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On a remarkable case of dynamical and physical interaction between middle and low latitude weather systems over Iran*

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ABSTRACT. This paper contains the results of a detailed study of a wet spell over and near north Iran during the second half of July 1956, which contributed to the severe floods in that country during that month. The daily sea level, 850, 700, 500 and 300-mb level charts for Asia, Eastern Europe and the adjoining areas for the period of the wet spell, the mean 700 and 500-mb charts for the month of July 1956 as a whole and the mean sea-level and 500-mb charts for the period of the wet spell only, along with the relevant thermodynamic diagrams have been studied. On the basis of this study, the broad conclusion is reached that the rainfall in Iran during the wet spell even over regions as far north as the Caspian Sea was fundamentally due to the extension of the Indian southwest monsoon into those regions during a month when the monsoon was abnormally active over the whole of India. This development was associated with an unusually pronounced Tibetan High shifting far to the west of its usual position. This abnormal situation resulted in the monsoon easterlies in the lower troposphere being drawn into Iran and the troughs in the middle and upper troposphere which were basically part of closed cyclonic systems in the higher middle latitudes, being blocked and thereby remaining quasi-stationary just to the west of the Caspian Sea. The wave-patterns in the upper tropospheric middle latitude westerlies under these conditions caused high level divergence over Iran which provided the *main* dynamical mechanism for lifting the monsoon air over that country. In addition, on the two days of peak-activity during the wet spell, colder air from the middle latitudes seemed to have undercut the warm humid monsoon air on the southern shores of the Caspian Sea and provided a *secondary* physical mechanism for lifting the monsoon air on those days. Thus we had in July 1956 the remarkable spectacle of monsoon rainfall over and near North Iran caused by dynamical and physical interaction between middle and low latitude weather systems over that country.

1. Introduction

The Indian southwest monsoon establishes itself over India by the beginning of July. Thereafter, it occasionally advances into West Pakistan in association with low-latitude westward moving systems from India. Under these synoptic conditions, Sind, Punjab (Pakistan) and the Northwest Frontier Province are invaded by the monsoon current. On rare occasions, the monsoon current also extends into the western parts of Baluchistan in extreme West Pakistan. As far as the author is aware, there are no cases in recorded literature of an incursion of the Indian southwest monsoon in areas to the west or northwest of West Pakistan.

July is normally a month of very low rainfall in Iran. During this month, the precipitation occurs under the influence of middle-latitude eastward moving systems whose centres lie far to the north of Iran. The moisture necessary for precipitation in Iran in July, as also in other months of the year,

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Fig. 1. Map showing important stations and rivers in Iran and the neighbouring countries

is provided by southwesterlies and westerlies from the Mediterranean Sea or the Persian Gulf. The author has not come across any literature to show that the moist air necessary for the precipitation has its origin anywhere other than in the Mediterranean Sea or the Persian Gulf, *e.g.*, in the Bay of Bengal or even the Arabian Sea.

Weickmann has made a synoptic study of precipitation in Tehran (Weickmann 1958). To quote his words, the occurrences of precipitation at Tehran reveal "an almost identical sequence of events during all seasons". "The main amount of precipitation occurs in connection with quasi-stationary fronts and is generally more of the warm front type". It is, however, difficult, according to Weickmann to recognise from the sea-level charts, the processes which lead to the precipitation. The main seat of activity, in Weickmann's opinion, is in the middle and upper troposphere. The divergence associated with various types of patterns in the waves in the upper westerlies (Ramaswamy 1956) seems to initiate, according to Weickmann, the lifting motion necessary for the precipitation. Weickmann's views about the mechanism of weather developments over Tehran, which is in the extreme north-west of Iran and is almost in middle latitudes, can, *prima facie*, be considered to be applicable to the rest of Iran also, as these regions lie in lower latitudes where fronts in the sense in which middle latitude meteorologists understand this term do not probably exist.

A map showing the important stations and rivers in Iran and the neighbouring countries is given in Fig. 1.

2. The disastrous floods in Iran in July 1956

In the second half of July 1956, Iran experienced one of the worst floods in recorded history. According to Press reports, hundreds of people were killed and thousands of people were rendered homeless due to these floods. In the area of Esfahan alone (Lat. 32°37′N, Long. 56°40′E), 250 human bodies were reported to have been recovered. Another 250 persons were reported to have been killed in the Kashan district (in central Iran). So serious was the situation created by these floods that the Shah of Iran was reported to have instructed his Government to treat the floods as a national emergency.

It may be recalled that July 1956 was a month of exceptionally vigorous monsoon over India, the rainfall averaged over the plains amounting to as much as 25 per cent above normal. This extremely important fact together with the incidence of severe floods in a country like Iran in a month of normally very low rainfall, urged the author to examine whether the vigorous Indian southwest monsoon and the general circulation over Asia during this month (Ramaswamy 1958, 1962) had anything to do with the "heavy rainfall" and the floods in Iran.

3. Basic material used in this investigation

The basic material for regions outside India and Pakistan used in this investigation was mainly from the U.S. Weather Bureau Publications entitled *Daily Series Synoptic Weather Maps, Part I — Northern Hemisphere Sea level and 500-mb charts* and *Northern Hemisphere Data Tabulations*. In the case of Pakistan, the data as received in India by landline telegrams or in synoptic broadcasts were used. For Indian data, the printed *Indian Daily Weather Reports* and the synoptic charts prepared in the India Meteorological Department were utilised.

The daily rainfall data of Iran were obtained from the Iranian Meteorological Department while those for Turkman S.S.R. and the neighbouring areas of U.S.S.R. were obtained from the Hydrometeorological Service, U.S.S.R. The total monthly rainfall figures for rain-recording stations in Iran were extracted from the Iranian Meteorological Department Annual publication entitled *Meteorological Year Book.*

4. Basic difficulties in this investigation

The greatest difficulty experienced by the author in this investigation was the inadequacy of upper air data over Iran and Saudi Arabia and the complete absence of meteorological information in respect of Afghanistan.

Another difficulty was the non-uniformity in the synoptic hours for which different types of data were available. The U.S. Northern Hemisphere charts contained printed maps for 1230 GMTfor sea-level and for 1500 GMT for 500-mb level. These analysed charts saved considerable labour for the author. However, the data for 850, 700 and 300-mb levels for this synoptic hour were not available. For these levels, the only source of data was the "*Northern Hemisphere Data Tabulations*" and they pertained to 02 GMT. Hence the author had specially to prepare the 02 GMT charts for these levels and also for the 500-mb level, the latter being necessary for ensuring space continuity of analysis at the 700 and 300-mb levels and time continuity with the analysis for 1500 GMT as contained in the U.S. Northern Hemisphere charts. The rainfall figures for the Iran stations were for a 24-hour period like the Indian and Pakistan rainfall data but the figures for some stations were for a 24-hour period ending at 03 GMT while those for the remaining stations were for a 24-hour period ending at 1500 GMT. The radiosonde data of Ashkhabad in Turkman S.S.R. which were extremely important in this study related to 02 GMT while the Pakistan radiosonde data were available only for 14 GMT.

Fortunately, these difficulties did not vitiate the conclusions of the author as he was studying only large-scale systems and large-scale weather developments. Further, the analysis of charts for the 500-mb level for two different synoptic hours separated by about 12 hours served to give additional confidence to the author that his analysis of the large-scale systems should be basically acceptable.

5. Analysis of the rainfall in Iran

Table 1 shows the rainfall recorded at stations in Iran during the period 15 to 31 July 1956. Similar data for Afghanistan were unfortunately not available.

An examination of Table 1 reveals the following —

(*a*) The wet spell* occurred mainly between 18th and 30th, the peak activity being on 21st. There was also a secondary maximum of activity on 28th.

(*b*) The rain belt broadly extended from southeast to north through west suggesting the intrusion of an anticyclonically curving moist tongue into Iran from a region to the east of that country (*see* Fig. 12).

(*c*) There was a maximum concentration of rainfall to the north of 35°N within a tract of about 250 km around the southern shores of the Caspian Sea.

(*d*) The rainfall amounts, though perhaps considerable for Iran for the month of July, were not really "very heavy" as tropical meteorologists understand this term. It is of course well known to Indian meteorologists that, in the southwest monsoon period in India, there may be very heavy rain at some stations and this fact may not come to light unless the network of rainfall recording stations in that area is very dense. Even making allowance for a similar possibility in Iran, the rainfall during the wet spell in July 1956 seems to have been less than what one would have expected from the severity of the floods reported. The conclusion from this is that apart from the rainfall, there must have been other causes for the floods.

6. Analysis of the daily and mean sea level isobars

The movement of the centres of the daily sea level systems or the variations in the configuration of the isobars during the period 17 to 29 July (corresponding to the wet spell between 18th and 30th) had no significant bearing on the spatial distribution of the rainfall or the amount of the rainfall†. The only point which came out of this analysis was that the configuration of the isobars was not unfavourable for the incursion of easterlies from north India and West Pakistan and was definitely unfavourable for the incursion of southwesterlies or westerlies from the Mediterranean Sea into Iran north of 35°N where the rainfall was a maximum.

