

# A study of the extension of cold waves at the surface in relation to upper winds at 3000 ft in India

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## 1. Introduction

Earlier studies in India in connection with the forecasting of minimum temperatures from antecedent meteorological elements such as dew point, dry bulb, wet bulb, maximum temperature etc, have been confined to individual stations. Ramdas and Narasimhan (1937) and Barkat Ali and Naqvi (1931, 1941) may be referred to for such studies. In this note, a study is made connecting the march of minimum temperatures over large areas of the country in the form of cold waves with antecedent upper winds.

It is well known that cold waves advance into India in the rear of western disturbances which move across north India and central parts of the country during winter. The advance of these waves being essentially an advective phenomenon, the progressive extension of low temperatures from day to day on the surface may be expected to be related to wind field at some appropriate level higher up. The level of upper winds to be chosen for such investigations should be such that it is neither so low as to be affected by ground friction nor so high as not to influence surface temperatures. We shall see whether, with the aid of upper winds at 3000 ft, one can forecast the extent up to which a particular minimum temperature isotherm is likely to advance over the surface in the course of next 24 hours from its position on a particular day in northern India during winter. Such an enquiry arises very often in the mind of the forecaster concerned with the issue of low temperature warnings.

## 2. Data and analysis

Six synoptic situations have been chosen in which well-marked cold spells appeared over Western Pakistan and northwest India and moved eastwards across the central parts of India, extending their sway in some cases as far south as Deccan (Desh) and Hyderabad. The cases studied were for the following periods—

- |     |                    |
|-----|--------------------|
| I   | 3—7 January 1949   |
| II  | 5—8 February 1949  |
| III | 8—12 February 1950 |
| IV  | 15—18 January 1953 |
| V   | 8—11 January 1954  |
| VI  | 18—23 January 1954 |

Except for some isolated peaks, the general ground elevation in north India and central parts of the country is not more than 2000 ft above sea level. The upper wind field considered in the study was for the altitude of 3000 ft above sea level. This level was chosen for the reasons that at lower heights wind flow is likely to be affected by ground friction whereas winds at very high levels may not influence the surface temperature very much.

From the synoptic working charts of the cold spells under study, the isotherms of minimum temperature for 50°F, 45°F and 40°F were copied out on separate charts, using one chart for each level of temperature. Thus, three charts were prepared for each spell, one showing position of 50°F isotherms of minimum temperature on successive

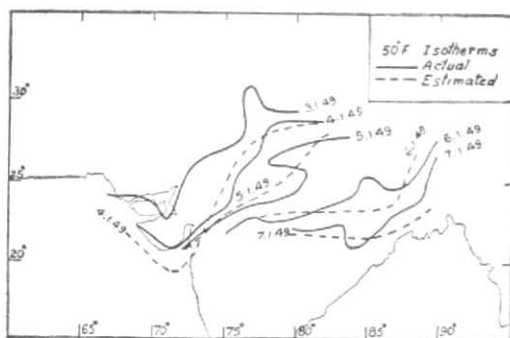


Fig. 1(a)

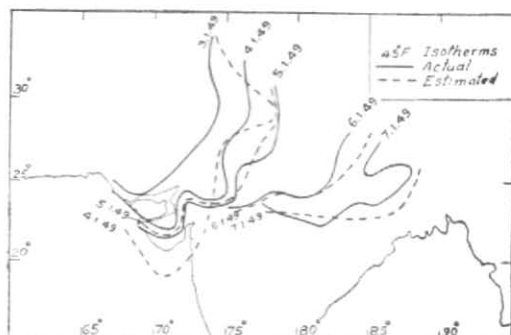


Fig. 1(b)

days, the second of 45°F isotherms and the third showing 40°F isotherms. These charts showed the progress of the particular minimum temperature line at the surface from day to day during the cold spell.

