

## A case study of the Westerly Jet over Trivandrum

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(Received 30 April 1966)

**ABSTRACT.** A study has been made of the formation of a cut-off low in a westerly trough at 500-mb near Trivandrum, with an associated westerly jet over it, during the period 11 to 13 December 1958. In addition to this localised jet over Trivandrum, there were also two other jets over the country.

### 1. Introduction

Rosby *et al.* (1947) were the first to discover the jet stream associated with the general circulation of the atmosphere in middle latitudes. Since then, the jet stream has been the subject of considerable study. A complete bibliography of our present knowledge has been presented by Reiter (1963) in the book *Jet-Stream Meteorology*.

In India, Ramanathan and Ramakrishnan (1933) were the first to find evidence of a wind maxima, roughly along 25°N in winter, from the study of pilot balloon winds. Since then several attempts have been made to locate and study the westerly jet over India, but its high location and scarcity of data were main handicaps in earlier investigations. In later studies, Koteswaram (1953) described the mean jet over India as a subtropical one, which lies in the tropical troposphere about 4 km below the tropopause. On a large number of days it maintains a westerly course parallel to the southern periphery of the Himalayan plateau. It is diverted towards the Indian Peninsula when transverse perturbations occur on the main westerly flow. Williams (1961) made detailed study of occasions when it moved south to the latitude of Madras (13°N). He found that the frequency of occurrence of the westerly jet over Madras reaches a maximum in the month of January. Koteswaram (1957) found that the intrusion of a frontal jet stream from higher latitudes also causes the southward shift of the subtropical jet.

In a recent work Krishnamurthy (1961) has described the subtropical jet as a pattern of three standing long waves which maintain a nearly steady state. A north-south shift of its wave pattern has been found by him to be more pronounced over the American Atlantic area. He has found it more steady over the Asiatic sector in winter when it hugs the south side of the Himalayan complex, which acts as a high level cold source, so that the oscillations are very slight.

In this paper a case is presented of the presence of a westerly jet at Trivandrum during the period from 11 to 13 December 1958. It was overlying a cut-off low formed in a westerly trough at 500 mb. In addition to this localised jet over Trivandrum, there were also two other jet streams over the country.

### 2. Data

For preparing the upper air charts extending from the equator to roughly 45°N, daily northern hemisphere data published by the U.S. Weather Bureau, were utilised. Data for India were obtained from the *Indian Daily Weather Reports*.

### 3. Synoptic situation

3.1. The charts of 500 mb from 9 December to 13 December 1958, are given in Figs. 1(a) to 1(e). The trough lines in these charts, have been shown separately in Fig. 1(f). On 9th a well marked trough in the westerlies extended to the Bay of Bengal from 45°N, 92°E through 35°N, 95°E. Another trough on the same day, extended from 45°N, 82°E to 35°N, 74°E. On the 10th northern end of the first trough was separated from the main trough at about 34°N; it moved eastwards rapidly and ran from about 43°N, 101°E to 35°N 105°E. The upper portion of the remaining trough moved eastwards by about 2-3 degrees, with its southern end further extending southwards. The second trough observed on 9th became feeble by 10th while moving slowly eastwards. The trough over the Bay of Bengal remained practically stationary between the 10th and 11th. The southern end of the trough, however, continued to extend southward in a southwesterly direction and was lying near the east coast, south of Madras. On 12th, the northern portion of this trough moved eastwards by about 5-7 degrees longitude while a low formed in the Arabian Sea west of the Cochin-Trivandrum coast, at its extreme southern end. On the following day, this low was cut off from the main trough and was lying as a weak residual

