Indian J. Met. Hydrol. Geophys. (1977), 28, 2, 233-242

551.515

Study of a western disturbance

M. S. SINGH and S. KUMAR

Meteorological Office, New Delhi

(*Received 11 September 1975*)

ABSTRACT. The intensification of a western disturbance which moved from central Iran to northwest India from 11 to 13 February 1975 has been studied. It has been shown that the system intensified when a pre-existing surface low over central Iran was overtaken by a strong upper frontal layer from the west. It has also been shown how the strength of this upper frontal layer was maintained during the whole period.

1. Introduction

Since the first enunciation of the relation between the upper westerly troughs and the surface cyclogenesis by Bjerknes and Holmboe (1944), the crucial role of a diffluent upper air trough in the westerlies overtaking a surface front for rapid cyclogenesis at the surface has been emphasised again and again (Petterssen 1956). Sutcliffe and collaborators (1950) applied this idea in a different way for day-to-day forecasting. They showed that thermal troughs and ridges as derived from the thermal winds between 500 and 1000 mb levels, can be used successfully for predicting surface cyclogenesis. Palmen (1951) in a series of studies brought out the existence of a frontal zone separating the tropical from the polar airmasses which he showed to be continuous throughout the globe in the middle levels, though it was broken near the surface as well as the tropopause. Newton (1958) studying the life-cycle of an upper air westerly trough noted that during the growing stage of the trough a strong mid-tropospheric frontal layer develops on its western flank and migrates eastwards with respect to the trough becoming almost uniform on all its sides at the peak of its development. Thereafter it migrates further east heralding the dissolution of the trough. He noted further that as this mid-tropospheric frontal layer migrates east, it establishes vertical contact with a pre-existing cold front at the surface and intensifies it. This is perhaps another way of emphasising the idea of Riehl and La Seur (1952) that frontal systems intensify below the exit zone of a westerly jet stream, because an intense frontal zone in the mid-troposphere and an intense jet higher up are concurrent processes (Palmen 1951) and are inseparable. Thus, the role of increasing upper level divergence for the intensification of a surface cyclone has been brought out in many ways by various workers (Palmen and Newton 1969).

In Indian latitudes too the role of upper level westerly troughs in the intensification of western disturbances has been emphasised again and again (Rao and Srinivasan 1969). Pisharoty and Desai (1956) suggested that migrating westerly upper air troughs with diffluence ahead may cause intensification of western disturbances. Singh (1963) and Dutta and Gupta (1967) showed in their case studies that it does happen in some cases. Recently again Singh (*see* Ref.) studied the intensification of a western disturbance over northwest India and found that it was preceded by the development of an upper air trough in the westerlies which was accompanied by the organisation of an upper tropospheric frontal layer as observed by Newton (1958). The frontal layer while migrating eastwards with respect to the trough intensified a feeble low lying over northwest India into a well-marked western disturbance. The accompanying jet-stream also supported that development as expected.

Presented here is another case study in which the development and movement of a western depression from Iran to NW India between 11 and 13 February 1975 has been discussed.

2. Low level features

A low pressure area located over south central Iran (north of Kerman) at 1200 GMT of 11th moved east and intensified into a depression over SW Afghanistan and neighbourhood, (IDWR) by 0300

