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A study of a typical case of interaction of an easterly wave with a westerly trough during the post monsoon period

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ABSTRACT. A spell of heavy rain which first occurred over south India and later gradually spread northwards in the course of about three days during the first week of December 1962 has been studied. An easterly wave which had been affecting south India on 1 December moved out into the Arabian Sea and interacted with a trough in the westerlies which was moving across Rajasthan and northern plains of India in association with a western disturbance. The result of the interaction on 2 December and on subsequent days, which was facilitated by the presence of an induced low in between them, was the formation of an extended trough in the low level easterlies. The northern part of the extended trough in which was embedded the induced low, then moved eastward and got fractured. The fracture of the waves was accompanied by the weakening of the trough systems, as well as the induced low. Unprecedented heavy rains for the month occurred in Madhya Pradesh and Vidarbha and broke the all-time record for the month at a number of stations during and after the formation of the extended trough.

1. Introduction

1.1. The post monsoon period, October to December, is a period in which the country witnesses the withdrawal of monsoon. The monsoon normally withdraws from the central parts of the country by the middle of October. However, in association with the movement of depressions and cyclones originating from the west central Bay and moving normally in a northwesterly or north-northwesterly direction, wet spells lasting for a few days and giving rise to heavy rains are experienced in Madhya Pradesh and Vidarbha during November and rarely in December. In the absence of such low pressure systems, heavy rains generally do not occur in Madhya Pradesh and Vidarbha in December. The normal regional rainfall for the month of December is less than 0·5 inch for Madhya Pradesh and less than 1·0 inch for Vidarbha.

1.2. During the first week of December 1962, an interaction of the waves moving in the low latitude and middle-latitude zonal streams from opposite directions resulted in unprecedented heavy to very heavy rain over some of the stations in Madhya Pradesh and Vidarbha. The heavy falls, in particular, and the overcast skies, in general, tempted the dailies to describe the period as a burst of *Second Monsoon*. The standing jowar and cotton crops were badly damaged in Vidarbha and Madhya Pradesh by the heavy rains though they were beneficial to *Rabi* crops.

1.3. In the present study, the authors have studied the synoptic situations that led to the interaction of the waves with special reference to the unprecedented heavy falls. The 12 GMT upper air charts for 900 metres and 9·0 km levels depicting the lower and higher tropospheric features respectively have been presented for the days discussed.

2. Synoptic situations

2.1. *On 2 December 1962*

2.1.1. An easterly wave which had arrived over the peninsula on 1 December entered the Arabian Sea on 2 December and was lying with its axis roughly along 73°E. In association with the easterly wave a feeble low pressure area appeared over the east central Arabian Sea off Konkan and Kanara coasts

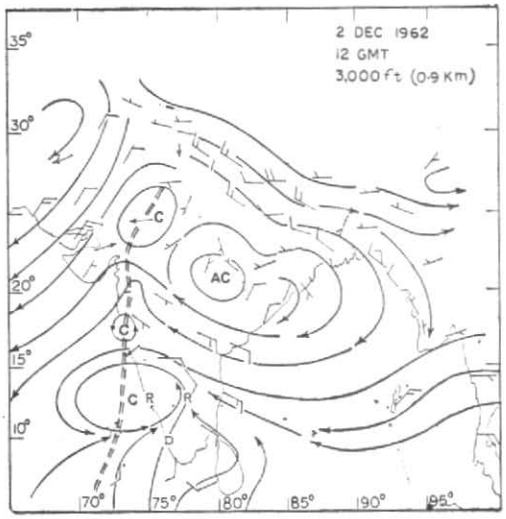


Fig. 1

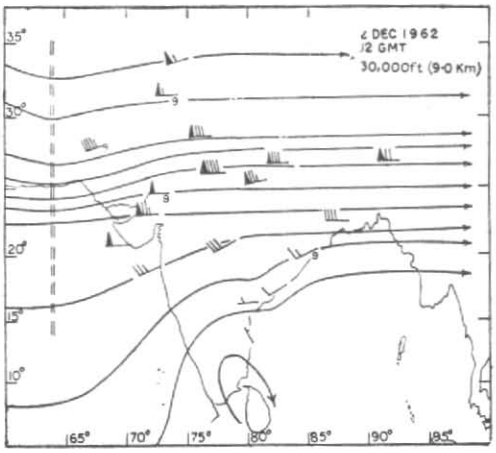
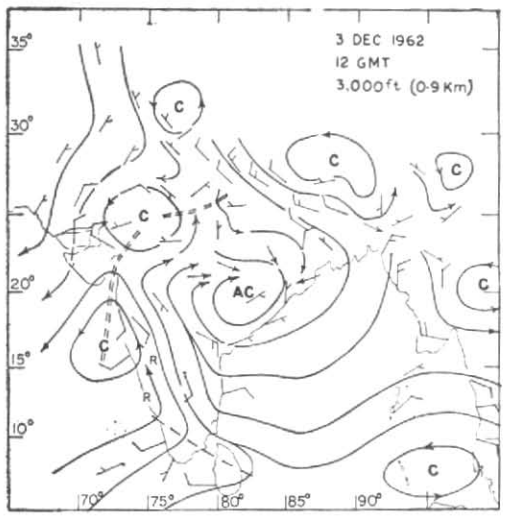