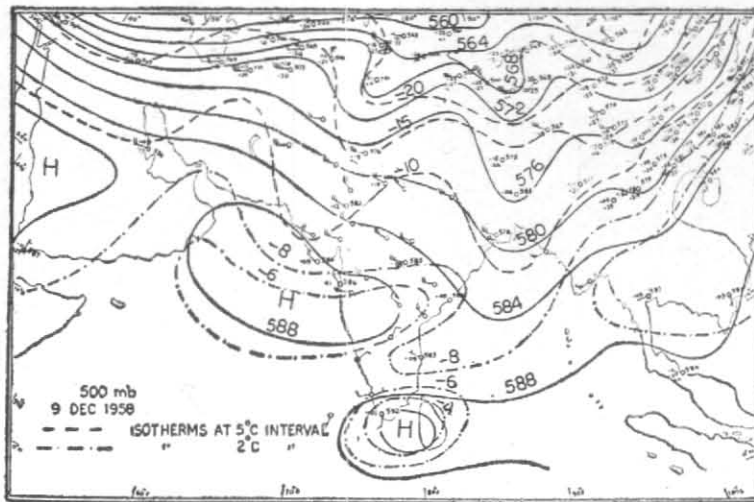


Fig. 1(a)

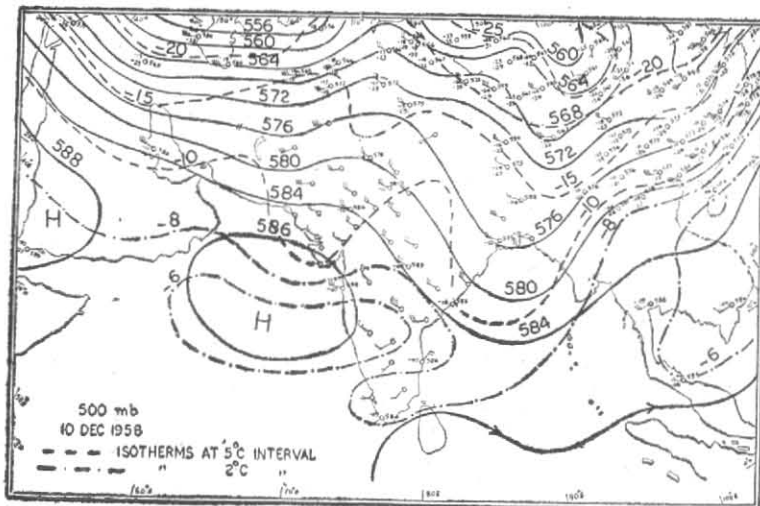


Fig. 1(b)

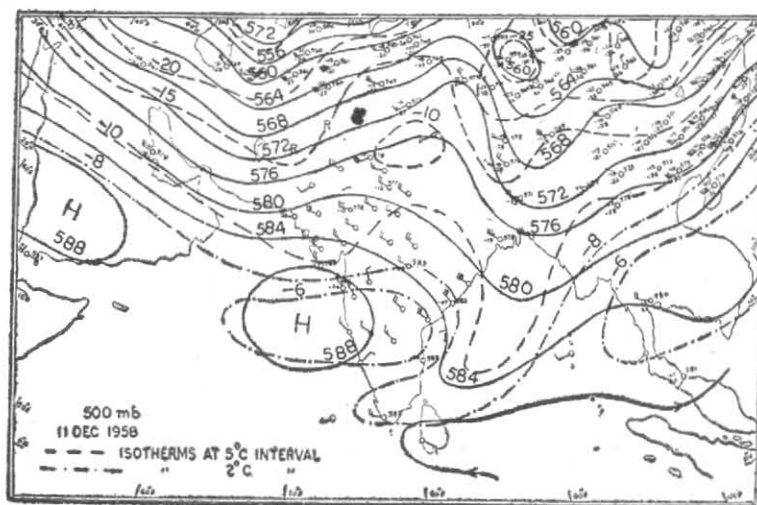


Fig. 1(e)

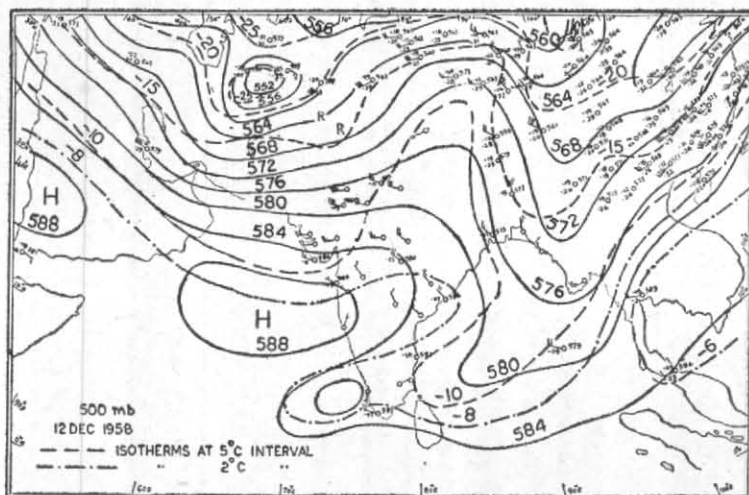


Fig. 1(d)