Fig. 2 shows the sea level systems at 1230 GMT on 20 July 1956. These are based on the analysis contained in the U.S. Weather Bureau Publication mentioned in Section 3. The isobars on the U.S. Maps were modified, when found necessary, over India and Pakistan where the data available to the author were far more than were available in the U.S. Weather Bureau publication. The frontal systems at 1230 GMT on 20 and 21 July 1956 and the rainfall in a 24-hour period ending at 03/15 GMT of 21st over and near Iran are also shown in Fig. 2. The frontal systems will be discussed in Section 7.

The mean sea level chart at 1230 GMT for the period 17 to 29 July 1956 was also prepared by reading off the isobaric values from the U.S. Weather Maps referred to above, at five-degree intervals of latitude and longitude between 30°E and 120°E and between 5°N and 60°N and computing the

*The duration of the wet spell has been given as 18th to 30th, corresponding to the dates on which the rainfall is *reported*.

†In order to examine the usefulness of this investigation in forecasting, the development of rainfall has been studied in this paper with reference to the synoptic chart *for an earlier hour* whenever possible. For the 500 and 300-mb levels, especially the latter, the chart could be chosen for a synoptic hour 24 to 36 hours earlier, with advantage, on account of the slowness of the movement of the flow patterns compared to the wind speed at these levels.

TABLE 1

Rainfall (mm) in Iran between 15 and 31 July 1956

Station	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31 July 1956	Total
Pahlavi (37°28′N, 49°28′E, —15 m a.s.l.)	—	—	—	—	—	—	1·9	—	—	—	—	—	—	42·9	24·8	—	—	69·6
Ramsar (36°54′N, 50°40′E, —20m)	—	—	—	—	—	7·6	6·6	—	34·1	19·0	3·1	1·0	—	6·3	4·0	—	—	81·7
Babolsar (36°43′N, 52°39′E, —21m)	—	tr.	—	tr.	tr.	10·4	25·4	—	—	7·4	—	—	1·3	6·1	—	—	—	50·6
Tajan (36°21′N, 53°12′E, 700m)	—	—	—	—	—	—	—	—	—	—	—	—	—	22·0	7·6	5·8	—	35·4
Gorgan (36°51′N, 54°28′E, 120m)	2·4	—	—	—	—	0·4	10·1	2·7	0·2	2·2	—	—	—	—	—	0·2	2·2	20·4
Rodbar (36°48′N, 49°25′E, 150m)	—	—	—	—	—	—	4·1	—	—	—	—	—	—	1·0	—	—	—	5·1
Looshan (36°37′N, 49°31′E, 500m)	—	—	—	—	—	—	21·4	—	—	—	—	—	—	—	—	—	—	21·4
Karesang (36°17′N, 52°22′E, 500m)	—	—	—	—	—	8·5	26·0	3·5	—	6·0	—	—	2·6	6·9	3·0	10·5	—	67·0
Ghorantalar (36°18′N, 52°45′E, 1000m)	—	—	—	—	—	7·2	22·6	—	4·9	3·4	—	3·7	5·4	12·0	3·4	7·3	4·5	74·4
Tehran/Mehrabad (35°41′N, 51°19′E, 1191m)	—	—	—	—	—	—	3·2	—	—	—	—	—	—	—	—	—	—	3·2
Latian (35°46′N, 51°41′E, 1400m)	—	—	—	2·0	4·8	15·0	6·5	—	—	—	—	—	—	—	—	—	—	28·3
Lar (35°52′N, 52°03′E, 2400m)	—	—	—	14·0	—	50·0	9·0	—	—	—	—	—	—	—	—	—	—	73·0
Abasabad (Ghom) (34°04′N, 50°36′E, 1400m)	—	—	—	—	—	—	7·2	—	—	—	—	—	—	—	—	—	—	7·2

TABLE 1 (*contd*)

Station	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31 July 1956	Total
Chahzand (33°55′N, 49°26′E, 2000m)	—	—	—	—	—	—	4·0	13·0	—	—	—	—	—	—	—	—	—	17·0
Pole Kale (32°23′N, 51°12′E, 1800m)	—	—	—	—	1·5	—	—	14·5	—	—	—	—	—	—	—	—	—	16·0
Kerman (30°15′N, 56°58′E, 1749m)	—	—	3·3	7·9	—	—	3·1	—	—	—	—	—	—	—	—	—	—	14·3
Jahrom (28°30′N, 53°33′E, 700m)	—	—	—	—	—	4·5	—	—	—	—	—	—	2·0	7·5	—	—	—	14·0

mean value at each grid-point. The mean sea level chart prepared in this manner also did not reveal any significant feature apart from what was shown by the daily sea level chart for 20th. The mean chart has, therefore, not been reproduced here.

7. Analysis of the frontal systems

In the 13 days of the wet spell (18th to 30th) frontal systems were found on 9 days to the south of 45°N and between 40°E and 70°E. Out of these 9 occasions, there were only 2 occasions (between 20th and 21st and between 27th and 28th) when the movement of frontal systems would have contributed to the development of precipitation during the subsequent 24-hour period. One such occasion (20-21 July) is illustrated in Fig. 2. To avoid undue congestion, only fronts which could possibly have influenced the weather over Iran have been shown in the diagram. The fronts are based on the analysis in the U.S. northern hemisphere charts. The positions of the fronts at 1230 GMT on 20th and 21st are shown in the figure. The stations which recorded rain in the 24-hour period ending at 03/15 GMT of 21 July, the day of peak activity during the spell, are also shown in the same figure by small shaded circles. The actual amounts have not been indicated to avoid congestion on the chart. The amounts may be seen in Table 1. It will be seen that the cold front on the 20th was associated with a closed cyclonic system in the higher middle latitudes whose centre lay at 1230 GMT at Lat. 57°N, Long. 57°E approximately. An anticyclonic system lay to the southwest of the low with its central region over the eastern shores of the Black Sea. The portion of the cold front with which we are concerned, lay at this time on the southeastern periphery of the anticyclonic system. During the next 24 hours, the closed low in the higher middle latitudes moved northwards and its centre lay at 1230 GMT on 21 July near Lat. 63°N, Long. 56°E. With the northward movement of the low, the anticyclonic system to its southwest extended southeastwards. The cold front on the southeastern periphery of the anticyclonic system, also moved southeastwards but as it moved towards the sub-tropics, it gradually began to lose its frontal characteristics and slowed down to become a quasi-stationary

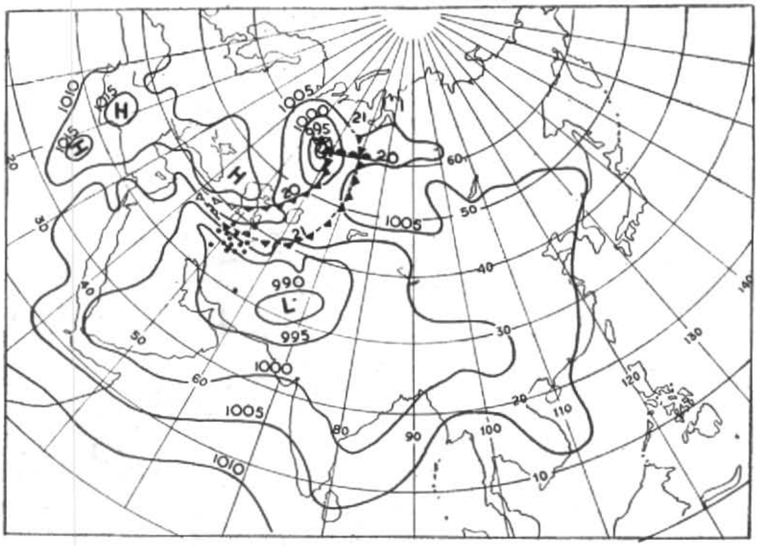

Fig. 2. The sea-level chart at 1230 GMT of 20 July 1956 and the rainfall in and near Iran ending at 03/15 GMT of 21 July 1956

Spikes shaded black and connected by a continuous line indicate a cold front at the surface. Teeth shaded black and connected by a continuous line indicate a warm front at the surface. Shaded spikes connected *by broken lines* indicate a cold front at the surface undergoing frontolysis. Shaded spikes and *teeth on opposite sides of a broken line* indicate a quasi-stationary front at the surface undergoing frontolysis. Hollow spikes and teeth on opposite sides of a broken line indicate a quasi-stationary front aloft undergoing frontolysis. The stations which reported rainfall are indicated by shaded circles. For actual amounts of rainfall see Table 1.

front undergoing frontolysis. It was located at 1230 GMT on 21 July very near the southern shores of the Caspian Sea and from there, it extended to the north through east. The history of this frontal system supports our view that the system had more of cold front characteristics (*see* Section 10) even at the quasi-stationary stage and that it contributed to the rainfall just on the southern coast of the Caspian Sea between 20 and 21 July.

