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A study of the Indian Northeast Monsoon season

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1. Introduction

The northeast monsoon period in India, as is well known, is from October to December. This is the main rainy season for most of the districts in the Madras State (Tamilnad). In the year 1946, Tamilnad (Fig. 1) received a rainfall of 31·2″ which was 73 per cent above the normal amount of 18·5″, while in the year 1949, the rainfall over this area was only 10·5″ which was 43 per cent below normal. The northeast monsoon rainfall for the years 1946-50 and the normal rainfall for this season are given in Fig. 2.

Krishna Rao and Jagannathan (1953) in their study of the northeast monsoon rainfall over Tamilnad have indicated that copious northeast monsoon rain occurs over Tamilnad when depressions or cyclonic storms in the Bay of Bengal move westwards and strike the Coromandel coast; and deficient northeast monsoon rain occurs when depressions and cyclonic storms move in some northerly direction and do not strike the Coromandel coast. Sen Gupta (1960) is of the view that the southward and the northward movement of the subtropical circulation system over the Bay of Bengal take place during the periods of sunspot maximum and sunspot minimum respectively, and the northward location of the subtropical circulation favours the approach of disturbances towards the Madras coast, thus causing greater rainfall over Madras State.

In this paper, an attempt has been made to study by means of Hovmöller diagram whether there are any distinguishing features in the large scale flow pattern over the entire Northern Hemisphere at the 500-mb surface, which characterise good and weak northeast monsoon seasons. For the purpose of this study, the year 1946 was taken as an example of good northeast monsoon rains, and the year 1949 as representing the case of defective northeast monsoon rains.

2. Preparation of Hovmöller diagrams

It is well known that the upper level charts are not so complex in character as the surface charts. Many of the minor singularities of surface charts which may be due to local orography are not reflected in the upper level charts. On the other hand, the great cyclonic and anticyclonic systems of the surface layer in the middle latitudes are not smoothened out on the 500-mb charts, but they appear as troughs and ridges respectively. In order to study the life history of individual major troughs and ridges, and also those of moderate development, Hovmöller (1949) constructed the trough and ridge diagram, which has come to be known after him.

The existence of a trough at a certain longitude within a specific latitudinal belt is brought out clearly, if the mean height of 500-mb surface within that latitudinal belt is plotted as a function of longitude. Similarly, the movement of a certain trough or ridge during several days can be followed by plotting the longitude of the trough as a function of time. These two procedures are

Fig. 1. Map of Tamilnad

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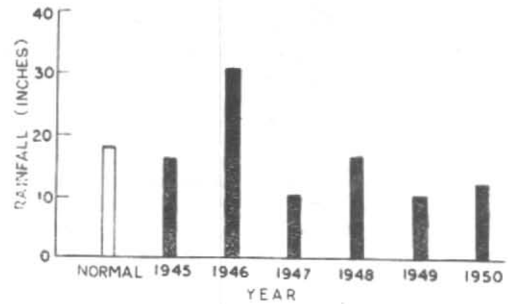


Fig. 2. Northeast monsoon rainfall for Tamilnad

combined in the Hovmöller diagram in which the mean height of the 500-mb surface within a certain latitudinal belt is plotted as a function of longitude and time.

The Historical Weather Maps for the months of October, November and December of the years 1946 and 1949 published by the U.S. Weather Bureau were utilised for preparation of these diagrams. From these analysed maps, the heights of 500-mb surface (at 0400 GMT) were read off at the intersection points between every fifth degree of longitude and the parallels of 40°, 45°, 50°, 55°, 60°, 65° and 70°N. This latitudinal belt was chosen to cover the extent of middle latitude systems. The average of the seven values gives the mean value of the height of the 500-mb surface along a particular longitude and within the specified latitudinal belt. Similar mean values are obtained for every fifth degree of longitude. Thus 72 mean values are obtained for each day and these values are plotted in a graph where the longitude and the date form the X and Y axes respectively. On drawing the isopleths for the mean height, the Hovmöller diagram gets completed.

Such Hovmöller diagrams were prepared for the months of October, November and December of the years 1946 and 1949. Figs. 3 and 4 are the Hovmöller diagrams for November of 1946 and 1949 respectively. Also in order to examine any significant variations in the large scale flow pattern in the Indian region, the latitudinal belt 10°N to 35°N was considered, and limited Hovmöller diagrams for the longitudes 70° and 95° E were prepared for these months for 1946 and 1949 (diagrams not presented).

3. Northeast monsoon in relation to 500 mb pattern outside the Indian region

The Hovmöller diagrams for the year 1949 bring out the persistence of a ridge for the major portion of the month in the longitudinal portion 30°—70° E (the European portion of the U.S.S.R.) (Fig. 4), whereas in the case of the Hovmöller diagram for the year 1946 (Fig. 3), the absence of such a ridge is conspicuous, and instead a series of troughs have affected this region. It seems the presence of a more or less blocking high in the Russian region is not conducive to good northeast monsoon rain over Tamilnad, while the passage of lows or cyclones in the European region favours a good northeast monsoon rain over Tamilnad.