Fig. 2



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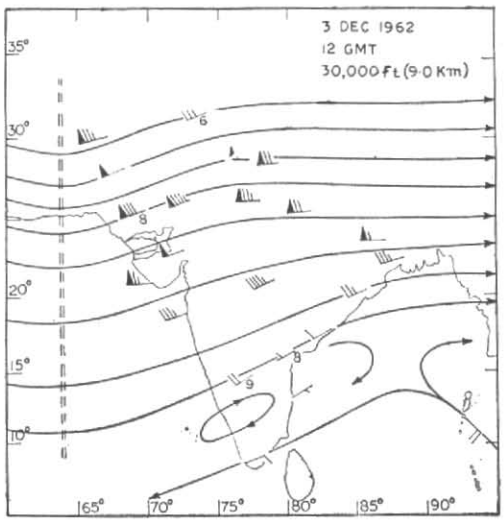


Fig. 4

Figs. 1–4. Streamlines

(C—Cyclonic, AC—Anticyclonic, R—Rain, D—Drizzle and L/C—Low clouds at the pilot balloon observatories. Winds with numbers close to the wind shafts in Figs. 2 and 4 indicate winds at levels lower than 30,000 ft)

with cyclonic circulations in the lower levels extending upto 4·5 km. In the course of the day, the circulation got intensified with an embedded secondary circulation appearing over the Konkan coast (Fig. 1).

2.1.2. A western disturbance was passing over the Punjabs as an upper air low with cyclonic circulation extending upto 6·0 km. At still higher levels the axis of the associated trough was roughly along 64°E (Fig. 2).

2.1.3. An induced low also had appeared over southwest Rajasthan and adjoining Gujarat with the associated cyclonic circulation extending upto 1·5 km (Fig. 1).

2.2. *On 3 December 1962*

2.2.1. The feeble low pressure area over the east central Arabian Sea was persisting on 3 December. The axis of the trough in easterlies was lying roughly along 72°E (Fig. 3). The cyclonic circulation associated with the easterly wave was well-marked and extended upto 4·5 km. The secondary circulation over Konkan coast was feeble. The seasonal anticyclone got shifted eastwards and was lying over the central parts of the country, Orissa and the adjoining parts of central Bay.

2.2.2. The western disturbance moved eastwards and was lying over Punjab (India) and neighbourhood. The trough in the westerlies associated with the western disturbance was well-marked and the axis of the trough was persisting roughly along 64°E (Fig. 4).

2.2.3. The induced low over Rajasthan got intensified and extended over the entire Rajasthan, Gujarat and west Madhya Pradesh (Fig. 3). The associated cyclonic circulation extended from surface upto 2·0 km. The induced low could also be seen at sea level as a low extending from Maharashtra to southwest Madhya Pradesh with pressure departures from normal varying between —2 mb and —4 mb.

2.3. *On 4 December 1962*

2.3.1. On 4 December the sea level low over the east central Arabian Sea was elongated and extended north upto Saurashtra coast. The upper air cyclonic circulation which was extending upto 4·5 km got intensified (Fig. 5). The axis of the trough was roughly along 70°E.

2.3.2. The western disturbance was persisting over Punjab (India) and neighbourhood. The associated trough in the upper westerlies, too, had markedly intensified and was seen persisting with its axis roughly along 66°E (Fig. 6).

2.3.3. The induced low persisted over west Madhya Pradesh, Gujarat and adjoining parts of Rajasthan with pressure departures from normal varying between —4 mb and—5 mb. The associated cyclonic circulation was well-marked and extended upto 1·5 km with the seasonal anticyclone pushed as far east as East Pakistan (Fig. 5).

