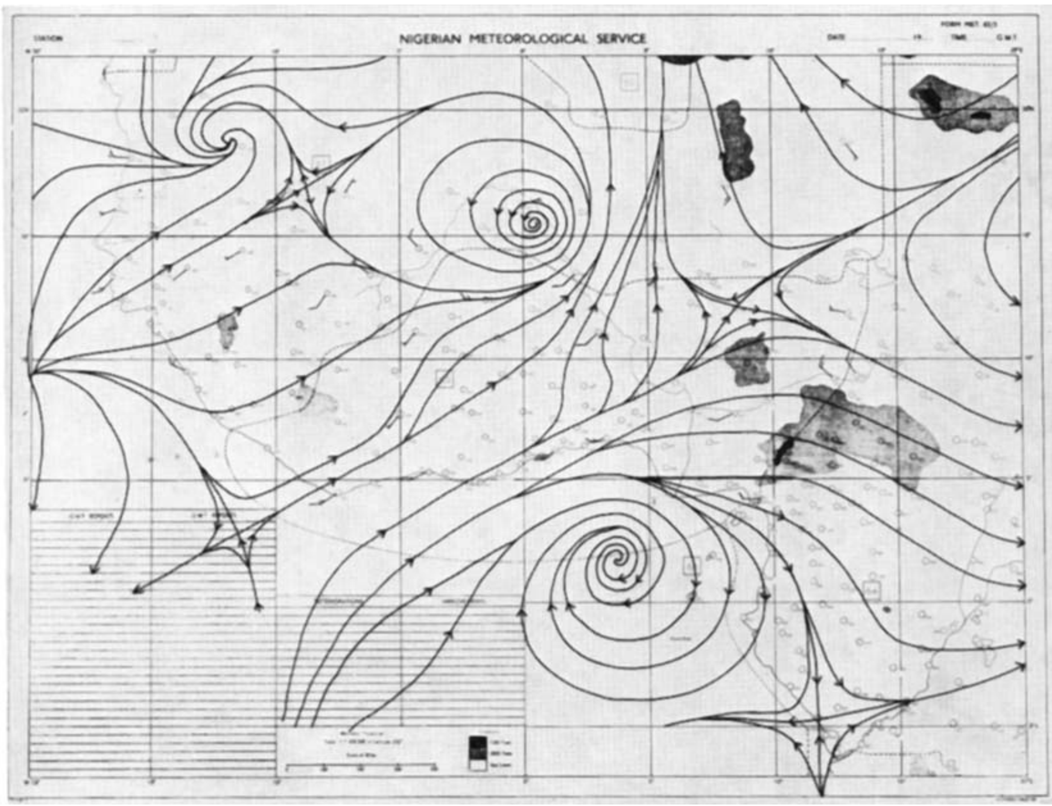

Fig. 2. 2 000 ft streamline analysis, 26 July 9601, 1600–2300 GMT.

(a) *Synopsis of cyclonic vortices and waves*

Figs. 2–4 represent typical streamline flow variations in space and time.

In Fig. 2, showing the flow at 2 000 feet, the only developments of synoptic importance were the four prominent vortices shown. The vortex farthest east had its centre at about 15° N 22° E.

At 850 mb (Fig. 3*a*) a prominent cyclonic vortex, *A*, sat over north of Nigeria and another one, *B*, was just east of the Cameroun Mountains. By the morning of 27th they had united into one spectacularly intense cyclonic circulation, *C*, in Fig. 3*c*. This vortex, *C*, however, weakened through the 27th, becoming quasi-stationary. Through the 28th, it appeared to be intensifying in this state, indicated by the infolding process of its principal asymptote.

The path of the centre of the original vortex, *A*, and then of vortex *C*, though in the main progressive, exhibited wave-like tendency (a probable indication of hydrodynamic stability of the vortex itself, but a connection with the diurnal variation of the I.T.C.Z. is not unlikely) while the development area in Fig. 3*c*, is closely followed by anticyclonic vortices as should be expected.

On occasions, vortices appeared at 700 mb (Fig. 4*d*), indicating the presence of deep moist south westerlies. In view of this, the 700 mb surface appears to be the base of the easterlies, above which a broad easterly flow dominates.

Easterly wavelike perturbations disturbed the basic steamlines and propagated through the broad stream. Super-position of Figs. 3*a*–*c* and Figs. 4*a*–*d* shows that with each wave may be associated a low-level cyclonic vortex. The sequence of changes from 26–28 July, 1960 at 700 mb shown in Figs. 4*a*–*d*, illustrate the development of a wave into a vortex. The wave, *W*, situated around 7° E, extending from 18° N to 5° N on the morning of the 26th (Fig. 4*a*), propagated slowly at first through the basic flow until the early afternoon of the 26th, pre-

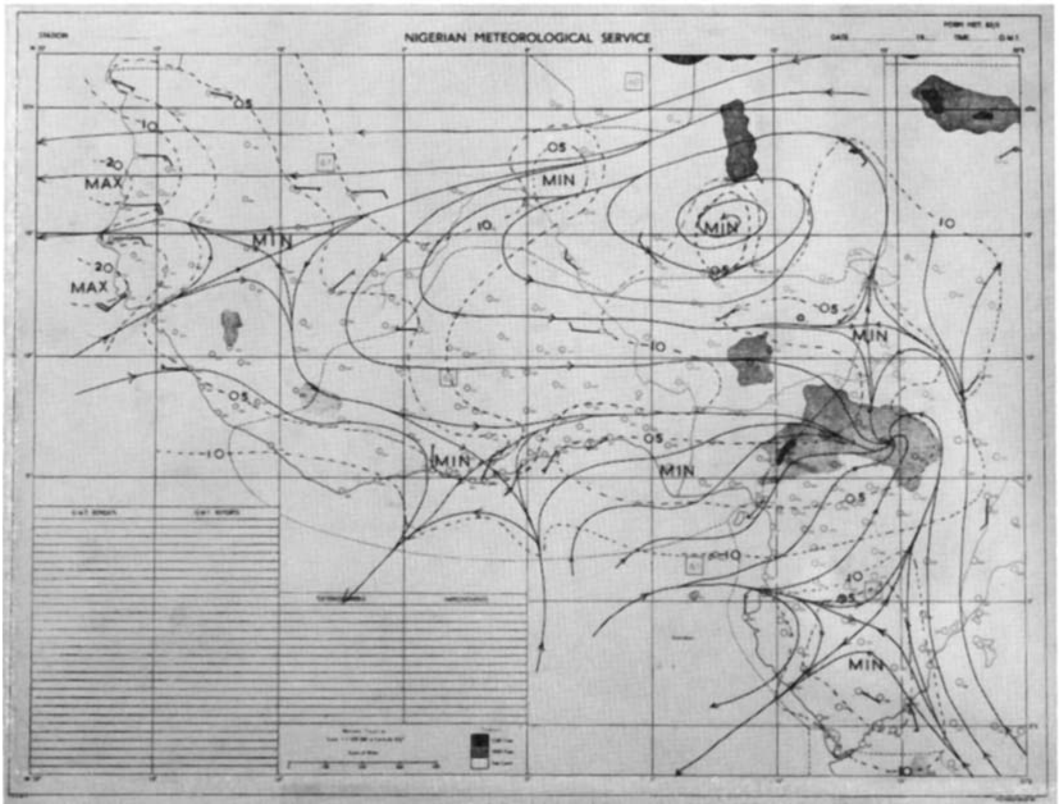

Fig. 3a. 850 mb wind speed (---) and streamline (——) analyses, 26 July 1960 0400–1100 GMT.

paratively timing the merger into a vortex C on the same day of vortices A and B at 850 mb in Fig. 3*b*. It however, developed fully in Fig. 4*c* in association with the newly formed spectacular 850 mb vortex, C, below (Fig. 3*c*).

By the evening of 27 July the wave had weakened, eccentrically shedding backwards its wave-trough (analysis not shown, but shown in Fig. 4*d* is the succeeding situation). This "eccentricity" is interpreted to be the preparatory stage for the creation of a cut-off outflow vortex in the SE sector of wave. The wave, W, completed its transformation into a vortex by the morning of the 28th.

