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On the utility of plotting vectorial changes of upper winds in forecasting developments and progress of important pressure systems

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ABSTRACT. A study has been made to find the usefulness, for forecasting purposes, of a critical examination of the 24-hour variations in the flow pattern of winds by plotting systematically vectorial changes of upper winds. It is seen that such charts, by providing a more definite picture of changes in the circulation pattern of winds, give an insight into the future trend of events in relation to developments of important synoptic situations, such as, the origin and movements of depressions or storms in the sea areas, formation of secondaries of western disturbances etc more readily and clearly than what is possible from a study of two consecutive wind charts.

1. Introduction

Weather forecasting is largely a well-reasoned extrapolation of the current synoptic situation and, as such, it is obviously of value to make a careful note of the past changes in the different meteorological elements, and to consider how far these observed tendencies are likely to persist and shape the future trend of events. Of the various meteorological elements required to be plotted normally on day-to-day charts according to International recommendations, two, namely, wind and pressure tendency, are change elements. In India, because of the predominance of the factor of diurnal variation of pressure and of the uncertainties of the correction to be applied in this regard, short-period pressure tendencies do not always provide reliable enough guide (Roy 1946), and recourse is, therefore, taken usually to studying the changes during a period of 24 hours. The other change element, *i.e.*, wind at various levels is plotted, and a streamline analysis of the charts is made with a view firstly to finding out the changes, if any, in the air mass character over different areas and, secondly, to depicting as accurate a picture as possible of the circulation pattern of winds at a particular synoptic hour. In tropical countries like India, where weather is often of intra-air mass type and is largely an effect of organised convection of the lower moist air mass, an estimate of the growth or decay of cyclonic vorticity, that is, of increased convergence or divergence in the wind stream, by a critical study of the circulation pattern of winds at the appropriate levels, is of the greatest significance for finding out if conditions are becoming more favourable for providing an originating impulse for updraft of the lower air. Much care has, therefore, to be taken for making an accurate and systematic streamline analysis of winds at various heights, particularly those in which the moist air circulates. Experience has shown that usually the most crucial level for purposes of such a study in India is the one at about 5000 ft, although during certain seasons, such as, in the pre-monsoon months, consideration of 3000-ft winds may often be more important for locating the regions of growth and progress of thunderstorm vortices. Also, in certain cases in which cyclonic circulation tends to develop first at a higher level and then extends downwards, a critical study of stream lines of winds at 10,000 ft or so may be helpful.

As mentioned already, an analysis of the wind field at different heights constitutes an item of routine technique for day-to-day forecasting in India and, along with this study, the forecaster also tries to note, in a general way, the changes in the circulation pattern that may have occurred during the interval between two successive charts. In the absence of a standardised method for a fully satisfactory streamline analysis of upper winds, with spacings between successive lines being given with due regard to the wind speed or with isotachs drawn accurately to represent the variation of speed in the same stream, a mere visual examination of two sets of charts does not always reveal the salient characteristics of the changes in the flow pattern from one occasion to another. For example, the superposition of a relatively weak cyclonic vorticity on a strong and predominantly translatory wind field, as occurs frequently at the head of the Bay of Bengal preceding the formation of a depression in the monsoon season, does not essentially alter the pre-existing flow pattern of winds. In these situations, a chart showing the vector changes of winds over and around the area often reveals quite prominently the tendency of a rotatory wind field being superposed gradually on the prevailing translatory wind system, and a timely detection of such a trend is of material help in giving an earlier notice of the possibilities of formation of a depression in that area. Similarly, with the anti-cyclonic flow of winds dominating as a rule over northwest India during winter, the approach of a western disturbance, or the development of its secondary, may not always lead to a fundamental change in the circulation pattern of winds over the area, but streamlines drawn on charts showing vector differences of winds between two synoptic hours may bring out clearly the tendency of a cyclonic vortex being superposed on the prevailing wind field.

2. Advantages of plotting vectorial changes of winds over using surface pressure tendencies for forecasting formation of depressions in the sea areas

A study of the day-to-day upper air flow pattern shows that at the initial stages of the formation of many of the depressions in the Bay of Bengal, cyclonic circulation tends to set up first at higher levels and then gradually extends to the surface chart. In some of these cases, the pressure changes at these higher levels, if available, might give an earlier indication of the formation of a depression than pressure changes at the surface. With limited number of radiosonde stations available in the country at present, and with the present limitations of the accuracy of pressure values at a particular height as given by such observations, it is rather difficult to make a correct picture of the isallobaric field at the higher levels on the basis of radiosonde data alone. There is, however, a good network of pilot balloon stations in India, and wind data as furnished by them are very much more dependable. As there is a simple and direct relation between wind and pressure tendency, it would be distinctly preferable to make use of wind data to get a qualitative but usually more dependable picture of the isallobaric pattern at the higher levels.

The equations of frictionless motion in the horizontal plane are

$$\frac{dv_x}{dt} = -\alpha\frac{\partial p}{\partial x} + \lambda v_y$$

$$\frac{dv_y}{dt} = -\alpha\frac{\partial p}{\partial y} - \lambda v_x$$

where $\alpha = 1/\rho$ and $\lambda = 2\omega \sin\phi$. The above equations may be written in vector form as follows—

$$\frac{d}{dt}(v_x\, i + v_y\, j) = -\alpha\left(\frac{\partial p}{\partial x} i + \frac{\partial p}{\partial y} j\right) + \lambda\,(v_y\, i - v_x\, j)$$

or $$\frac{d\boldsymbol{v}}{dt} = -\alpha\nabla p + \lambda\,(v_y\, j \times k + v_x\, i \times k)$$

$$= -\alpha\,\nabla\, p + \lambda\,\boldsymbol{v} \times k$$

where, i, j, k are unit vectors along x, y, z axes of co-ordinates. Multiplying vectorially by k, the above equation may be written as

$$\frac{d\boldsymbol{v}}{dt} \times k = -\alpha \nabla p \times k + \lambda \boldsymbol{v} \times k \times k$$

$$= -\alpha \nabla p \times k - \lambda \boldsymbol{v}$$

$$\text{or } \boldsymbol{v} = \frac{-\alpha \nabla p \times k}{\lambda} + \frac{1}{\lambda} k \times \frac{d\boldsymbol{v}}{dt}$$

Differentiating this equation partially with respect to time, we obtain

$$\frac{\partial \boldsymbol{v}}{\partial t} = -\frac{\alpha}{\lambda} \boldsymbol{I} \times k + \frac{1}{\lambda} k \times \frac{\partial}{\partial t}\left(\frac{d\boldsymbol{v}}{dt}\right)$$

where $\boldsymbol{I}$ represents isallobaric gradient. According to Brunt and Douglas (1928), the last term in the above equation is negligible compared to $\frac{\partial \boldsymbol{v}}{\partial t}$. Hence $\frac{\partial \boldsymbol{v}}{\partial t} = -\frac{\alpha}{\lambda} \boldsymbol{I} \times k$ approximately.

This shows that the vectorial change of wind at a station is related to the isallobaric gradient and is tangential to isallobar. It also follows from the above equation that the circulation of the vector changes of winds will be cyclonic in a region where there is isallobaric 'low', and anti-cyclonic where there is an isallobaric 'high'. Thus, a study of the flow pattern of wind changes in the higher levels enables us to locate the isallobaric 'lows' and 'highs' there. Also, according to Petterssen (1940), circular (or nearly circular) cyclonic centres move in the direction of the isallobaric gradient (*i.e.* from rising towards falling pressures), whereas anti-cyclonic centres move in the opposite direction. Therefore, if the wind changes indicate cyclonic circulation with its central region away from the centre of the wind circulation round the depression, the latter is likely to move in the direction as indicated by the former. In cases in which the cyclonic circulation on the wind change chart lies just above the depression, it is more likely to remain stationary for a time and concentrate further in the same position. On the other hand, if an anti-cyclonic circulation on the change chart is seen superposed on the field of the depression, it is an indication that the depression is weakening. A critical study of charts showing vectorial changes of winds at different levels is thus likely to be of help in forecasting not only the formation and movement of a depression but may also provide indications of their possible intensification or weakening.

3. Upper wind changes and depressions and cyclonic storms

In the following paragraphs are discussed in some detail the cases in which charts showing day-to-day vectorial changes of upper winds have been found to be of help for more accurate prognosis of unsettled conditions, depressions and cyclonic storms in the Indian Seas.