As already mentioned, in 1946 a series of troughs at 500-mb level have passed through this region and it should be expected that England, the Western and Central European region must have been affected by a series of depressions. From the publication *Weather* 1946, it is noticed that during November

1946, there was frequent as well as prolonged rainfall over England, due to the passage of a series of depressions.

In the northeast monsoon season of the year 1960, especially in November, the rainfall over Tamilnad was in excess. The weather over British Isles in this month was generally similar in character to that in November 1946, with often heavy and prolonged rainfall. Much of Western and Central Europe also had excessive rainfall and flooding while snow has fallen heavily over mountain (*Weather* 1960). Thus there seems to be an association between weather over European region and the Indian northeast monsoon.

4. Northeast monsoon in relation to the 500 mb pattern over India

The limited Hovmöller diagrams for the good northeast monsoon season of 1946, show that the heights of the 500-mb surface between Long. 70° to 80° E were less than those between longitudes 85° to 95° E. In other words, the western portion of the subtropical high cell was lying over 85° and 95° E. Such a situation is perhaps favourable for the steering of tropical cyclones towards the Madras coast, leading to good rainfall over Tamilnad.

The Hovmöller diagrams for the year 1949 bring out the feature that the heights of the 500-mb surface between longitudes 70° and 80° E were greater than those between longitudes 85° and 95°E. From this, it can be inferred that the eastern portion of the subtropical high cell was over the peninsula. This factor is perhaps responsible for the storms in the Bay not reaching the Madras coast.

To understand the features in the limited Hovmöller diagram better, the average for the whole month at longitudes 70°, 75°, 80°, 85°, 90° and 95° E was determined from the individual values of the mean height of the 500-mb surface (within the latitudinal belt 10° and 35° N) and was plotted against the longitude. The graph for the month of November for the years 1946 and 1949 are presented in Fig. 5.

It may be seen that in the year 1946, the lowest value of the average height of 500-mb surface was along longitude 70°E indicating that the subtropical high was to the east of this longitude, whereas in 1949, the lowest value was along longitude 85°E indicating that the eastern portion of the subtropical cell was over the region between longitudes 70°—85°E. This is schematically illustrated in Figs. 6(a) and 6(b). This reasoning is substantiated by the actual streamline pattern of the monthly mean winds for November for the years 1946, 1949 (Figs. 7a and 7b).

From the above considerations it may be deduced that the location of the western portion of the subtropical high cell, over and near the Madras coast is favourable for good monsoon, while the location of the eastern portion of the subtropical high cell is not favourable for such rain.

Actually in November 1960* especially during the period 1 to 23 November, when the northeast monsoon rainfall was in excess over Tamilnad, it was noticed from the wind pattern at 6·0 km level on the individual days that the western portion of the subtropical high cell was located close to the Madras coast, thus favouring the occurrence of good rainfall over Tamilnad.

From the day to day analysis of 500-mb charts for the Asian area, it is noticed that these subtropical high cells (one located over Arabia and Arabian Sea, the other located over Bay of Bengal, Burma and neighbourhood) oscillate eastwards and westwards.

*These ideas and the verification of them from the daily working charts were presented at the weekly map discussion held on 17 November 1960 at the Meteorological Office, Poona and also at one or two subsequent map discussions.