The second occasion of frontal action (*i.e.*, between 27 and 28 July) was likewise associated with a surge of colder air towards the sub-tropics in association with a southeastward movement of an anticyclonic system at sea level from near the Black Sea to the south of the Caspian Sea. This system was seen on the 1230 GMT sea level charts of 27 July as a diffuse system to the west of the Black Sea but it became very pronounced during the next 24 hours and had extended southeastwards. It is not clear whether this accentuation and southeastward movement of the high had anything to do with a trough which lay to the northnorthwest of the Aral Sea on 27th and which moved eastwards and became more marked during the next 24 hours. Whatever may have been the cause of the accentuation of the anticyclonic system, it is reasonable to assume that a cold front developed ahead of this system well *before* 1230 GMT of 28 July (*see* Section 10). With the southeastward movement of the high, the cold front also correspondingly moved southeastwards. However, as it moved towards the subtropics, it began to lose its frontal characteristics and dissipate. At 1230 GMT of 28 July, it extended from southwest to northeast across the Caspian Sea and from there to the east of the Aral Sea.

The extreme southwestern end of this cold front which was the only portion of the front important in our discussion, touched the extreme northwest of Iran (Tabriz-Pahlavi region) at 1230 GMT on 28th at the dissipating stage and might have contributed to the rainfall in that region. Pahlavi (Lat. 37°28 'N, Long. 49°28'E) reported 43 mm of rain on 28th.

The thermodynamic aspects of these fronts have been discussed in Section 10.

8. Analysis of the daily 850-mb charts

By far the most important feature of the 850-mb charts during the second half of July 1956 was the persistence of southeasterlies over north and east Iran. During this period, there was either a closed or elongated (extending from WNW to ESE) low over south Iran with a high over and near the north Caspian Sea and Turkman S.S.R. region. The southeasterlies appeared to be an extension of the easterlies over Punjab (India), Punjab (Pakistan) or the southwesterlies or southerlies over Sind and south Baluchistan which had cyclonically curved round the low over south Iran and become southeasterlies. The synoptic situation between 19 and 25 July was of special interest as it showed that the southeasterlies over north and east Iran, at least during a small part of spell, could be associated with the westward movement of a low pressure wave from India. A closed cyclonic circulation which lay in the Bay of Bengal off the Orissa coast on 19/20th moved later across north India westnorthwestwards. It could be identified as an elongated low extending from the west of Persian Gulf to the North Arabian Sea off the Mekran coast on 25th. The upper air charts for 24 and 25 July gave the best flow-pattern evidence during the spell, of the incursion of monsoon easterlies (*i.e.*, the deflected monsoon stream north of the monsoon trough line) into Iran. For a further discussion of the charts for these two days, see Section 9.

Fig. 3 shows the 850-mb chart at 02 GMT on 21 July 1956 which was the day of peak activity during the spell in Iran. The rainfall over India, Pakistan and Iran (Afghanistan data were totally not available) during a 24-hour period ending at 03 GMT of 22 July or at an earlier synoptic hour have been superposed on this diagram. It may be incidentally added that although the winds over Ashkhabad (in Turkman S.S.R. *north* of Iran — *see* Fig. 1) on 20th as seen in Fig. 3 were WNW, they were eastsoutheasterly on a number of days during the wet spell.

9. Analysis of daily 700-mb charts

The most important feature of the 700-mb charts during the period under review was a persistent high between 35°N and 50°N to the east of 55°E. To the south of this anticyclonic system, there was generally a cyclonic circulation. During the period 24th to 28th, this cyclonic circulation was more pronounced due to the 'low' which had moved from the Bay of Bengal off the Orissa coast westnorthwestwards across India and Pakistan, *vide* Section 8 above.

Consequent on the above configuration of the contours, conditions were favourable throughout the wet spell for a flow of the monsoon easterlies from India and northwest Pakistan into Iran north of latitude 30°N from an easterly or southeasterly direction.

In the higher middle latitudes, there was a quasi-stationary low over the region extending between 50°N and 65°N and between 30°E and 60°E. The trough-line associated with this low extended southwards just to the west of the Caspian Sea from north of Trans-Caucasia to Iraq. This trough was much more pronounced at the 500 and 300-mb levels as will be seen in Section 11.

Fig. 4 shows the 700-mb chart for 02 GMT on 21 July 1956, *i.e.*, for the same synoptic hour as the 850-mb chart shown in Fig. 3. The rainfall shown in Fig. 3 which corresponds to the peak-activity during the spell may be compared with the flow pattern at the 700-mb level in Fig. 4.

As pointed out in Section 8, the flow-patterns on 24 and 25 July showed best, the

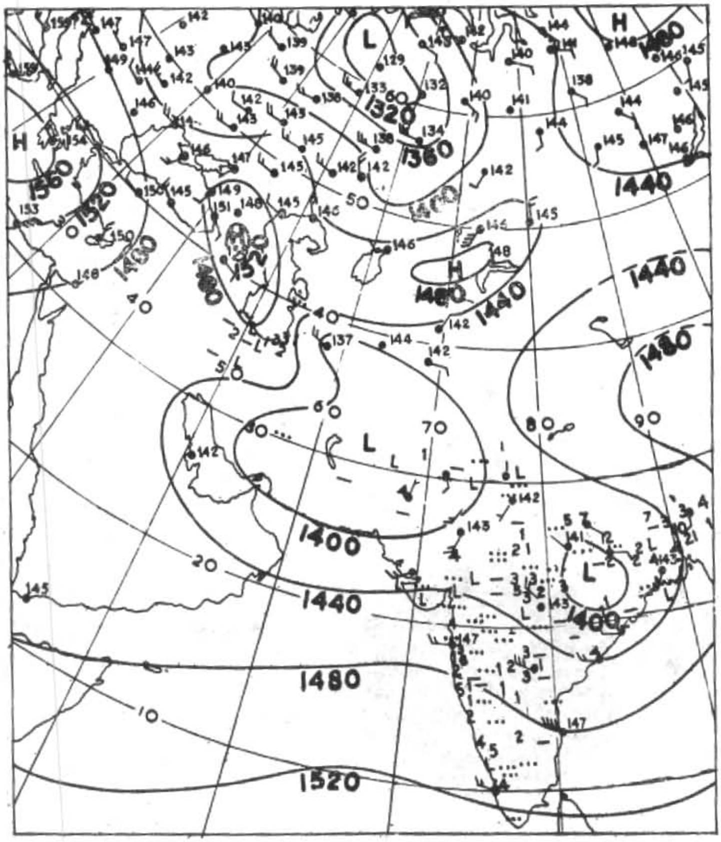

Fig. 3. The 850-mb contours at 0200 GMT of 21 July 1956 and the subsequent rainfall in a 24-hour period in and around Iran, India and Pakistan

(Rainfall data for Afghanistan not available)

The contours are at intervals of 40 geopotential metres. Note the southeasterlies over most of north and east Iran. Three dots indicate rainfall between 0·1 and 2·4 mm. A dash indicates rainfall between 2·5 and 4·9 mm. The symbol L indicates rainfall between 5·0 and 7·5 mm. Amounts more than 7·5 mm are plotted in whole cm.

incursion of the deflected Indian monsoon into Iran. However, the rainfall during 24-hour periods subsequent to the synoptic hours of these charts was not as much as on 21st shown in Fig. 3. This was because the mechanism for lifting the monsoon air was less effective on these days. This aspect is discussed in Sec. 13. The 700-mb pattern for one of the above-mentioned days — the 25 July — is reproduced in Fig. 5. The 700-mb pattern has been preferred to the 850-mb pattern for purpose of illustration as the greater part of Iran is on a plateau.

10. Analysis of the thermodynamic diagrams

A comparison of the radiosonde data of Calcutta (Lat. 22°39′N, Long. 88°27′E), Allahabad (25°27′N, 81°44′E), Delhi (28° 35′N, 77°12′E) and Karachi (25°0′N, 67°0′E) and those available for Ashkhabad (38° 05′N, 58°22′E) in Turkman S.S.R. (*see* Fig. 1) during the second fortnight of July 1956

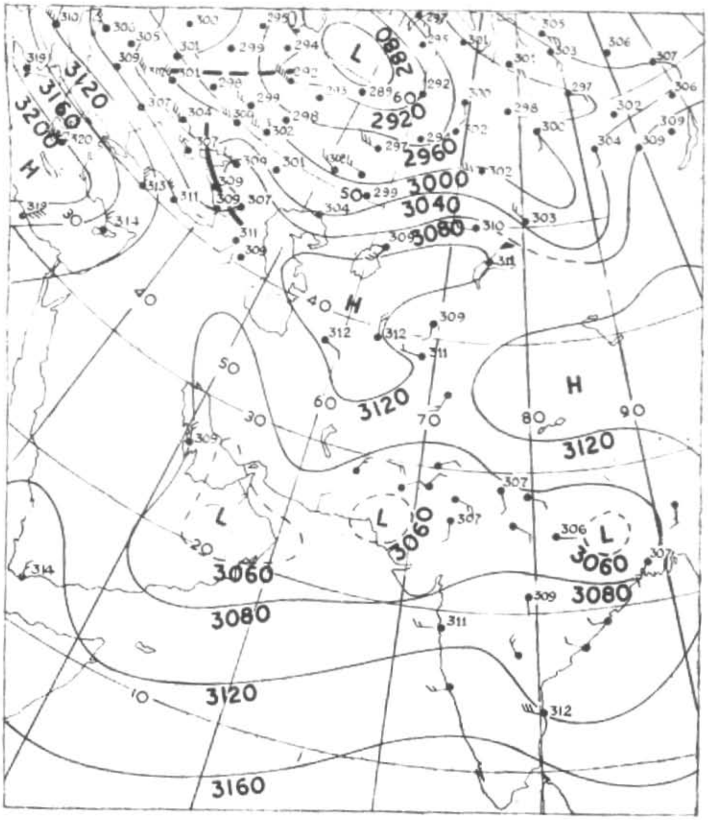

Fig. 4. The 700-mb contours at 0200 GMT of 21 July 1956

(Same convention in plotting as in Fig. 3)