2.4. *On 5 December 1962*

2.4.1. On 5 December the elongated low pressure area over the east central Arabian Sea was persisting with circulation extending upto 3·0 km (Fig. 7). The axis of the trough had retrograded and was lying roughly along 72°E.

2.4.2. The western disturbance had moved away across Jammu and Kashmir. The axis of the associated trough in upper westerlies was roughly along 70°E (Fig. 8).

2.4.3. The upper air cyclonic circulation associated with the induced low had distinctly broken up into two separate cells; one was lying over south Rajasthan, Gujarat and adjoining parts of west Madhya Pradesh and the other was lying over east Madhya Pradesh (Fig. 7). The associated cyclonic circulations were extending from surface upto 2·0 km. However, the pressure departures from normal were all positive over the entire country with minimum values over the central parts of the country showing the weakening trend of the low pressure areas.

2.4.4. A fresh easterly wave came over the southwest Bay (Fig. 7).

2.5. *On 6 December 1962*

2.5.1. On 6 December the low pressure area over the east central Arabian Sea weakened and a feeble circulation associated with the low could be seen moving into the land over north Konkan and adjoining parts of Saurashtra and Gujarat (Fig. 9).

2.5.2. The trough in upper westerlies rapidly moved eastwards and its axis was roughly along 72°E (Fig. 10).

2.5.3. The upper air low over Gujarat and neighbourhood moved northeastwards

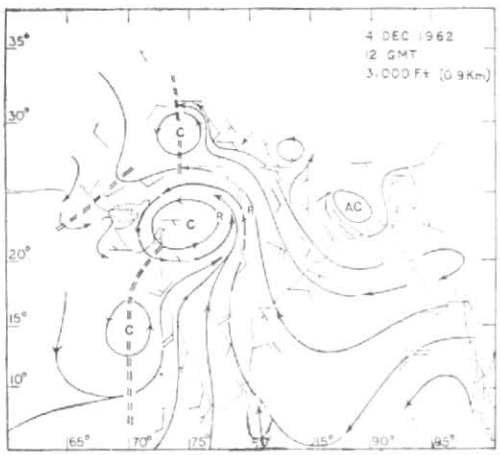
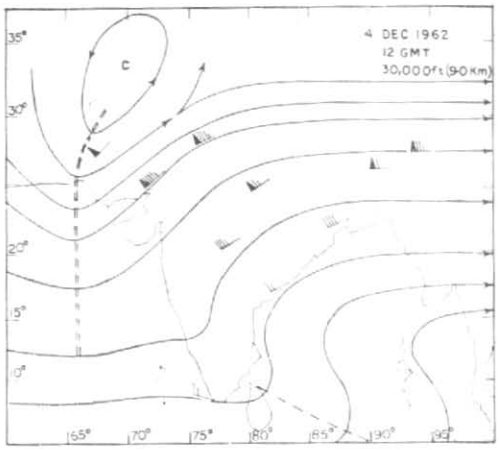


Fig. 5



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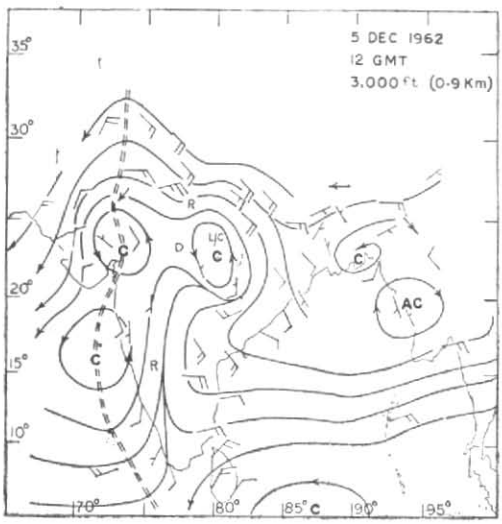

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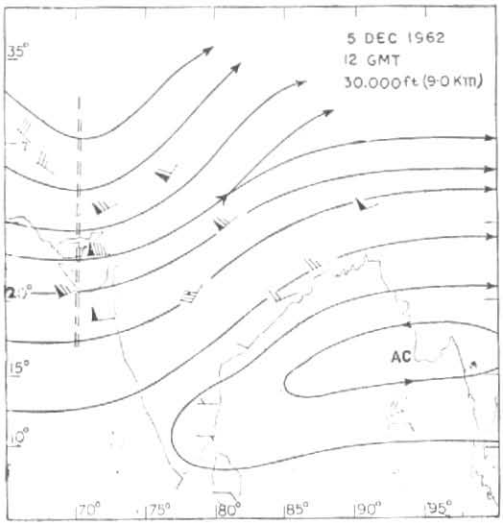

Fig. 8

Figs. 5–8. Streamlines

(C—Cyclonic, AC—Anticyclonic, R—Rain, D—Drizzle and L/C—Low clouds at the pilot balloon observatories. Winds with numbers close to wind shafts in Fig.8 indicate winds at levels lower than 30,000 ft

and weakened and lay over west Madhya Pradesh and adjoining parts of east Rajasthan; the other upper air low over east Madhya Pradesh also moved a little eastwards and weakened.