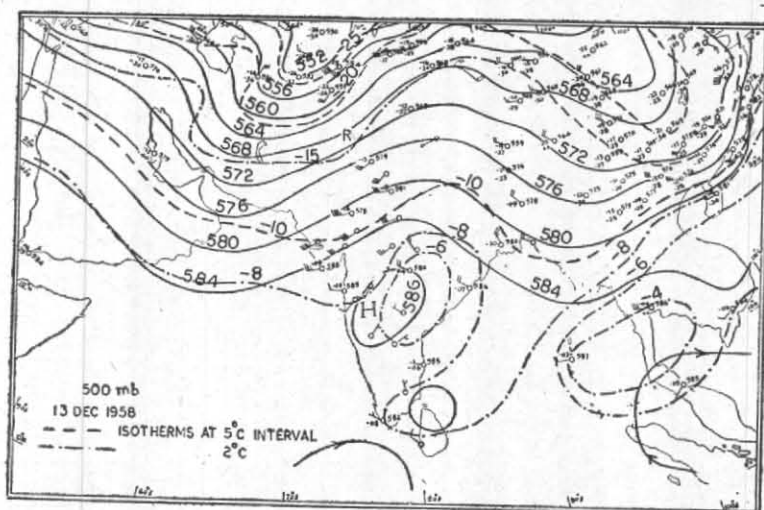


Fig. 1(e)

low over northeast Ceylon. The positions of this trough, during the period are depicted in the Fig. 1(f).

3.2. In Figs. 1(a) to 1(e) isotherms are depicted as broken lines. They are drawn at an interval of  $5^{\circ}\text{C}$  for temperatures below  $-10^{\circ}\text{C}$ . An interval of  $2^{\circ}\text{C}$  has been used for temperatures above  $-10^{\circ}\text{C}$ . It will be seen that isotherms and contour patterns were parallel in the trough over the Bay. Contours are, however, seen to follow the isotherm pattern in the southward extension of the trough. The thermal trough shown by the isotherm of  $-8^{\circ}\text{C}$  may be seen extending upto the Kerala coast even on 10 and 11 December whereas a trough in isobaric contours extended to this area only on 12 December. The thermal ridge patterns shown by isotherms west of this trough extended from east Sinkiang to the central parts of the country. They appear

to have played a significant part in the southward extension of the thermal trough, and thus brought in colder air to southern India.

3.3. Sea level pressure over Trivandrum showed a marked decrease from 9 to 13 December. 03 GMT synoptic observation of Trivandrum on 9th reported surface pressure as 1014.1 mb which lowered by about 3 mb during next four days and reached to 1010.8 mb at 03 GMT on 13 December 1958. It showed the increasing tendency in subsequent observations.

#### 4. Vertical time-section charts

4.1. Vertical time-section charts for Madras and Trivandrum for the period 9 to 15 December 1958 are given in Figs. 2(a) and 2(b) respectively. Fig. 2(a) shows the existence of a subtropical jet stream over Madras during the period 12 to