Dotted lines have been drawn at an odd interval of 20 geopotential metres. Note that the flow-pattern over North and East Iran is an extension of northeasterlies and easterlies over Northwest India and West Pakistan.

shows that the air stream over north Iran as represented by Ashkhabad especially after the 19th had nearly the same thermodynamic characteristics (Roy 1946) as those of the deflected monsoon easterlies* over northern India and west Pakistan. For purpose of such a comparison, the author would have of course liked to compare the pseudo-potential wet bulb temperatures over Ashkhabad with similar data for Karachi, Delhi, Allahabad and Calcutta. Unfortunately, however, dew point/wet bulb temperature data were not available for Ashkhabad. Nevertheless, the run of the dry bulb curves for Ashkhabad nearly along the saturation adiabatics, without any evidence of subsidence inversion in the lower levels, the remarkable closeness of the temperatures over Ashkhabad with those over Delhi, Allahabad, Calcutta and Karachi at the same levels, the run of the wet bulb curves for the Indian and Pakistan stations mentioned above, making due allowance for instrumental and other errors and the examination of all these data with reference to the flow-patterns over south Asia as seen on the

*In A. K. Roy's terminology, the characteristics of deflected monsoon easterlies correspond to $E_m T$ or the transitional Equatorial Maritime airmass

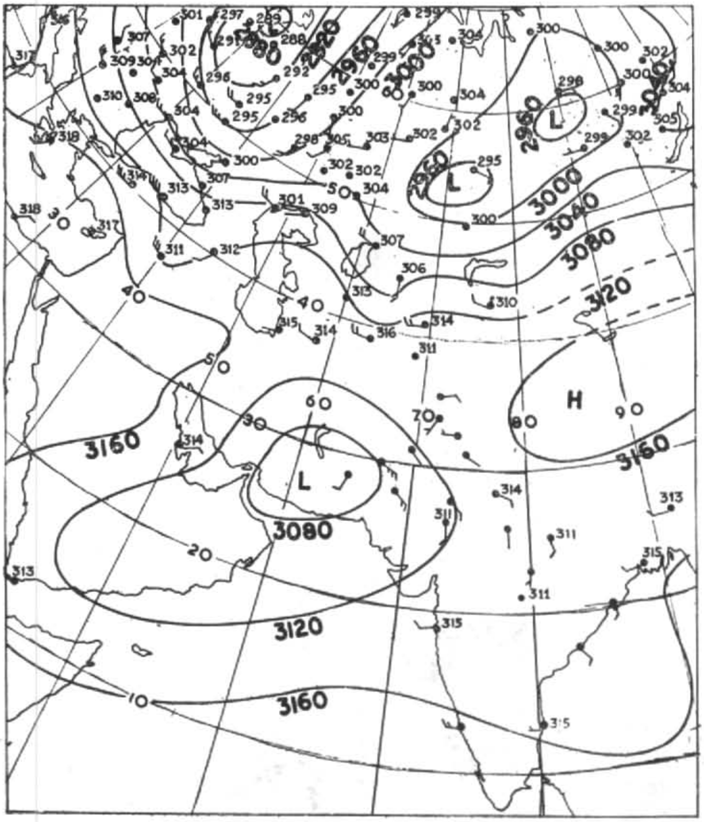

Fig. 5. The 700-mb contours at 0200 GMT of 25 July 1956
(Same convention in plotting as in Fig. 3)

Note the low over West Baluchistan and extreme Southeast Iran carrying the monsoon southeasterlies from Northwest India and West Pakistan into Iran north of Lat. 30°N.

850 and 700-mb level upper air charts gave sufficient evidence to show that we were dealing with the deflected Indian southwest monsoon stream over north Iran.

Fig. 6 shows the Dry and Wet Bulb curves of Calcutta for 15 July and of Delhi and Karachi for 17 July 1956. The curves of Delhi and Calcutta are the mean of the curves for 02 GMT and 14 GMT for the respective stations. The mean curve was utilised to minimise the effect of errors, if any, in Indian radiosonde data. The data for Karachi were available for 14 GMT only.

The 02 GMT Dry Bulb curve of Ashkhabad for 21 July and the mean Dry Bulb curves of $E_m T$ air over Calcutta and Agra (*see* Fig. 1) during the month of July as published by Roy (1946) have also been shown on the same figure for comparison.

The different dates mentioned above have been selected for the *daily* curves of Calcutta, Delhi and Karachi on the basis that air from Calcutta at the windspeeds which actually prevailed below 700-mb level during the spell would take about 2 days to reach Delhi and the air from Delhi or Karachi below 700-mb level would take 3 to 4 days to reach Ashkhabad.

The closeness of the Dry bulb curve of Ashkhabad with all the other Dry bulb

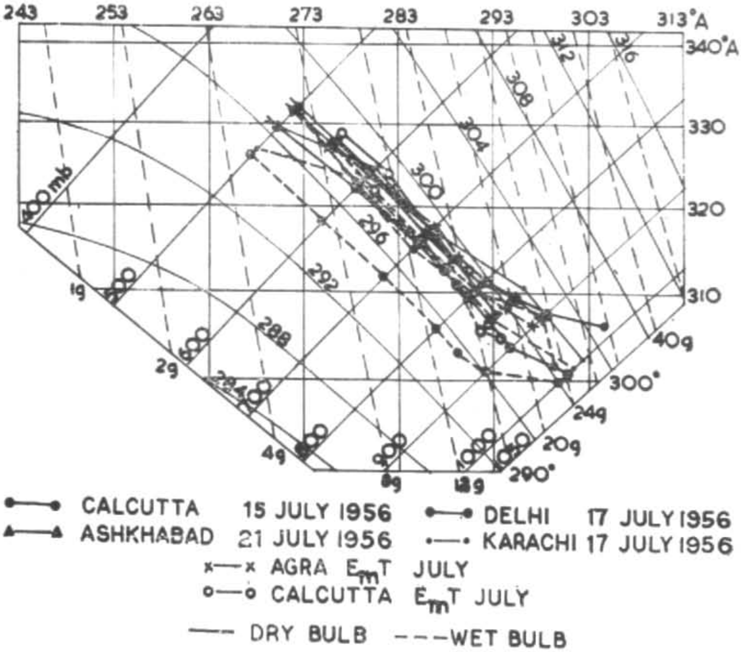

Fig. 6. A comparative study of tephigrams of Ashkhabad (Turkman S. S. R.), Karachi, Delhi, Agra and Calcutta

Note the remarkable closeness of all the curves between 850 and 550 mb levels

curves in the figure is very interesting and supports the views expressed in the earlier paragraph.

With regard to the use of curves of different dates, it should be added by way of clarification that these dates were chosen just to argue out our case on a kinematic basis. We could have chosen other days as well to establish our point. As stated in the earlier part of the paper, the active monsoon conditions persisted over the Indo-Pakistan sub-continent over a long period and this made the comparative analysis of the tephigrams a simple matter. Indeed, the uniform monsoon characteristics as revealed by the tephigrams were extraordinary and showed that we were dealing with a case of large-scale invasion of the Indian southwest monsoon current over an exceptionally vast stretch of South Asia for an unusually long period.