2.5.4. The south of peninsula came under the influence of the fresh easterly wave moving westwards along the southwest Bay and the winds over the peninsula were having a northerly orientation (Fig. 9).

3. The distribution of rainfall

3.1. On 3 December morning fairly widespread rainfall had occurred over south

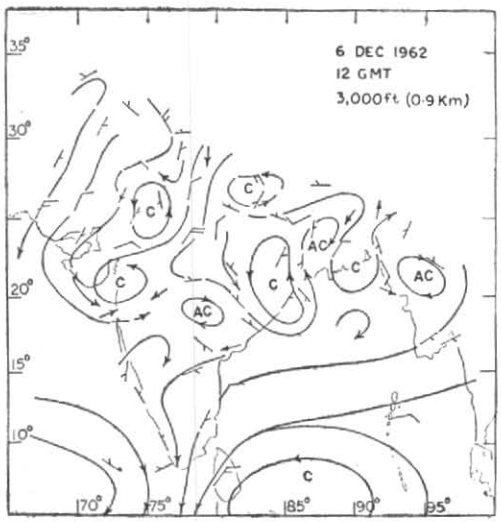

Fig. 9

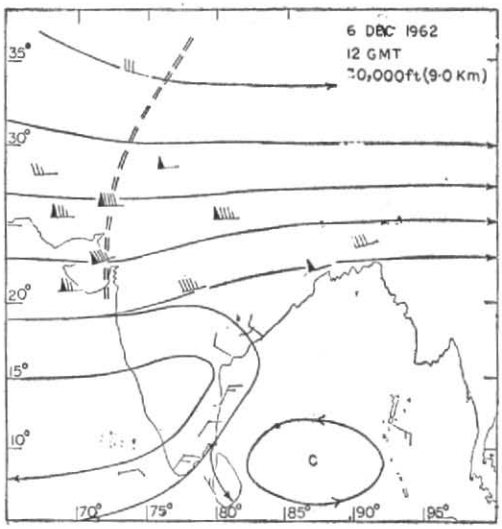

Fig. 10

Figs. 9–10. Streamlines

(C—Cyclonic, AC—Anticyclonic, R—Rain, D—Drizzle and L/C—low clouds at the pilot balloon observatories)

peninsula and the rainfall distribution showed an extension of the rainfall along Kanara coast and over southern portions of Maharashtra (Fig. 11). Ahmednagar and Vengurla reported heavy falls of 7 cm each. Other chief amounts of rainfall were — Bangalore 5·8, Karwar 4·4, Jagdalpur 4·2, Arogyavaram 3·8, Bhir 3·5, Pamban 3·3, Mahabaleshwar 3·0 cm. There was no rainfall distinctly apart from those associated with the easterly wave.

3.2. On 4 December morning there were widespread rainfall with scattered heavy falls over a wide belt extending from Mysore to west Madhya Pradesh with notable absence of rainfall along the east coast of the peninsula (Fig. 12). There was no rainfall over the country outside this belt which occurred in association with the easterly wave. The chief amounts of rainfall (in cm) were—Ratnagiri 7·5, Vengurla 7·2, Jalgaon 7·1, Bellary 6·5, Cuddapah 4·9, Indore 4·7, Gulburga 4·5, Malegaon 4·3, Arogyavaram 3·7, Karwar and Kurnool 3·2 each, Anantapur 3·1 and Raichur and Gadag 3·0 each.

3.3. The rainfall of 5 December morning showed an extension of the belt of rainfall that had occurred on 4 December northward and all over the central parts of the country. There were scattered rain over Punjab (India)—Fig. 13. The heavy falls occurred mostly over the belt which extended from Maharashtra to Madhya Pradesh. The chief amounts of rainfall (in cm) were— Mandla 16·6, Kondul 15·0, Devgad 13·9, Seoni 11·0, Chhindwara 9·0, Nagpur 6·1, Palghat 5·6, Pachmarhi 5·3, Ratnagiri and Karwar 4·9 each, Bombay (Colaba) 4·8, Bellary 4·6, Vengurla 4·2, Betul 4·0 and Jabalpur 3·8.