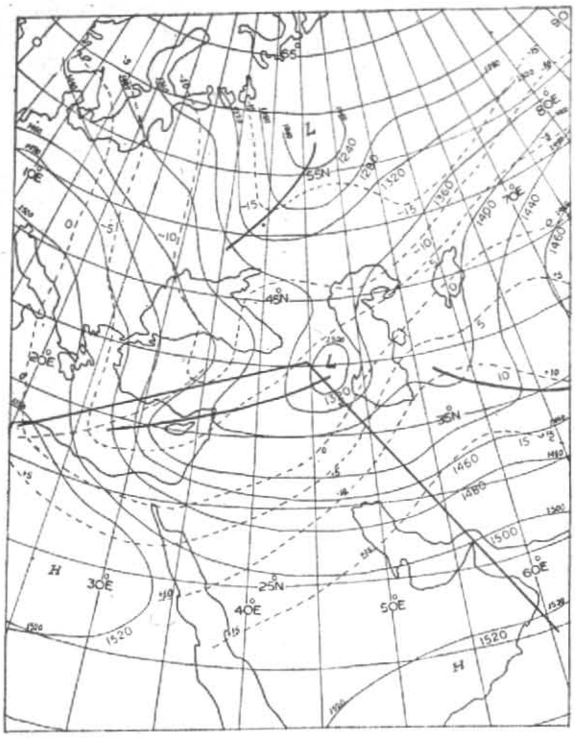


Fig. 1 (a)
850 mb chart of 1200 GMT on 10 February 1975

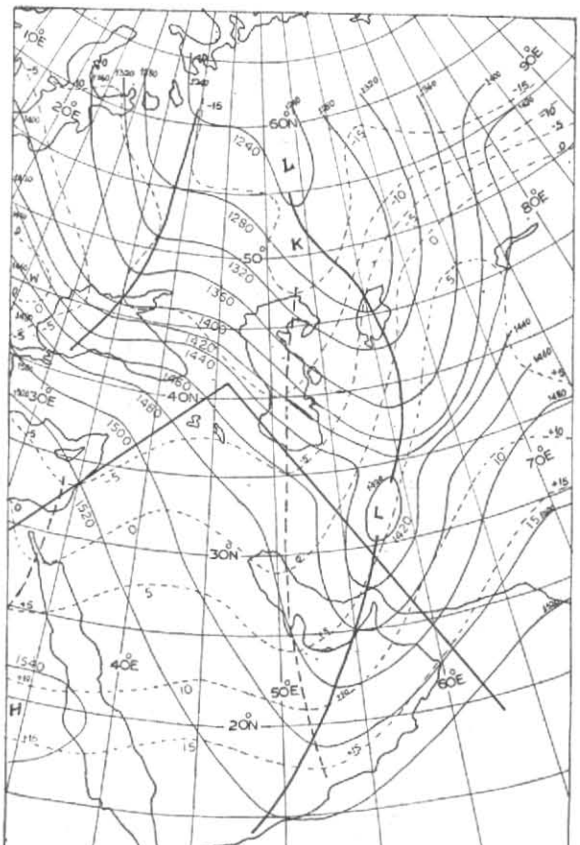


Fig. 1 (b)
850 mb chart of 1200 GMT on 11 February 1975

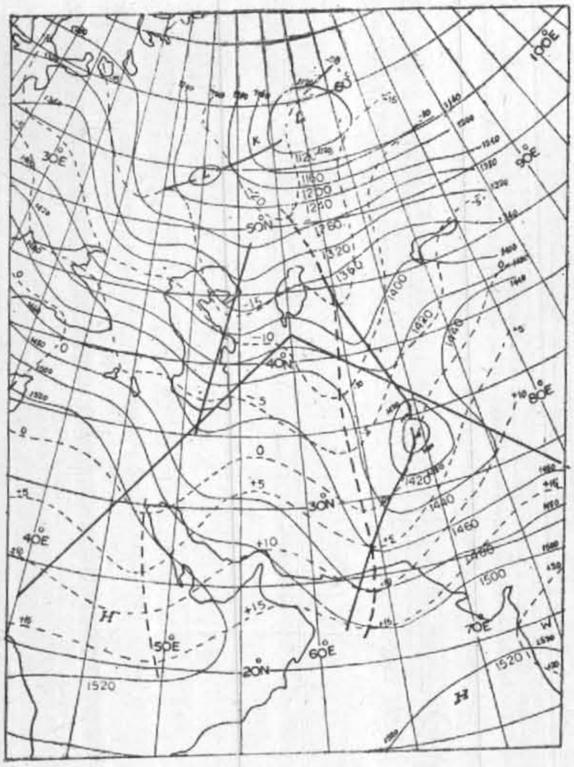


Fig. 1 (c)
850 mb chart of 1200 GMT on 12 February 1975

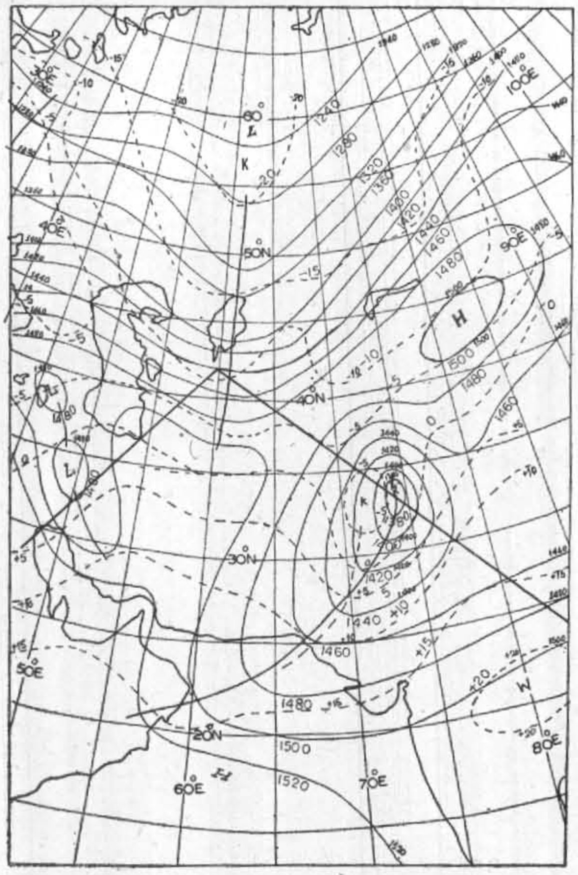


Fig. 1 (d)
850 mb chart of 1200 GMT on 13 February 1975

GMT of 12th. It moved ENE'wards during the next twentyfour hours and was located over J & K and the adjoining areas and showed further intensification. Amritsar showed a pressure departure of —11.3 mb at 0300 GMT of 13th. The system moved to the Western Himalayas the next day.

The weather activity associated with this system was very intense. On the 11th, a number of stations in south and central Iran reported dust/sandstorms with wind exceeding 40 kt. Over Indian region, as per the reports of the 13th, rain/snow was widespread in the hills of west U.P. and fairly widespread in H. P. and J. & K. Rain/thundershowers were also widespread in the Punjab and Haryana. On the 14th also there were reports of widespread rain/snow in H. P. and fairly widespread rain/snow in J. & K. and hills of west U. P. Rain/thundershowers were widespread in the plains of west U. P. and scattered in east U. P. Satellite pictures also showed extensive cloudiness on 12th and 13th (Figs. 4 a & b), though no organized pattern could be discerned perhaps due to hilly terrain. We would like to study this system, particularly its intensification between the 11th and 13th.