(b) *Easterly perturbations over West Africa*

Figs. 4*a–d* are reproductions of the progress over West Africa of a typical easterly wave associated with active development of squally line-of-thunderstorms "carried" in the wave through its entire history.

Prior to the 26th there was a nascent wave in which bad weather was not observed (there was not enough data to confirm actual nil weather) but which had heavy cloud in a belt of streamline convergence. The Squall Line of this investigation, however, first manifested itself on the surface as linear heavy cloud distributions and/or in terms of bad weather such as rain or rain-showers, better known as Precipitation Line, and later gave squalls with semi-vortical (concavo-convex) thunder-cloud distribution (Figs. 5). Fig. 6 shows successive positions of the Squall Line relative to the 850 mb vortex center propagating westward during the period.

In the vertical, the Line comes as a quasi-vertical wedge carried in the flow through the upper levels, and slopes slightly to the east. The "wedge" is defined as the loci of the wave-axis joining the neutral point at a low level, say the 5 000 ft, to the upper shearline, say at 10 000 ft and so on. The slope of the wedge as calculated

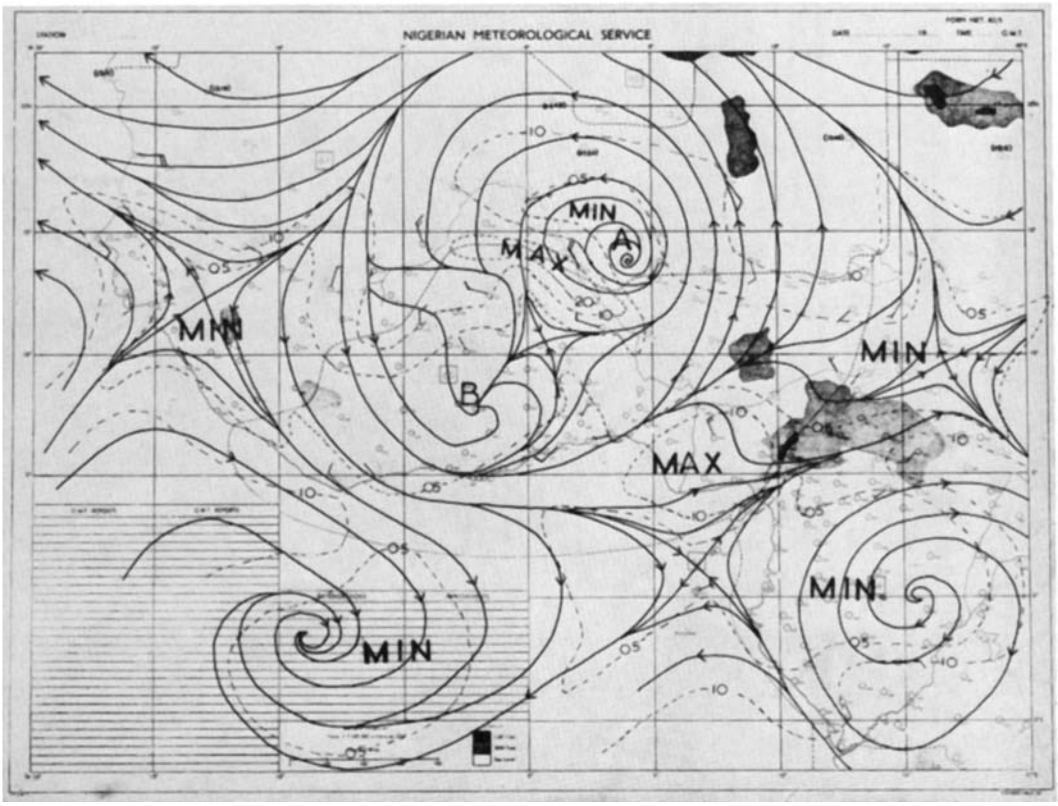

Fig. 3b. 850 mb wind speed (---) and streamline (——) analyses, 26 July 1960, 1600–2300 GMT.

rather crudely from the various charts analysed is believed to vary between 1/30 and 1/50 during the initial active stage of the Line.

Super-position of Figs. 3*a–c* and Fig. 6 showed that a Squall Line merely hangs on an 850 mb vortex with no indication of preferred sectors for its location. This contrasts the analysis of Matthews & Gilchrist (1961) which showed "Line Squalls" as always preceding a vortex of low pressure at the same level.

The only occasion on which the Line was observed to lie just ahead of an 850 mb vortex was on the evening of 26th. The reason was rather obvious: the 700 mb wave *W* (Fig. 4*a*) had broken and weakened, and sustenance of the Line fell on the 850 mb vortex *C* (Fig. 3*c*).

Comparison of the latitudinal extent of the Line on the surface chart with the amplitude of its parent 700 mb wave suggests its dependence on the amplitude of the easterly wave (Figs. 4*c* and 5*b*). In this investigation, the maximum stretch of the Line was approximately 2 000 km N–S. There was no indication that it shortened although thunderstorm activity along the length decreased, as soon as the associated or sustaining wave broke or collapsed.

(c) A typical linear perturbation

All indications were that a squall line is a linear perturbation forming an integral part of the easterly wave perturbation. Therefore, a representative Squall Line with a trajectory spanning West Africa from 26–28 July, 1960 was examined in some detail. It was chosen because, after identification on 26 July, 1960, in association with wave *W* as a mature westward moving, N–S Squall Line in the north eastern corner of Nigeria at about 10° E and between 10° and 15° parallels, it lived the entire length of the area moving with an average speed of about 30 kt. The following is a review

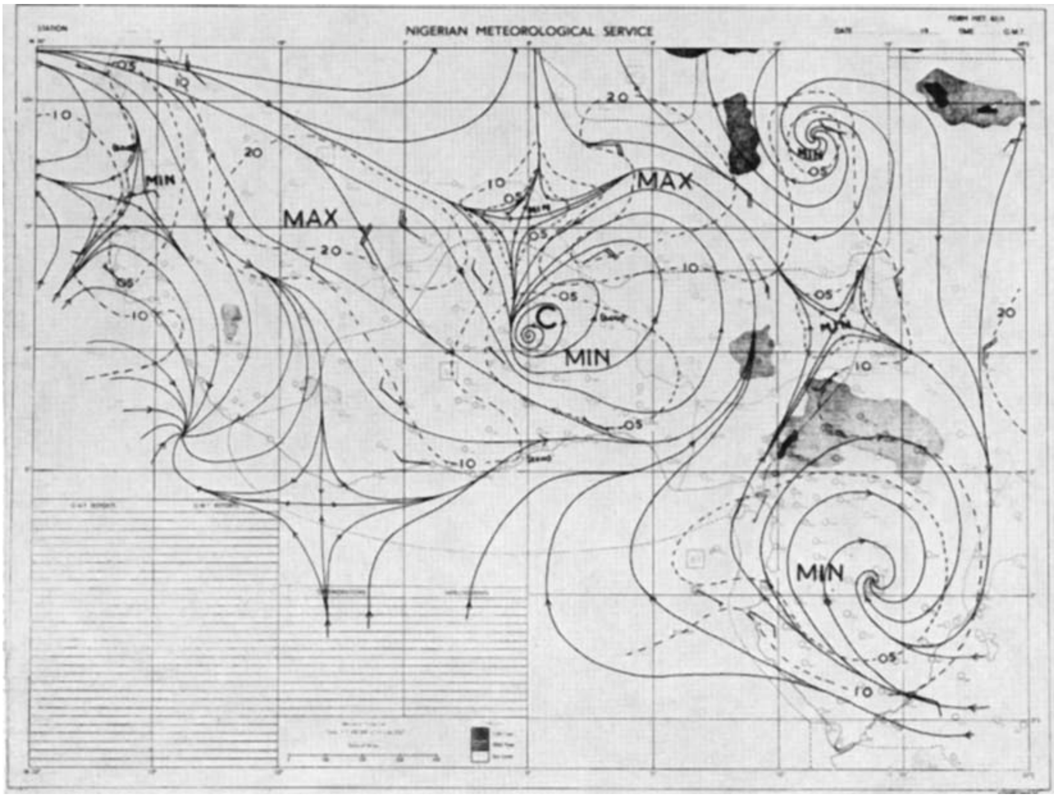

Fig. 3c. 850 mb wind speed (---) and streamline (——) analyses, 27 July 1960, 0400–1100 GMT.

on the Line in the vertical as well as in the horizontal covering successive twelve hour positions, because all the relevant charts have not been presented.