HOVMÖLLER-DIAGRAM FOR

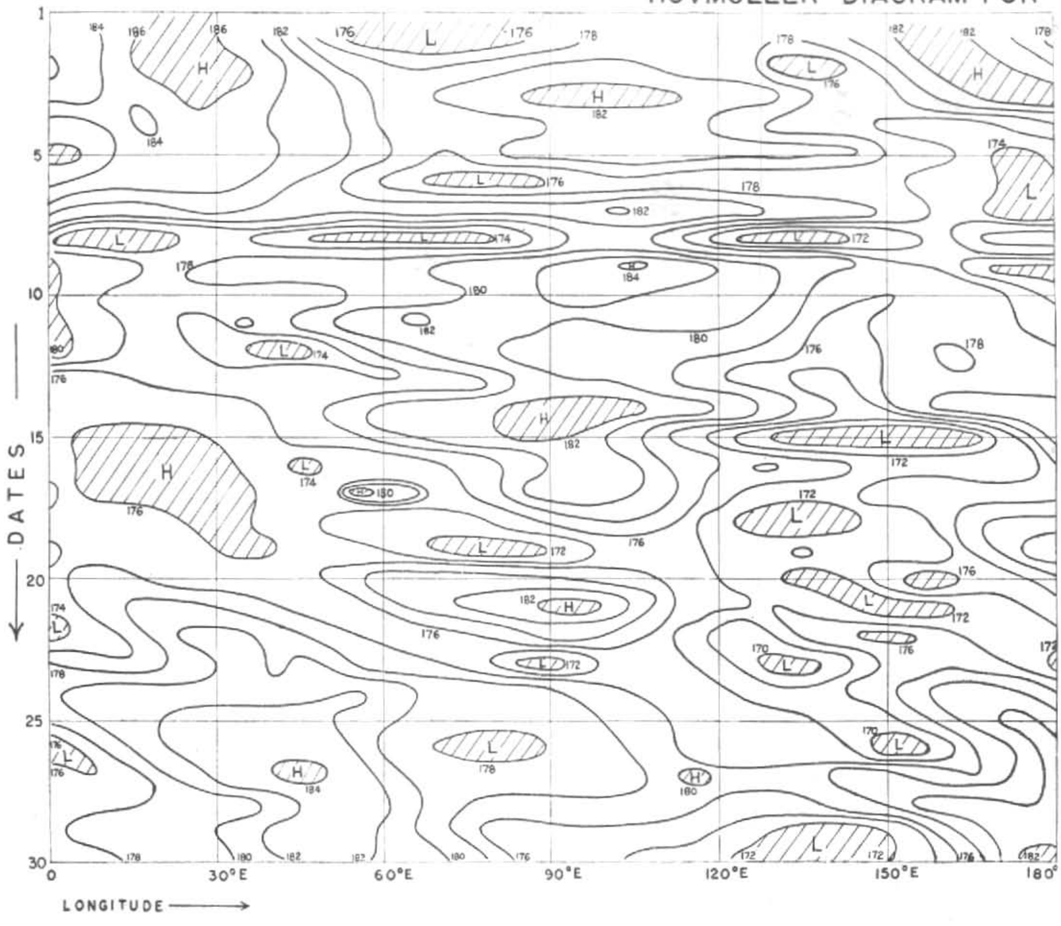
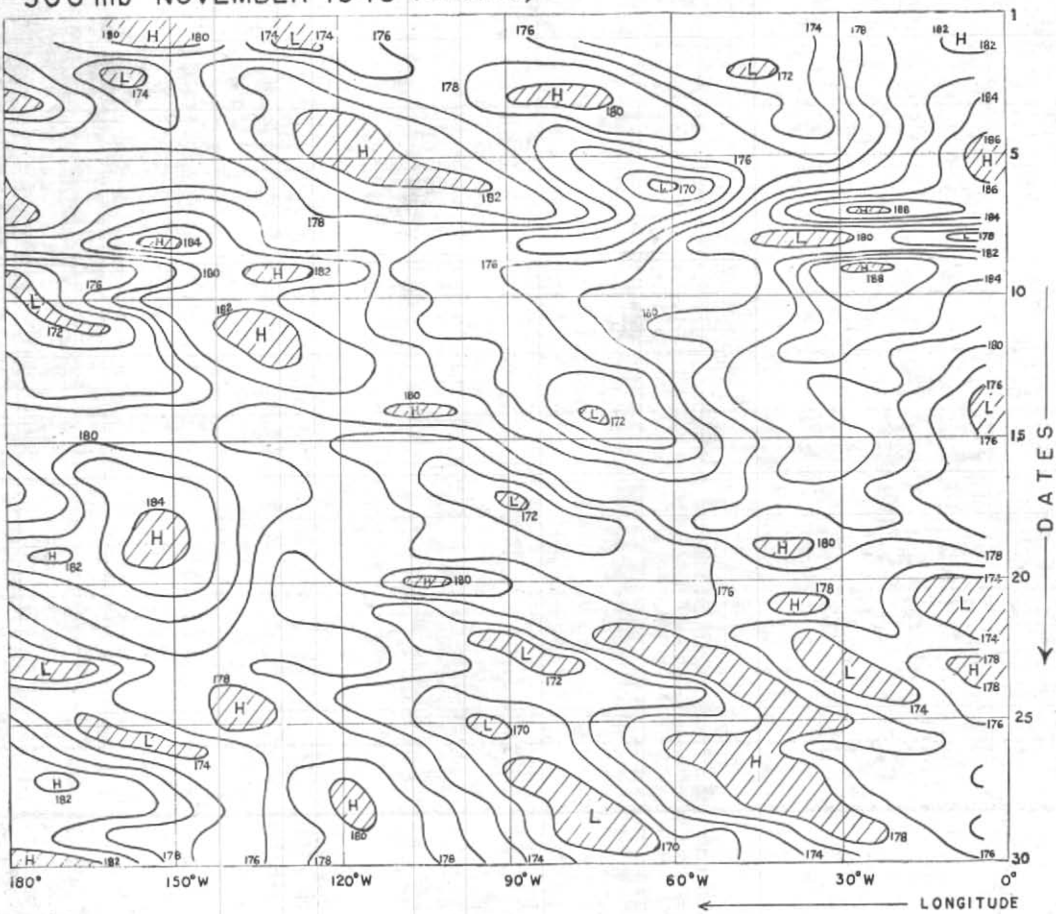


Fig. 3. Progression of pressure systems

Isopleth value in hundreds of geopotential

500 mb NOVEMBER 1946 (04 G.M.T.)