Next, the upper winds were considered for all the stations located on the temperature line of each date. The pilot balloon stations in India record two ascents per day (at 0200 and 0900 GMT) and a good number of these stations have ascents at a third hour (2100 GMT) also. For each station 0200 GMT winds were assumed to prevail during the five hours 0000 to 0500 GMT, the 0900 GMT winds for the period 0500 to 1500 GMT and 2100 GMT winds for the period 1500 to 2400 GMT. Assuming that the minimum temperature isotherms move with the upper winds at 3000 ft above sea level, the position of the isotherm on the next morning was derived, taking into account the upper wind speeds and directions of all the stations lying on the minimum temperature line or very near it. For the second day of the spell the upper wind data of stations lying on the actual temperature line of the day was used and so on. In this way the anticipated displacements of the isotherms were found for all the days of each spell assuming that the temperature lines moved with the 3000 ft upper winds taking into consideration the upper wind data of all observations available during the 24 hours. The positions of the isotherms as derived from the upper winds were also indicated on the same charts that contained actual temperature lines so that for each day the posi-

tions of the actual and derived isotherms can be compared. In the charts that are reproduced in this paper (*vide* Figs. 1 to 6), the actual isotherms are shown in continuous lines and the derived isotherms are shown in broken lines. The different charts for the same cold spell are sub-numbered a, b and c.

Brief remarks about the synoptic situation associated with each cold spell and on the study of the comparisons between actual isotherms and their derived positions are given separately for each of the cold spells in Sections 3 to 8 below. In Section 11, the general conclusions that can be drawn from this study are summarised.

### 3. 3 to 7 January 1949 (Case I)

*Synoptic situation*—On 4 January 1949, a western disturbance was moving eastwards across the hills of the east Punjab and the west Uttar Pradesh and in its rear, a cold wave from the west was moving across west Rajasthan. The cold wave extended into the east Punjab, east Rajasthan, the west Uttar Pradesh and Madhya Bharat on the 5th when minimum temperatures below freezing point were reported from north Rajasthan and the adjoining parts of the southeast Punjab. The cold wave moved into east U.P., Vindhya Pradesh and Bihar on the 6th and abated within the next two days.

The actual position of the 50°F isotherm on the 4th was more or less the same as the position derived on the basis of upper winds except in Kutch, Saurashtra and Gujarat



Fig. 2(a)

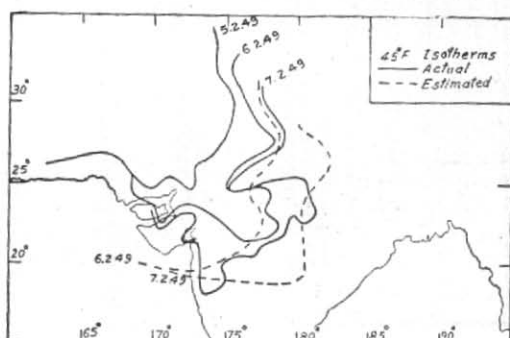


Fig. 2(b)

where the actual position has slightly lagged behind. On the 5th the actual and derived positions of this temperature line agree, except for minor differences in some areas. On the 6th and 7th also, the advance of the 50°F line is more or less the same as that indicated by the upper winds.

In the case of the 45°F line, on the 4th near the foot of the Himalayas, the actual low temperature line is in advance of its derived position. In the central portion, the actual and derived positions more or less coincide except for a little lag near the Delhi area. When approaching Kutch, Saurashtra and Gujarat, as in the case of the 50°F line, the upper winds indicated more rapid progress than what has actually happened.

On the 5th, 6th and 7th the two lines practically coincide over the major portion except for some lag when the temperatures advance into east U.P. and Bihar.

The 40°F isotherm did not show much progress and its movement being very slow, correlation with upper winds was not tried (chart not reproduced).

#### 4. 5 to 8 February 1949 (Case II)

*Synoptic situation*—A western disturbance was moving eastwards through west Uttar Pradesh on the 5th. A secondary of the disturbance had also appeared over Madhya Bharat and the adjoining areas. By the 6th, the disturbance over Uttar Pradesh was pas-

sing away and the secondary over Madhya Bharat had moved into Chota Nagpur and the adjoining parts of Vindhya Pradesh. Moving eastwards into sub-Himalayan West Bengal on the next day, the secondary passed away across the Eastern Himalayas on the 8th and filled up.

In association with these, night temperatures fell appreciably in west Rajasthan, Saurashtra and Kutch on the 5th, and a cold wave had enveloped west Madhya Pradesh, Saurashtra and Kutch and the northern parts of the Bombay State by the 6th. The cold wave had pervaded the whole of the Bombay State and Hyderabad on the 7th. Advancing further east and south, it extended into northeast India, Rayalaseema and the Andhra Desh on the 8th and started abating on the next day.