Case 1. Cyclonic storm in the Bay of Bengal —July 1951

Up to the evening of 15 July 1951 weather was nearly seasonal in the north and central Bay of Bengal, where more or less uniform stream of southwesterly monsoon prevailed generally. The streamlines drawn on the upper wind chart of the 16th morning (Fig. 1A) show little change, and the flow pattern continues to be mainly translatory. Charts showing vector changes (Fig. 1a) of winds along and near the coast, between the morning of 15th and the morning of 16th, however, indicate that a bifurcation of streamlines was apparently taking place over the north and central Bay of Bengal, suggesting a tendency of gradual imposition of a rotatory wind-field over the pre-existing pattern. The morning upper wind chart of the following morning (Fig. 1B) also shows no marked change in the flow-pattern of winds from that on the previous day. A reference to the vector change chart of the day (Fig. 1b), however, indicates a definite superimposition of a cyclonic vortex over the north Bay of Bengal on the earlier translatory wind-field over that area. The effect of this superposition on the actual wind field becomes apparent only on the following

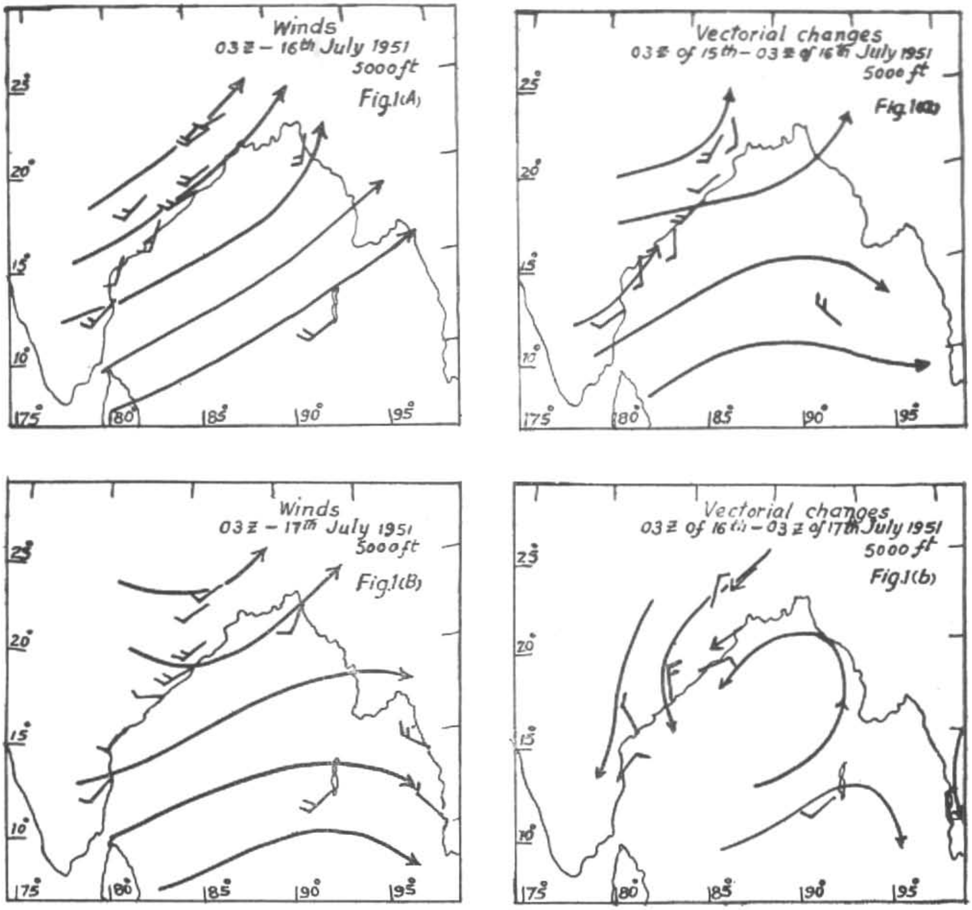

Fig. 1 (A, a, B, b)

morning, when the upper wind chart at 5000 ft shows a circulation of the cyclonic type over the north and central Bay of Bengal. The change chart on this day indicates further accentuation of the cyclonic vorticity over roughly the same area. The actual flow-pattern of winds on this day (Fig. 1C), together with the change pattern as in Fig. 1(c), has to be taken as a pointer to the unsettled conditions over the area persisting there and becoming somewhat more marked. It is seen from the charts of the 19th that the unsettled conditions in the above area actually became more marked, and eventually led to a low pressure wave moving westwards across the south Orissa coast. The westerly movement of this low pressure wave was clearly indicated by the change chart of the 19th.

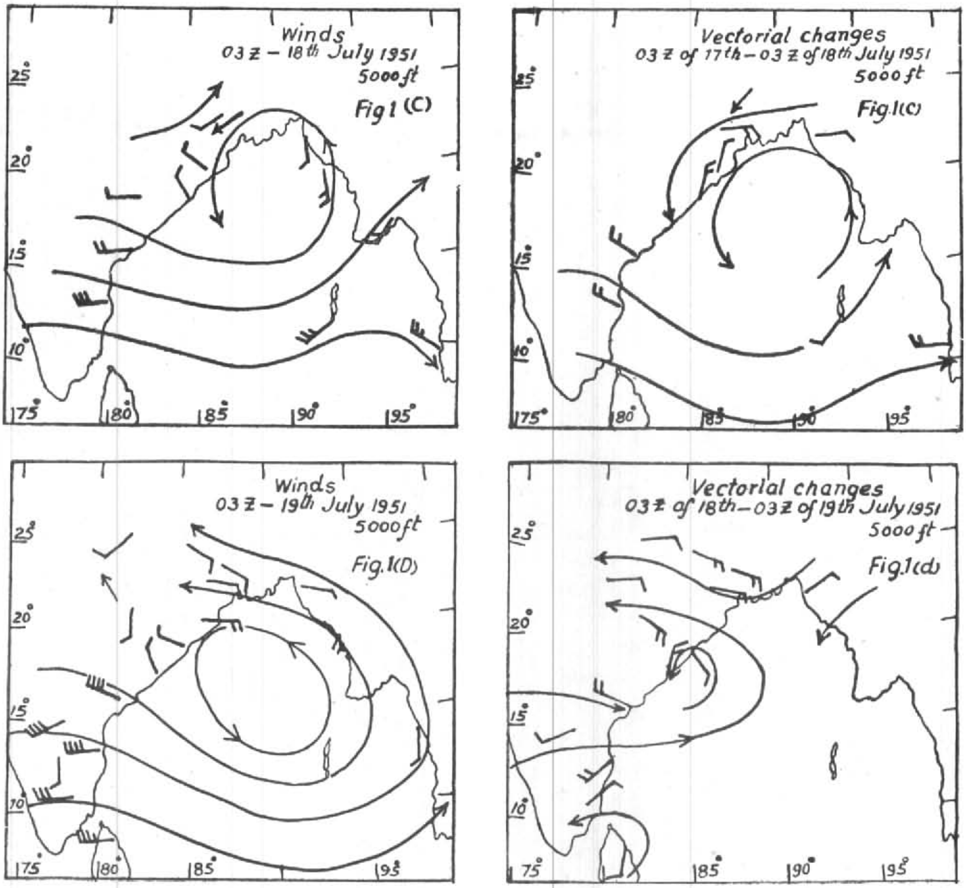

Fig. 1 (C, c, D, d)

The charts for the next few days showed that, while the monsoon trough continued to extend into the north and central Bay of Bengal, a cyclonic vorticity, as indicated by the wind change charts, first appeared over lower Burma and then moved into the central Bay. As a result, conditions became gradually unsettled over the north, and central Bay of Bengal and after further accentuation, developed into a depression by the morning of the 23rd. The depression later intensified into a cyclonic storm which was centred at 0300 GMT on the 25th near lat. 19°N long. 87°E. The charts showing actual winds at 5000 ft and wind changes during past 24 hours from the 24th onwards are shown in Figs. 1(E) to 1(H). Unfortunately, lack of winds from a number of stations on the morning of 23rd made it difficult to prepare a reasonably satisfactory

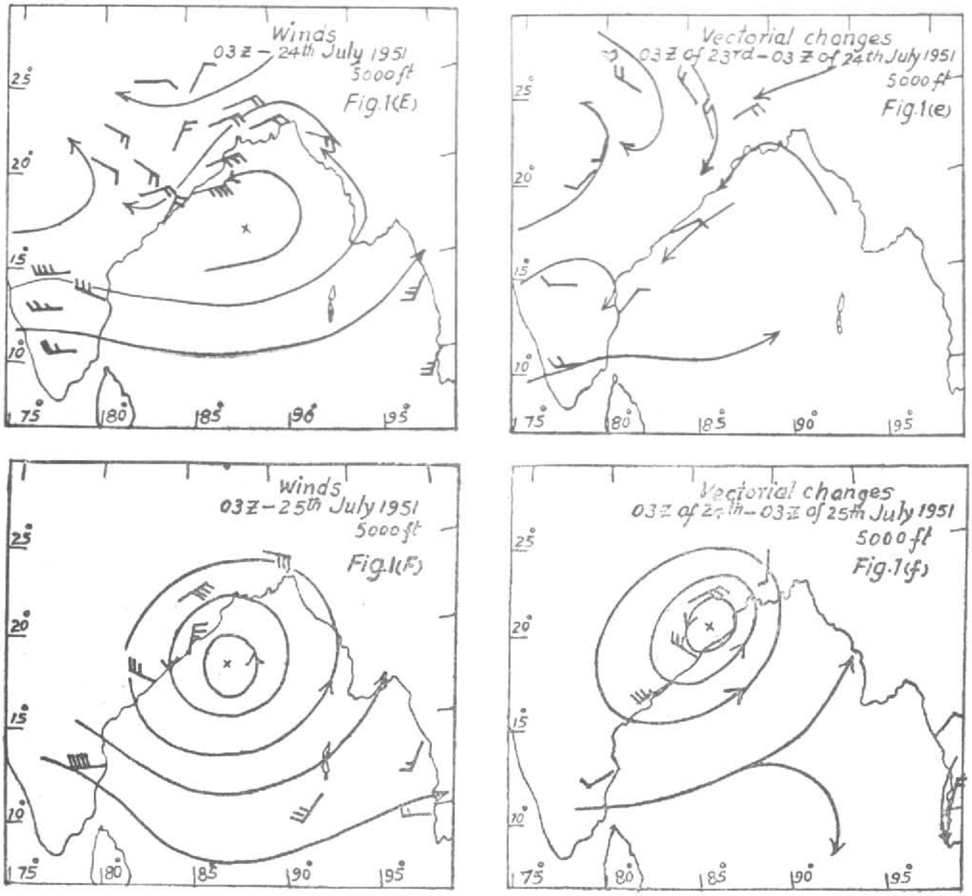

Fig. 1 (E, e, F, f)

change chart for the 24th and, as such, to fix the centre of the change circulation pattern on that day. However, marked shear in a cyclonic sense of the vector changes of winds at Asansol and Jamshedpur (Fig. 1e) could probably be taken as an indication that this centre lay to the northwest of the centre of the depression, suggesting movement of the depression in that direction.