within latitudinal belt 40°—70°N

feet, *e.g.*, 182 means 18200 gp ft

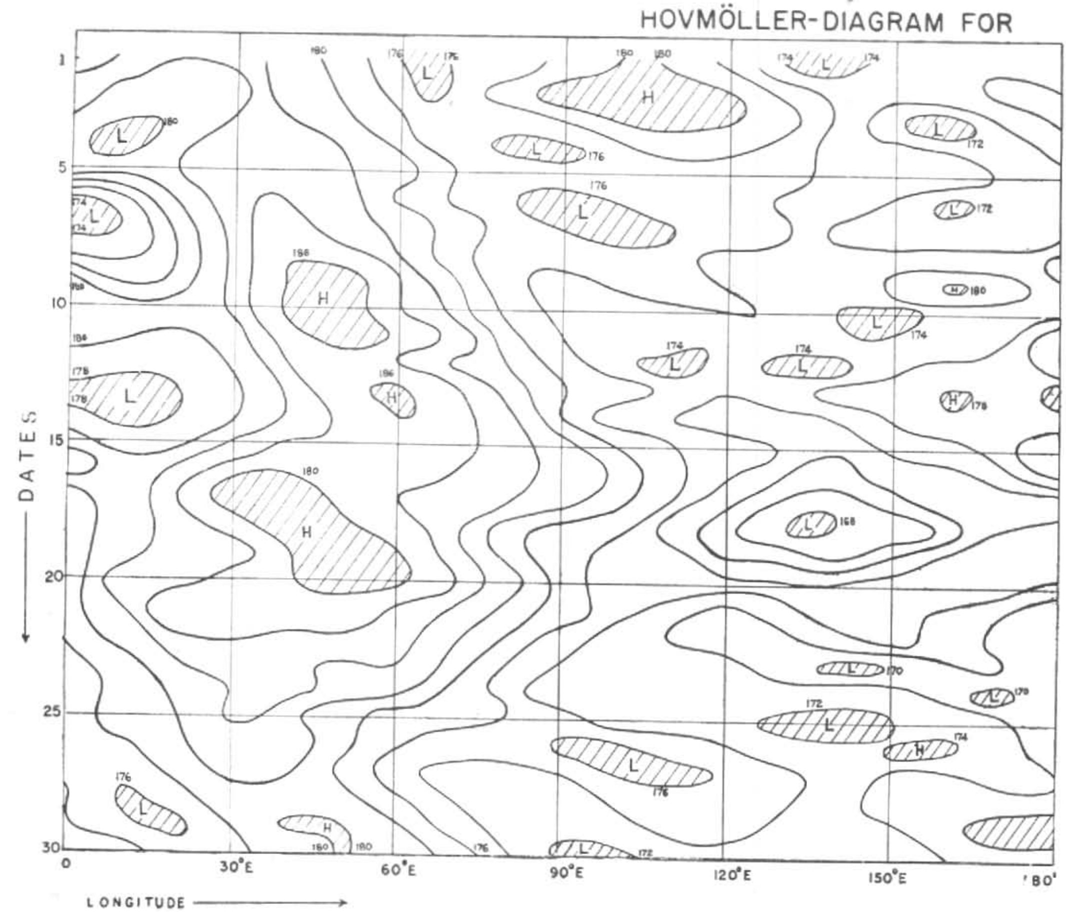
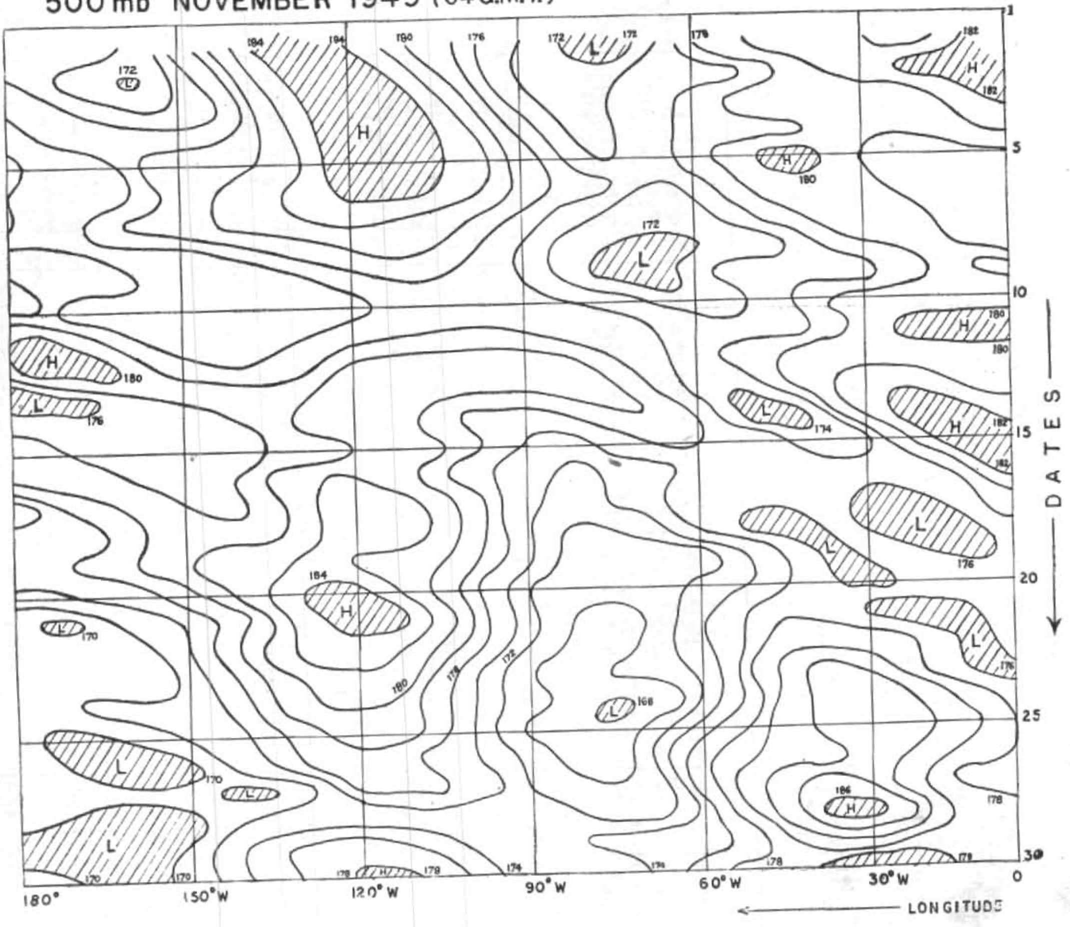


