Mausam, (1979), 30, 1, 9-20

551.579.4 : 551.166 : 551.589 (282.253) "1962"

Very large floods in the *Brahmaputra* river in August 1962 Part I : Synoptic aspects*

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ABSTRACT. The large-scale synoptic situations from the time of onset of the southwest monsoon to the end of August in 1962 over the catchment of the *Brahmaputra* (including that of the *Tsangpo*) have been studied using the synoptic charts prepared in India and those published by the Japan Meteorological Agency. Time-sections of the upper winds over Gauhati (26° 11′ N, 91° 45′ E) and of the heavy rainfall at the India Meteorological Department stations over the Brahmaputra basin were also studied for all important situations. It has been shown that the lee-vortices which develop to the southeast of the Tibetan plateau play a very important role in the occurrence of very heavy rainfall over and near Pasighat (28° 06′ N, 95° 23′ E) in the extreme northeast of Arunachal Pradesh and over the eastern half of the Tsangpo. The conclusion is drawn that frequent and exceptionally heavy rainfall over these area was predominantly responsible for the phenomenal discharge of the *Brahmaputra* at Pandu near Gauhati on 24 August 1962. The genesis of the lee-vortices to the southeast of the Tibetan plateau has also been discussed. The need for the development of synoptic climatology of the above-mentioned area with special reference to weather over the Brahmaputra basin, is pointed out.

1. Introduction

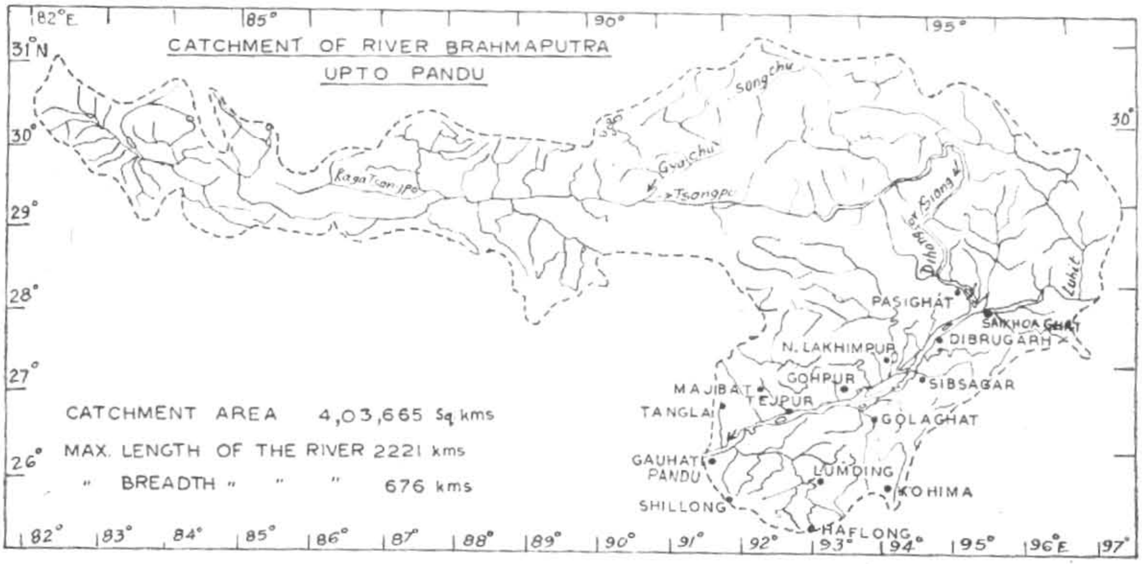
Floods in the *Brahmaputra* river (Fig. 1) are an annual visitation and they cause very heavy losses to the country year after year. Detailed investigations on the synoptic aspects of these floods have, however, so far been very limited. This is presumably due to the fact that upper air data to the north of India required for such investigations have been seriously lacking. The river flows for about 1700 km to the north of the main Himalayan range before it enters India in the extreme northeast and no meteorological data of any kind pertaining to the areas to the north of India were available till 1961. The opening of the Northern Hemisphere Exchange Centre at Delhi in 1961 has, no doubt, provided us with some of the required data but even now, adequate data are not available for high level analysis over the Tibetan plateau. We do not also have even now any information about the actual rainfall over the Tsangpo (*see* Fig. 1). Consequently, any assessment of the large-scale synoptic systems associated with the floods, *e.g.*, large scale convergence or divergence, will necessarily fall very much short of the ideal. For a detailed description of this river, the reader is referred to *India's Water Wealth* by Rao (1975).