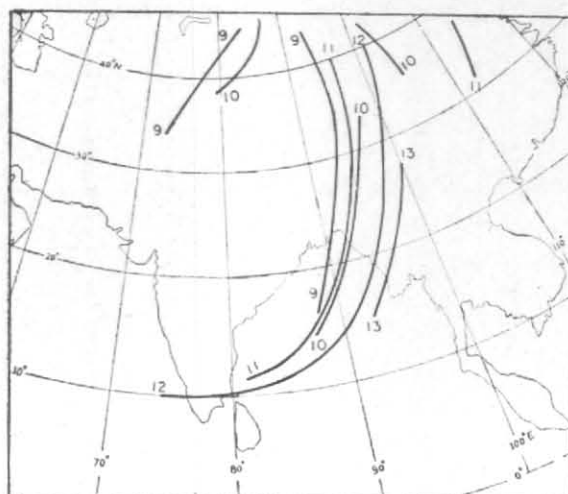


Fig. 1(f). Trough lines during 9-13 December 1958

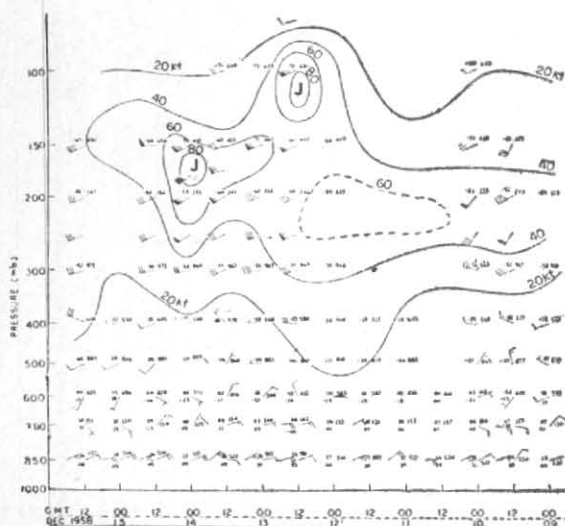


Fig. 2(a). Vertical time-section of Madras

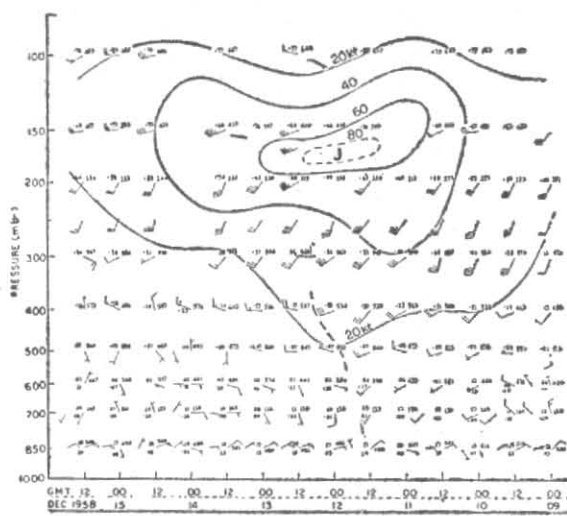


Fig. 2(b). Vertical time-section off Trivandrum

14 December at 13-15 km. Though wind reports at higher levels from 12 GMT of 10th to 00 GMT of 12th are absent, another wind maxima roughly near 12 km can be inferred from the available wind reports and vertical cross-section charts given at Figs. 4(a) to 4 (c). The maximum value, probably of the order of 70-80 kt, was on 12 December.

4.2. Strong westerly flow of the order of 40 kt and above over Trivandrum between 12 to 14 km during 10 to 14 December will be noticed from the vertical time-section chart at Fig. 2(b). The normal wind speed at Trivandrum for the month of January (a representative month for winter) is southwesterly with wind speed of the order of 10-15 kt at 12 km (Sreenivasiah and Ramakrishnan 1957). The wind speed of 50 kt at 150 mb at 1200 GMT of 10th, 55 kt at 200 mb at 1200 GMT of 11th and 75 kt at approximately

175 mb at 1200 GMT of 12th suggest rather strongly the existence of a westerly wind of jet strength over Trivandrum at an altitude of about 13 km. It had a maximum wind strength at 1200 GMT of 12th.

##### 5. Wind speed profiles

Wind speeds at 6 km and above, at all the RS/Rawin stations in India, for the three consecutive observations of 00 and 12 GMT of 12th and 00 GMT of 13th are shown in Fig. 3. Upper wind reports over Bombay were not available for 12 GMT observation of 12th. In absence of these, the winds of Poona have been used, which is the nearest station available. The following points are observed from this diagram.