Fig. 4. Progression of pressure systems

Isopleth value in hundreds of geopotential

500 mb NOVEMBER 1949 (04 G.M.T.)



within latitudinal belt 40°—70°N

feet, *e.g.*, 182 means 18200 gp **ft**

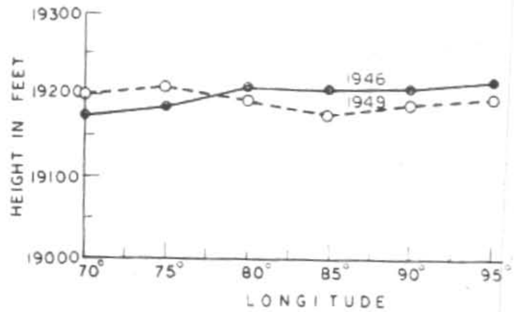


Fig. 5. Monthly average height of 500 mb surface in November

(within latitudinal belt 10° to 35°N)

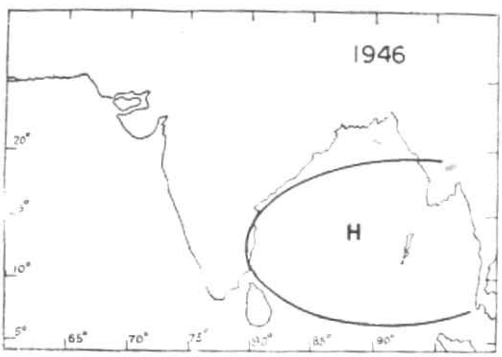


Fig. 6(a)

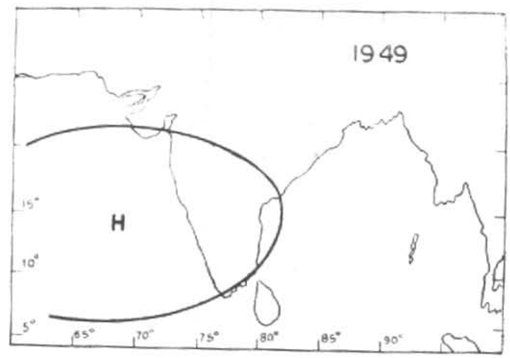


Fig. 6 (b)

Schematic representation of location of sub-tropical high cell

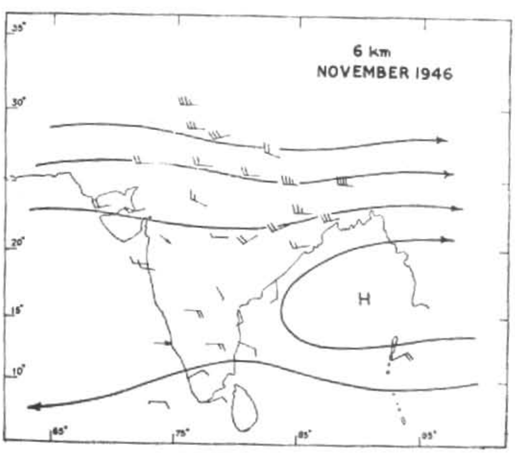


Fig. 7(a)

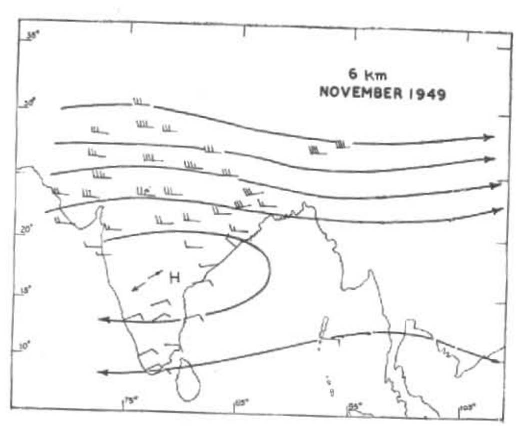


Fig. 7(b)

Stream line pattern for the monthly mean winds

By noticing the trend of movement of these high cells it may be possible to anticipate periods of good or weak northeast monsoon rains over Tamilnad.