That the tephigram of Ashkhabad during this wet spell was basically of the Indian monsoon type has also received confirmation from a study of the tephigrams of this station for a synoptic situation of the diametrically opposite type in another year in the southwest monsoon period. Fig. 7 shows the Dry bulb and Wet bulb curves of Ashkhabad for one such situation namely on 5 August* 1957. This day was one of "break-monsoon" conditions in India and the 500-mb charts for this day have been published by the author in one of his earlier studies (Ramaswamy 1962). On this day, the Tibetan High, in striking contrast to what we shall see further in the present study, had practically collapsed at the 500-mb level. The tephigram for Ashkhabad for this day shown in Fig. 7 may be compared with the tephigram for the same station on 21 July* 1956 in Fig. 6. The curve for the latter date has also been reproduced in Fig. 7 so that the

*July and August are both equally typical "southwest monsoon" months in the Indo-Pakistan sub-continent

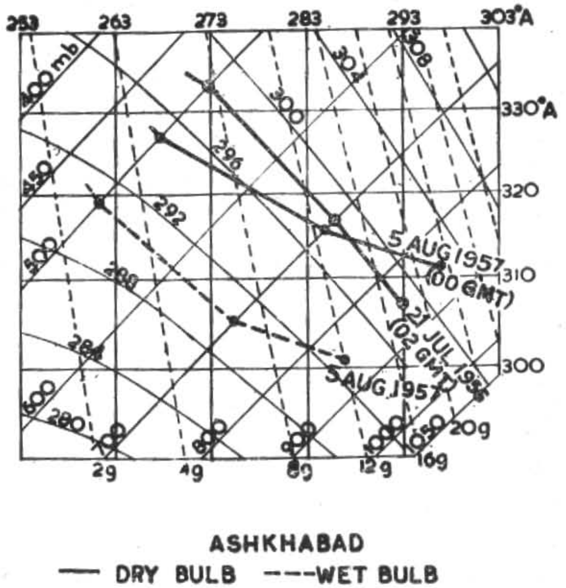

Fig. 7. A comparative study of the air over Ashkhabad on 5 August 1957 and 21 July 1956

Note the striking difference between the dry bulb curves on these 2 days. Note also the dryness of the air on 5 August 1957 which corresponds to "break-monsoon" conditions over India

contrast between the two curves may be more readily appreciated. The two curves have been shown only upto the 500-mb level in Fig. 7 as these are the only portions of the curves relevant to the present discussion. The much more unstable trend of the curve for 5 August 1957 and the dryness of this air stand out conspicuously by the side of the curve for 21 July 1956 which runs almost along a saturation adiabatic curve.

With regard to the cold frontal action between 20 and 21 July and between 27 and 28 July discussed in Sec. 7, the author has examined all the available data of the radiosonde stations (*see* Fig. 1) — Babusheri (42°52′N, 41°08′E), Tbilisi (41°41′N, 44°57′E), Lenkoran (38°44′N, 48°50′E) — between the Black Sea and the Caspian Sea for the above mentioned periods and also for 2 days prior to the respective periods and compared these data with those of Ashkhabad for the periods 20th to 21st and 27th to 28th respectively. The study has shown that below the 500-mb level, the air near Babusheri on the eastern shores of the Black Sea was 10° to 13°C colder than the Indian monsoon air over Ashkhabad and that this air from the Black Sea region had warmed up as it moved southeast towards the western shore of the Caspian Sea. Even, then, it was 7° to 9° C colder than the monsoon air over North Iran as represented by the data of Ashkhabad. It is, therefore, reasonable to expect that the cold fronts ahead of the anticyclonic systems referred to in Sec. 7, while moving from the Black Sea had cold frontal characteristics even at the stage of frontolysis on both these occasions and that the colder air undercut the warmer humid monsoon air over the Iranian shore of the Caspian Sea and augmented the rainfall activity over that area between 20 and 21 and between 27 and 28 July respectively.

11. Analysis of the daily 500-mb charts

The 500-mb analysis presented in this

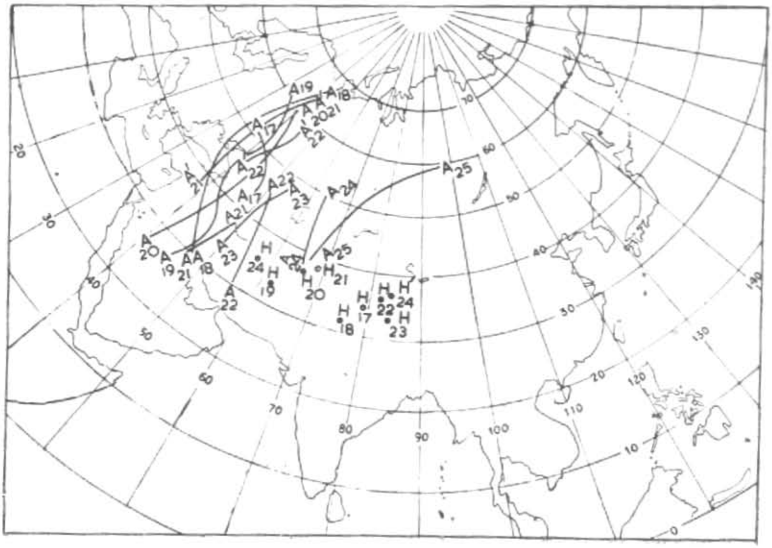

Fig. 8. The quasi-stationary troughs and the centres of the closed Tibetan Highs at the 500-mb level, 17—25 July 1956

Note the retrograde motion of the trough between 17th and 18th and to the south of Lat. 39°N between 19th and 20th

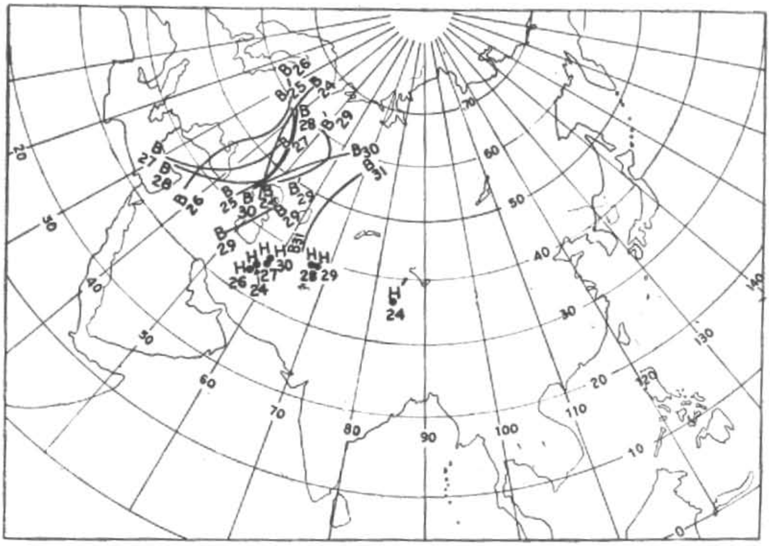

Fig. 9. The quasi-stationary troughs and the centres of the closed Tibetan Highs, 24—31 July 1956

Note the retrograde motion of the trough between 25th and 26th and between 29th and 30th. Note also the rapid eastward movement of the trough between 30th and 31st synchronising with the "disappearance" of the Tibetan closed High (on 31st).

Section are based on the 1500 GMT 500-mb Northern Hemispheric charts of the U.S. Weather Bureau and the 0200 GMT 500-mb charts for Asia and the neighbouring areas prepared by the author.

Figs. 8 and 9 show the trough lines which moved from Eastern Europe eastwards across Asiatic U.S.S.R. The systems have been shown in two diagrams instead of one to avoid undue congestion and consequent difficulty of the reader in following the movement of the troughs. For the same reason, troughs which moved eastwards beyond the Aral Sea or those whose southernmost ends did not extend upto north Caspian Sea and would, therefore, have not directly influenced weather developments over Iran have not been shown.

The trough lines for the same trough on the successive days have all been marked by the same letter, *e.g.*, A. On some days, the trough line split into two. On such occasions, the trough line in the higher latitude was marked as A′. The dates have been indicated by a suffix, *e.g.*, as A_{17}, A_{18}, A'_{19} etc.

The centres of the Tibetan High when this high was found as *a closed system* are also shown in the same figures by the letter H with the corresponding dates as suffixes.

On some days, the Tibetan High appeared as two separate closed cells inside an extensive high region. In such cases, the closed high nearer Iran has been marked as H and the one further to the east has been marked as H′, *e.g.*, as H_{17}, H_{18}, H'_{18} etc.

An examination of Figs. 8 and 9 reveals the following—

(*a*) During the period under review, two troughs which we shall refer to as A and B moved eastwards across the Caspian Sea.

(*b*) Trough A was characterised by very slow eastward movement and *occasionally even by retrograde motion.* It, however, moved relatively quickly eastward after the 23rd. On the 24th, it lay to the east of the Aral Sea and thereafter it moved away further north-eastwards. This quasi-stationary character of the trough was intimately connected with the movement of the closed cell of the Tibetan High. The closed anticyclonic cell moved *westwards* from 17th to 19th and remained to the west of 70°E on 20th and 21st. It may be recalled that 20-21 July was the period of peak activity during the spell. The closed anticyclonic cell "jumped" eastwards by more than 12 degrees longitude on 22nd and remained near about the same position on 23rd and 24th. A new small anticyclonic cell formed near 65°E on 24th on which date trough B appeared to the west of the Caspian Sea.

(*c*) The history of the movement of trough B was very similar to that of trough A. The "blocking"* by the Tibetan High was also similar. The trough B remained to the west of the Caspian Sea till 30th — the last day of the spell. The closed anticyclonic cell also remained to the west of 70°E till 30th. The closed cell suddenly disappeared from the chart on 31st. The trough also rapidly moved eastwards after the 30th and lay to the east of the Aral Sea on 31st.