(1) Over Amritsar (only one ascent of 00 GMT of 13th is available), there is wind maxima of more than 100 kt just below 12 km. Maximum

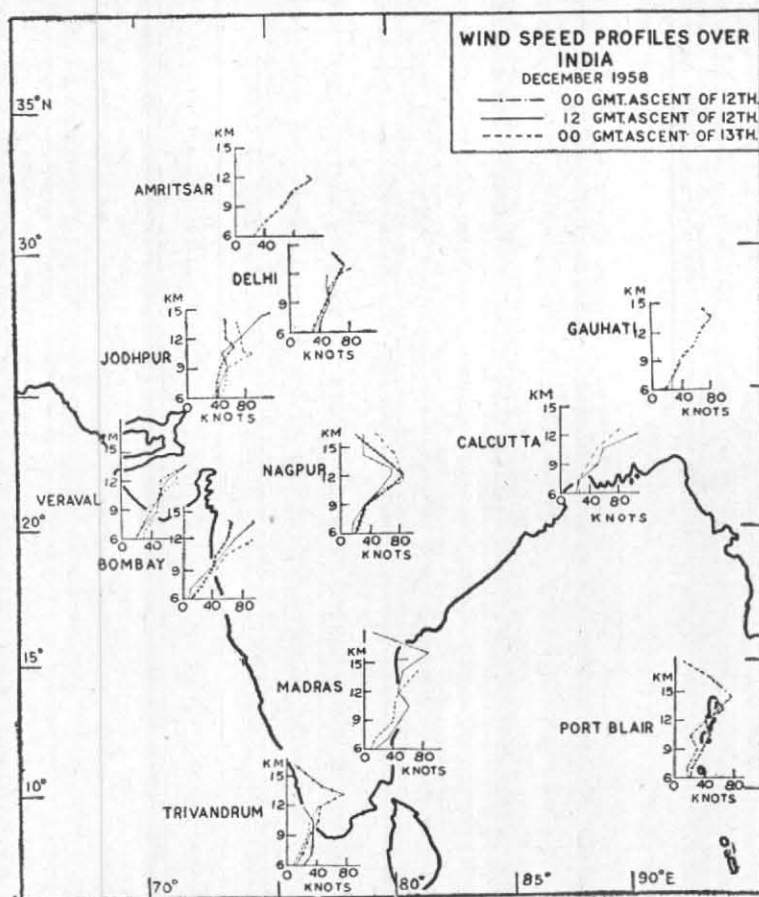


Fig. 3

speed over Delhi is also at about 12 km but speed is only of the order of 80 kt. (The three ascents of Jodhpur did not give consistent reports).

(2) The ascents over Nagpur extend on all the three occasions well above the level of wind maxima at 12 km. The flights over Santacruz and Veraval indicate a wind maxima at about 13 km, while Calcutta suggests the level of maximum wind to be close to 12 km.

(3) The Madras ascent of 12 GMT on 12th extends above the wind maxima near 16 km. In the subsequent flight, the level of maximum wind appeared to be lower. The wind report of 12th morning over Port Blair indicates maximum wind speed at 13 km but on the 13th morning, it is observed at about 14.5 km. Ascents over Trivandrum show the presence of a wind maxima at 13 km on 12th evening. The flight on the 13th morning, which terminated at 12 km suggests increasing wind speed above 12 km. The speed curve of these two ascents and the wind speed of 55 kt at 12 km on 11th evening, show that the speed of 22 kt at 12 km reported on the 12th morning, is not correct.

From the above description of the wind maxima, we may draw the following conclusions—

(a) A jet stream of core winds 80–100 kt lay over northern India near the latitude of Amritsar.

(b) There was also a jet stream over central India with its axis running roughly from Bombay to Calcutta.

(c) Lastly, there was a jet stream of core winds of 70–80 kt over southern India, extending south upto Trivandrum.

#### 6. Cross-section charts

Vertical cross-section charts along 80°E for 00 and 12 GMT of 12th and 00 GMT of 13th are given in Figs. 4(a) to 4(c). The cross-section charts bring out the three jet streams over the country described in the foregoing paragraph. The isopleths drawn by dotted lines, in these charts, are based on the estimated wind speeds.