5. Some theoretical considerations

So far, we have been discussing mainly about the difference in the contour pattern at 500-mb level. Perhaps an attempt may be made to understand how this difference in the pattern affects the mechanism causing rainfall.

As the name northeast monsoon implies, near the surface layers, the winds over Tamilnad during this period are northeasterly to easterly. When the eastern portion of the subtropical high cell at 500 mb is located over this region, the winds at this level also become northeasterly. Thus from the surface at least upto 6·0 km, the winds are mainly northeasterly. On the other hand if the western portion of the subtropical high cell is located over this region at 500 mb the winds at this level will be southeasterly (southwesterly).

Let us consider these two cases, after resolving the winds into northerly and easterly components, we shall take up northerly components first.

Case 1. Northerly component maintaining same strength (Fig. 8a)—If the northerly component has the same strength, then there is no shear in the vertical.

Case 2. The northerly component at lower levels is replaced by the southerly component at higher levels—Let us assume for simplicity of discussion, that there is uniform shear in the vertical. The horizontal positive (cyclonic) vorticity vector AB will be pointing towards west (as in Fig. 8b). If there is a positive rate of change of vertical velocity along AB (for example with downward vertical motion at A and upward vertical motion at B) the vorticity vector will get tilted to position say A′B′ (See Fig. 8c). Because of this tilting A′B′ can be resolved into the horizontal vector A′C′ and the vertical vector C′B′. Thus

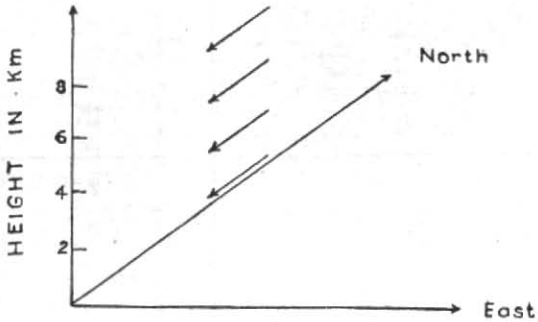


Fig. 8(a)

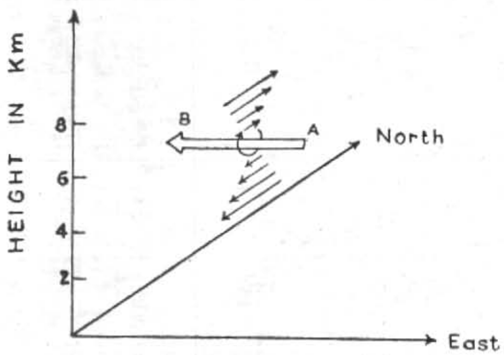


Fig. 8(b)

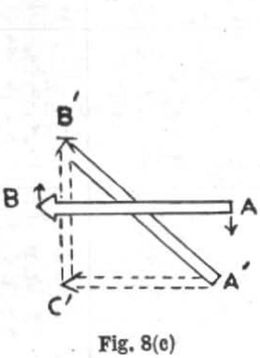


Fig. 8(c)

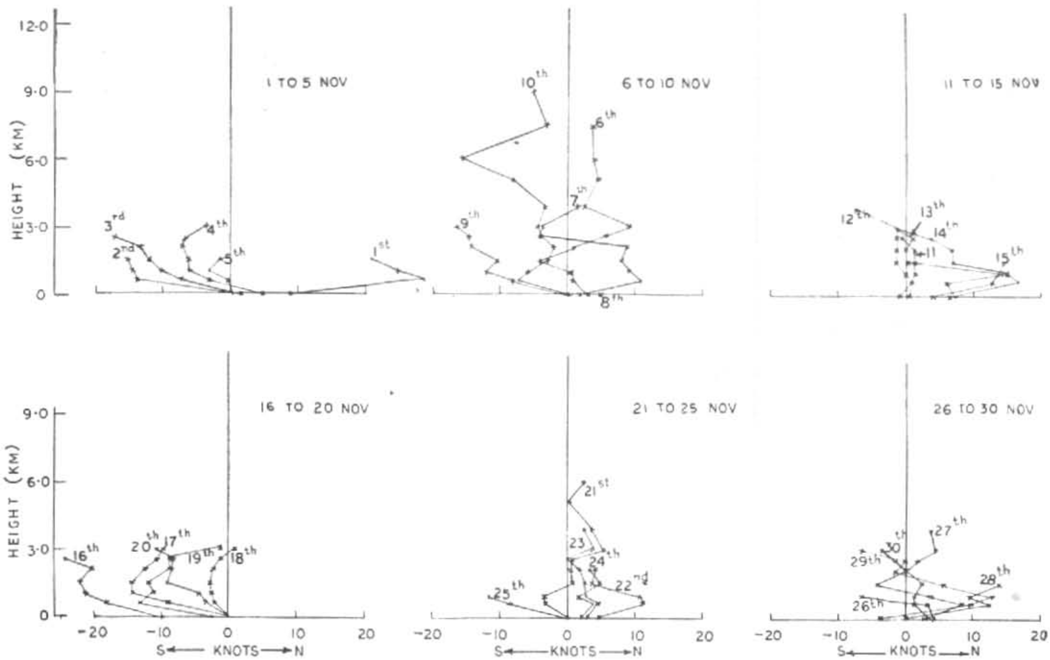


Fig. 9(a). N and S components of upper winds over Madras at 0700 IST in November 1946

a vertical component of cyclonic vorticity gets 'generated'. This generation of vertical component of vorticity can lead to development or intensification.