3.4. The rainfall distribution as recorded in the morning of 6 December is shown in Fig. 14. The distribution shows a further extension of the rainfall northeastwards with scattered heavy falls over Kanara coast and the central parts of the country. Chief amounts of rainfall (in cm) were — Gondia 10·1, Sironcha 8·0, Vengurla 7·4, Ramagundam 5·8, Coonor 5·4, Kolhapur 5·2, Hyderabad (Hakimpet) 5·1, Karwar 4·9, Gulbarga 4·8, Kondul 4·1, Nagpur and

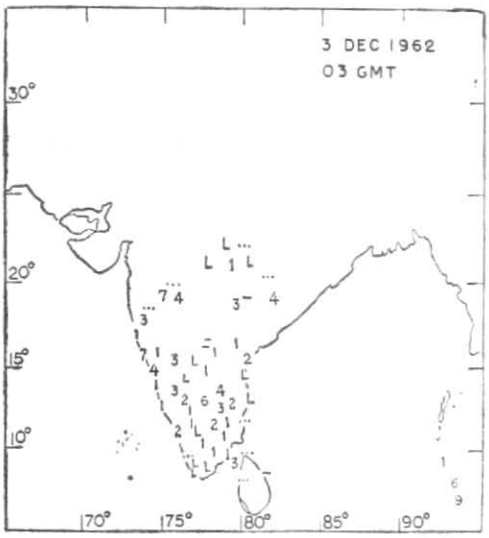

Fig. 11

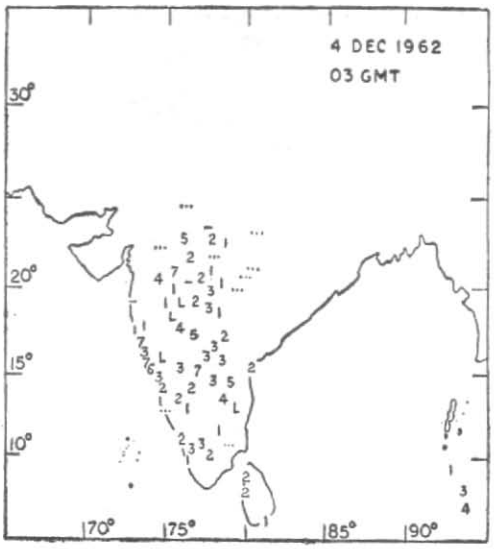

Fig. 12

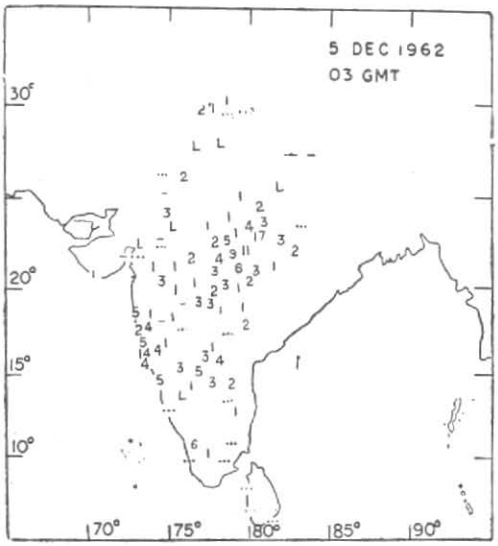

Fig. 13

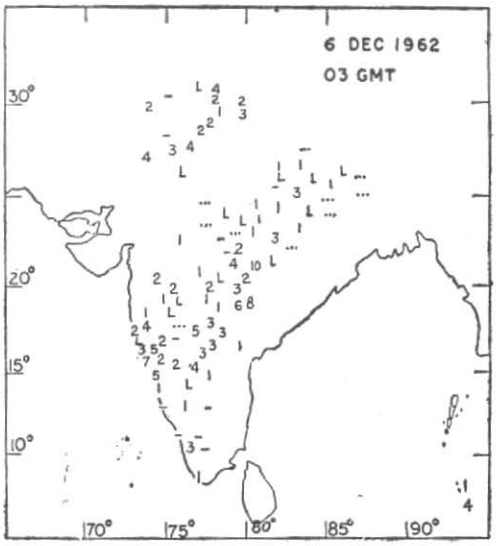

Fig. 14

Figs. 11–14. Rainfall amounts in cm for 24 hours ending at 03 GMT

Nagaur 3·6 each, Mahabaleshwar, Mussoorie and Alwar 3·5 each and Palghat 3·4.