On the 6th and 7th, the actual minimum temperature line for 50°F practically coincided with its expected position except for a little difference near the Jhansi-Gwalior area on the 6th. On the 8th, the actual minimum temperature line showed some lag behind its derived position near the Orissa coast. But towards Assam and East Pakistan there was a greater advance of the cold wave than indicated by the upper winds. The lag near the Orissa coast may be attributed to the warming influence of the coastal areas and the marked advance in the Assam area may be the effect of Katabatic flow of cold air from the hilly areas of Assam and the adjoining East Pakistan.

The 45°F actual line on the 6th, agreed more or less with the derived line except in Kutch, Saurashtra, Gujarat and north Deccan (Desh) where it lags considerably behind. On the 7th again there is considerable lag of the actual behind its expected position. It may be mentioned that from the 6th to 7th the rate of advance of the temperature line had slowed down considerably and thereafter there was very little advance of temperature of this order.

The advance of the 40°F isotherm was not considered since temperatures of the order of 40°F did not prevail to any appreciable extent on any area.

#### 5. 8 to 12 February 1950 (Case III)

*Synoptic situation*—A western disturbance from Baluchistan had moved northeastwards and was lying as a depression over the west Punjab on the 8th. Moving further northeast it filled up by the 10th. In the rear of this depression a cold wave gripped northwest India and the central parts of the country and temperatures near or below freezing point were recorded at many stations in Rajasthan and the adjoining districts of the Punjab on the 10th. The cold wave extended its way over the Uttar Pradesh, the central parts of the country, the Deccan and the Konkan on the next day. Moving further eastwards it advanced into West Bengal and Assam on the 12th and started abating the next day.

The actual 50°F line on the 9th, is very different from its derived position. This is because the upper wind data for 8th was not adequate to give a reliable estimate of the derived position. The only upper wind data on the isotherm available on the 8th were those of Ambala, Lahore and Jacobabad. Ambala and Lahore were indicating strong southeasterly winds at 0200 GMT and 0900 GMT of the 8th, which changed over to westerlies at 2100 GMT and 0200 GMT of the next day. Under such circumstances of radical changes, upper winds do not seem to provide indications of the extent of advance of the cold waves. No data were available to



Fig. 3(a)

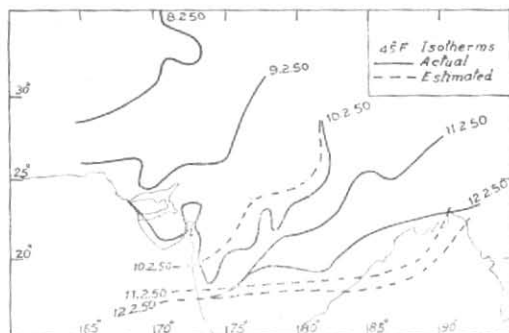


Fig. 3(b)

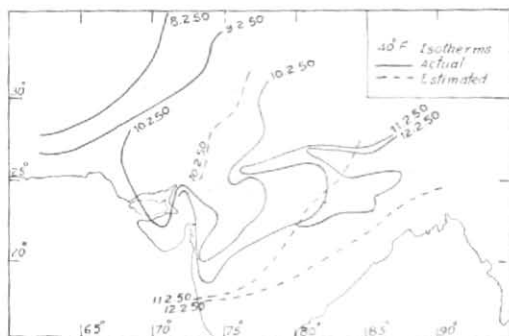


Fig. 3(c)

estimate the advance into south Rajasthan and Sind.

On the 10th, the actual 50°F line was a little ahead of the anticipated position. From the 10th to the 11th, the advance of the 50°F line was appreciably less than that indicated by the upper winds. Similar was

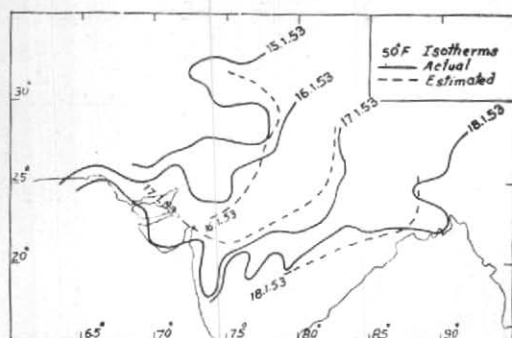


Fig. 4(a)

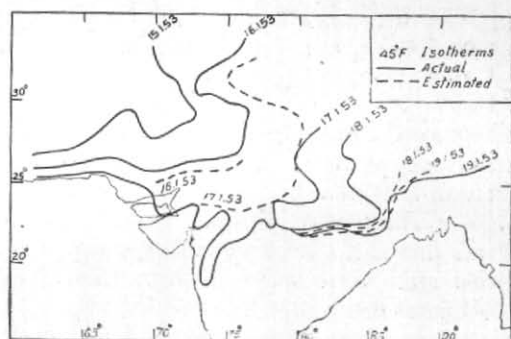


Fig. 4(b)

also the case on the 12th. It is thus seen that in this case there was a very rapid advance of the cold wave in the initial stages whereas at the later stages, the rate of advance was considerably less.