From the actual and shear-wind charts of the 25th morning—Figs. 1(F) and 1(f), it is seen that the centre of the shear-wind circulation was about 125 miles to the northwest of the centre of the storm. The storm moved in a northwesterly direction, crossed the Orissa coast near Puri and weakening gradually moved away further northwestwards. The pronounced anti-cyclonic vorticity on the

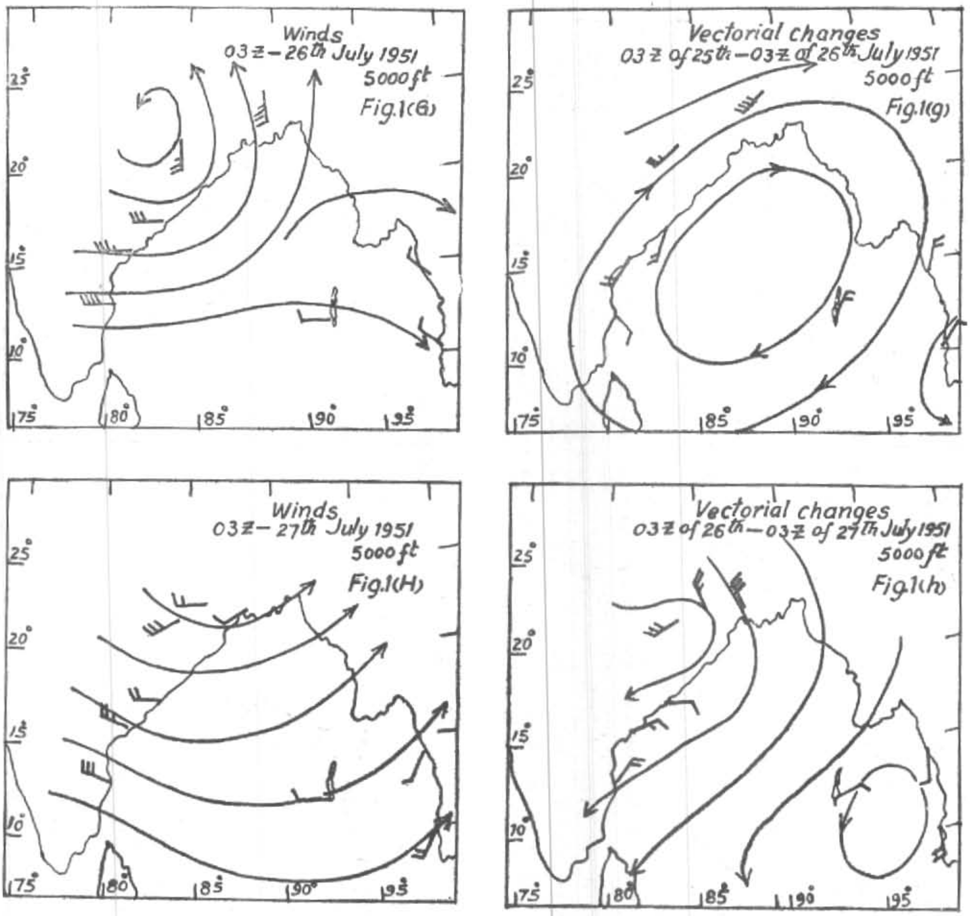

Fig. 1 (G, g, H, h)

shear-wind chart on the 26th and 27th brings out clearly the rapid weakening of the cyclonic system and of its being merged with the seasonal trough over the Gangetic valley. Meanwhile, an important feature on the wind change chart of the 25th morning was the superposition of a cyclonic vortex which was moving westwards across the Gulf of Siam. This vortex was well-marked over the Tenasserim on the 26th, and moved into the Andaman Sea by the 27th. Port Blair reported 4″ of rain on the 28th morning, and 3″ on the 29th morning. These heavy falls of rain over the Andamans could not be anticipated or accounted for on the basis of any strengthening of the southwest monsoon current over the area, but is readily explicable from consideration of the effect of convergence, on the basis of the shear-wind charts.

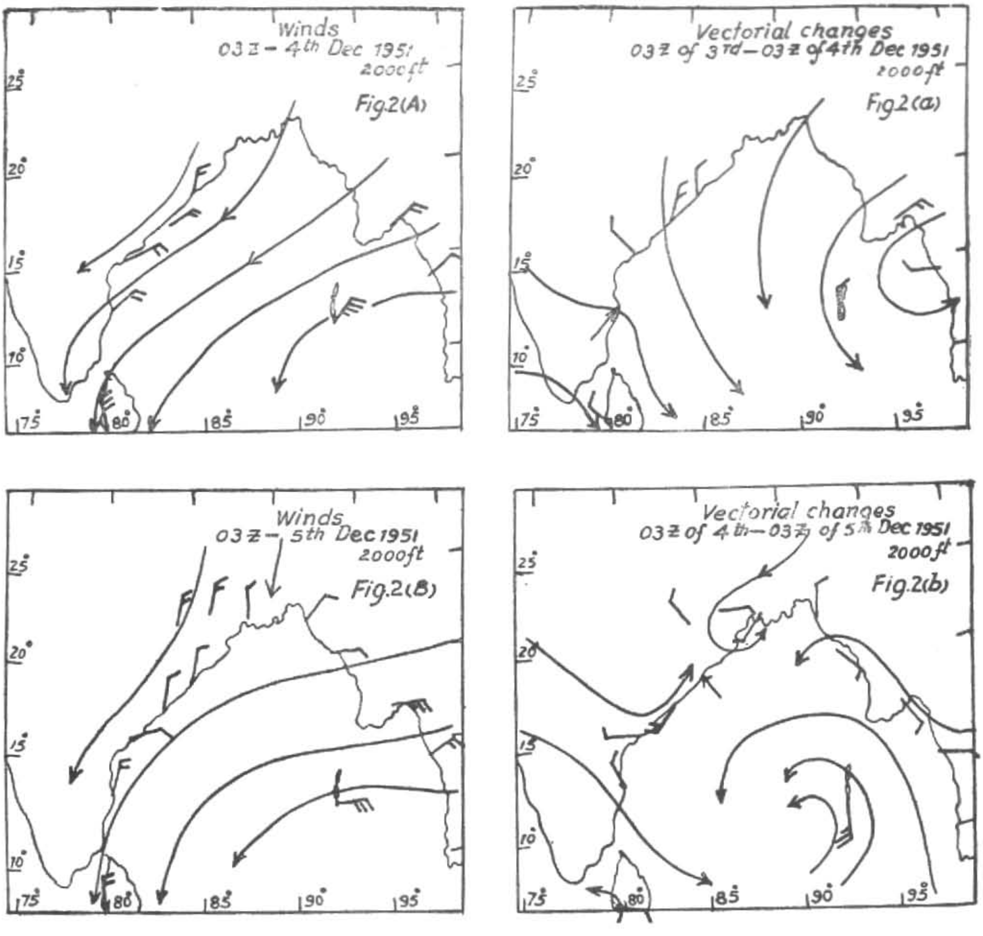

Fig. 2 (A, a, B, b)

Case 2. Cyclonic storm of the Bay of Bengal— December 1951

On the morning of the 4th, the winds were northeasterly over the Bay of Bengal and the Andaman Sea. No wind observation above 2000 ft was available at Port Blair. The 0300 GMT upper winds and shear-winds at 2000 ft over Port Blair and coastal stations around the Bay are shown in Figs. 2(A) and 2(a) respectively. The shear-wind chart representing the change in past 24 hours shows a cyclonic vorticity developing over Tenasserim and the adjoining Andaman Sea. The chart showing wind changes at 2000 ft between 0300 and 0900 GMT of the day showed southeasterly wind-shear at Port Blair, suggesting movement westwards of the above cyclonic vortex,