3.5. On 7 December, practically no rain was recorded over the country except for scattered rain over the south interior Mysore (Fig. 15). However, the occurrence of fairly widespread fogs over the northern parts of the country was something significant.

3.6. Though the wet spell lasted only for

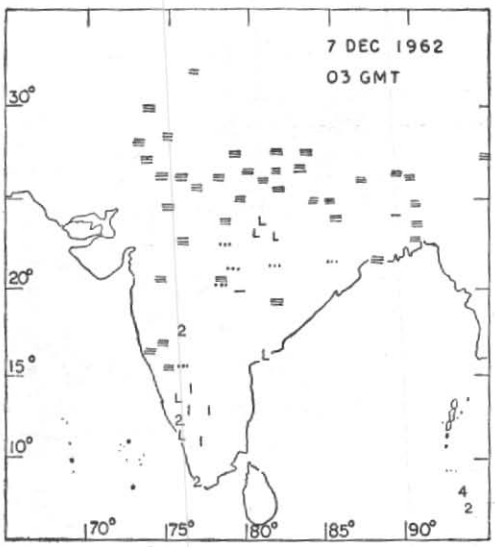

Fig. 15. Rainfall amounts in cm for 24 hours ending at 03 GMT

Fogs that were reported either as present or past weather at 03 GMT are also indicated

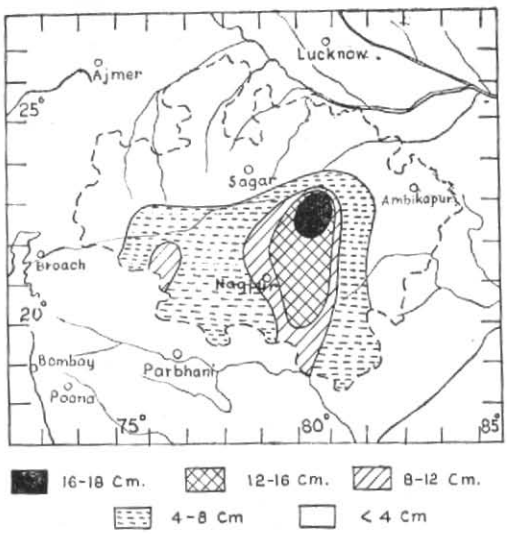

Fig. 16. Total rainfall for the period 3–6 December 1962 (both days inclusive)

Area included — Madhya Pradesh and Vidarbha

a few days, some of the heavy to very heavy falls which occurred over some of the stations in Madhya Pradesh and Vidarbha between 3 and 6 December broke the all-time record for the stations for the month of December. A list of such stations is shown in Table 1. The total rainfall that occurred over the different stations during the spell of three days between 3 and 6 December is pictorially shown in Fig. 16.

4. Discussion

4.1. *The interaction of waves on 2 December 1962*

4.1.1. The formation of a series of lows roughly along the same longitude close to the west coast of the peninsula resulted in the interlocking of the easterlies and the westerlies. The interlocking of the waves in the westerly and easterly zonal streams was facilitated by the presence of an *induced low* in between them. Moreover, it has been recognised by forecasters in India that the easterly waves that travel westwards across the southwest Bay show a tendency to get retarded when they come over the Ceylon–Comorin area. This tendency of the easterly wave coupled with the appearance of an induced low at a higher latitude but roughly along the same longitude appears to have helped the interlocking of the two streams.

4.1.2. The moist air from the eastern side of the easterly wave started flowing towards the eastern side of the westerly trough. The Maharashtra and neighbourhood were thus invaded by the moist air. That the interlocking of the two may increase the rainfall associated with the westerly trough has been pointed out by Pisharoty and Desai (1956). However, in this case, the westerly trough brought in very little moisture and the rainfall pattern as recorded on 3 December morning (Fig. 11) confirms the view that all the rainfall were due to the easterly wave only. The scattered heavy falls along the Kanara coast and Maharashtra were due to the secondary circulation that existed over the Konkan coast on 2 December.