The behaviour of the 45°F isotherm was more or less similar to the 50°F isotherm in this spell.

The 40°F line advanced appreciably on the 10th more than what was indicated by the winds. But the wind data available were meagre. The run of the 40°F isotherm was a little irregular on the 11th but in general, it coincided with the position indicated by the wind data. On the 12th there was appreciable lag in the advance of low temperatures in the wake of the wind.

#### 6. 15 to 18 January 1953 (Case IV)

*Synoptic situation*—A well-marked western disturbance was moving away north-eastwards across the Punjab(P) and neighbourhood on the 16th and in its rear temperature was falling in south Punjab (I), west U.P., Rajasthan and Saurashtra. On the 17th, northerly air had extended over the country up to Lat. 20°N. Night temperatures had also fallen appreciably over the country outside northeast India and the south Peninsula. On the next day, night temperatures fell in northeast India also outside Assam and sub-Himalayan West Bengal.

Sufficient upper wind data were not available on the 15th for the estimation of the advance of the 50°F isotherm southwards into Sind and Kutch on the 16th. Near the foot of the Punjab Himalayas the 50°F line advanced rather more rapidly than expected. Otherwise the 50°F line on the 16th practically coincided with the calculated position. On the 17th and 18th also the agreement between the actual and calculated positions is generally good except for minor differences.

In the case of the 45°F line, the upper wind data were not sufficient to estimate its position north of Lat. 20°N on the 16th. But the position indicated by the available data practically coincided with the actual. On the 17th there was a very rapid advance of the cold wave along the foot of the U.P. Himalayas which was not indicated by the upper winds. In the rest of North India, the actual position generally coincided with the estimated position except for a tongue of cold air which moved into the north Deccan (Desh).

On the 18th, on the other hand, the upper winds indicated a greater advance of the cold air north of Lat. 24°N than what actually happened, though south of it the cold wave extended almost to the extent expected. On the 19th, the actual and the estimated positions were very nearly the same.

There was no marked advance of temperatures of the order of 40°F and hence no

attempt was made to correlate the progress of these isotherms with the winds.

#### 7. 8 to 11 January 1954 (Case V)

*Synoptic situation*—A western disturbance was moving away eastwards across the Punjab hills on the 9th and at the same time a secondary was forming over Vindhya Pradesh and neighbourhood. Night temperatures had fallen appreciably in Rajasthan and north Gujarat. On the next day, the secondary disturbance was moving away eastwards across north Bihar and the adjoining areas of sub-Himalayan West Bengal and in its rear, night temperatures had fallen markedly in Gujarat, north Deccan (Desh) and Madhya Bharat. By the 11th, the secondary was moving away across upper Assam and the cold wave had extended to east U.P., Vindhya Pradesh and east and southwest Madhya Pradesh. By the 12th, the secondary disturbance had moved away.

Sufficient upper wind data were not available to estimate completely the position of the 50°F line on the 9th. From available data it is, however, seen that in northwest India the advance was more rapid than expected. In the Gujarat Saurashtra area, however, the upper winds indicated a greater advance than what happened. On the 10th the estimated and the actual positions coincided except in the U.P. area where the actual line lagged slightly behind. On the 11th and 12th, the positions practically coincided.

The upper wind data available on the 7th were too meagre to estimate the position of the 45°F line on the 8th. On the 9th the actual and estimated positions practically coincided except for a slight lag in the case of the actual line in the north Gujarat area. On the 10th and 11th, the positions practically coincided. After the 11th, there was very little advance of temperatures of the order of 45°.