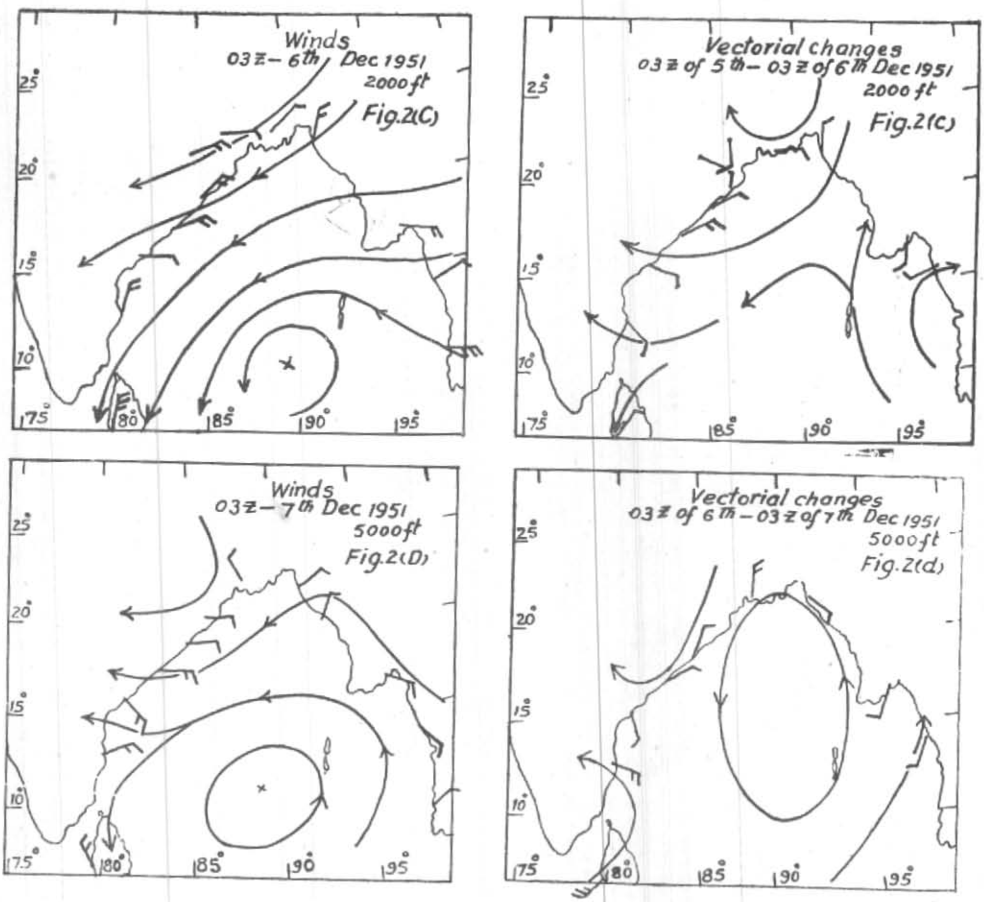

Fig. 2 (C, c, D, d)

On the 5th morning, wind at 2000 ft over Port Blair was strong easterly, while the wind-shear was southerly about 25 knots—Figs. 2(B) and 2(b). This shows that conditions by then had become markedly unsettled in southeast Bay and were apparently rapidly concentrating into a depression. Actually, a rapid development of the situation took place in course of the next 24 hours, and by 0300 GMT on the 6th, a cyclonic storm developed with its centre near lat. 10°N and long. 89½°E. Due to the absence of winds at Port Blair, the wind-shears above the station between the 6th and the 8th could not be determined. The 5000-ft wind shear charts, based on available winds at coastal

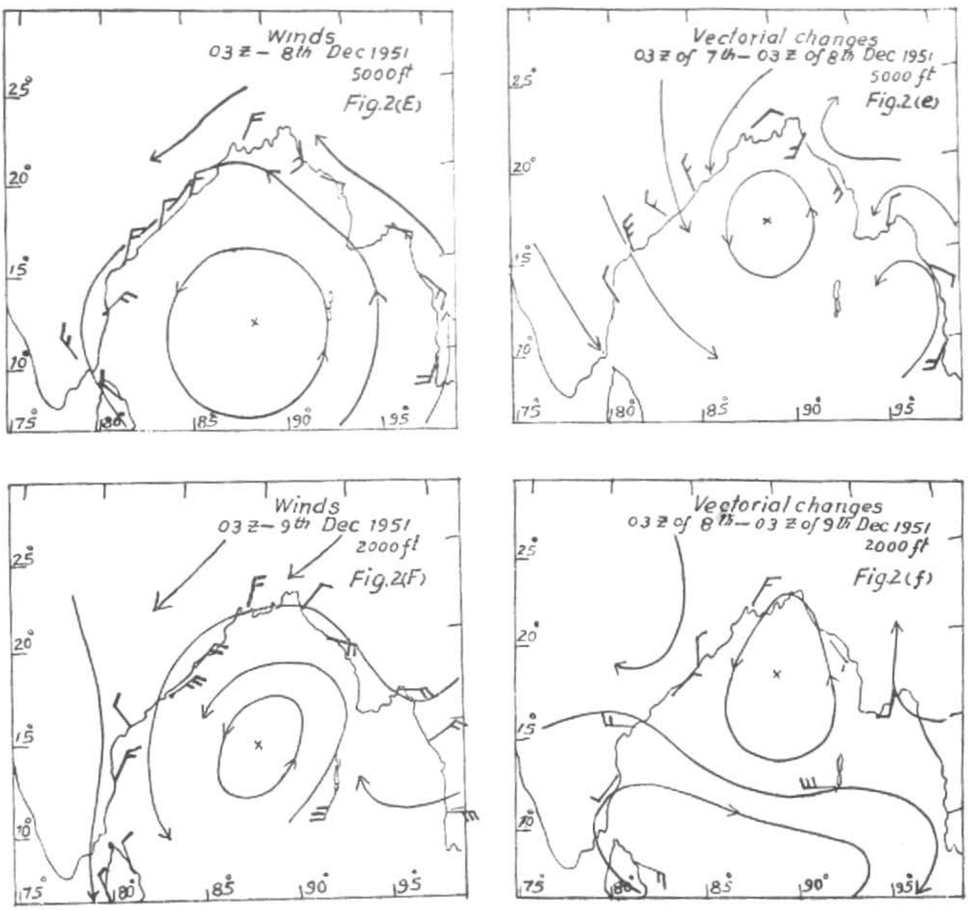

Fig. 2 (E, e, F, f)

stations for the 7th and 8th—Figs. 2(d) and 2(e), however, give a clear indication of the growth of cyclonic circulation over the north Bay of Bengal. The pressure change charts at 0300 GMT of the 8th showed a general pressure fall along the entire east coast, the fall being slightly more in the region between Madras and Calingapatam. The indications on the shear-wind chart of 8th (Fig. 2e), however, definitely favoured a northward movement of the cyclonic storm. The shear-wind charts of the day further showed that a fresh cyclonic vorticity was apparently developing over the Andaman Sea. Heavy rain amounting to 4" at Port Blair recorded on the 8th and again on the 9th was apparently associated with this growth of cyclonic vorticity over the area and the associated convergence effect.

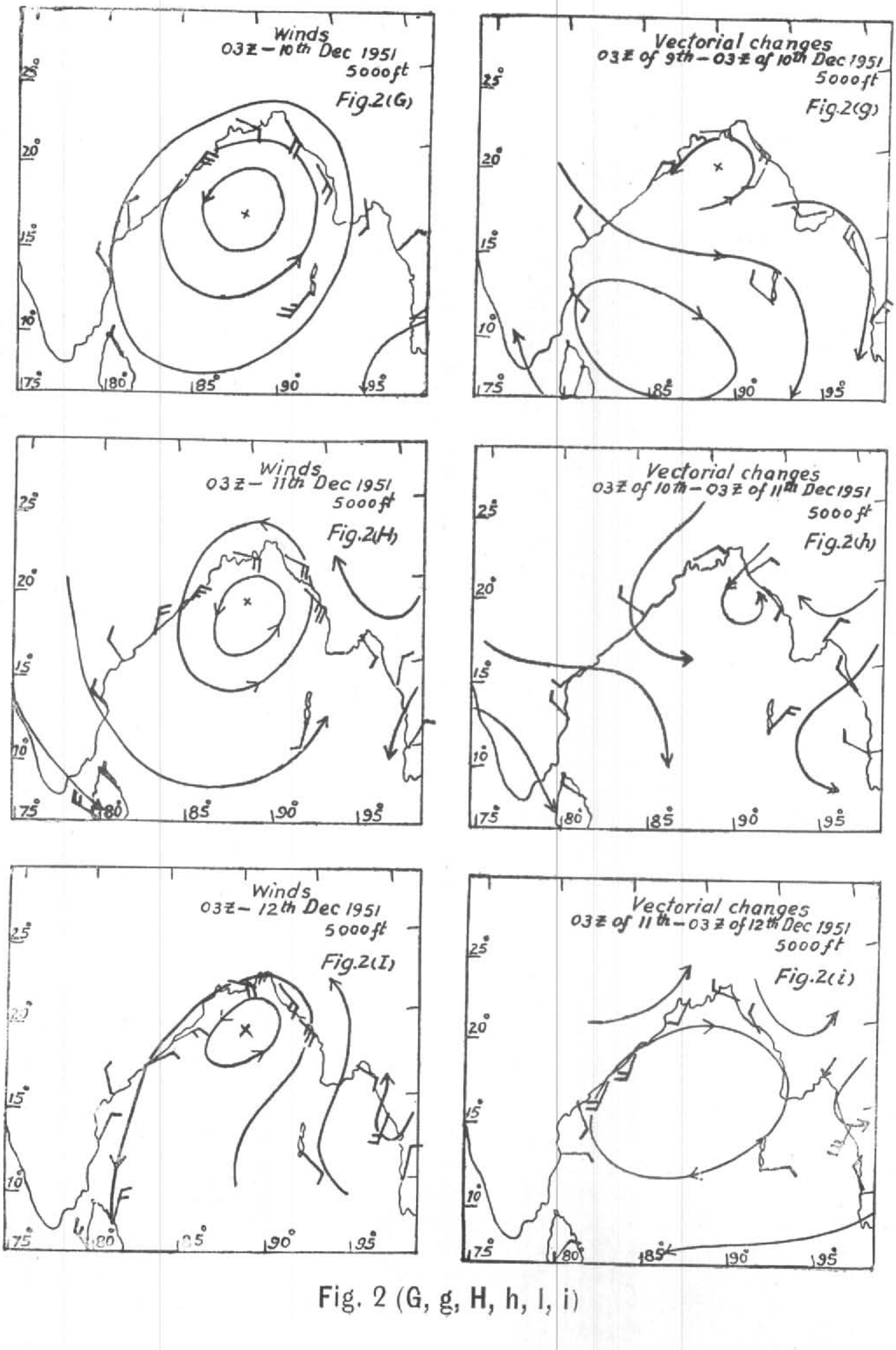
Winds
03Z – 10th Dec 1951
5000 ft
Fig. 2(G)
Vectorial changes
03Z of 9th – 03Z of 10th Dec 1951
5000 ft
Fig. 2(g)
Winds
03Z – 11th Dec 1951
5000 ft
Fig. 2(H)
Vectorial changes
03Z of 10th – 03Z of 11th Dec 1951
5000 ft
Fig. 2(h)
Winds
03Z – 12th Dec 1951
5000 ft
Fig. 2(I)
Vectorial changes
03Z of 11th – 03Z of 12th Dec 1951
5000 ft
Fig. 2(i)
75°
80°
85°
90°
95°
10°
15°
20°
25°