26 July. Morning regime: A 700 mb trough-line was situated at 7° E, extending from 18° N to 5° N. Below at 850 mb was a region of westerly to south-westerly, light winds (Fig. 3*a*). At 500 mb the flow was north-easterly with speeds between 10 kt and 20 kt. There was a sub-jet wind maximum 2 400 kt to the west and another about the same distance to the south-east. The position of the associated line was indicated at about 10° E, lying along the direction of the south easterly flow behind the trough-line, and almost passing through Nguru (12°53′ N, 10°28′ E) and Potiskum (11°42′ N, 11°02′ E). The W–E position of the southern limit of air of northern origin within 0–18° E longitude was at about 18° N latitude.

Nguru has had thunder earlier than the time of the chart, but at 0600 GMT it reported an ESE wind-gust of 20 kt, indicating the Line must have just passed the station. At this time, Potiskum has had thunder but the wind was now easterly/light, which implied the Line was to the west of the station. There was significant distribution of low cloud around the line, and reports of thunderstorms behind and ahead were not farthest than 600 km away. This was the mature stage of the line which was more active in the northern half of the middle portion.

26 July. Evening regime: The 700 mb trough-line of the morning appeared to have remained stationary. But the wave observed there in the morning had collapsed leaving in view a "compression" wave observed in the motion field behind the line which continued moving westwards.

At 300 mb the flow was E–ESE. The western finger of the wind maximum core (30 to 40 kt) was about 1 000 km to the WSW, while the eastern fingers were 2 000 km and 2 200 km to the NE and SE of the surface line respectively.

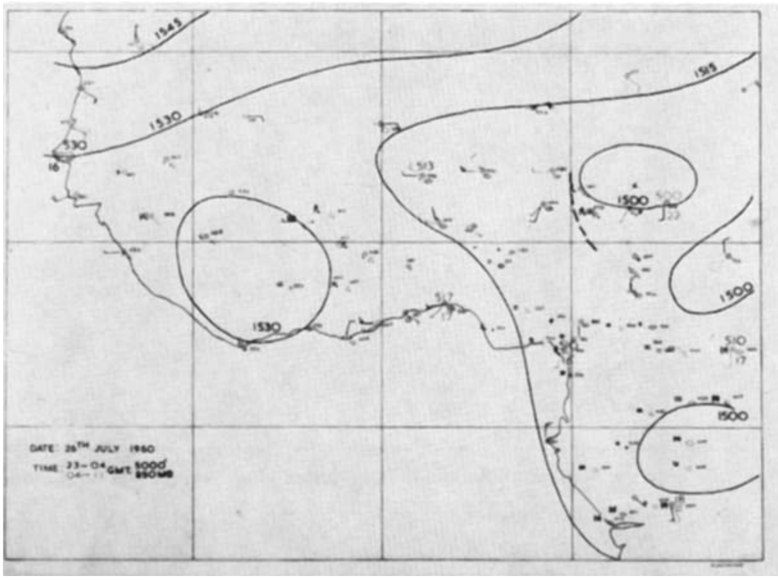

Fig. 3d. 850 mb contour analysis (after Gilchrist & Matthews), 26 July 1960, 2300–0400 GMT, 0400–1100 GMT.

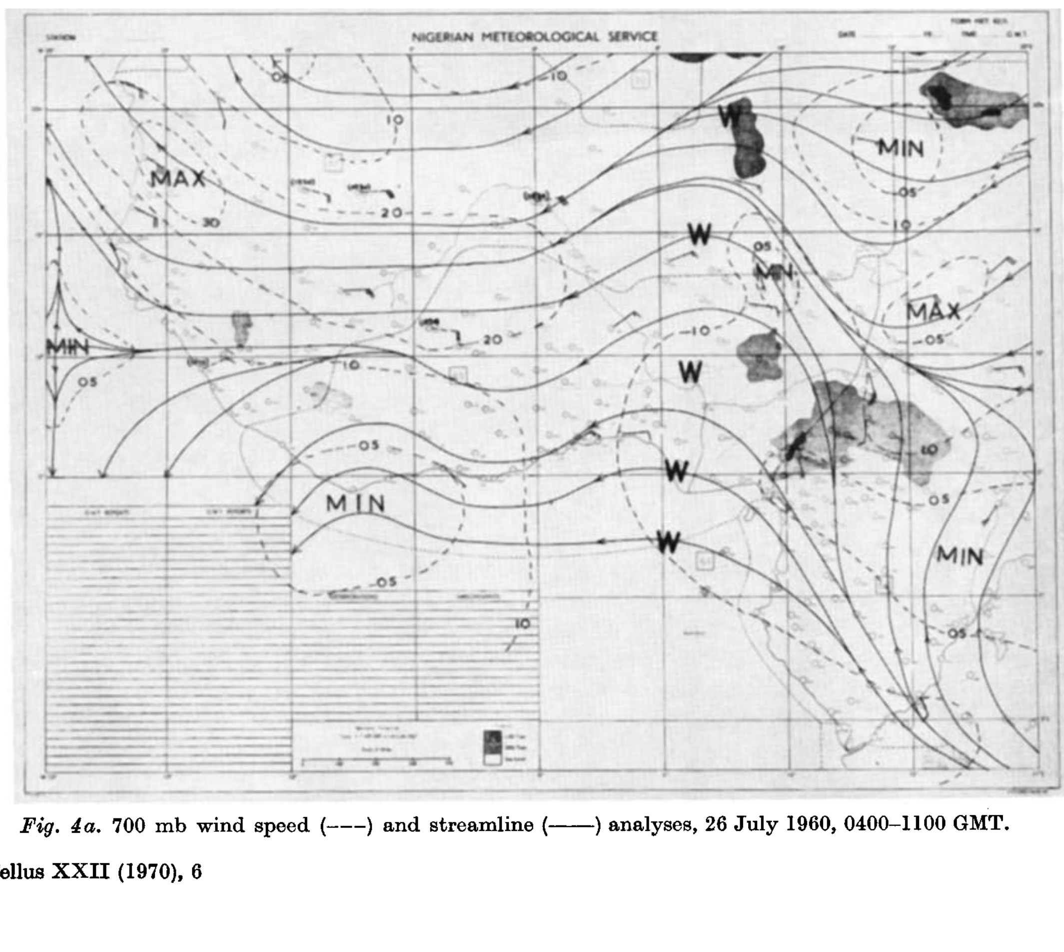

Fig. 4a. 700 mb wind speed (---) and streamline (——) analyses, 26 July 1960, 0400–1100 GMT.