As in the case of the 45°F isotherm, the data available were too meagre to estimate the position of the 40°F line on the 8th. The data on the 8th were not sufficient to estimate the position on the 9th also north of

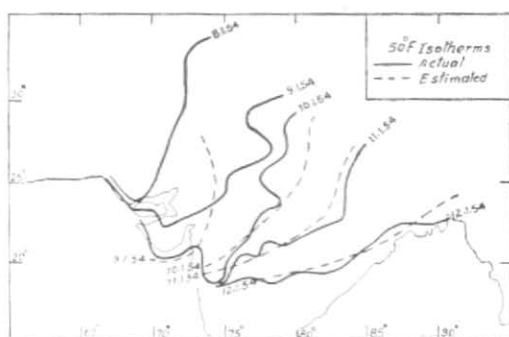


Fig. 5(a)

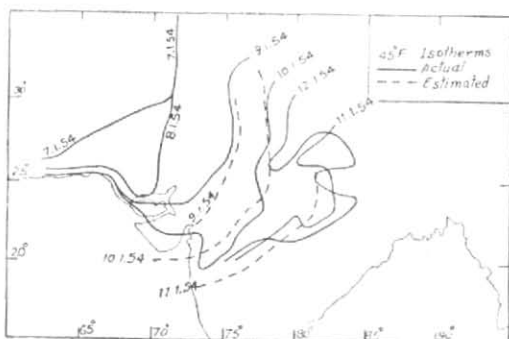


Fig. 5(b)

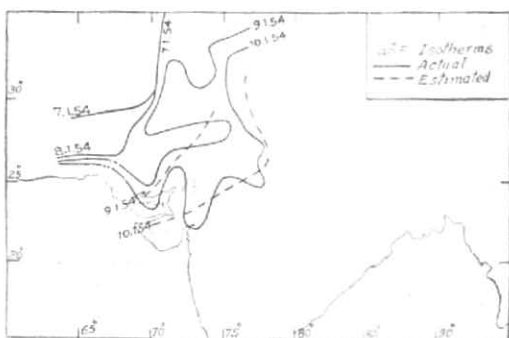


Fig. 5(c)

Lat. 24°N, but south of it there was general agreement between the actual and calculated positions. On the 10th, the position as far as could be estimated nearly coincided with the actual line. After the 10th, temperature of the order of 40°F did not extend further eastwards.

## 8. 18 to 23 January 1954 (Case VI)

*Synoptic situation*—A cyclonic circulation associated with the secondary of a western disturbance appeared over northeast Rajasthan and the adjoining areas on the 18th. The disturbance moved over to the Punjab (P) on the 19th. Moving further northeastwards, it passed away across north Punjab (I) on the 21st. In the rear of this disturbance, night temperatures had started falling in northwest India, north Gujarat, Saurashtra and Kutch on the 20th. There was a further fall in night temperature in the above areas on the 21st and the drop in temperatures extended into Madhya Bharat. On the 22nd, night temperatures fell markedly in north Madhya Pradesh and Vindhya Pradesh and by the 23rd, practically the whole of northwest India, southwest U.P., the central parts of the country and Chota Nagpur were in the grip of the cold wave.

On the 20th, the actual position of the 50°F isotherm more or less coincided with the estimated position. In north Gujarat, Kutch and Lower Sind, the position could not be estimated for want of upper wind data. On the 21st and 22nd also the actual and calculated positions were in good agreement except in Saurashtra, where the actual position lagged behind, presumably owing to the warming influence of the sea.

Wind data were too meagre to enable the positions of the 45°F lines on the 19th and 20th respectively to be computed. The actual line on the 21st agrees very closely with the anticipated position except over the southwest Rajasthan and Sind area. It should be mentioned that the available upper wind data were too meagre in this case. On the 22nd the actual line and the estimated one are in good agreement. On the 23rd also, agreement between the two is fairly good except for some lag along the foot of the Himalayas.

What has been stated above regarding the 45°F line is also generally true of the 40°F line except that on the 22nd the actual line shows

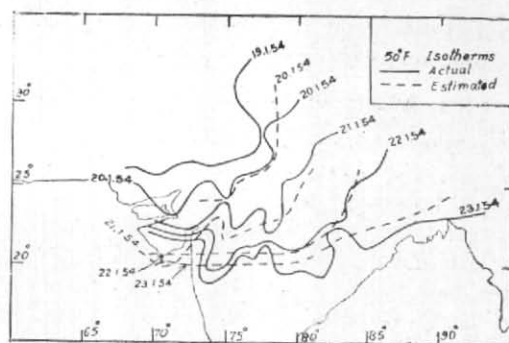


Fig. 6 (a)