Fig. 2 (G, g, H, h, I, i)

As indicated by the wind-shear charts, the storm followed a northerly course, and was centred near lat. 14½°N, long. 88½°E on the morning of the 9th. At 0300 GMT on this day, the pressure fall was relatively greater along the north Circars coast and south Orissa coast but, as indicated by the growing anti-cyclonic tendency of the circulation off Coromandel and south Circars coasts and increasing cyclonic vorticity over the north Bay (*vide* Fig. 2 f), the storm continued to move northwards and was centred near lat. 17°N, long. 89°E on the 10th morning. Fig. 2(g) shows that the cyclonic circulation on the wind-shear chart over the north Bay had moved slightly towards NNE, while an anti-cyclonic circulation covered the entire Bay, outside the extreme northern zone, and also the Andaman Sea. During the next 24 hours, the cyclonic circulation on the wind-shear chart showed a further slight movement towards NNE (Fig. 2h). The pressure change chart of the 11th showed a fall in Chota Nagpur, north Orissa and in northwest end of the Bay, and rise elsewhere. Yet, as indicated by the circulation tendency on the wind-shear chart, the storm moved slowly towards NNE and was centred near lat. 19½°N, long. 89½°E at 0300 GMT on the 12th. While the upper wind circulation over the Bay continued to be cyclonic, the wind-shear chart of the 12th (Fig. 2 i) showed a definite anti-cyclonic circulation over the whole area, suggesting that the storm was weakening rapidly. In the next 24 hours the storm weakened into a depression. Later, it weakened further and lay as a trough of low pressure off Arakan coast and became unimportant after some time.

Case 3. Cyclonic storm in the Bay of Bengal—June 1950

On the morning of 8 June 1950 weather was more or less seasonal in the north Bay, although marked weakening of winds over north Orissa coast and Gangetic West Bengal suggested possible extension of the monsoon trough into the head Bay of Bengal. The streamlines drawn on the shear wind chart at 5000 ft at 0300 GMT of the day (Fig. 3 a) showing a well-marked cyclonic circulation over the greater part of the north Bay, however, are very suggestive, and give a clear and advance indication of development of a cyclonic system over the area. On the next morning, the surface chart and also the wind circulation at 5000 ft showed that conditions had become unsettled in the north Bay, and the shear wind chart indicated further concentration of cyclonic vorticity in the northeast Bay of Bengal (Figs. 3B and 3b). By the 8th morning a depression formed in the northeast Bay. During the next two days cyclonic circulation on the shear wind chart persisted over the same area suggesting further concentration of the depression there. Actually, the depression steadily intensified into a cyclonic storm, which was centred about 35 miles northnortheast of Sandheads on the morning of the 10th. Pressure falls and their departures from normal, as shown by the 0300 GMT charts of the 10th, indicated a northerly movement of the storm. The upper wind and the shear wind circulations at 5000 ft at 0300 GMT of the 10th are shown in Figs. 3(C) and 3 (c) respectively. It is seen that the centre of the shear wind circulation was near Ranchi, about 200 miles northwest of the storm centre and, apparently, more in conformity with this indication, the storm moved in a northwesterly direction in the course of the next 24 hours.

Case 4. Cyclonic storm in the Bay of Bengal—November 1952

Ships' reports received on the 24th morning indicated generally light winds but rather cloudy weather in the south Bay of

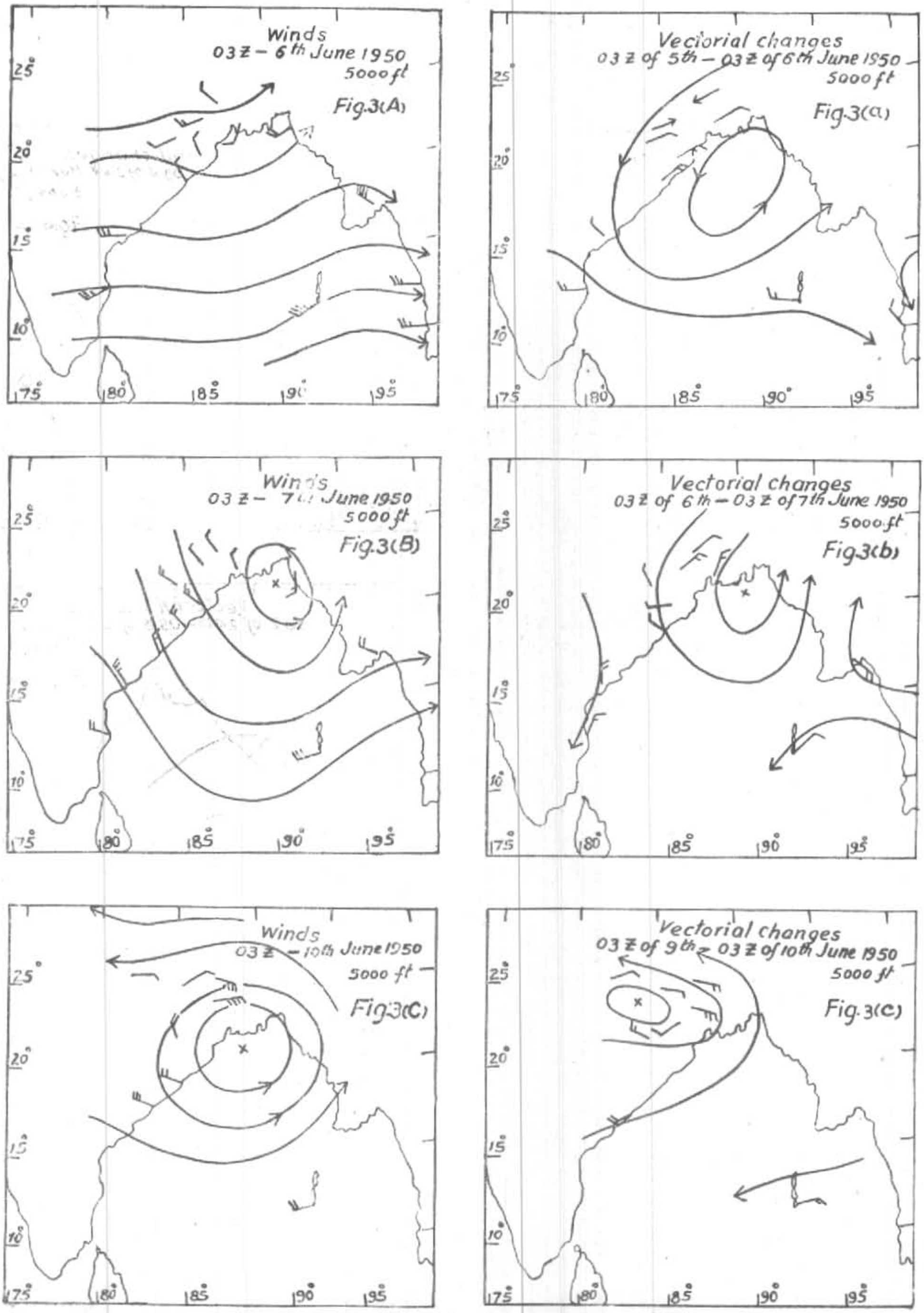
Winds
03Z – 6th June 1950
5000 ft
Fig.3(A)
Vectorial changes
03Z of 5th – 03Z of 6th June 1950
5000 ft
Fig.3(a)
03Z – June 1950
5000 ft
Fig.3(B)
Vectorial changes
03Z of 6th – 03Z of 7th June 1950
5000 ft
Fig.3(b)
Winds
03Z – 10th June 1950
5000 ft
Fig.3(C)
Vectorial changes
03Z of 9th – 03Z of 10th June 1950
5000 ft
Fig.3(c)
25°
20°
15°
10°
75°
80°
85°
90°
95°

Fig. 3 (A, a, B, b, C, c)