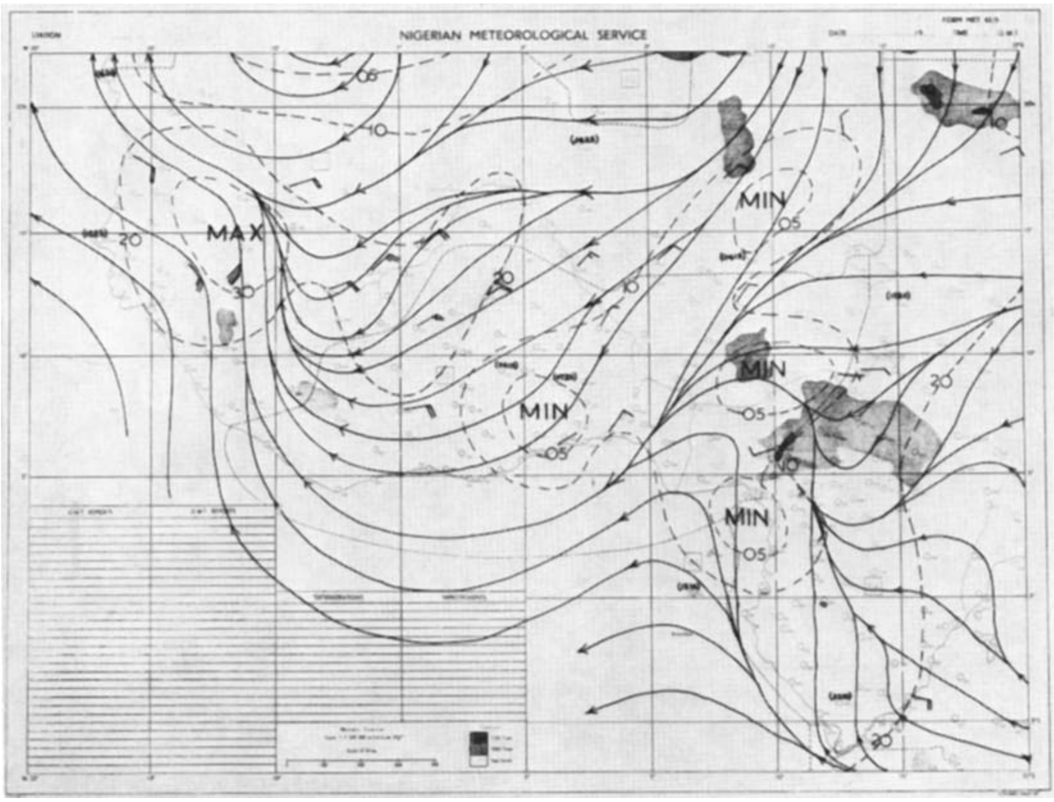

Fig. 4b. 700 mb wind speed (– – –) and streamline (——) analyses, 26 July 1960, 1600–2300 GMT.

The wave-trough had lost the Line, an event due to the breaking and weakening of the wave which remained now to its ESE. Meanwhile the Squall Line found at 850 mb a vortex-host whose centre had moved down from 15° N 8° E, its morning position, to 15° N 4° E, a mere 1 degree to the west of the surface position.

The position of "Squall Line" at 1800 GMT is shown in Fig. 5*a*. The speed was about 25 kt travelling some 700 km to the west of its 0600 GMT position and now was at about 5° E, the lower part trailing to about 12° E.

The north-south extent of the surface line was probably farther than shown, but it had definitely benefited from the afternoon convection although at the material time appeared weak in the trailing southern portion.

Note an advantage of the analysis of the field of composition which involved delineating areas with more than 4/8 low cloud cover. The prominent "floating" shroud of low cloud along the Line in the northern middle portion was useful in fixing the position of the Line. One or two thunderstorms were reported not farthest than about 600 km on either side of the Line.

27 July. Morning regime: The "compression" wave of the evening of the 26th had developed and its trough-line lay at 5° E. The nothern limit of the disturbed streamlines was at about 16.5° N, the southern, about the Equator.

At 850 mb the two cyclonic vortices of the previous evening have now combined into a spectacular cyclonic vortex.

At 300 mb the flow was from the SE and winds were diverging (Fig. 7). The sub-jet wind-maximum fanned out at the Bight of Benin, some 800 km to the SE of the line; one finger ran southward and another continued over Sierra Leone, through the southern regions of West Africa.

Fig. 5*b* shows the surface Squall Line along the Greenwich over Ghana. It probably exten-

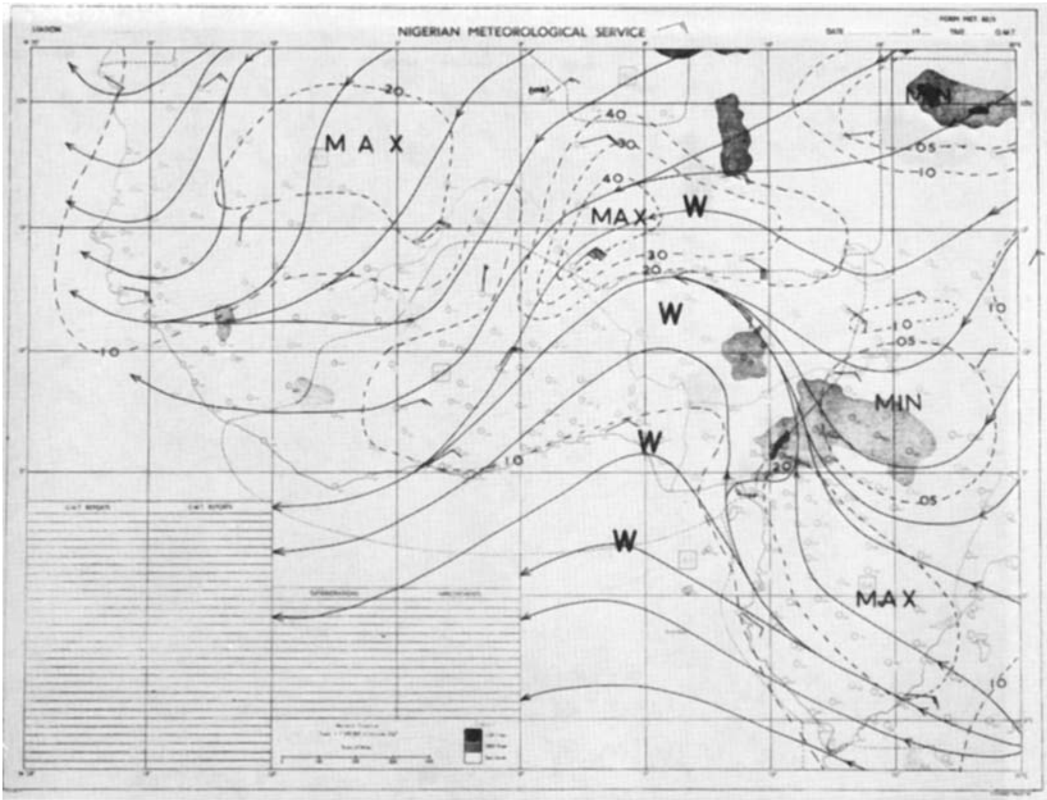

Fig. 4c. 700 mb wind speed (– – –) and streamline (——) analyses, 27 July 1960, 0400–1100 GMT.

ded into the sea, but there were no observation to justify this. The Line, which obviously had been weakening lay directly beneath the 850 mb vortex but was closely associated with the 700 mb wave. During the night hours, slight acceleration of Line was apparent with nearly all stations reporting thunder. However, it is significant that the strongest reported wind was 10 kt on the line. The average I.T.D. W–E position within 10° W–5° E was at about 17.5° N latitude. We normally could not have been able to fix the line but its presence was highlighted by the close banking of low clouds. The line was more active in the middle and southern portions with convection there, with widespread subsidence just immediately behind as well as in the northern portion.

27 July. Evening regime: At 700 mb the main trough-line was at 4° E, and the shearline ran backward through the Cameroun territory into the Chad Republic.

The almost elliptical 850 mb vortex was centred at about 12.5° N 3° W.

At 300 mb an anticyclonic vortex had moved into low latitudes, centred at 20° N 0.5° E. The flow over the surface line at this level was south–easterly and was generally convergent.

The surface line over the Ivory Coast was feeble but still slightly active in its northern portion.

With the shift of the anticyclone, there resulted a steady subsidence in the air ahead of the line during the morning. The low cloud cluster analysis highlighted the presence of the line; there was no medium cloud at all. Low cloud reports are small CuSc, with isolated reports of Cb. It is significant that no weather was reported along the line, but there were reports of thunderstorms behind. It is suggested that this was the Instability Line stage of Squall Line and may in fact be called a Cloud Line.