In Figs. 1(a) to 1(d) are reproduced the 1200 GMT 850 mb charts of 10th through 13 February 1975. On the 10th, there is a low west of Caspian Sea with its trough line extending SW'wards. There is no other system seen to the south or east except a trough line SE of Caspian Sea. On the 11th (Fig. 1 b) the low west of Caspian Sea moved east and weakened creating a deep trough line extending ENE-SW from Aral Sea to Arabia. On this trough line could be seen the low which intensified north of Kerman on this day. It is now well-marked upto 850 mb. In the next 24 hours (Fig. 1 c) this low moved ENE and was centred near 34°N, 70°E as a depression (IDWR). The trough line to the north has weakened, though it is still well-marked southwest of it. The thermal trough to its west is quite prominent and extends

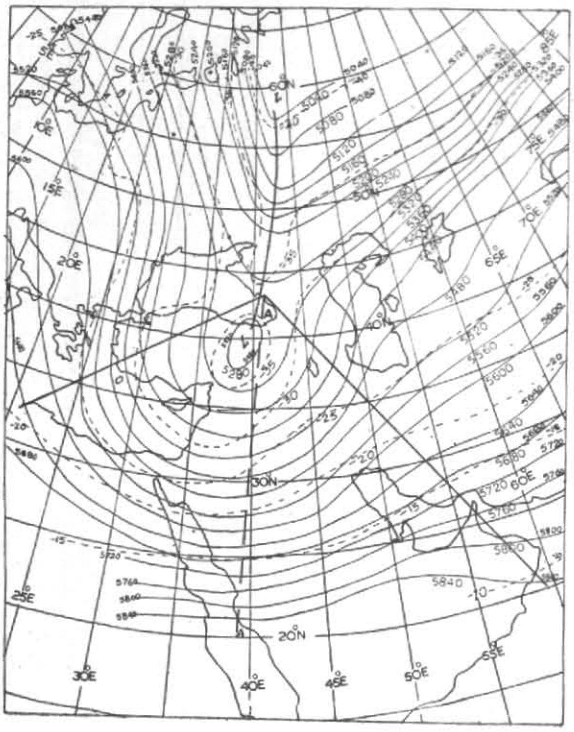


Fig. 2 (a). 10 February 1975

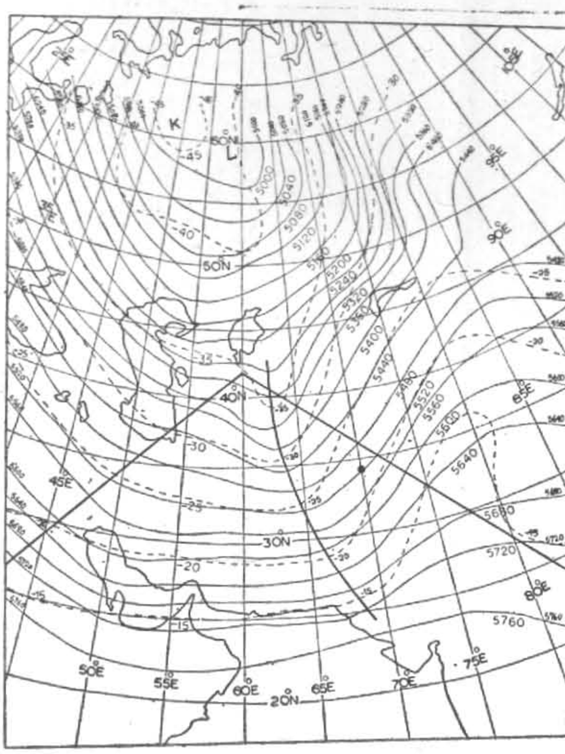


Fig. 2 (b). 11 February 1975

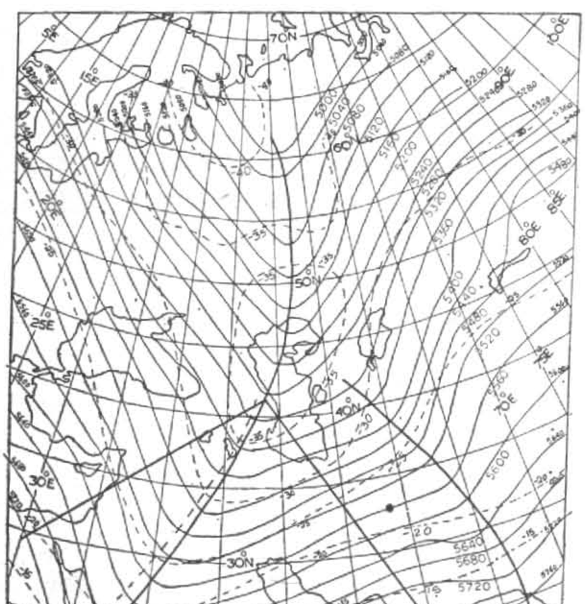


Fig. 2 (c). 12 February 1975

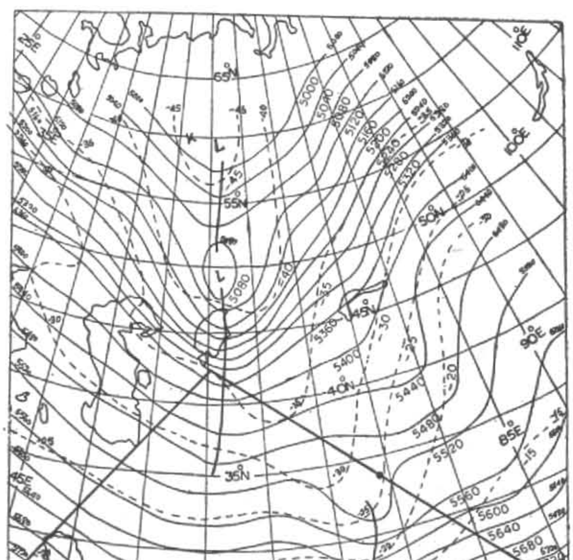


Fig. 2 (d). 13 February 1975

Figs. 2 (a-d), 500 mb charts of 1200 GMT

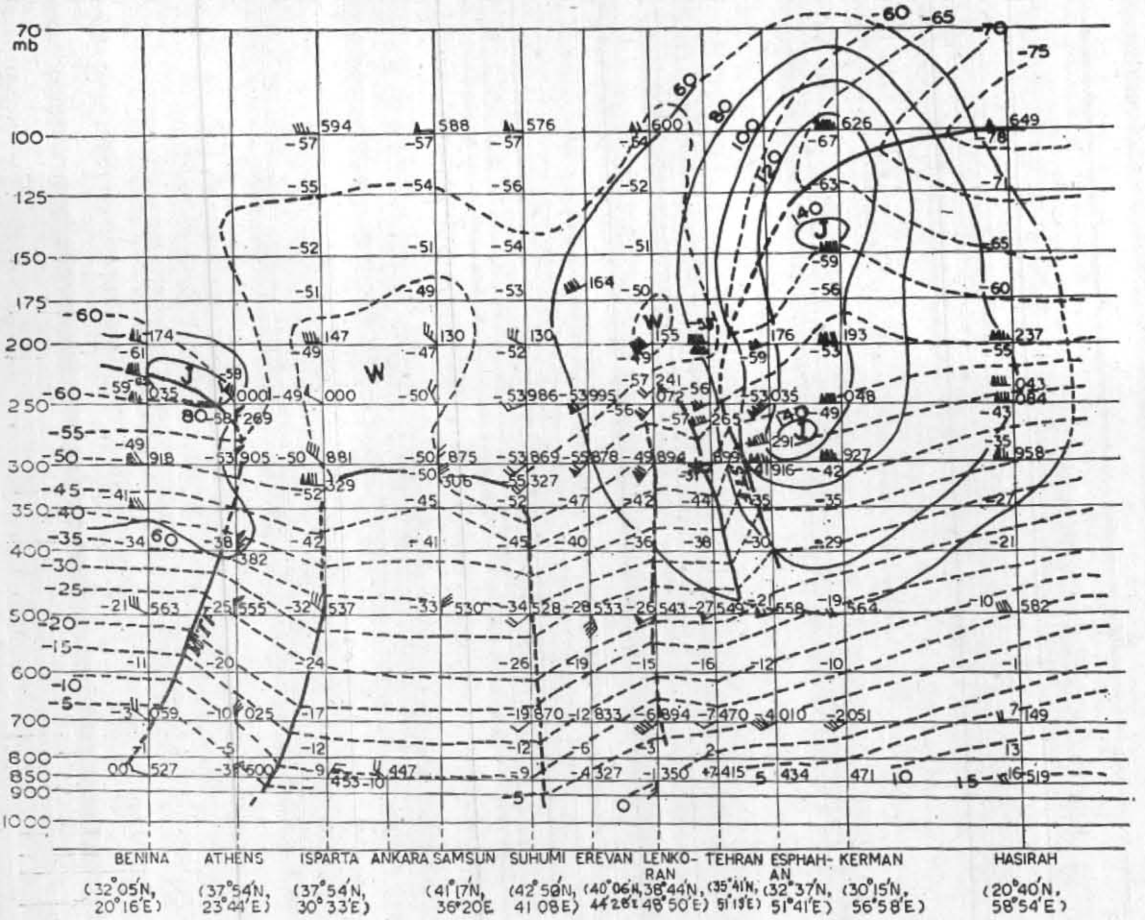


Fig. 3 (a)

Vertical cross-section at 1200 GMT on 10 February 1975

Thick lines — fontal surface & tropopauses, Thick dashes — fontal discontinuities, Thin lines — isotherms, Dashed lines — isotherms, STF — subtropical front, MTF — Midtropospheric front and SF — Surface front

deep from north to south roughly along 65°E. By 1200 GMT of 13th (Fig. 1 d) the depression moved to J & K, centred at about 34°N, 74°E and intensified further. The thermal trough is still to the west and very deep, particularly in the southern part.

3. Upper air features

Figs. 2(a) to 2(d) present 500 mb charts of 1200 GMT for the period 10 to 13 February 1975. At 1200 GMT of 10th (Fig. 2 a) a cut-off low could be seen at the southeastern corner of the Black Sea. There is a pool of cold air at its centre. The next day (Fig. 2 b) this low disappeared leaving a sharp trough line from 60°N, 50°E to 20°N, 35°E. The pool of cold air, however, is still present over Caspian Sea and to its north. It is on this day that the surface low developed north of Kerman. Its daily position has been shown by a circle on the relevant charts. By 1200 GMT of 12th (Fig. 2 c) the southern part of the trough line shifted east and extended NW-SE from Aral Sea to southwest Rajasthan and a deep thermal trough line appeared along with it. The surface low could be seen located east of this trough line. On the 13th (Fig. 2 d) the trough line weakened completely except in the vicinity of the low level system. Actually it formed part of the system now. The thermal trough line to its west is, however, very prominent on this day.