In such a mechanism for rainfall, if there is heavy rain at the coast and adjoining interior parts, one should expect a decrease of rainfall out at sea. If, however, there is downward motion at B and vertical motion at A, the vertical component of vorticity generated will be negative. This mechanism will not lead to development or intensification.

If we consider the easterly component, on similar consideration, one should expect a decrease of easterly components with height and a positive rate of change of vertical velocity towards north for occurrence of rainfall and, the rainfall will be more towards the north.

From the above, it becomes apparent, that for good northeast monsoon the northerly components of winds at the surface should be replaced by winds with southerly components at higher levels; in the case of easterly components, they should decrease with height. This approach brings out the importance of shear in the vertical. If the northerly component of say 10 to 15 knots, changes to southerly component at a fairly low level say 5000 to 10,000 ft the shear and hence the horizontal cyclonic vorticity will be larger than in the case when the change takes place at 20,000 ft level or above. In the former case one can expect greater development or intensification. If the easterlies decrease with height the rainfall will be more towards the north; if they were to increase with height, the rainfall will be more towards the south.

In order to test these ideas, the pilot balloon winds at the various levels over Madras for the month of November 1946 and 1949 have been resolved into north and

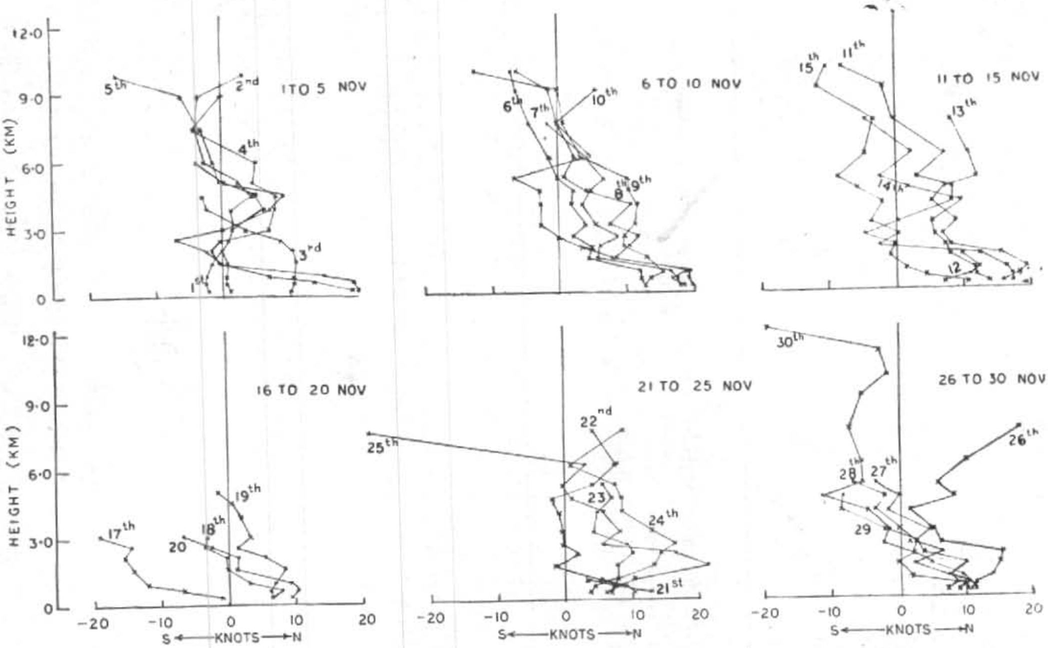


Fig. 9(b). N and S components of upper winds over Madras at 02 GMT in November 1949

south components and are presented in Figs. 9(a) and 9(b); the easterly component for the year 1949 is presented in Fig. 9(c). (In 1946, as there was rain on most of the days —Fig. 10—, the flights did not extend beyond 3-km level, and hence the easterly component diagram has not been included.) The twenty-four hours rainfall reported at Madras for these two periods are given in Fig. 10. In Fig. 9(a) the winds even at the lower level are from a southerly direction, and the southerly component shows a general tendency to increase with height. During the period 22nd to 25th, the winds have weak northerly components and from Fig. 10, it is seen that there was no rain during the period 20 to 23 November.

From Fig. 9(b), it is seen that the wind at the surface has strong northerly components of the order of 20 knots on most of the days. Also the winds have northerly components from the surface at least upto 6·0 km level on most of the days. But during the period 15 to 20 November 1949, the only period when there was rainfall, the winds near the surface had weak northerly components of the order of 10 knots, and these northerly components decreased in strength, with height.

From Fig. 9(c), it is seen that the easterly components are of the order of 10 knots. There is not significant variation with heights in the strength of the easterlies except on a few occasions.