In view of the limited number of temperature and wind observations available at the higher altitudes, conclusions that can be inferred are necessarily of a tentative nature. It will be seen from the available data that taking

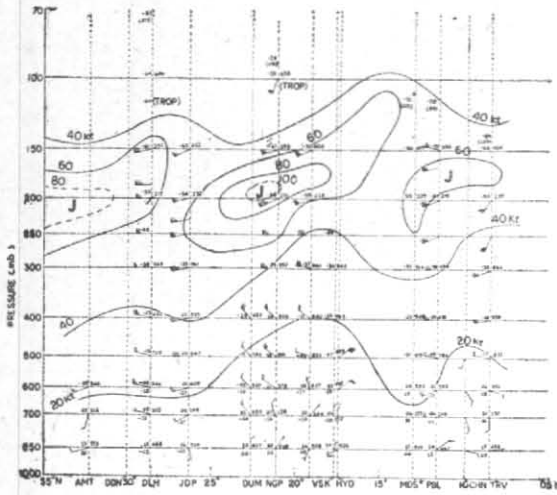


Fig. 4(a). 00 GMT of 12 December 1958

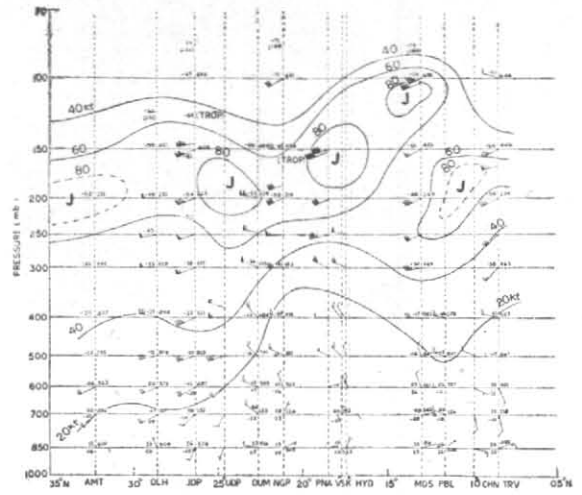


Fig. 4(b). 12 GMT of 12 December 1958

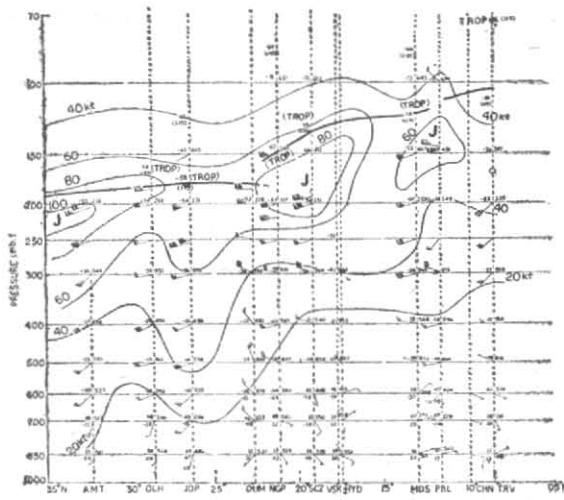


Fig. 4(c). 00 GMT of 13 December 1958

Fig. 4. Vertical cross-section charts of 12 and 13 December 1958

TABLE 1

Temperature (°C)	Altitude (mb)	Station	Date and time of observation (Dec 1958)
TYPE I			
-58	180	Delhi	13/0000 Z
-58	175	Jodhpur	13/0000 Z
TYPE II			
-64	120	Delhi	12/0000 Z
-65	130	Jodhpur	12/1200 Z
-69	150	Nagpur	12/1200 Z
-67	150	Nagpur	13/0000 Z
-69	136	Bombay	13/0000 Z
TYPE III			
-75	100	Nagpur	12/0000 Z
-78	125	Madras	13/0000 Z
-78	105	Trivandrum	13/1200 Z

temperature as the criterion, there appears to exist three types of tropopauses over the country (Table 1).

Temperature differences between Types I and III are quite marked and are of the order of 20°C. The altitude difference between the two is approximately 75 mb. Evidently Type II is the intermediate tropopause. Type I has appeared on Delhi/Jodhpur latitude on 13th morning. Type II tropopause over Delhi/Jodhpur latitudes observed on 12th has shifted southward to Nagpur/Santacruz latitudes on 12th evening/13th morning.