Looking at the upper air features as evidenced by 500 mb charts, there appeared nothing which could be said to be particularly suitable for the low level development. Hence we examined the thermal characteristics closely. Before we discuss these, it may be seen that the pool of cold air which was seen clearly upto 11th at 500 mb level, showed

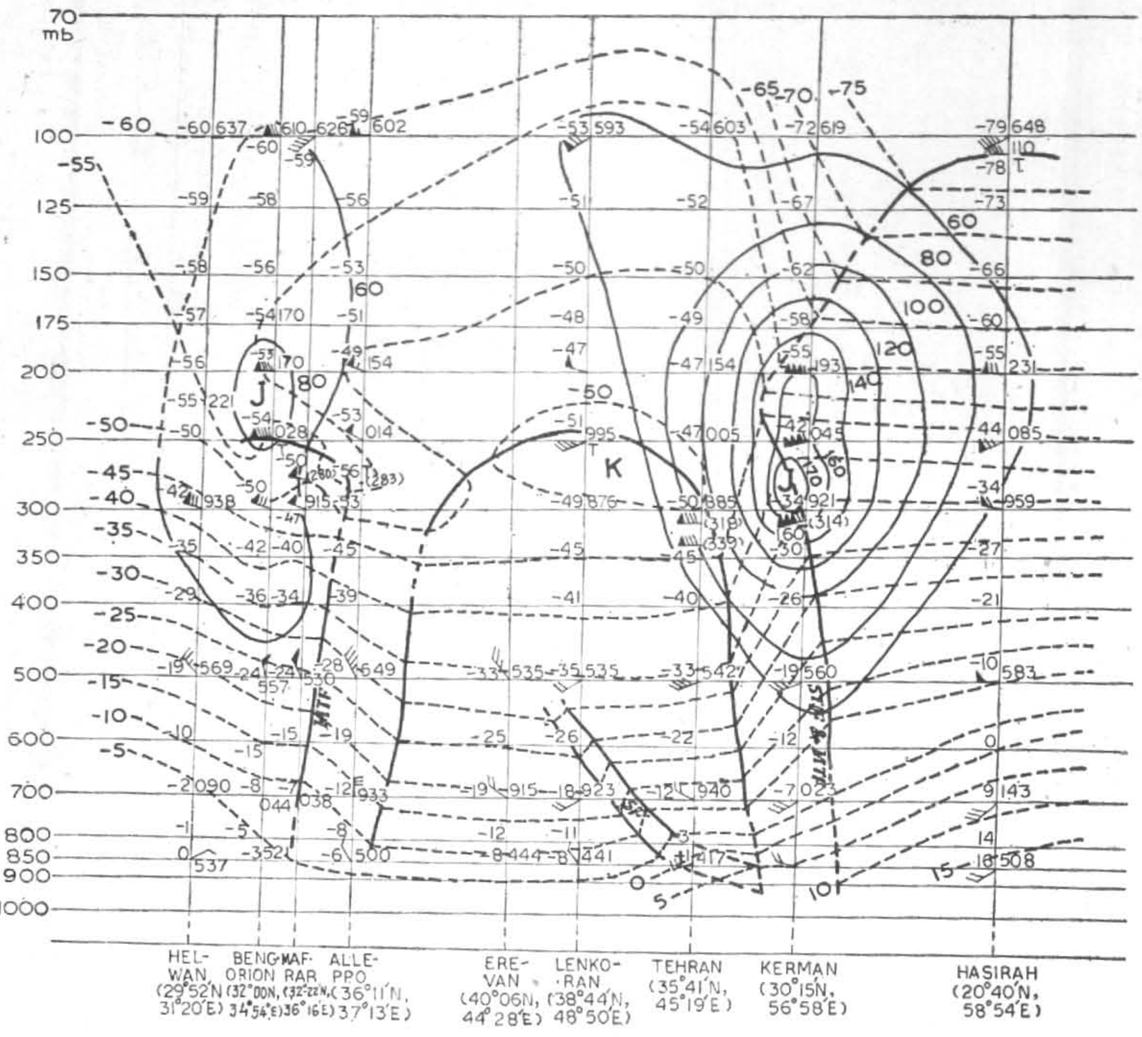


Fig. 3 (b)

Vertical cross-section at 1200 GMT on 11 February 1975
(Legend same as Fig. 3 a)

southward shift for the next two days creating a deep thermal trough to the southeast. Because of this, a deep baroclinic zone was created throughout the low and middle troposphere, particularly to the east of the thermal trough. And it was in this region that the low level system was located from 11th to 13th.

4. Analysis

To study the thermal characteristics of the atmosphere during this period vertical cross-sections were made along lines drawn on the Figs. 2(a) to 2 (d). These cross-sections were made SW-NE-SE in such a way that the northern portions were kept in the middle. Here we have followed Newton's (1958) method of three dimensional analysis. Figs. 3 (a) to 3 (d) present the vertical cross-sections pertaining to Figs 2 (a) to 2 (d).