TABLE 1

	Station	Highest rainfall (mm) recorded in 24 hours			
		In December with date (prior to 1962)		In December 1962 with date	
1	Neemuch	22·4	30 Dec 1892	25·4	5 Dec
2	Indore	45·0	6 Dec 1928	46·7	4 Dec
3	Chhindwara	10·9	9 Dec 1956	90·2	5 Dec
4	Seoni	68·3	26 Dec 1909	103·4	5 Dec
5	Betul	21·6	31 Dec 1950	40·4	5 Dec
6	Jagdalpur	38·3	10 Dec 1882	41·6	3 Dec
7	Nagpur	45·7	23 Dec 1884	61·0	5 Dec
8	Yeotmal	13·7	30 Dec 1950	29·9	7 Dec
9	Gondia	13·2	31 Dec 1956	101·4	6 Dec
10	Champa	17·5	29 Dec 1954	19·6	5 Dec
11	Mandla	28·5	28 Dec 1950	166·4	5 Dec

4.2. *Intensification of the induced low on 3 December 1962 and the extension of moist air into the central parts of the country*

4.2.1. The induced low got intensified on 3 December possibly under the influence of the trough in the westerlies and the intensified induced low played an important part in accelerating the flow of the moist air along the peninsula and towards the central parts of the country.

4.3. *The extension of moist air further over the central parts of the country on 4 December 1962*

4.3.1. The elongation of the sea level low over the east central Arabian Sea upto Saurashtra coast with a slight shift to the north from its original position on 4 December indicated that the amplitude of the easterly wave had increased due to the interaction of the two waves.

4.3.2. The intensification of the trough in the upper westerlies with its southsouthwesterly winds in the middle troposphere and southwesterly winds of jet speed at upper troposphere (Fig. 6) lying in the forward sector of divergence played an important role in intensifying the circulation associated with the induced low and in drawing the moist air from southerly latitudes in the lower troposphere.

4.3.3. The presence of the induced low over west Madhya Pradesh, Gujarat and the adjoining parts of the Rajasthan in the west and the presence of the seasonal anticyclone which had then shifted to East Pakistan in the east resulted in the marked flow of moist air from the Arabian Sea and further south and the moist air from the Bay along a belt extending from peninsula to the central parts of the country (Fig. 5).

4.3.4. As a result the velocity convergence was a maximum over Madhya Pradesh and most of the stations over Madhya Pradesh and entire Maharashtra reported rain or thunderstorm as the present weather most of the day.

4.4. *The weakening of the waves and extension of the moist air over the northern parts of the country on 5 December 1962*

4.4.1. The weakening of the easterly wave, as well as the trough in the westerlies, was indicated by the pressure departures from normal which became positive all over the country.

4.4.2. The pressure departures associated with the induced low were negative (—2 mb) in the morning but became positive by evening, though they were the minimum for the country as a whole, showing a weakening of the low.

4.4.3. The weakening of the two waves and their slight movement along their original path resulted in the fracture of the cyclonic circulation associated with the induced low into two cells, though there was incursion of moist air further north and as far as Uttar Pradesh, Punjab (I) and Bihar under its continued presence.

4.5. *The final fracture of the waves on 6 December 1962*

4.5.1. The rapid eastward movement of the trough in the upper westerlies was accompanied by simultaneous movement of the two cells of cyclonic circulation associated with the induced low at the lower levels.

4.5.2. The coming in of a fresh easterly wave over the southwest Bay resulted in the break of flow of the moist air from the south to the north.

4.5.3. The circulations over the central parts of the country were aligned more or less along the same latitudes by evening and they started drawing the dry continental air from the north (Fig. 10) and the skies started clearing up rapidly. Later when the circulations weakened and merged with one another the seasonal pattern set in.

5. Vectorial changes of wind and heavy rainfalls

5.1. *Introduction*

5.1.1. Roy and Rai Sircar (1955) have shown that the vectorial changes of wind at a station is related to the isallobaric gradient and is tangential to the isallobar. They have also shown that the vector-changes of winds will be cyclonic in a region where there is an isallobaric 'low' and anticyclonic where there is an isallobaric 'high'.

5.1.2. Most often the heavy rainfalls of monsoon period have direct relationship with the surface lows with the heavy falls occurring mostly in the southwest sector of the lows and along the axis of the monsoon trough. In the present case, the 24-hour vector-changes of wind have been studied for evenings of the two days when there were unusual heavy rains. The 850-mb level has been chosen as most representative of lower tropospheric circulation and the amounts of rainfall as recorded at 12 GMT of the respective days have also been plotted to show the influence of the 'lows'.

5.2. *The heavy falls of 4 December 1962*

5.2.1. The vector-changes of wind between 3 December evening and 4 December evening are shown in Fig. 17. The flow pattern of wind changes show that there was an isallobaric low over southwest Madhya Pradesh and adjoining parts of Gujarat. The trough as well as the axis of the trough, were also well-marked with east Madhya Pradesh and Vidarbha lying in the maximum convergence zone of the trough. That explains why east Madhya Pradesh and Vidarbha got the maximum rain by the morning of 5 December (Fig. 13). The isallobaric 'high' over the extreme south peninsula and adjoining Arabian Sea prevented the rainfall from occurring over the Malabar and south Kanara coasts.