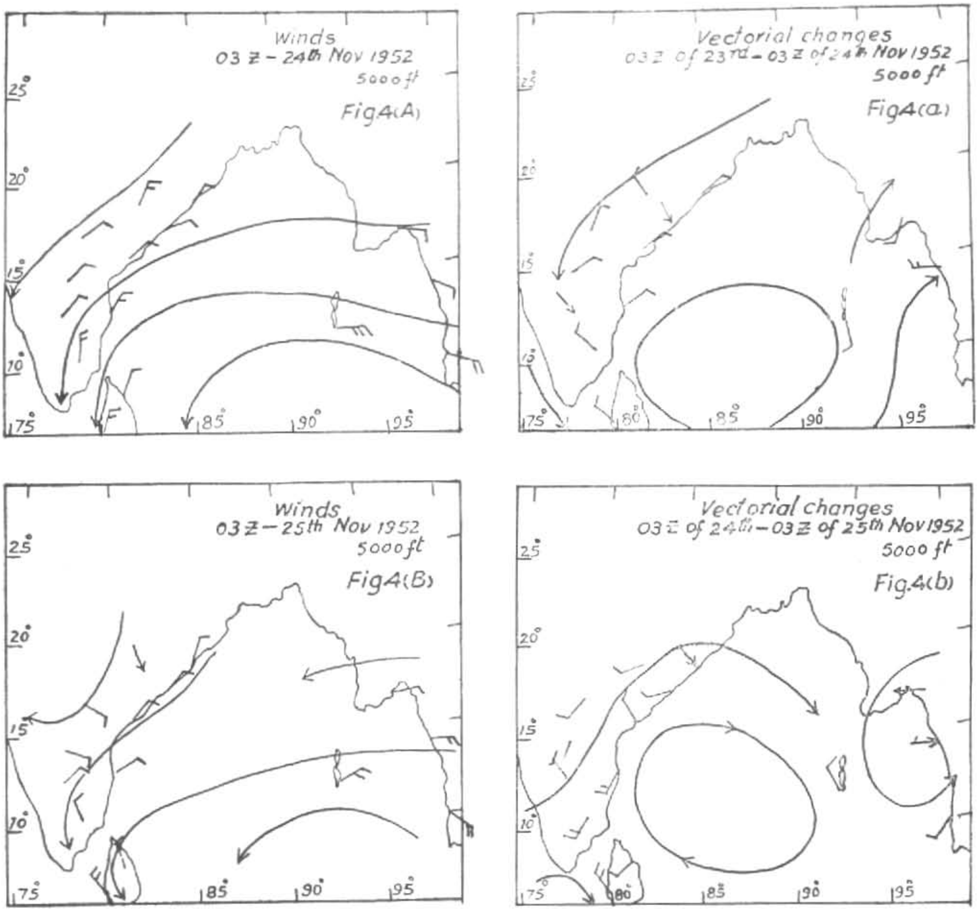

Fig. 4(A, a, B, b)

Bengal. The upper wind and shear wind circulations at 5000 ft at 0300 GMT on that day are shown in Figs. 4(A) and 4(a) respectively. While the upper wind circulation appeared to be more or less seasonal, the shear winds showed a tendency of cyclonic circulation over the south Bay. Fairly widespread rain, as reported by ships, over the area during the next 24 hours was apparently associated with increased convergence as indicated by the cyclonic circulation on the wind shear chart of the 24th. An examination of the corresponding charts for the next day, *vide* Figs. 4(B) and 4(b), however, shows that

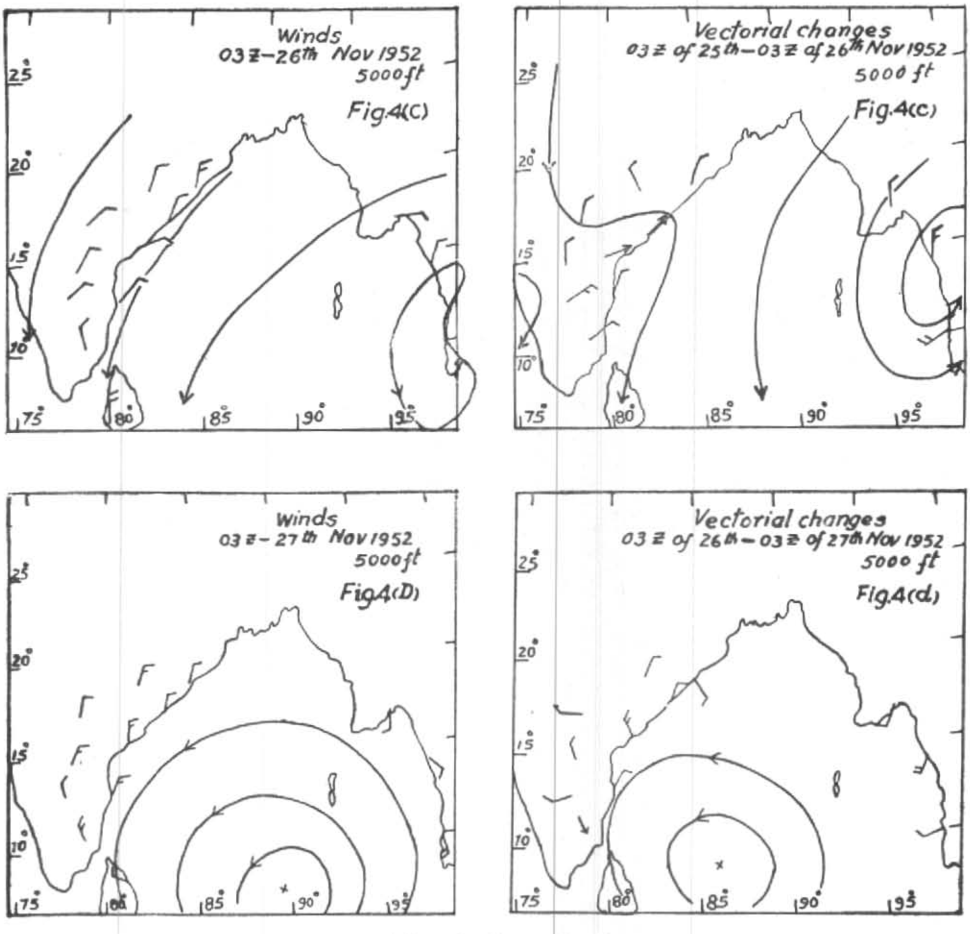

Fig. 4 (C, c, D, d)

although the trough over the south Bay was getting somewhat better developed, the cyclonic vorticity on the windshear chart of the previous day was giving way to a circulation of the anti-cyclonic type and that, on the other hand, a cyclonic vorticity was developing over the Andaman Sea. During the next 24 hours conditions became unsettled in the Andaman Sea and circulation up to 5000 ft became cyclonic. Also, pressures over the area began to fall and departures of pressure from normal became negative and acquired rather high values. By 0300 GMT on 27th, the unsettled

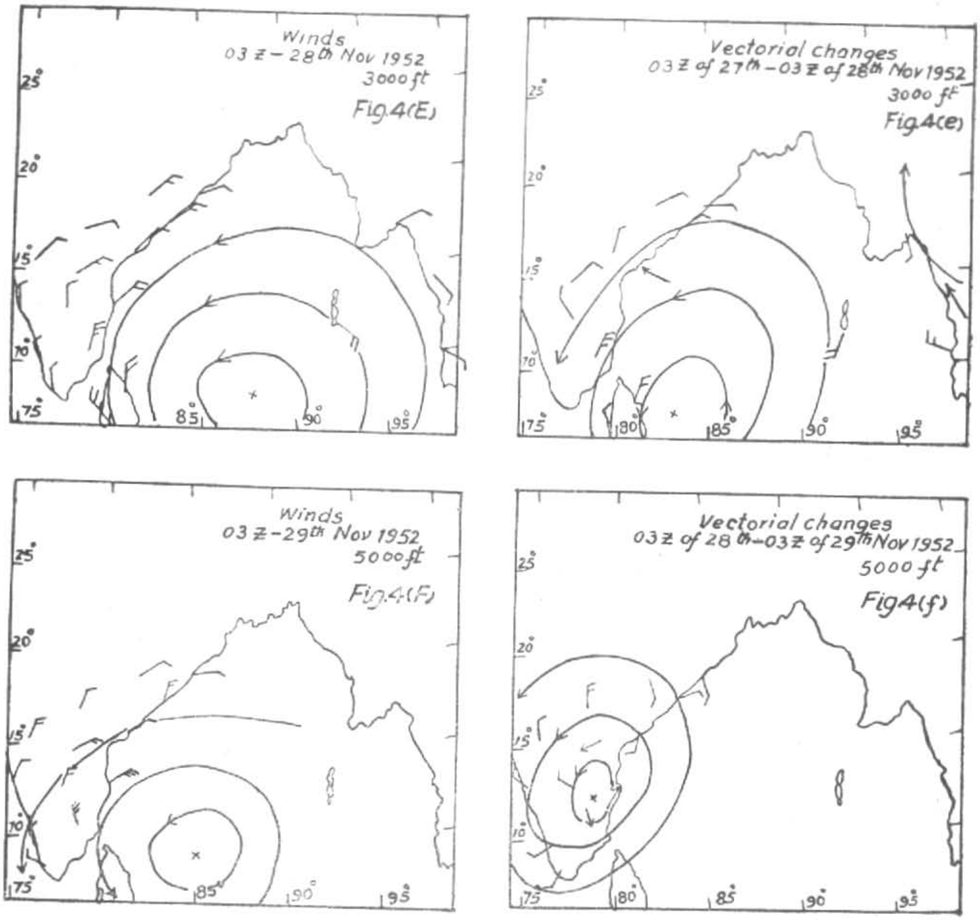

Fig. 4 (E, e, F, f)

conditions moved into the southeast Bay of Bengal and rapidly concentrated into a depression. This quick intensification could be anticipated on the basis of the wind shear chart of the 26th. During the next 24 hours the depression intensified into a cyclonic storm, which became severe and was centred near lat. 8°N, long. 87½°E on the morning of the 28th. The upper wind and shear wind circulations at this stage are shown in Figs. 4 (E) and 4(e) respectively. It is interesting to note that unlike case 2, in which the cyclonic circulation on the shear wind chart lay far north of the cyclonic centre, in this case the circulation of the shear-wind chart coincided more or less or lay slightly to the west