5. Discussion

Fig. 3(a) shows that the western flank of the cut-off low had a weak frontal layer upto about 400 mb. It was still not seen on its eastern flank. In fact, an examination of Fig. 2 (a) reveals that the frontal layer was more intense on its southern flank along the line AA, though we do not have adequate data to prepare a cross-section there. 1000-500 mb thickness chart (not reproduced) also showed the concentration of thickness lines in this zone. On the east side only a baroclinic zone exists which, however, extends throughout the troposphere. The polar air is in the middle with its characterisitc tropopause at about 300 mb. There is a subtropical front also extending down to 400 mb. We should particularly note the condition of atmosphere around Kerman (40841) where the surface low intensified in the next twentyfour

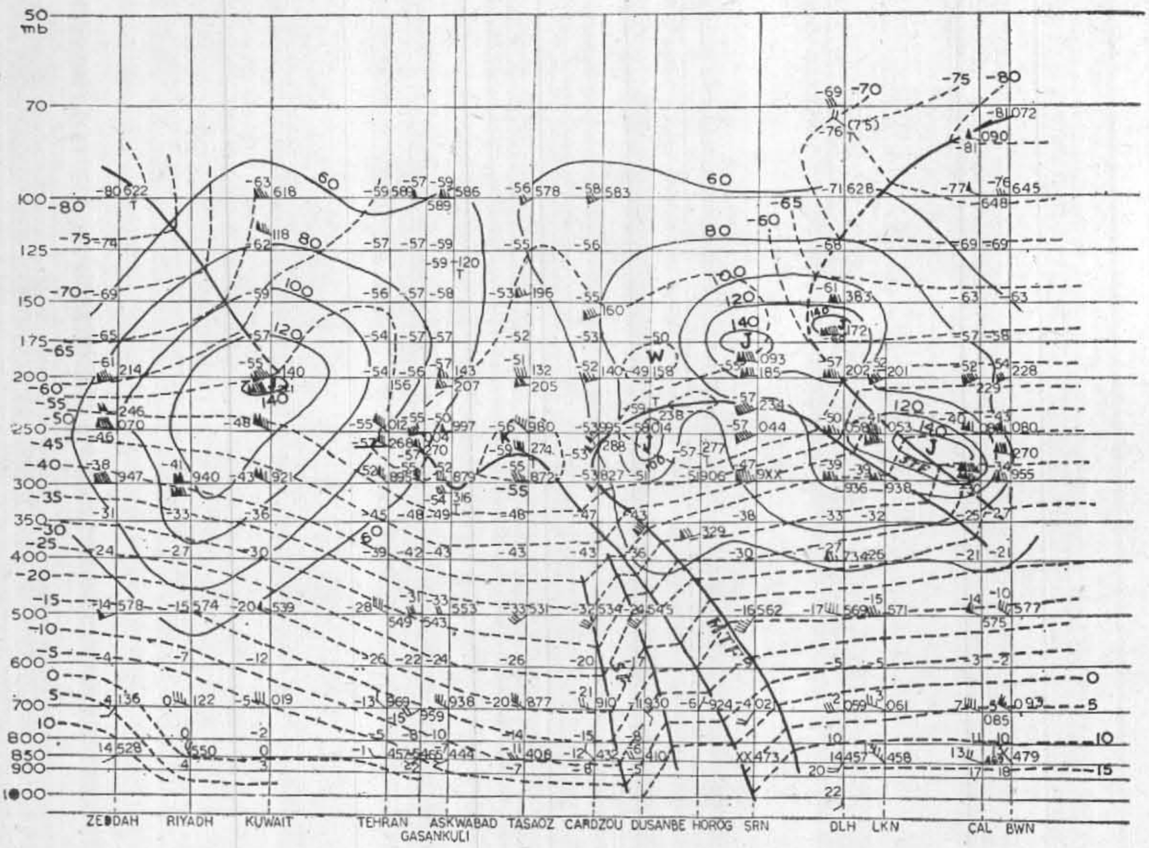


Fig. 3 (c)

Vertical cross-section at 1200 GMT on 12 February 1975
(Legend same as Fig. 3 a)

hours. We can see that a mild baroclinity exists around this station between 700 and 400 mb levels. The jet-stream core located over it is at 150 mb level with a speed of 135 knots.

Fig. 3 (b) represents the condition at 1200 GMT of 11th when the surface low showed marked intensification. It can be seen that the weak frontal layer on the west side of the trough still exists, mostly upto 400 mb level. But the baroclinic zone to the east has organised into a deep frontal layer. It is particularly well-marked above 700 mb. It is almost vertical above Kerman, an indication of its extreme intensity. It appears that the strong frontal layer of the previous day (along the line AA in Figs. 2 (a) moved over to Kerman area on this day and established vertical contact with the feeble surface low approaching from the southwest, thus creating very favourable condition for its rapid intensification (Newton 1958). It appears, the process of intensification started from the 11th morning itself. Another proof of the approach of the frontal layer from the west is the approach of the accompanying jet. The jet over Kerman has now intensified to above 160 kt and is at about 300 mb level. Its core is unusually broad in the vertical extending from 320 to 200 mb level. It is apparent, therefore, that this is the polar jet accompanying the frontal layer which approaching Kerman from the west has combined with the existing sub-tropical jet above. Thus, the intensification of the surface low took place as expected. It is worth noting, however, that though quite a significant surface cyclogenesis took place, the system is still quite weak in the upper levels as can be seen in Fig. 3 (b). It shows quite a slant in comparison to upper frontal layer. At the surface the two systems seem to be superimposed as observed by Newton (1958) also. This type of development is actually very common over North America where "well developed polar front is often confined to the lower troposphere in the immediate locale of cyclogenesis although a frontal layer extending through the whole troposphere may be present up-stream from the cyclone" (Palmen and Newton 1969).