The UNESCO have recently (1976) released a publication entitled *World Catalogue of Very Large Floods*. The catalogue contains a list of floods in India in selected catchments together with hydrological information pertaining to these floods. It is seen from the publication that the peak rate of flow in the *Brahmaputra* river reached the very high figure of 72700 cubic metres per second at Pandu. This is the third highest figure of peak discharge in any Indian river as published in the UNESCO catalogue referred to above.

With regard to the earlier synoptic studies of these floods, it should be mentioned that Datta & George (1966) had studied the synoptic situation which led to these floods. Dhar *et al.* (1975) had recently given a description of these floods on the basis of gauge data available with them. They had also referred to the synoptic disturbances over India in the monsoon period of 1962 which, in their opinion, contributed to the development of the floods. The synoptic study reported in the present paper goes into the entire problem *de novo*† and in much greater depth than the investigations of the earlier workers. As this is a very detailed study of the synoptic aspects, it is being pulished separately as Part I of our studies. The hydrological

*Based on a lecture delivered by the first author before the Indian Meteorological Society at Delhi on 21 July 1978.

†A very brief summary of our earlier work on the same problem and containing our tentative conclusions at that time, may be seen in *Vayu Mandal*, 1977, 7, 3 & 4. The present paper is based upon much more data to the north of the Himalayas, which subsequently became available to us in charts published by Japan Meteorological Agency, Tokyo.



(COURTSEY : CENTRAL WATER COMMISSION, GOVT. OF INDIA)

Fig. 1. Catchment of the *Brahmaputra* river upto Pandu (near Gauhati)

aspects will be discussed separately in another paper as Part II of our contribution.

It is customary among hydrologists to study the antecedent rainfall over a period of only 30 days prior to the date of peak-discharge. However, in view of the phenomenal discharge of the river in the present case, the authors felt that it would be preferable to study the abnormalities in the synoptic situations over the *Brahmaputra* and the *Tsangpo* right from the time of onset of the southwest monsoon over the former State of Assam*

2. Basic material used in the synoptic study

The daily synoptic charts available in the India Meteorological Department at Weather Central, Pune and at the Weather Forecasting Office at Safdarjung Airport, New Delhi, for the months May, to August 1962 and the daily weather maps published by the Japan Meteorological Agency, Tokyo were utilised in the study.

The authors could not get State raingauge rainfall for any of the monsoon months of 1962. Hence, they had to be satisfied with rainfall data of the observatories maintained by the India Met. Dep. The observatories were only 14 in number and their locations may be seen in Fig. 1. The rainfall data of these 14 stations were taken from scrutinised rainfall records maintained by the India Meteorological Department.

3. Rainfall analysis

Table 1 contains the rainfall figures and statistics relating thereto, in respect of the 14 India Met. Dep. observatories for the period 1 June to 24 August 1962.