The rainfall in and around Iran was carefully examined with reference to the 500-mb contour patterns during the wet-spell period specially with a view to see whether the rainfall activity could be associated with any of the schematic patterns of divergence in the upper westerlies in the subtropics (Ramaswamy 1956†). This examination presented considerable difficulty mainly because

* The Ural mountains might have contributed to the "blocking" of the troughs lying to the north of 50N° (Academica Sinica 1958). It cannot, however, be denied that the blocking of the troughs to the south of 50°N which was far more important in our case, was overwhelmingly determined by the abnormal westward shift of the Tibetan High.

† The dynamics of these schematic patterns have been dealt with on pages 49 to 52 of the author's paper referred to.

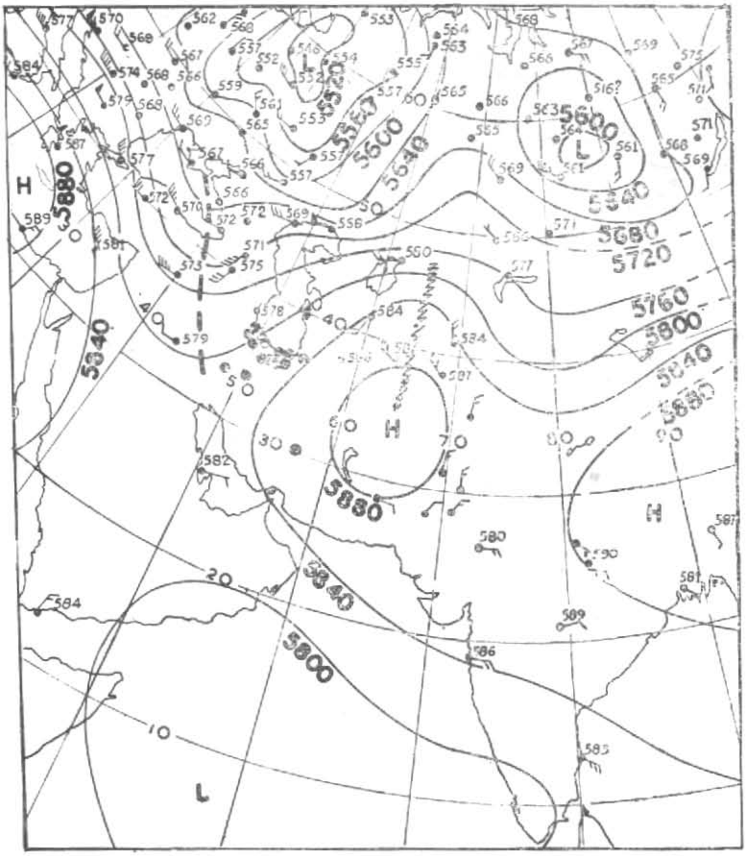

Fig. 10. The 500-mb contours at 0200 GMT of 20 July 1956 and the rainfall in and around Iran in 24 hours ending at 03/15 GMT of 21 July 1956

(Same convention in plotting as in Fig. 3)

Contours are at intervals of 40 geopotential metres. Thick dashed line is a trough line and thick zig-zag line is a ridge-line. Thick big shaded circles in and near Iran indicate stations which recorded rain. Small shaded circles are stations where PB/RS/RW data are plotted. Note the position of the trough to the west of the Caspian Sea and the closed high over Afghanistan and northeast Iran. Note also that most of the area of rainfall lies in a region where the rate of change from cyclonic to anticyclonic curvature (with nearly uniform shear) is a maximum.

the upper air information available over and near Iran was inadequate to fix the contour patterns over those regions with full confidence. Nevertheless, it was possible to state in a rough and very qualitative way that in the majority of cases, the rainfall was associated with a sinusoidal pattern in the region in which the cyclonic curvature was changing to anticyclonic curvature down stream and *the rate of change* of curvature (with uniform shear) was *a maximum*. In a few cases, the precipitation occurred just ahead of a trough line or just in the rear of a ridge where there was an abrupt change in curvature with reasonably uniform shear. It also appeared that the distribution of rainfall increased when the wave-pattern became more marked and the amplitude of the trough increased (causing a more rapid change in curvature upstream) and when a closed anticyclonic cell moved to the west of 70°E closer to the trough producing a confluent ridge* (*i.e.*, a region of increasing anticyclonic shear upstream). The confluent ridge was much more conspicuously seen at the 300-mb level, where there was also a jet stream embedded in the ridge near the apex.

Fig. 10 shows the 500-mb contour pattern at 02 GMT on 20 July 1956. The rainfall which occurred over and near Iran in a 24-hour period ending at 0300/1500 GMT on 21 July is also shown superposed on the figure. It will be seen that the rainfall has occurred ahead of the trough line in association with a sinusoidal pattern in the region in which the shear was reasonably uniform and the rate of change of curvature was a maximum. However, on the eastern shores of the Caspian Sea, some confluence was perhaps taking place in the rear of the ridge and the divergence associated with this pattern might have made some contribution to the rainfall over that area. The confluent ridge is seen more conspicuously at the 300-mb level (*see* Fig. 1).

12. Analysis of the daily 300-mb patterns

While analysing the 300-mb charts, considerable attention was devoted to maintaining time and space continuity in the analysis. For this purpose, the 500-mb analyses which were based on much more data were fully used as a check-up on the 300-mb analysis. Greater weight was also given to the winds than to the radiosonde height values especially in the Indian region. All doubtful values of radiosonde heights were checked up with reference to the data for the previous and following days whenever this was possible.

The statements made in Sec. 11 about the development of rainfall in Iran in relation to the contour-patterns were even more true at the 300-mb level than at the 500-mb level. From the analysis, it was possible to state qualitatively and on a very broad basis that the development of rainfall was in most cases in the region of positive vorticity advection associated with rapidly decreasing cyclonic curvature and/or increasing anticyclonic curvature (with uniform shear). There were also fairly clear indications that the spatial distribution of rainfall increased with the approach of a closed anticyclonic cell nearer the trough resulting in rapidly increasing anticyclonic curvature and increasing anticyclonic lateral shear in the rear of a ridge. On such occasions there was also a jet stream near about the apex of the ridge.

Fig. 11 shows the 300-mb pattern at 02 GMT on 20 July 1956 and the rainfall during the 24 hours period ending at 03/15 GMT of 21 July, which was the day of maximum activity during the wet spell (*see* also Figs. 3 and 4). It will be seen that most of the rainfall was associated with the sinusoidal pattern in the region in which the rate of change of curvature was a maximum. However, on the eastern shores of the Caspian Sea, there might have been an additional contribution due to the slight confluence in the rear of the ridge. The 60-knot wind at Tashauz

* This has been referred to as S_vR pattern by the author in his earlier studies (Ramaswamy 1956). It could however, be more appropriately called as "confluent ridge". Hence this term has been used in this paper

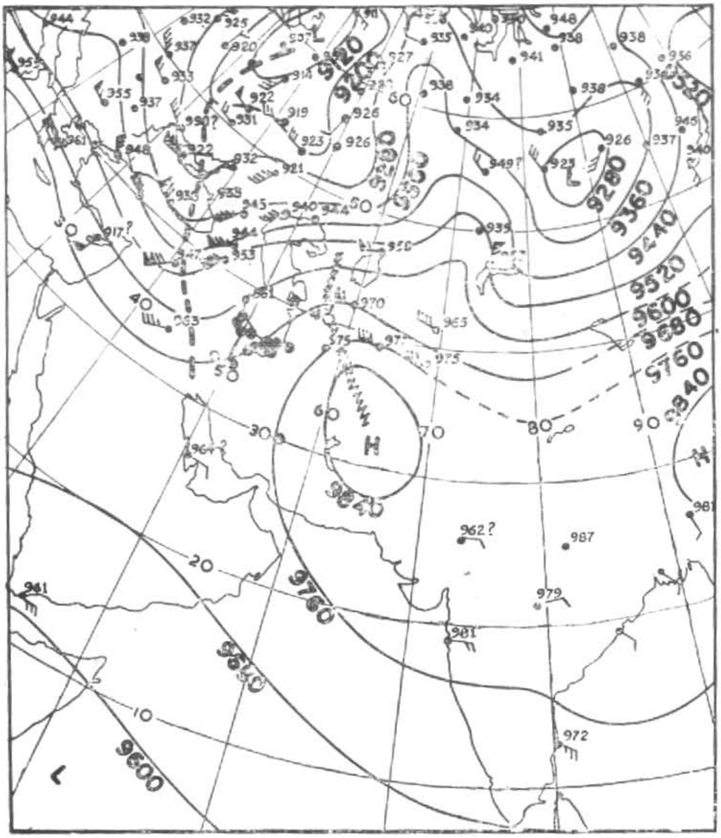

Fig. 11. The 300-mb contours at 0200 GMT of 20 July 1956 and the rainfall in and around Iran in 24 hours ending at 03/15 GMT of 21 July 1956

Contours are at intervals of 80 geopotential metres. Otherwise same convention in plotting as in Fig. 10. Note that most of the area of rainfall lies in a region where the rate of change from cyclonic to anticyclonic curvature (with nearly uniform shear) is a maximum

at the apex of the ridge and the rainfall at Gorgan and Krasnovodsk on the east coast of the Caspian Sea may be noted (*see* Fig. 1).