5.3. *The heavy falls of 5 December 1962*

5.3.1. The vector changes of wind between 4 December evening and 5 December evening are shown in Fig. 18. The isallobaric 'low' of 4 December evening lying over southwest Madhya Pradesh and adjoining parts of Gujarat had split into two lows with one lying over southwest Madhya Pradesh and the other, which was relatively deep as may be seen from the strength of wind changes, lying over the Bihar plateau and adjoining parts of east Madhya Pradesh and West

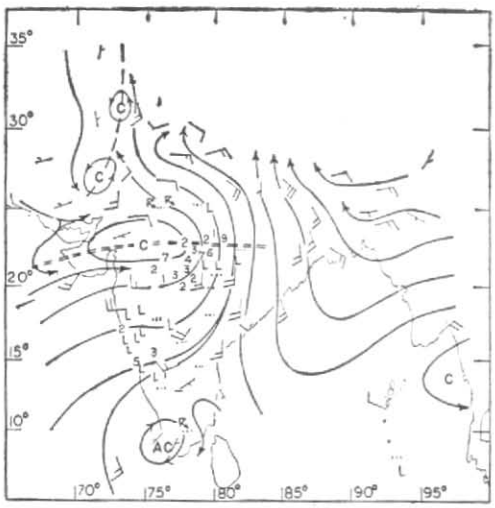

Fig. 17. 24-hour vectorial changes of wind between 12 GMT on 3 December and 12 GMT on 4 December 1962 for the level 5000 ft (1·5 km)
Rainfall amounts in cm for the nine hours ending at 12 GMT on 4 December and thunderstorms reported either as present or past weather at 12 GMT on 4 December are also shown. (C—Cyclonic, AC—Anticyclonic)

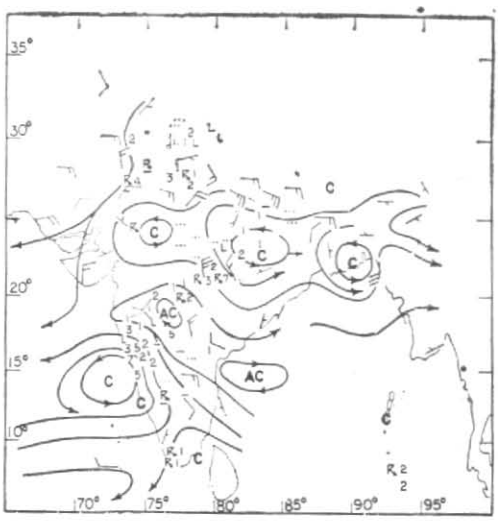

Fig. 18. 24-hour vectorial changes of wind between 12 GMT on 4 December and 12 GMT on 5 December 1962 for the level 5000 ft (1·5 km)
Rainfall amounts in cm for the nine hours ending at 12 GMT on 5 December and thunderstorms reported either as present or past weather at 12 GMT on 5 December are also shown. (C—Cyclonic, AC—Anticyclonic, c—calm)

Bengal. The isallobaric high over the extreme south peninsula had given way to an isallobaric 'low'.

5.3.2. It may be seen that east Vidarbha was then in the southwest sector of the 'low' over Bihar plateau. Gondia recorded a very heavy rain of 10 cm by the morning of 6 December. A reference to Fig. 14 showing the rainfall pattern realised by 6 December morning shows the close relationship of the isallobaric lows to the rains. The low over southwest Madhya Pradesh being less intense than the other could not bring about much rainfall over west Vidarbha and southwest Madhya Pradesh.

5.3.3. The rainfall along the Kanara coast, north interior Mysore and Maharashtra were presumably due to the trough in the easterlies.

6. Conclusion

The above study and discussions lead to the following conclusions in brief.

6.1. The interaction of an easterly wave with a trough in the westerlies which is often obscure in the lower tropospheric levels, is facilitated by the presence of an induced low in between them. The induced low serves as a link for the interactions of the two waves travelling in low latitude and middle-latitude zonal streams from opposite directions.

6.2. While the cause of the wet spell over the central and northern parts of the country during the post-monsoon period was the interaction of an easterly wave with a trough in the westerlies, the cause of the heavy rains was the presence of an induced low in between them.

7. Acknowledgement

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