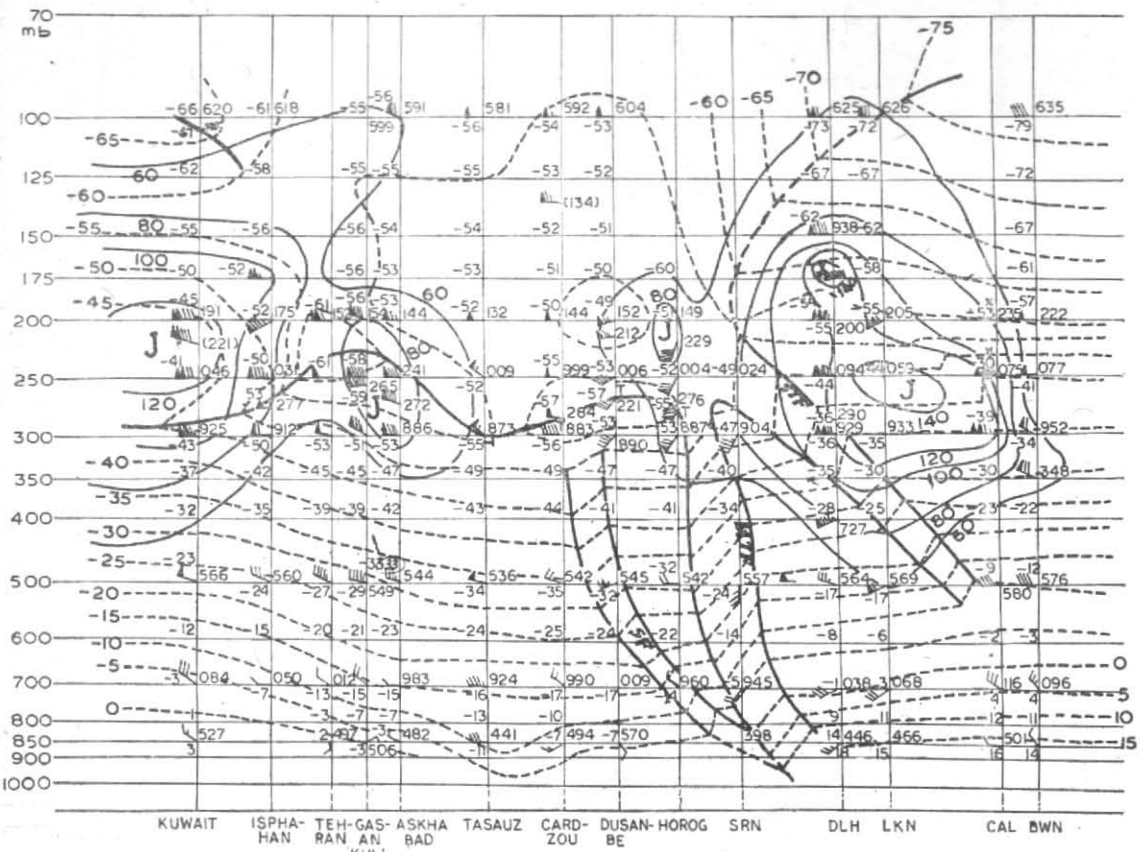
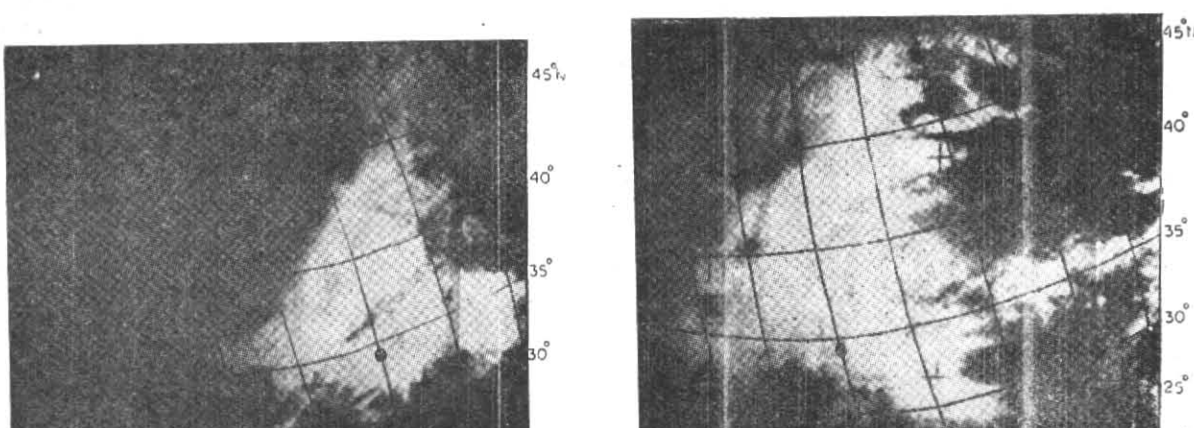


Fig. 3 (d)

Vertical cross-section at 1200 GMT on 13 February 1975
(Legend same as Fig. 3 a)