28 July. Morning regime: The air in some

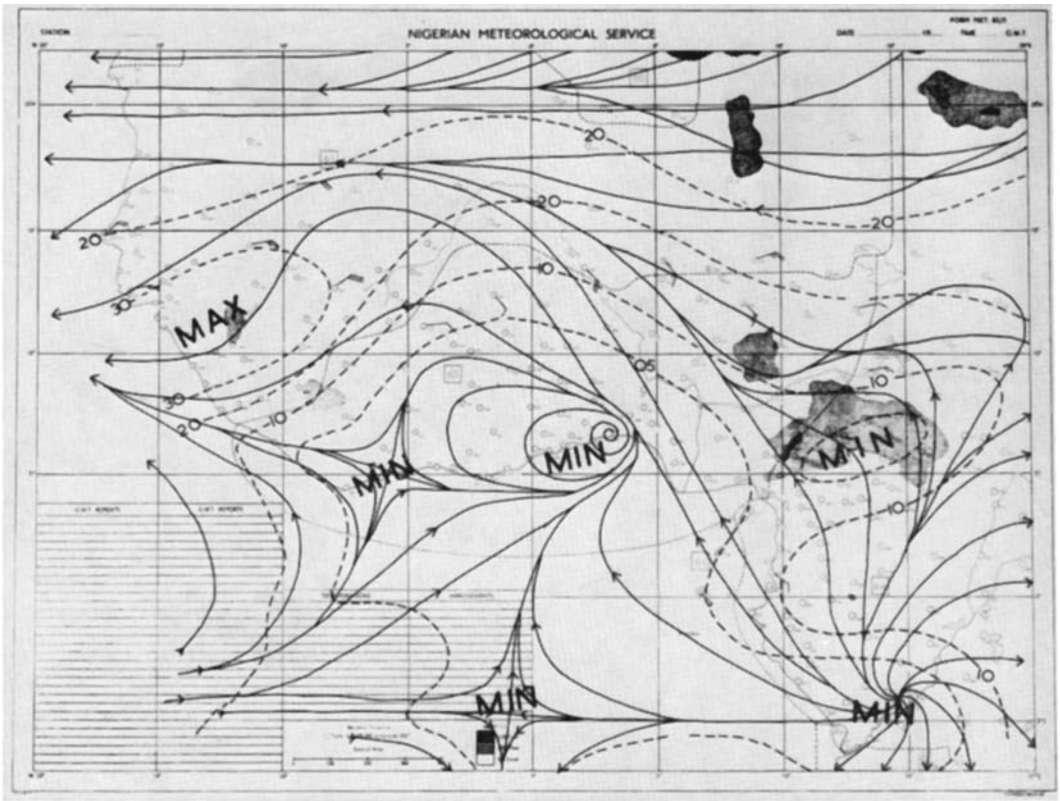

Fig. 4d. 700 mb wind speed (– – –) and streamline (——) analyses, 29 July 1960, 0400–1100 GMT.

parts of the new vortex at 700 mb was probably gradually subsiding at this level, for there were only small Sc in the vicinity, while the 850 mb vortex at 11.5° E was folding in its principal asymptote.

The surface line had moved, hanging from the lower forward sectors of the 850 mb vortex, and the I.T.D., with the characteristic bulge around the longitude of the Line, was at about 16° N.

At 300 mb the flow was north-easterly in the area, and the air on the periphery of the vast anticyclone was subsiding. The sub-jet wind maximum had decreased and appeared to have retreated some 2 800 km from the surface line.

The surface line consisted of slight intermittent rain and drizzle (Precipitation Line) in the vicinity of the southern portion. Subsidence was still very prominent, and reports of thunderstorms came from the rear of the northern section.

28 July. Evening regime: The 700 mb wave was shown to be in the process of transforming completely into a vortex. The troughline lies NE-wards of Liberia.

At 850 mb the cyclonic vortex had remained almost stationary, but a newly formed cyclonic vortex lay to its east.

The associated surface Line with some thundery activity on it lay on the 15 degree longitude, just west of Sierra Leone. The southern end was probably trailing along the coast. Note, again, the heavy low and medium cloud clusters around it which highlighted the Line's existence.

3. Low tropospheric divergence considerations

The divergence field patterns were of great interest in this investigation. They were mapped for 850 and 700 mb levels. Corresponding rainfall charts were also constructed. These maps will be presented in a subsequent paper.

However, Table I gives qualitative assess-

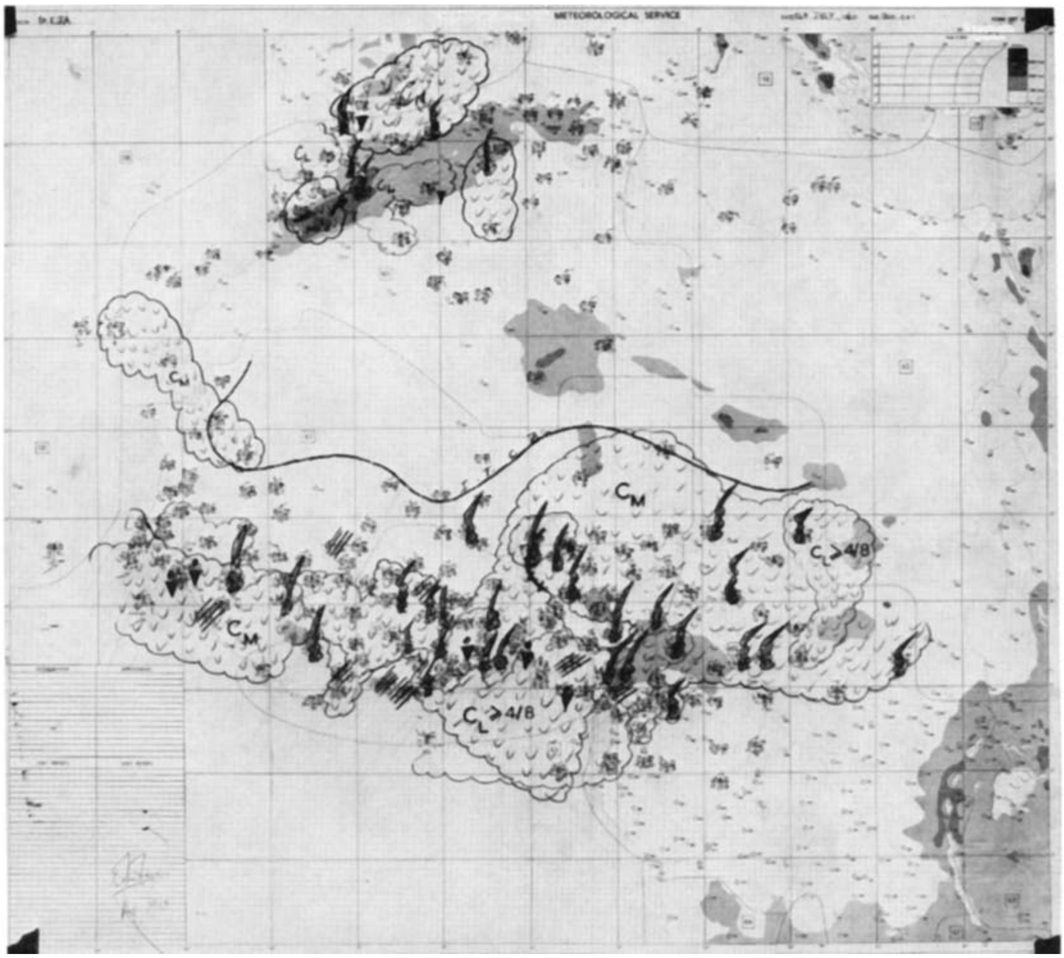

Fig. 5a. Surface cloud and weather analyses (symbols, conventional), 26 July 1960, 1800 (1600–2300) GMT (Medium cloud—C_M; low cloud greater than 4 oktas—$C_L \geq 4/8$; cumulonimbus—CB.)

ments of the divergence field in the vicinity of the Surface Line. There was often appreciable divergence in the outskirts up to 850 mb, moderate divergence from 700–500 mb, and some convergence above. The following comments were distinguished and pertinent:

No systematic pattern of divergence distribution about the 850 mb cyclonic vortex was in evidence; although the divergence charts for the level and the rainfall charts (alternatively, surface-weather) exemplified a correlation between general distribution of rainfall (belonging to the "monsoon" regime) and areas of negative divergence (convergence) within a narrow layer at 850 mb. The divergence around this level may therefore be taken as representative of the mean divergence within the first 5 000 feet layer, or so, above the surface.

On the other hand, a clearer pattern of divergence distribution revealed itself on the 700 mb divergence charts. At middle-levels net divergence prevailed ahead of the trough-line, and net convergence to the rear. But they were concentrated around the upper left and lower precincts of the wave-crest respectively.