In explaining the rainfall with reference to the divergence-patterns, it need hardly be emphasized that the divergence-pattern would be "effective" in producing rainfall, only when there is moist air (in the present case, monsoon air) vertically below in the lower troposphere, to be lifted. *Per contra,* there may be monsoon air below but if the flow-pattern in the upper troposphere is such that there is no divergence, significant rainfall will not occur over that region, notwithstanding all the moisture which may be present vertically below unless, of course, there is low-level convergence due to other causes, independent of upper divergence. This is illustrated by the synoptic situations on the 24 and 25 July 1956. In Sections 8 and 9 we had stated that the flow-patterns at the 850 and 700-mb levels on these two days gave irrefutable evidence of the incursion of deflected monsoon easterlies into Iran. Nevertheless, the weather developments on these two days were significantly less than on the

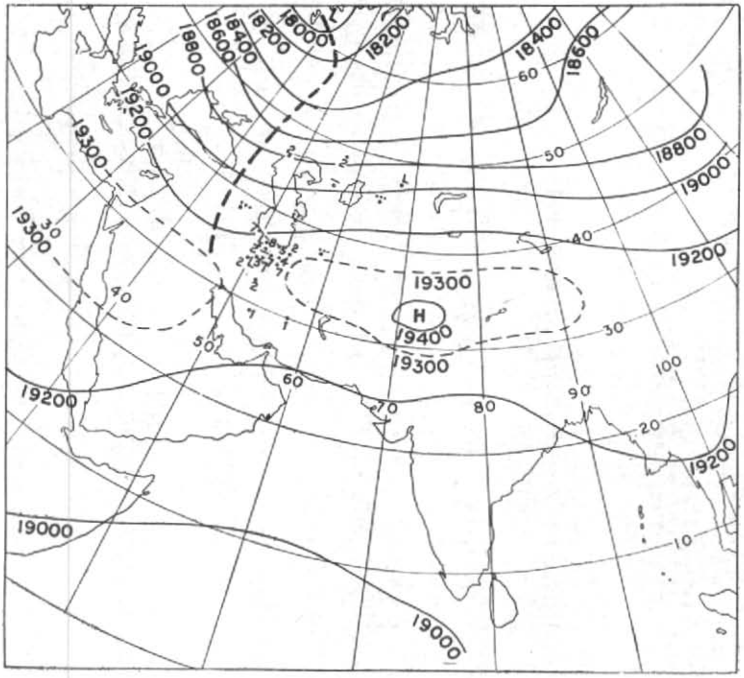

Fig. 12. The mean 500-mb contours during the period 17 to 29 July 1956 and the total rainfall in and around Iran during the wet spell

Contours are at intervals of 200 geopotential feet. Note the concentration of rainfall ahead of the trough line and around the anticyclonically curving closed odd contour of 19300 geopotential feet of the Tibetan High. Convention in plotting rainfall is the same as in Fig. 3. The general pattern of rainfall suggested the intrusion of an anticyclonically curving moist tongue into Iran from a region to the east of that country

21st and 28th because the 500 and 300-mb troughs on the former two occasions were of small amplitude, the variation of curvature ahead of the trough line was significantly less and there was no contribution to upper divergence by the shear-term.

13. Analysis of the mean 500-mb chart for the wet spell

Fig. 12 shows the mean 500-mb contour pattern during the wet spell from 17 to 29 July 1956. The mean pattern was prepared by reading off the contour values on the U.S. Northern Hemisphere 1500 GMT chart at intervals of five degrees of latitude and longitude between 30°E and 120°E and between 5°N and 60°N and computing the mean value for the period at each grid-point. The total rainfall during the wet spell at each of the stations included in Table 1 is also shown in Fig. 12.

An examination of the diagram reveals the following —

(*a*) There was a trough extending from 65°N to 35°N with the trough line running more or less parallel to the meridian 45°E to the west of the Caspian Sea and extending to Lat. 35°N or even further south.

(*b*) The Tibetan High lay much to the west of its usual position. Its western boundary corresponding to the closed contour of 19,300 geopotential feet extended as far to the west as Long. 55°E. A comparison of this mean diagram for the spell with

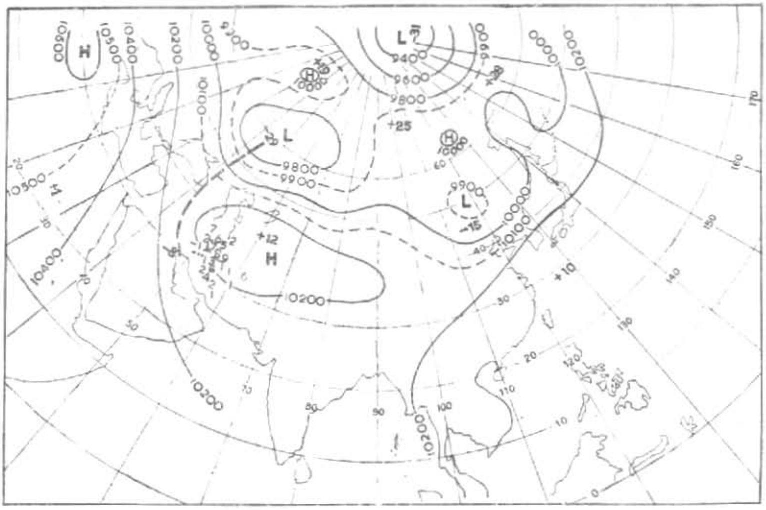

Fig. 13. The mean 700-mb contours over Asia and Eastern Europe in July 1956 and the total rainfall in Iran in that month

Contours are at intervals of 200 geopotential feet. Contour anomaly values are in tens of geopotential feet. Note the abnormal position of the "Tibetan High" and the mean trough to the west of the Caspian Sea. Convention in plotting rainfall is the same as in Fig. 3. Note that the total rainfall during the month follows the same pattern with respect to the mean monthly contours as the rainfall during the wet spell in Fig. 12 follows the mean 500-mb contour during the wet spell

the mean contour for the month of July based on the data for several years (Academia Sinica 1957) shows that the central region of the closed *Tibetan High had shifted westwards by more than 20 degrees longitude.* The author is, of course aware that the U.S. Northern Hemisphere charts on the basis of which the mean 500-mb chart for the wet spell has been prepared, contain little data over Tibet and China and that the isopleths over this region have been drawn by the U.S. Weather Bureau by extrapolation from data of stations bordering the region and by other techniques. Nevertheless, the westward shift of the closed high is far too large to be explained away as due to insufficiency of Chinese and Tibetan data on the U.S. Northern Hemisphere charts.

(*c*) The rainfall during the wet spell as a whole, occurred ahead of the mean trough line and around the anticyclonically curving contour of the mean Tibetan High. Subparagraph (*b*) in Section 5 is relevant in this connection.

A comparison of Fig. 12 with Figs. 8 and 9 would suggest that the abnormal position of the Tibetan High was the major controlling feature of the situation and that the "blocking action" of this high was responsible for the quasi-stationary character of the troughs A and B (Figs. 8 and 9) and of the "merging of the two troughs into one" in the mean chart for the spell.

14. Analysis of the mean 500-mb charts for July 1956

The mean chart for July 1956 as a whole *i.e.*, including the wet-spell period, was prepared from 1500 GMT U.S. Northern Hemisphere charts in the same way as the mean 500-mb chart for the wet spell period. This chart (not reproduced here) showed the same pattern as the mean chart for the wet spell: the trough line to the west of the Caspian Sea and the Tibetan High were virtually in the same positions as during the wet spell. There was, however, a faint indication that there were two closed contours of the Tibetan High—one between 55° and 65°E to the southeast of the Caspian Sea and another in the same latitude between 85° and 95°E. The significance of the close similarity between the mean chart for the month of July 1956 as a whole and the mean chart for the wet spell only, is discussed in Section 17.

15. Analysis of the mean 700-mb chart for July 1956

Fig. 13 shows the mean 700-mb contours and anomalies for the month of July 1956 as a whole, over Asia, and the neighbourhood. These are based on the mean 700-mb contour and anomaly chart prepared by the Extended Forecast Division of the United States Weather Bureau. To avoid undue congestion on the chart, the isopleths of the anomalies have not been drawn, but the positions of the centres of the anomalies and the maximum values of the anomalies positive as well as negative, at the anomaly centres have been shown in the diagram. The total rainfall in July 1956 at each of the rainfall stations ("synoptic" as well as "climatological" stations) (Iranian met. Dep. 1958) have been superposed on the mean contour diagram.

An examination of this composite diagram reveals the following—

(*a*) The "Tibetan High"* which, according to Koteswaram (1956), builds up over the Asian monsoon region only *above* 500 mb is seen as a very pronounced high even at the 700-mb level to the west of Tibet.