The above will suggest that the two extreme types of tropopauses are linked through an intermediate type, making the break appear less distinct. However, jet streams appear associated with transitions from Type I to II and Type II to III. (Jet stream over Amritsar is associated with transition from Type I to II and the subtropical jet stream over Bombay is associated with a transition from Type II to III).

## 7. Discussions

7-1. With the available data, we have tried to show the existence of three jet streams over India during this period. A strong westerly wind belt extended to as low a latitude as that of Trivandrum, *viz.*, 10°N. There was another instance in 1956 when the westerly winds over

Trivandrum reached near jet strength. (Trivandrum 09 GMT of 10 February 1956—240°/61 kt and Tiruchirapalli 09 GMT of 10 February 1956—240°/70 kt). In this case Madras was seen to be under the grip of strong westerlies for a period of about six days, *i.e.*, from 8 to 13 February 1956. Southward movement of the subtropical jet to the latitude of Madras has been found to be rather frequent by Williams (1961), the maximum frequency of this being in the month of January. The existence of strong westerly winds of jet value has been also observed on a number of occasions over Aden (12°N), during winter months. Riehl (1954) has described a case of the existence of a localised westerly jet in central Pacific, at as low a latitude as 15°—20°N during the summer season in the month of July.

7-2. Cressman (1948) has arrived at the conclusion that following periods of large amplitude long waves, westerlies tend to shift southward. In the case referred to in this paper, the presence of a long wave pattern, the southern end of which extended to the Bay of Bengal, can be seen from the 500 mb charts shown in Figs. 1(a) to 1(e). The trough lines in these charts, have been shown separately in Fig. 1(f). Rossby *et al.* (1947) have found that contours and isotherms are generally in phase in these patterns, and cold vortices are formed on the south side of the



zonal current. It is interesting to note here that in lower latitudes, owing to the smaller coriolis force, a smaller pressure gradient can produce winds of jet strength. It will be seen from the Figs. 1(a) to 1(e) that the location of jet stream coincided with areas of steep north-south isotherm gradient at 500 mb. A rough estimate of the intensity of the jet stream aloft can be also made from the magnitude of this thermal gradient.

#### 8. Acknowledgements

The author is grateful to Dr. P.K. Das, Director Northern Himesphere Exchange and Analysis Centre and Shri C. J. George, Meteorologist for kindly going through the manuscript and offering valuable suggestions.

The author also had the advantage of ample discussions with Dr. P. Koteswaram on the analysis of charts produced in this study.

#### REFERENCES

- |                                              |      |                                                                                                                                    |
|----------------------------------------------|------|------------------------------------------------------------------------------------------------------------------------------------|
| Cressman, G. P.                              | 1948 | <i>J. Met.</i> , <b>5</b> , 2, pp. 44-57.                                                                                          |
| Koteswaram, P.                               | 1953 | <i>Indian J. Met. Geophys.</i> , <b>4</b> , 1, pp. 13-21.                                                                          |
|                                              | 1962 | <i>Meteorology in relation to High-Level Aviation over India and surrounding areas</i> —Proc. Symp., India met. Dep., pp. 101-107. |
| Krishnamurthy, T. N.                         | 1961 | <i>J. Met.</i> , <b>18</b> , 2, pp. 172-191.                                                                                       |
| Ramanathan, K. R. and Ramakrishnan, K. P.    | 1933 | <i>Nature</i> , <b>132</b> , p. 932.                                                                                               |
| Reiter, E. R.                                | 1963 | <i>Jet-Stream Meteorology</i> . The Univ. Chicago Press.                                                                           |
| Riehl, H.                                    | 1954 | <i>Tropical Meteorology</i> , McGraw-Hill Book Company, Inc., New York, pp. 249-251.                                               |
| Rosby, C. G. <i>et al.</i>                   | 1947 | <i>Bull. Amer. met. Soc.</i> , <b>28</b> , pp. 255-279.                                                                            |
| Sreenivasaiah, B. N. and Ramakrishnan, K. P. | 1962 | <i>Meteorology in relation to High-Level Aviation over India and surrounding areas</i> —Proc. Symp., India met. Dep., pp. 75-92.   |
| Williams, S. D.                              | 1961 | The Westerly Jet Stream over Madras. Presented in the Seminar of Aeronautical Sciences, Bangalore.                                 |