In the main, a belt of convergence along which the Line was always sandwiched between belts of divergence in which were found definite centres of maxima and minima. These, however, were situations when

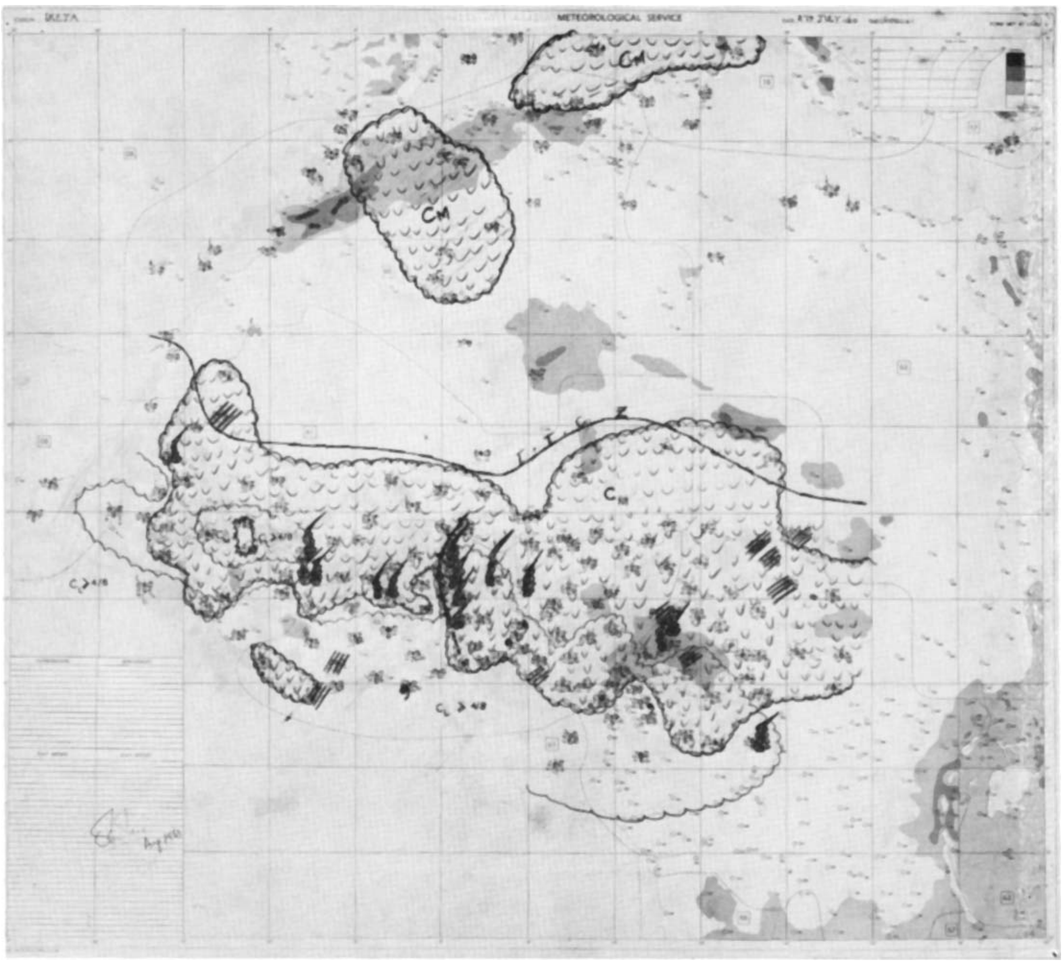

Fig. 5b. Surface cloud and weather analyses (symbols, conventional), 27 July 1960, 0600 (0400–1100) GMT. (Medium cloud—C_M; low cloud $C_L \geq {}^4/_8$; cumulonimbus—CB.)

the flow was modified by the behaviour of meso or synoptic-scale system such as the Squall Line (meridional Line of convection clouds, and of squally weather) carried in the wave, thus causing temporary mid-level convergence ahead and divergence at the upper right rear sector of the trough-line. This was so because the Line, once formed generally moved slightly faster than the easterly wave, transferring with it the associated convergence and establishing itself ahead of the trough-line. The charts for the evening of 26th, Figs. 4*b* and 5*a*, form a good illustration. The difference in the circulation patterns of the easterly wave of tropical Pacific and that of tropical Africa have been emphasized.

The foregoing therefore affords a general statement concerning the status of the West African Easterly Wave, similar in many respects to the classical Riehl's and Palmer's models. Both models are not wholly tenable in West Africa; but Palmer's is more representative.

4. Low-level vortices and easterly waves

(a) *Local weather associated with cyclonic vortex*

In West Africa it has become the practice to associate easterly waves at 700 mb, and more particularly lower level (850 mb) vortices, with periodicities in the weather. At a Nigerian Meteorological Service Symposium, D. K. Rao

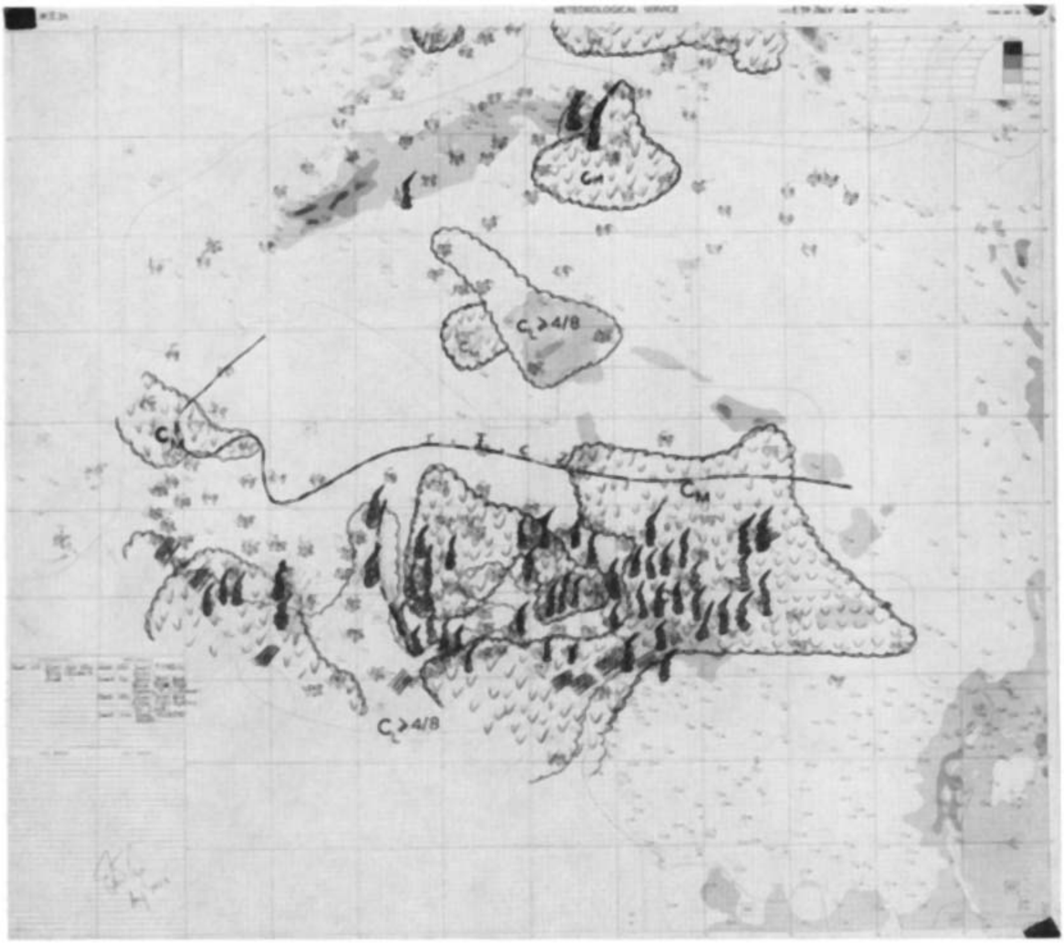

Fig. 5c. Surface cloud and weather analyses (symbols, conventional), 27 July 1960, 1800 (1600–2300) GMT. (Medium cloud—C_M; low cloud $C_L \geq {}^4/_8$; cumulonimbus—CB.)

(1963) demonstrated the importance of these cyclonic vortices, and of waves, in the horizontal free-hand streamline patterns and claimed certain associations with regard to weather distribution. The weakness in this method has been pointed out earlier.

The general weather regime has here been shown to be widespread medium clouds and rain south-west to east of cyclonic centres. This investigation showed clearly that rain fell most where there was general streamline confluence and velocity convergence.