(*b*) The positions of the mean trough and of the Tibetan High are very consistent with those in the mean 500-mb charts for the month as a whole and for the wet-spell period only, *vide*, discussions in Sections 13 and 14.

(*c*) The abnormal position of the Tibetan High has resulted in a positive anomaly of 120 feet at the western end of the high near Lat. 40°N, Long 60°E. Considering that this positive anomaly relates to the month of July *as a whole* and that July is normally a month of relatively weak gradients, the positive anomaly of 120 feet is very significant.

(*d*) The mean trough itself is in an abnormal position as seen from the negative anomaly of 290 feet at the centre of the low from which the trough extends.

(*e*) The circumpolar vortex is unusually intense and contracted (Kreuger 1956) and is associated with a deep negative anomaly of 310 feet at 80°N (only a portion of the vortex is seen in the diagram).

(*f*) The rainfall in Iran in July 1956 as a whole has occurred well ahead of the mean trough line and around the anticyclonically curving contour of the mean Tibetan High as in the case of rainfall during the wet spell, *vide* sub-para (*b*) in Sec. 5 and sub-para (*c*) in Sec. 13.

A comparison of the rainfall during the wet spell with the rainfall at the same stations during July 1956 as a whole shows that most of the rainfall of the month occurred during the wet spell, *i.e.*, between 18 and 30 July. The significance of this fact in relation to the mid-tropospheric patterns during the wet spell and the month of July 1956 as a whole will be discussed in Sec. 17.

16. A case of dynamical and physical interaction between middle and low latitude systems

Based on the above detailed study, we are now in a position to arrive at a few broad generalisations.

During the second half of July 1956, there was more or less a continuous incursion of easterlies and southeasterlies from India into Iran (across West Pakistan) especially in the eastern and northern parts of Iran. An examination of the flow patterns below 700-mb level and the available tephigrams indicated that the easterlies which had invaded Iran must have been the deflected Indian southwest monsoon air to the north of the equatorial trough line (referred to in Indian meteorological literature as the axis of the monsoon trough). It is important to emphasize that this deflected monsoon air, though it had travelled as far northwest as the Caspian Sea, was a low latitude airstream in its origin.

*The Tibetan plateau extends to 700 mb over a broad area and to 500 mb and above in many ranges. However, for convenience in terminology, the term "Tibetan High" is being used in this paper even while referring to the high at the 700-mb level to the north of the Indo-Pakistan sub-continent

Past synoptic experience shows that it is only rarely that the Indian southwest monsoon reaches west Baluchistan. Yet, during the period studied in this paper, it seemed to have reached as far northwest as the Caspian Sea. The present study has established on a quasi-empirical basis that this unusual development is connected with certain large-scale developments in the middle and upper troposphere to the north of the Indo-Pakistan sub-continent which also led to an abnormally active monsoon over the whole of India during this month (Ramaswamy 1962). The Tibetan High had become unusually pronounced and shifted westwards by as much as 20 degrees longitude to the west of its usual position at the 700, 500-mb levels and most likely also at the 300-mb level. This high in the abnormal position would have drawn the monsoon easterlies in the lower troposphere at least at 700-mb level from India into Iran across West Pakistan. In this Tibetan High, closed anticyclonic cells had frequently formed to the west of 70°E and "blocked" the eastward movement of the troughs in the upper tropospheric westerlies. The position of the Tibetan High and the closed anticyclonic cells in it were such that quasi-stationary troughs lay close to the west of the Caspian Sea in the middle and upper troposphere. These troughs, it may be emphasized, were basically part of closed cyclonic systems in the higher middle latitudes. The configuration of the contours of this trough and of the Tibetan High in general and of the closed anticyclonic cells in particular, was such that the middle and upper troposphere over Iran experienced persistent positive vorticity advection, *i.e.*, divergence. In general, this positive vorticity advection was more in the north of Iran than in the south of that country. It also tended to be a maximum on certain individual days in association with the contour-characteristics on those days.

These quasi-stationary upper divergence systems, which were middle-latitude systems, lay just over the regions where the low latitude air stream with monsoon characteristics had pervaded the troposphere below 700 mb. Consequently, there was vigorous dynamical interaction between the middle and low latitude weather systems as a result of which the monsoon air was "pulled up" and gave precipitation in and around the southern shores of the Caspian Sea and at times even further to the south and east.

The troughs in the middle latitude westerlies were part of closed cyclonic systems which extended down to the sea level and had typical fronts. In the rear of the cold fronts associated with these cyclonic systems or of those which formed ahead of anticyclonic systems moving southeastwards, there was occasional invasion of much colder air from the higher middle to the lower middle latitudes during the wet spell.

On two such occasions, the colder air from the north came down close to the southern shores of the Caspian Sea. This cold air mass, though it began to get warmed up during its motion towards the subtropics was still colder and consequently denser than the deflected Indian southwest monsoon humid air on the southern shores of the Caspian Sea. Consequently there was physical interaction between the two air masses thereby providing an additional mechanism for lifting the monsoon air on the occasions referred to.

Thus we had during the second half of July 1956, the remarkable spectacle over north and east Iran of low latitude and middle latitude systems dynamically and physically interacting with each other to cause an abnormal monsoon rainfall over that country, which contributed to the disastrous floods reported in the Press in that month. Of the two mechanisms, the dynamical mechanism was obviously the more important one and constituted the main mechanism, as it persisted throughout the wet spell. The physical mechanism was a secondary mechanism as it operated effectively only on two days during the entire wet spell.

17. Mechanism of the rainfall in July 1956 outside the period of the wet spell

In Sections 13, 14 and 15 we had made the following factual statements—

(*i*) Most of the rainfall in Iran in July 1956 at the stations for which data were available to the author, had occurred during the wet spell between 18 and 30 July.

(*ii*) The rainfall during the wet spell was associated with a quasi-stationary trough to the west of the Caspian Sea and a closed Tibetan High at the 700 and 500-mb levels which had shifted far to the west of its usual position.

(*iii*) The mean positions of the quasi-stationary trough and the Tibetan High, during July 1956 (as a whole) were virtually the same during the wet spell.

This may mean either (*a*) that even the little rain which fell during the month outside the wet spell, could have been due to the same mechanism* as during the wet spell, *viz.*, the incursion of monsoon air from India and an unusually pronounced Tibetan High occupying an abnormal position and causing a "blocking action", or (*b*) that the abnormal synoptic features of the wet spell were so marked that they were reflected in the monthly mean pattern also.

Considering the synoptic climatology of Iran, the explanation given in (*b*) above seems to be much more plausible and this would make the wet spell a truly exceptional case of advance of monsoon in Iran. However, this can be firmly established only by another investigation making use of the rainfall data of *all* the synoptic and climatological stations in Iran.

18. A few comments on the Tibetan High

The present investigation and the previous studies by the author have shown that the Tibetan High becomes unusually pronounced and shifts on a large scale in certain synoptic situations. Closed anticyclonic cells also form within this 'high', disappear in the same position and reappear in other parts of the 'high'. The 'high' also contracts and at times even collapses during low index circulation in middle latitudes when large amplitude troughs extend from middle latitudes into north India and Pakistan (Ramaswamy 1962).

One of the explanations for the existence of the Tibetan High is that the large extent and high elevation of the plateau serve to heat directly the middle troposphere and to produce a strong solenoidal field in the upper troposphere for driving a clock-wise circulation (Koteswaram 1958, 1960). While this may be true to a large extent, there is hardly any doubt that the observational facts stated above have to be taken into account in postulating any modification of the above theory about the mechanism of the formation and maintenance of this Tibetan High.

19. Acknowledgements

This investigation could not have been undertaken but for the co-operation so kindly extended to the author by the Meteorological Services of Iran, U.S.A. and U.S.S.R. The author would express his gratitude to—

(*a*) Dr. M. H. Ganji, the Director General of the Iranian Meteorological Service, for supplying daily rainfall data of the synoptic and climatological stations in Iran,

(*b*) Dr. Jerome Namias, the Chief of the Extended Forecast Division of the U.S. Weather Bureau for supplying the full Northern Hemisphere chart for July 1956, and

(*c*) The Chief of the Hydro-meteorological Services of U.S.S.R. for supplying daily rainfall data of stations in U.S.S.R. adjoining the Caspian Sea, the Aral Sea and Iran.

*The mechanism is totally different from the normal mechanism of July rainfall in Iran which has been described in the Introduction, *viz.*, middle latitude eastward moving systems and the supply of moisture from the Mediterranean Sea or the Persian Gulf

Mr. M. Venkataramani of the Headquarters Office of the India Meteorological Department, New Delhi, made most of the computations and plotted all the charts and tephigrams. The author would like to express his gratitude to Mr. Venkataramani for the enormous labour put in by him. The author would also express his warm and sincere thanks to Sarvashri Harnam Singh and Harbans Singh for some of the computations and express his gratitude to Shri K. S. Venkataraman, Meteorologist-in-charge, Safdarjung Airport, New Delhi, for going through the manuscript of this paper and making helpful criticisms.

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