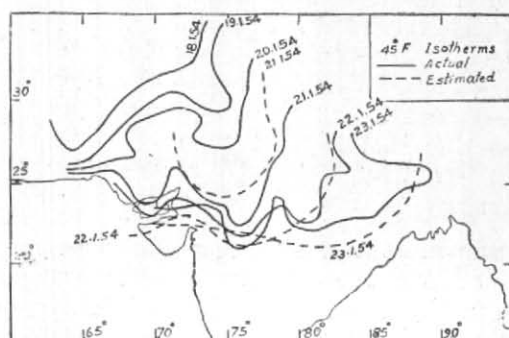


Fig. 6(b)

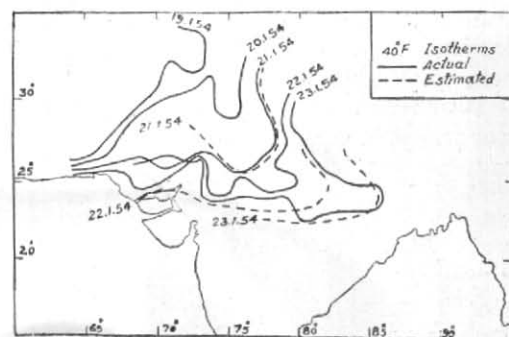


Fig. 6(c)

a lag behind the anticipated position. On the 23rd also, over the east U.P.-Bihar area the upper winds indicated a more rapid advance of the low temperature than what actually took place.

### 9. Progress of departure of minimum temperatures

In some of the six cases mentioned above, another aspect studied was whether the departure lines of minimum temperatures, say  $-4^{\circ}\text{F}$ ,  $-8^{\circ}\text{F}$ ,  $-12^{\circ}\text{F}$  show any progressive advance and whether the movements of the departure lines could be correlated with the upper winds. The departure lines, especially  $-8^{\circ}\text{F}$  and  $-12^{\circ}\text{F}$ , did not however indicate well defined movements that could be traced from day to day and correlated with the upper winds. Hence this aspect was not further pursued.

### 10. Practical utility of the Method

From the practical point of view of the forecaster who has to issue temperature warnings for the next twentyfour or thirtysix hours by about forenoon of a day, the use of upper wind data at later hours in the day for the derivation of the next morning's isotherm line has no interest although such comparisons will bring out the extent of relationship investigated. To assess the practical value of this relationship between upper winds and movement of cold waves at the surface, the next day's isotherms were also derived using only 0200 GMT winds at 3000 ft of the previous day and charts similar to those mentioned in the previous paragraphs prepared. These are not, however, reproduced in the paper. It was seen that in the majority of cases the advance of the lines estimated from the 0200 GMT winds alone is practically the same that estimated from the 0200, 0500 and 2100 GMT winds. There were differences only in a few cases where the 0900 and 2100 GMT winds were appreciably different from the 0200 GMT winds. The forecaster with his experience may be able to anticipate the modifications that the 0200 GMT winds are likely to undergo in

the course of the day and thus take into effect these changes in estimating the subsequent position of the isotherm.

### 11. General conclusions

1. The isotherms of  $50^{\circ}\text{F}$  and  $45^{\circ}\text{F}$  minimum temperature generally move with upper winds at 3000 ft.

2. The movement of  $40^{\circ}\text{F}$  isotherms is very slow and lags very much behind upper winds at 3000 ft.

3. In the few cases where (1) above is not true there are more instances when the temperature lines lag behind their derived positions than otherwise, thus enabling the forecaster to anticipate the farthest limit beyond which the next day's minimum temperature line is not likely to extend.

4. In the case of severe cold wave however, when they first advance into India from the northwest the initial advance is more than what is indicated by upper wind data.

5. In the coastal strips, some allowance has to be made for the retardation of the isotherms owing to the warming influence of the sea. On the other hand, in mountainous areas, the effect of cooling due to katabatic flow and the consequent accentuation of cold spells has also to be borne in mind.

6. The 0200 GMT upper winds can be utilised to a good approximation for deriving the positions of the isotherms on the next day especially when the slight changes that the 0200 GMT upper winds are likely to undergo during the course of the day could also be anticipated.

### 12. Acknowledgement

The author has great pleasure in thanking Shri Y. P. Rao for suggesting this study and for the interest he took in its progress.

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