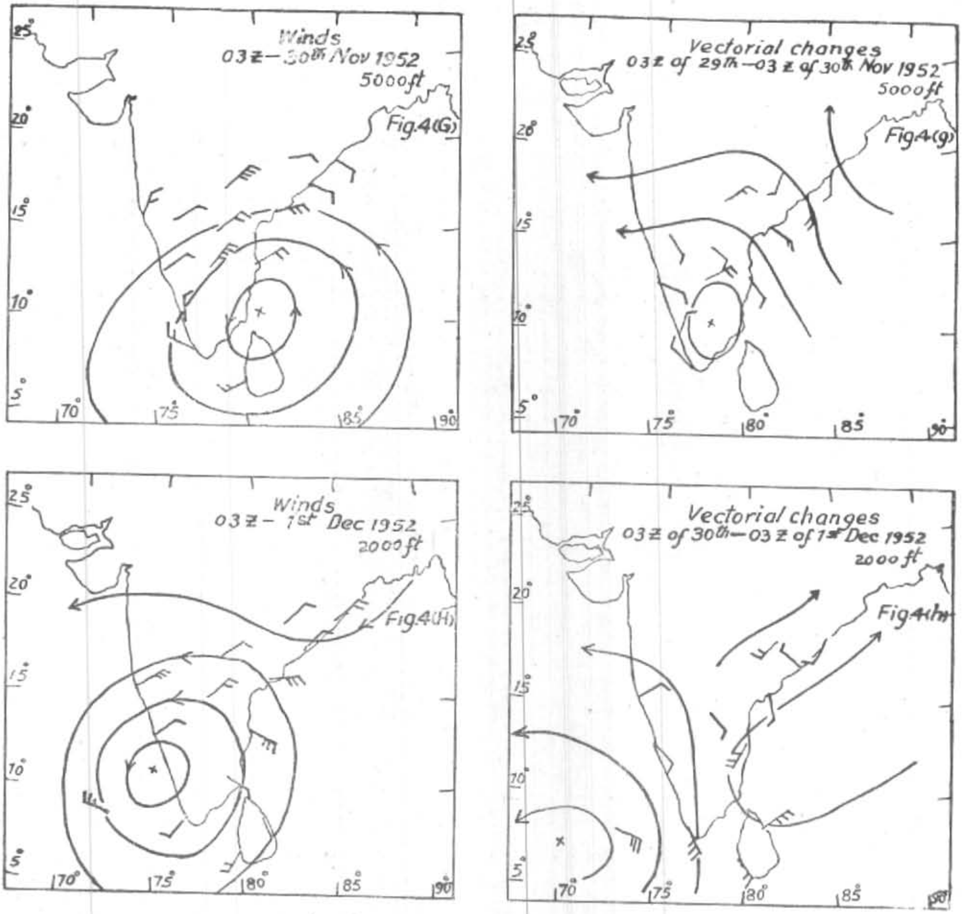

Fig. 4 (G, g, H, h)

of the circulation centre at 5000-ft level. The storm continued to move generally westwards and was centred about 60 miles southeast of Negapatam at 0300 GMT on the 30th. The centre of the shear-wind circulation at this time was about 155 miles west of the storm centre—Figs. 4 (G) and 4(g). Moving westwards the storm crossed coast just south of Negapatam in the evening, and after weakening into a depression and following a westerly course emerged into the Arabian Sea off Malabar coast. The upper wind and shear wind circulations of 1 December are shown in Figs. 4(H) and 4(h). As indicated by the circulation on the shear-wind chart, the depression moved away westwards across the southeast Arabian Sea.

4. Vectorial changes of winds and western disturbances

The western disturbances during the winter season usually follows a track across the extreme north of the country, and the rainfall associated with them is more frequently restricted to Kashmir, the East Punjab and the Western Himalayas, while weather further to the south is often the result of the secondaries induced by these disturbances. Exact location of a western disturbance, particularly one of a relatively feeble nature, and also timely detection of the possible developments of its secondary, are found to be rather difficult at times, as the associated cyclonic wind-system around the field of such disturbances is often masked by the normal anti-cyclonic circulation which dominates during this season. It is seen that the plotting of wind-shear charts helps, to some extent, the location of a western disturbance and, as such, also the forecasting of weather associated with it. The usefulness of the wind-shear chart in this regard has been examined with reference to a number of synoptic situations but, with a view to saving space, only one such case is discussed below.

A western disturbance lay over the North West Frontier Province on 30.1.1952. At 0300 GMT of the next day, the main disturbance was apparently passing through Kashmir. The prevalence of SW'ly to SE'ly winds over the N.W.F.P., Baluchistan, Sind, West Rajasthan and adjoining regions, however, suggested possible advance of yet another disturbance from the west, although its extact location was difficult. Figs. 5(A) and 5(B) show the winds at 5000 ft at 0300 GMT on 30th and 31st respectively, while the Figs. 5(a) and 5(b) show the 24-hour changes of winds at the same level on the two dates. The wind-shear chart of 30th helps the location of the western disturbance over the N.W.F.P. with much greater definiteness than is possible otherwise. Also, on the basis of the change chart for the 31st, it becomes apparent that a cyclonic circulation—probably a well-marked secondary of the western disturbance—was developing over south Baluchistan and the adjoining sea area. In the course of the next 24 hours, the secondary actually developed over south Baluchistan and the sea area off the Mekran coast —Fig. 5(C)—which shows the morning upper winds at 5000 ft on 1 February. The wind-shear chart for this morning—Fig. 5(c)—shows a well-marked cyclonic circulation with its centre over West Rajasthan. In conformity with the indications as given by this chart, the secondary moved eastnortheastwards and lay over West Rajasthan on the following morning—Fig. 5(D). Again, the wind change chart of this day—Fig. 5(d)—is found to be quite informing, in as much as it portrays fairly correctly the trend of development of the circulation pattern by the following morning, and possible movement of the secondary towards northeast. The disturbance actually moved in a northeasterly direction, and caused widespread rain in east Rajasthan, west Uttar Pradesh, and the Punjab-Kumaon hills.

5. Upper wind changes and convective showers

During the late winter or early summer season, change charts of winds are also found to be helpful in forecasting the belts of thundershowers, which seem to be associated largely with the developments of cyclonic vortices on or near the line of discontinuity between the dry *PcTc* or *Tc* air from north or northwest, on one side, and modified or stagnant *Tc* or *TcTm* air from south to southeast, on the other. In illustration of this, three sets of charts (Fig. 6) are added showing (*i*) morning winds at 5000 ft, (*ii*) vector changes during the preceding 24 hours of winds at the same level and (*iii*) distribution of rainfall during subsequent 24 hours for the three days, 8, 9 and 10 February 1953. It will be seen from these charts that, although the wind discontinuity between the dry northerlies and the relatively moist southerlies ran roughly in the same way on all the three days, the distribution of rainfall during the successive twentyfour hours was substantially different in the three cases. It is interesting to note that the wind change charts indicated growth of cyclonic vorticity over distinctly different areas on the three days, and that the area of principal weather coincided in general with the region or regions over which the shear wind circulation was cyclonic.

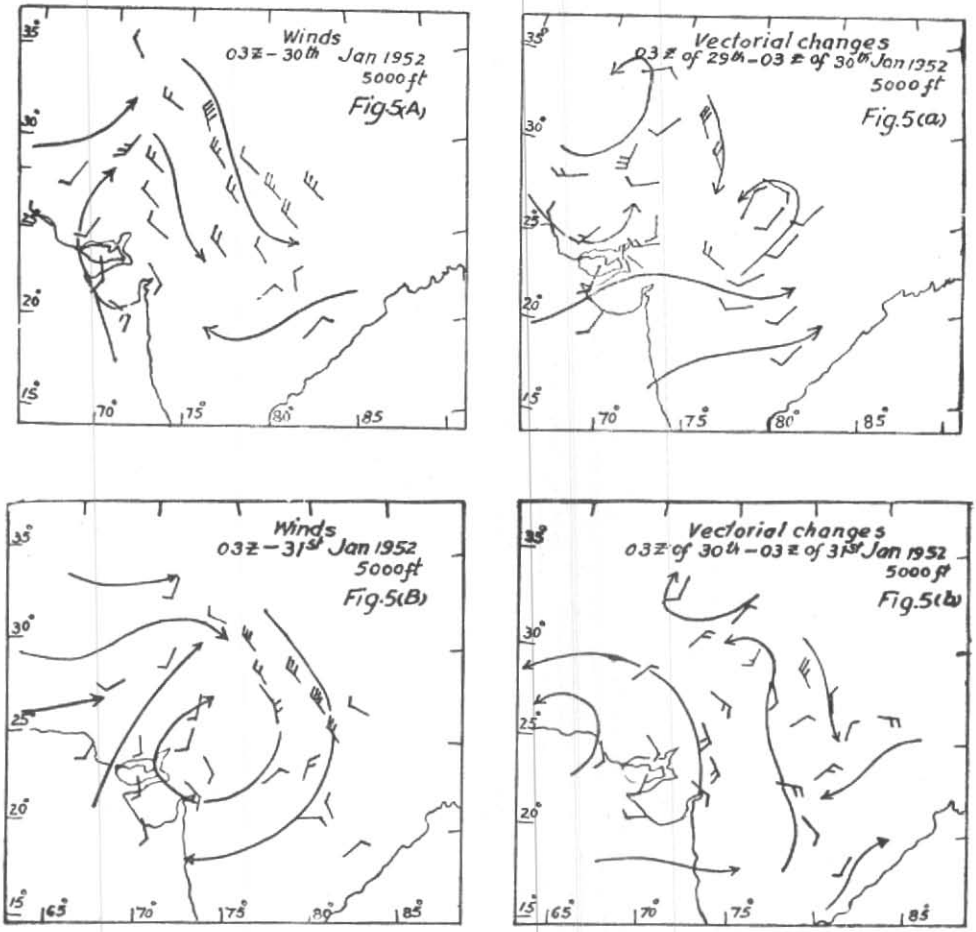

Fig. 5 (A, a, B, b)