However, a unique type of synoptic regime may result in areas of explosive convective activity and from travelling lines of squally thunderstorm (Line Squalls) or Squall Lines (Figs. 5). This was usually found associated with an easterly wave, consistent with the flow properties described in Section 3.

Squall Lines in association with tropospheric vortices should be watched closely for later development on or after passage into the Atlantic in the vicinity of Cape Verde Islands, for they may transform into tropical storms. It is suspected that the Squall Line treated in this paper intensified into a bigger system over West Atlantic.

(b) *Some characteristic features of cyclonic vortices*

Features of cyclonic vortices revealed by the charts analysed include the following:

(i) Vortices migrated within about 10–15

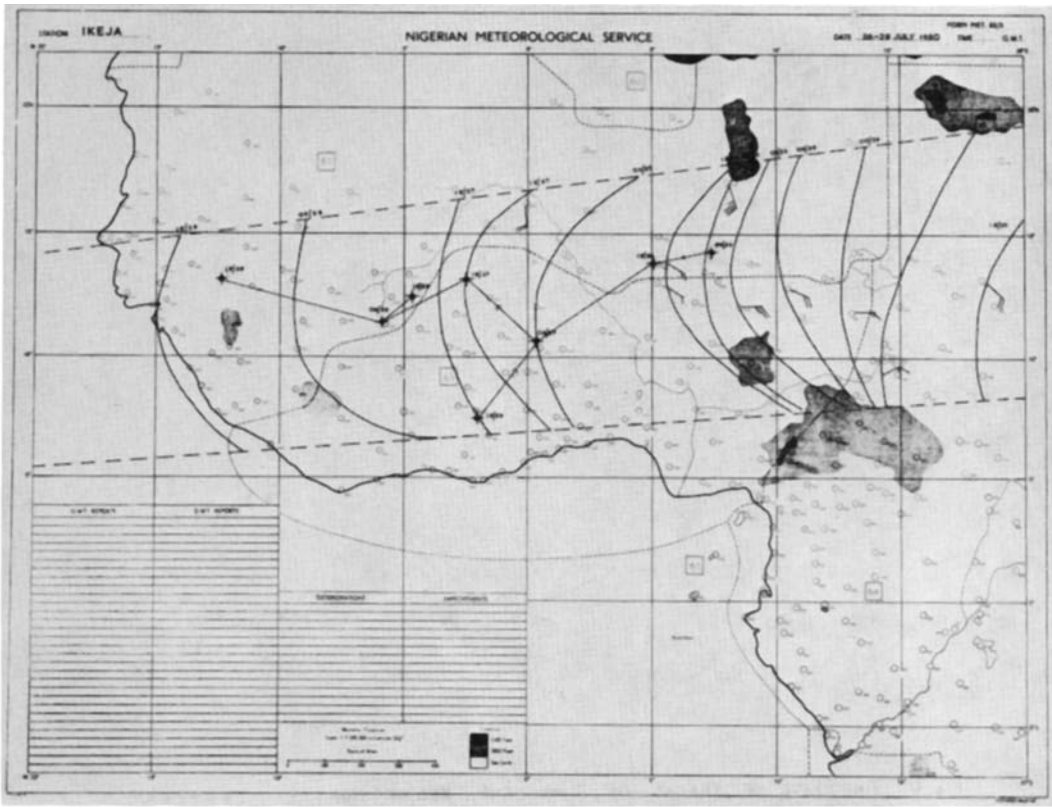

Fig. 6. Time/date of tracks of line and 850 mb vortex centers.

degrees *south of the surface position of the Intertropical Discontinuity* (*I.T.D.*) (called I.T.B., Intertropical Boundary, by some West African meteorologists) and originate somewhere east of 30° E in an airstream in which the velocity does not exceed 25–35 kt.

(ii) When a vortex extended down to the surface its axis was inclined upwards toward the SE–E (120°).

(iii) A vortex, in the main, progressive, could be somewhat erratic in movement, not as regular as Matthews & Gilchrist's (1961) contour charts claimed—the paths of individual vortex will vary from day to day as the general flow varies, and the tendency is for the vortex centre to execute a weak sinusoidal oscillation, reminiscent of well-known diurnal motion of the I.T.C.Z. aloft.

(iv) A doublet appears to be a rare formation; however, when formed, it is shortlived because the one of the pair which is dynamically stable gets quickly damped out.

(v) The average movement of a vortex could be anywhere between 10 and 14 degrees of longitude in 24 hours.

(vi) A Squall Line, linear or semi-vortical and lying roughly N–S may exist in association with a mid-tropospheric (850 mb) vortex in such a way as to suggest itself as feeding on the vortex and like a hanging vortex-tube through which momentum or energy flows into lower latitudes. The converse is not necessarily true.

(c) *Some characteristic features of easterly waves*

The following are the outstanding features of easterly waves:

(i) Waves were most prominent in the monsoon dominated middle-southern regions of West Africa and appeared to move regularly, particularly with reference to the morning flow-structures, making accurate tracking and observation of activity possible.

(ii) Waves in a train had half-wave lengths between 7 and 9 degrees of longitude (around

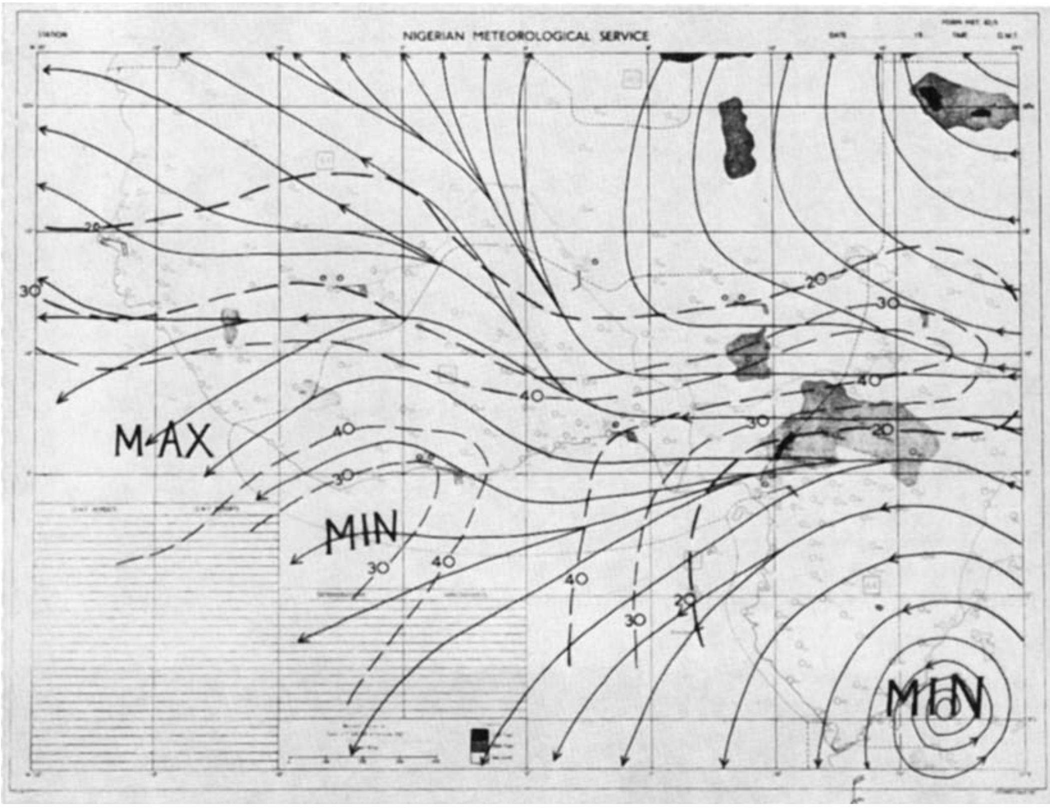

Fig. 7. 300 mb wind speed (---) and streamline (——) analyses, 27 July 1960, 0400–1100 GMT.

1 000 km), but occasionally as large as 20–25 degrees when dry spell may be associated with the larger interval of wave passage. Average movement of a wave may be 10–14 degrees of longitude in 24 hours.