(a) 12 February 1975 at 11*h* 31*m* 41*s*

(b) 13 February 1975 at 10*h* 21*m* 21*s*

Fig. 4. ESSA-8 Satellite imagery on 12 and 13 February 1975

In the next twentyfour hours (Fig. 3 c) the frontal layer to the west has weakened into a moderate baroclinic zone while to the east it is still quite intense extending throughout the troposphere, though slightly weaker than on the previous day. In fact, on this day the cross-section is along a line much ahead of the upper air trough and ahead of the surface low also, which is not proper. It should have been close to the trough line and west of the surface low. But data is almost *nil* in that region. We also observe that the low level system has now strengthened and has become quite prominent extending upto 400 mb. On this diagram could also be seen the sub-tropical front over the Indian region which is quite-well marked extending down to 350 mb. The jets on this day are showing complicated structure because of the polar jet-stream combining with the normal subtropical jet. In this cross-section, the low level system appears separate from the upper frontal layer in low levels. This is because of the cross-section being drawn to the east of the low level system. It is believed that the two systems are superposed in the low levels as has been the case on the previous as well as the following day (Fig. 3 d).

On the following day also (Fig. 3 d) the upper frontal layer to the east is quite strong and associated with it the low level system has further strengthened and extended upto 300 mb. In fact, both the systems now look more or less similar in strength, though the upper frontal layer is clearly connected with the polar as well as the middle tropopause whereas the lower system is completely under its shadow. Thus the surface low developed in combination with the upper level system which remained domineering all the time. The sub-tropical front is quite extensive on this day as expected when the low level developments have been taken place (Singh 1971). It is extending down upto 500 mb.

5. Remarks

It may be mentioned again that the intensification of surface low is possible only so long as the system is under the influence of the upper level divergent field. The same has been brought out clearly upto 1200 GMT of 11th. But afterwards it could not be established conclusively for want of data between Kerman and Srinagar. On 12th and 13th, it has, however, been shown that the upper frontal layer was present on both these days and was quite strong. Now looking at the Figs. 2(c) and 2(d), it is observed that the trough at 500 mb was to the west of the surface low and it also coincided with the thermal trough. There was a strong zone of baroclinity in the region of the trough particularly to its east. Besides, the cross-sections made on the 12th and 13th are away from the trough and in a region of almost straight or even slightly anticyclonic flow where the frontal system in general will be weaker than in the trough region (Palmen and Newton 1969). In this case, particularly when the strong baroclinic zone is close to the trough, it is reasonable to assume that the frontal layer at the trough was much stronger than in the regions shown. In other words the surface low remained in the approach region of the upper frontal layer on the 12th and 13th also and consequently intensified.

Now, the upper frontal layer which developed in conjunction with the cut-off low on the 10th remained strong upto 13th, though the cut-off low had disappeared on the 11th itself. How did it maintain its strength? For this, it appears that the pool of cold air which was associated with the cut-off low (Figs. 2 a, b) is responsible. As explained earlier, it showed southward shift creating a deep baroclinic zone througout the low and middle troposphere and the latter maintained the strength of the frontal layer.

6. Conclusions

It is apparent from the above study that what is needed essentially for the development of many a western disturbance (as evidenced by the pressure fall) in Indian region is the approach of a well organised upper tropospheric frontal layer in the westerlies over a pre-existing surface low. And this organisation of the upper front and its movement eastwards mostly occurs in association with the upper air troughs. It has been shown here that cut-off pool of cold air (accompanying a cut-off low) which normally shifts south subsiding (Palmen and Newton 1969) can also maintain the strength of the upper frontal layer even after the cut-off low, with which it was associated, has disappeared. It has also been shown that a western disturbance in Indian region is not so prominent even in its most developed stage as the upper frontal layer, which approaching from the west, intensifies it. It is rather the same as observed over America.

Acknowledgements

Authors take this opportunity to thank the Director, N.H.A.C., who kindly provided the chart and other data and to the A.P.T. Unit, Bombay R.C., for providing satellite photographs.

REFERENCES

Bjerknes, J. and Holmboe, J.	1944	*J. Met.*, **1**.
Dutta, R. K. and Gupta, M. G.	1967	*Indian J. Met. Geophys.* **18**, 1, p. 45.
India Met. Dep.	1975	*Indian Daily Weather Report.*
Newton, C. W.	1958	*Geophysica*, 3-4, pp. 357-374.
Palmen, E. and Newton, C. W.	1969	Atmospheric circulation systems—International Geophys. Series, **13**.
Palmen, E.	1951	*Compendium of Meteorology*, American Met. Soc.
Petterssen, S.	1956	*Weather Analysis & Forecasting*, **1**, Mc.Graw Hill Book, Co., New York.
Pisharoty, P. R. and Desai, B. N.	1956	*Indian J. Met. Geophys.*, **7**, pp. 333-338.
Riehl, H. and La Seur, N. E.	1952	*Forecasting in middle Latitudes*, Met. Monographs, **5**, Am. met. Soc.
Rao, Y. P. and Srinivasan, V.	1969	Forecasting Manual (Pt. III), 1.1. India met. Dep.
Singh, M. S.	1963	*Indian J. Met. Geophys.*, **14**, 2, p. 156.
	1971(a)	*Ibid.*, **22**, 1, p. 1.
	1971(b)	*Ibid.*, **22**, 2, p. 149.
	—	Influence of westerly troughs on the development of western disturbances over India (Under publication).
Sutcliffe, R. C. and Forsdyke, A. G.	1950	*Quart. J. R. Met. Soc.*, **76**, pp. 189-217.