During the summer season, when short-lived convective weather phenomena are confined mostly to late afternoons and evenings, and when, following a sequence of such weather, the horizontal flow pattern of winds, as observed on one morning, often reappears on the following day more or less in the same position, 24-hour changes of winds may not always be quite useful, and it is necessary to prepare wind shear charts based on changes during a short period of 6 hours or so, preferably between morning and noon.

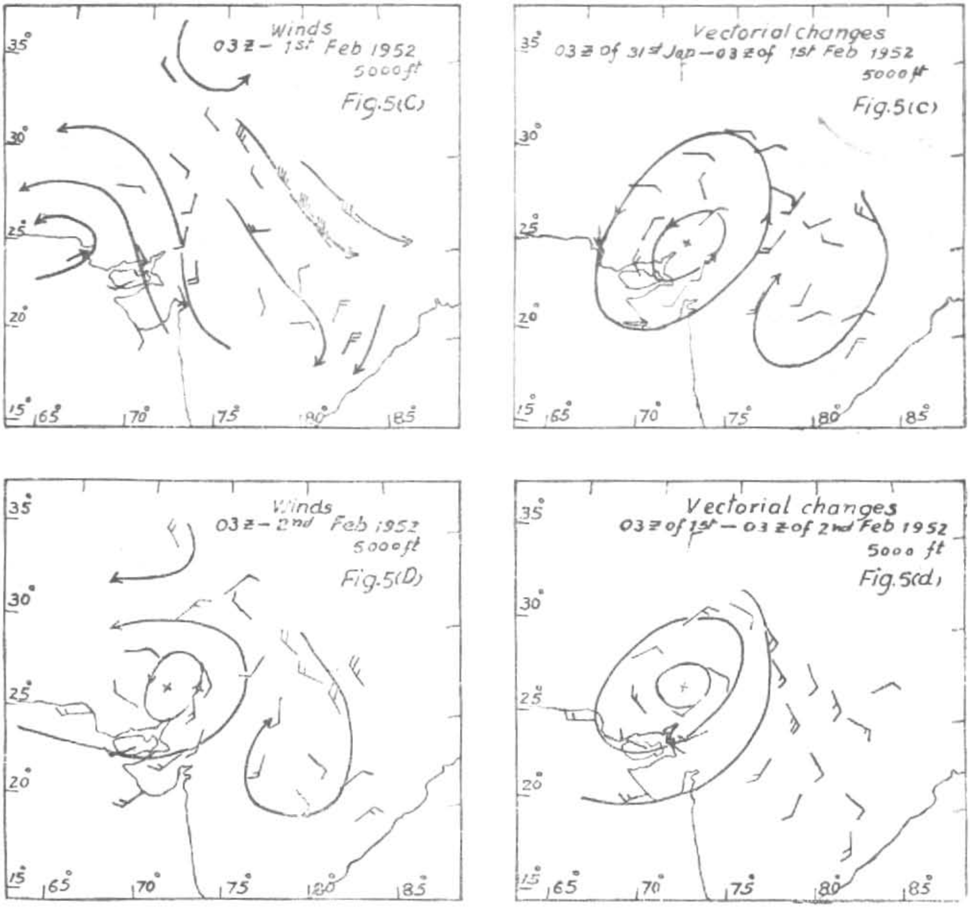

Fig. 5 (C, c, D, d)

6. Conclusion

The basic idea underlying the suggested use of charts showing vector changes of winds at certain crucial heights is that, by providing information about the circulation tendency during a given period, it often enables one to make reasonably correct anticipation of what the future development of the circulation pattern is going to be. The few cases which have been included in the paper, by way of illustration, serve to show that in the tropics, where weather processes are chiefly non-frontal and ascent of moist air causing weather developments is governed largely by the nature and intensity of the vorticity in the humid air field, the use of such charts is of material help in the prognosis of synoptic situation twentyfour hours hence and is particularly so in relation to forecasting of movements and future developments of depressions and cyclonic storms.

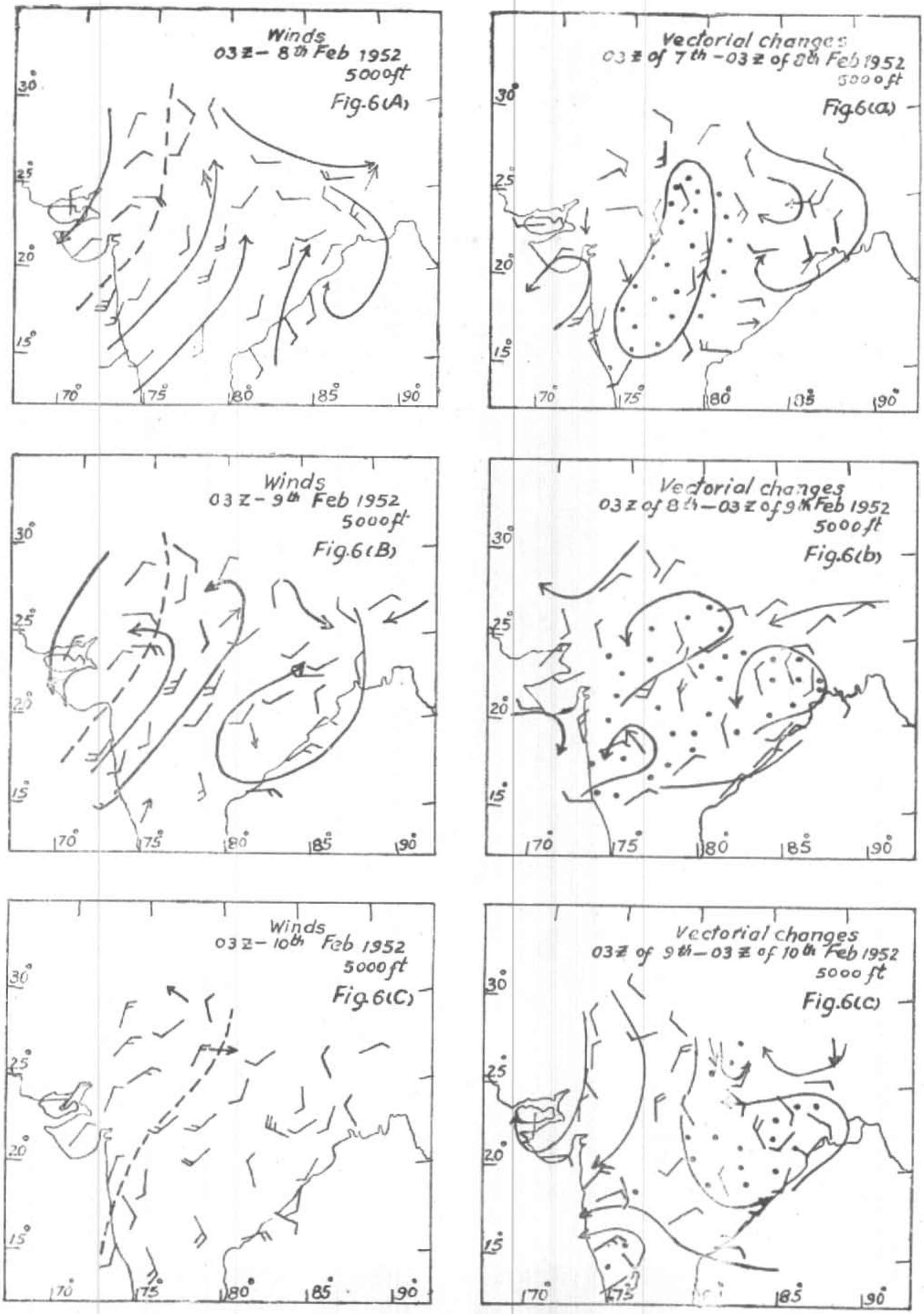

Fig. 6 (A, a, B, b, C, c)

: : : Areas getting the thundershowers in the evening

7. Acknowledgements

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REFERENCES

Brunt, D. and Douglas, C. K. M.	1928	*Mem. R. met. Soc.*, **3**, 22.
Petterssen, S.	1940	*Weather Analysis and Forecasting*, pp. 397-400.
Roy, A. K.	1946	*India met. Dep. Tech. Note*, 22.