(iii) The farthest north of the disturbed streamlines of a wave was at about 20 to 22° N latitude, the amplitude decreasing from the equator towards the north.

(iv) The Southern part of a mature wave featured predominently large clouds with vertical development and there appeared to be frequent and general occurrence of weather associated with these cloud formations in preferred wave-sectors: usually thunder in the NW–SE, while there were significantly squally thundershowers or thundery-rain in the E–SW areas of the trough axis.

(v) Some waves which affect West Africa may originate from a "wave pool" around Equatorial Africa, as break-aways from the quasi-permanent meridional waves in the easterlies; and a greater number much east of 30° E.

(vi) A Squall Line however weak was always associated with a developed wave particularly a mature one and vice versa. There was no tendency for the one case-studied to be completely independent of the 700 mb wave during history.

5. General remarks regarding perturbations

(i) During the period, the sub-tropical ridgelines of the Southern and Northern Hemispheres approached each other with height and became the prominent features of the flow above 400 mb.

(ii) It appeared the wave, *W*, underwent a complete and definite life cycle though not completely dissipating. It is likely that this is a characteristic of all waves traversing the West African area (Table 1).

Table 1. *Qualitative estimates of divergence in the immediate surrounding of line*

Date...	26 July 1960		27 July 1960		28 July 1960	
Time G M T ...	04–11	16–23	04–11	16–23	04–11	16–23
700 mb wave amplitude ...	18° Lat − 5° Lat 13° Lat	15° Lat − 5° Lat 10° Lat	17° Lat − 0° Lat 17° Lat	15° Lat − 5° Lat 10° Lat	17° Lat − 7° Lat 10° Lat	17° Lat − 10° Lat 7° Lat
Layer						
300 mb	C–StD–C	C–D–C	C–StD–C	C–StD–C	C–StD–C	D–StC–D
500 mb	C–StD–C	St–StC–D	D–StC–D	C–StD–C	C–D–C	C–D–C
700 mb	SD–MC–SD	StD–StC–MD	MC–SD–StC	C–D–C	D–StC–D	C–StD–C
850 mb	D–MC–StD	D–C–D	D–MC–D	D–C–D	D–StC–D	D–StC–D
2 000 ft	C–StD–C	D–StC–D	Indeterminate	D–C–D	StD–StC–D	Indeterminate
Surface	Not available					
State of development of Squall Line	Mature active stage	Weakening stage	Rejuvenating stage	Dissipating (or old-age) stage		

C, Convergence (negative divergence); D, divergence; S, strong; St, slight; M, moderate.

Example: D–C–D = Net convergence along extent of line; divergence around it.

On approaching the Nigerian borders near 5° E, there was a clear tendency for the 700 mb wave to reach a minimum in intensity, accompanied by a decrease in associated cloud activity. The decrease in isotach maximum in the neighbourhood evidenced this event which occurred during the late evening of 26th.

The associated squall line was also observed to decelerate from around 5–7° E, picking up and accelerating on clearing the area into Ghana territory reaching River Volta by 27th morning around which time activity increased. (Figs. 4*b* and 5*a*).

It was tempting to suggest a possible water-temperature effect on these systems when the Niger running NW–SE and the Volta, N–S in the areas were being traversed during the night of 26th and morning of 27th. How this effect would operate is not too clear because of the seemingly opposite effects of the rivers concerned. It is also likely that an investigation into the association of the squall line with the Jet discussed later may hold the clue. However, this subject is outside the scope of this paper.

(iii) All told, the structural features of easterly waves which were embedded in a generally convergent basic current at middle levels appear unique. The convergence associated with the waves, between zones of divergence clearly possessed a singular characteristic, the physical existence of the Squall Line. Hence wave evidence the cause of Squall Line. The determination of the former may however require a third parameter.

(iv) The usually shortlived mid-tropospheric waves or vortices at 500 mb were restricted to 15° *north of the geographical equator*. Such a wave was superimposed on a 700 mb wave-troughs. When it was out of phase with the wave trough, it accelerated with speeds between 15 and 25 kt. (They night be dispersive pressure waves merely causing localised perturbations in the mid-tropospheric easterlies.) No associated weather was apparent.

(v) High level charts could prove most helpful in daily weather prognosis, particularly for the 300 mb and 200 mb. On these charts the Tropical Easterly Jet nearer the Equator, a feature of promising reliability in West Africa could be easily located. Qualitative principles to be applied are similar to those of Westerly Jets: Areas beneath the right entrance and the left exit of Jet are characterised by development and low-level cyclogenesis. Most of the period, the investigated Squall Line was observed on the northern side of the Jet axis, obviously in the area of impressed low-level cyclogenesis.

(vi) It was clear that air of middle latitude origin can reach well south into very low latitudes. This further demonstrates the inter-action between high and low latitudes could be connected with initiation of a wave—a phasing with a "monsoon" burst preceeded by the southward plunge of colder air.

(vii) Contrary to existing knowledge that the northern limit of the I.T.D. is around 20° N, we observed that because of waves on the discontinuity at low levels, 2 000 feet, for example, it can and indeed reached 25° N. The W–E line we call the I.T.D. on the surface should coincide with the northern limit of the disturbed part of the easterly flow, beyond which no weather of the easterly type is to be expected. This view is confirmed by Fig. 1 at page 234 of Hamilton & Archbold (1945).

(viii) Of the levels analysed the 700 mb appeared to be the most useful in tracking perturbations especially squall lines, upon which synoptic status has thus been confirmed, during the season characteristic of July. More significant is the fact that Squall Lines (Lignes de Grains) move with a speed approximating the maximum isovel behind it at 700 mb at or around the time of formation. During eventual motion, it is determined by the local rate of convergence of air at the same level.

6. Conclusions

During the period under study definite connections between disturbances over West Africa and their surface manifestations were evident.

The 700 mb has here been shown to be actively connected with well organised linear flow perturbations. Streamline analysis has also been shown to be capable of affording early observation of evolution and the eventual development of an easterly wave, rendering intensification and collapse of wave comparatively easier features to predict. As cloud distribution and weather in West Africa have been shown to be bery closely associated with the wind-field, it is velieved that continued investigation will give better and more accurate results.

The most important result of these analyses, therefore, is that an easterly wave model incorporating the middle level (700 mb) trough and its succeeding ridge as integral features of the flow is one which describes best the majority of observations of significant weather zones and which puts on a firmer basis, the physical existence of the westward propagating well organised linear or semi-vortical disturbance (line-of-squally-thunderstorms) characterising the West African weather. The 850 mb chart is certainly useful but it is considered mainly sufficient in assessing only the general distribution of rainfall or weather (for low level Aviation purpose), whilst the 700 mb should prove most useful in tracking organized perturbations of synoptic scale.

Finally, two prominent features evident from this series of charts are: (i) The vortices of the lower troposphere; and (ii) Westward propagating (easterly) waves together with their closely associated Squall Lines and characteristic weather.

But it appears that the more frequent low-level perturbations do not particularly depend upon high-tropospheric flow for their day-to-day existence.

The present state of the density of the upper-air observation network particularly that used in this investigation is considered still inadequate when compared with the *status quo* in the American tropics, in spite of the laudable efforts of African Nations through the World Meteorological Organisation since the Second World War. The results here are therefore tentative and further work will be necessary to confirm our deductions, especially with the availability satellite data being used to great advantage.

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СИНОПТИЧЕСКИЕ ВОЗМУЩЕНИЯ ЦИРКУЛЯЦИИ НАД ЗАПАДНОЙ АФРИКОЙ

Использование данных по ветру для уровней: 2 000 футов, 850, 700, 500 и 300 мб и деталь-ный анализ района Западной Африки на синотиаческих картах обнаружили некоторые хпрактерные черты атмосферной циркуляции, особенно в связи с активностью восточных волн в средней тропосфере над этим районом.

Описывается эволюция квазивихревого возмущения, движение в котором имеет тот же ритм, что и при распространении восточной волны на поверхности 700 мб.

Делается заключение, что модель восточной волны, включающая ложбину (и гребень) на уровне 700 мв в качестве интегральной особенности потока, лучше всего описывает большинство существенных для погоды зон и объясняет существование движущихся к западу квазивихревых грозовых линий, часто пересекающих центр Западной Африки во время сезонов дождей.