To verify these ideas further, the north and the east components of the winds over Madras during November 1960, when there was good northeast monsoon rain over Tamilnad, were studied (Figures not included). During the period 1 to 21 November 1960, except for two or three days, there was rainfall at Madras every day. The northerly components at the surface did not exceed 10 knots; the change from northerly to southerly components took place between levels 5000 and 10,000 ft a.s.l. and the

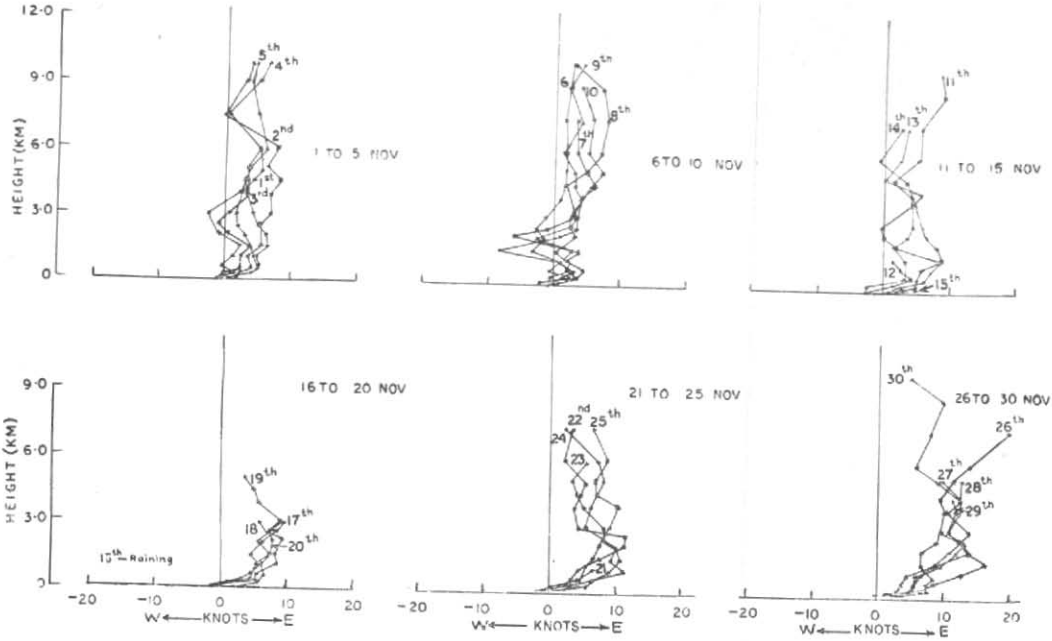


Fig. 9(c). E and W components of upper winds over Madras at 02 GMT in November 1949

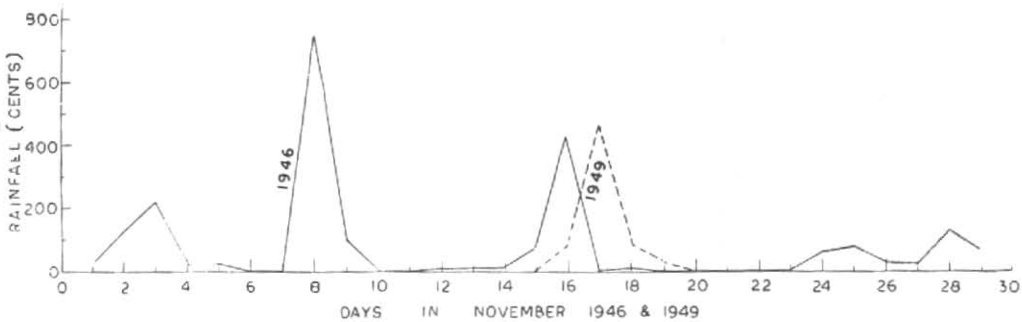


Fig. 10. Rainfall at Madras

(as reported at 0830 IST of the date)

southerly components generally increased with heights upto 40,000 ft. During this period the easterlies generally decreased from 10,000 ft to 30,000 ft. After 21 November 1960 there was no rain till the end of the month. During the period 21 to 25 November 1960, the change from northerly to southerly took place at higher level, *i.e.*, about 20,000 ft and during the period 26th to 30th, the northerly components extended from the surface upto 20,000 to 30,000 ft. The easterlies increased with height, during the same period.

Thus the ideas presented in the previous paragraphs seem to be verified very well.

6. Conclusions

1. The presence of a Blocking High in the European portion of U.S.S.R. is not favourable for good northeast monsoon rain over Tamilnad, whereas the absence of such a high seems to be favourable.

2. The location of the westward portion of the subtropical high at 500-mb level near the eastern coast of the country is favourable for good northeast monsoon, while the location of the eastern portion of the subtropical high cell is not conducive for such rain.

3(a). If the northerly components of winds at lower levels over Tamilnad is not strong and is replaced by southerly components at higher levels, and if this change takes place at fairly low levels, say 5000 to 10,000 ft the situation is favourable for good rains. If the northerlies were to persist from the surface upto 6·0 km or more, it is not favourable for good northeast monsoon rains.

3(b). If the easterlies decrease with height, the rainfall will be more towards the north; if they were to increase with height, the rainfall will be more towards the south.

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