It will be seen from Table 1 that Pasighat in the extreme northeast of Arunachal Pradesh is the only station in the Brahmaputra basin (upto Gauhati) which recorded more than 250 mm of rainfall in 24 hours and had more than 75 mm of rainfall in 24 hours on 16 occasions during the above-mentioned period. The number of such occasions drops off to very low figures at stations further down in the catchment of the *Brahmaputra.* It is hardly necessary to point out that rainfall in Pasighat area alone could not have led to the phenomenal peak discharge of 72700 cubic metres per second. *We therefore infer that heavy rainfall must have occurred over a much larger area further upstream*

*Assam was the name, formerly in vogue for a complete State in extreme northeast India. This State has recently been politically divided into a number of divisions like Arunachal Pradesh, Meghalaya, Mizoram etc. However, for facility of each reference the name "Assam" will be used in this contribution whenever the entire area has to be referred to. The political division Arunachal Pradesh which will be frequently used in this paper is the northernmost division of the former State of Assam. The station Pasighat which will figure prominently in our discussions lies in the extreme northeast of Arunachal Pradesh. It is a *plain-station* at an altitude of 157 m asl.

TABLE 1

Rainfall (mm) in 24 hours ending 03 GMT as recorded at India Met. Dep. observatories over Brahmaputra basin (1 June to 24 August 1962)

India Met. Dep. observatory and its abbreviated symbol	Coordinates of station		Highest recorded rainfall (mm)	Number of occasions when rainfall (mm) in 24 hours occurred within specified limits				Number of occasion of 75 mm or more in 24 hrs
	Lat. (°N)	Long. (°E)		More than 250	249 to 200	199 to 150	149 to 75	
Pasighat (PSG)	28° 06′	95° 23′	320·8	3	0	1	12	16
Dibrugarh (DBH)	27° 29′	95° 01′	103·2	0	0	0	3	3
North Lakhimpur (LKR)	27° 14′	94° 07′	119·0	0	0	0	7	7
Sibsagar (SBG)	26° 59′	94° 38′	74·0	0	0	0	0	0
Tezpur (TZP)	26° 37′	92° 47′	80·6	0	0	0	1	1
Gohpur (GHP)	26° 50′	93° 35′	59·2	0	0	0	0	0
Golaghat (GLT)	26° 31′	93° 59′	97·2		0	0	1	1
Majbat (MJT)	26° 45′	92° 21′	235·0	0	1	0	3	4
Tangla (TNL)	26° 39′	91° 55′	59·0	0	0	0	0	0
Gauhati (GHT)	26° 06′	91° 53′	66·8	0	0	0	0	0
Shillong (SHL)	25° 34′	91° 53′	63·6	0	0	0	0	0
Lumding (LMD)	25° 45′	93° 11′	63·6	0	0	0	0	0
Kohima (KHM)	25° 38′	94° 10′	104·6	0	0	0	2	2
Haflong (HFL)	25° 10′	93° 01′	128·8	0	0	0	4	4

(*in the catchment of the Tsangpo*—Fig. 1). And this is confirmed by the synoptic patterns which we shall discuss in this paper.

It is relevant to mention in this connection that, in addition to Table 1, we had prepared similar heavy rainfall tables for the periods 1 to 30 June, 1 to 31 July and 1 to 24 August 1962. A similar table showing the daily rainfall (irrespective of the amounts) for the 30-day period (24 July to 23 August1962)—the period of "antecedent rainfall" accepted as a standard by hydrologists — was also prepared. All these tables bring out the same features as Table 1 except for minor differences. Hence, they have not been reproduced here.

4. Analysis of the synoptic situations

An analysis of the daily synoptic situations during the months May to August 1962 suggests that the abnormal floods in the third week of August 1962 were probably not solely due to heavy rainfall during the 30-day period prior to the peak discharge but, in some way, may be connected with the succession of such spells of heavy rainfall one after the other from the last week of May 1962 to the third week of August 1962. The synoptic situations associated with these spells have been described below with illustrations from synoptic material.

(a) *Unusually early advance of the monsoon over the catchment of the river in May 1962*

The early advance of the monsoon was associated with a depression which formed in the Bay of Bengal on 24 May and moved into Upper Burma by 26 May *vide* Fig. 2. Monsoon air brought into the lower troposphere over the Brahmaputra catchment in association with this low pressure system, was "pulled up" by the high level divergence in the westerlies in the middle and upper troposphere as seen in the sinusoidal wave-pattern (Ramaswamy 1956) in the upper westerlies over

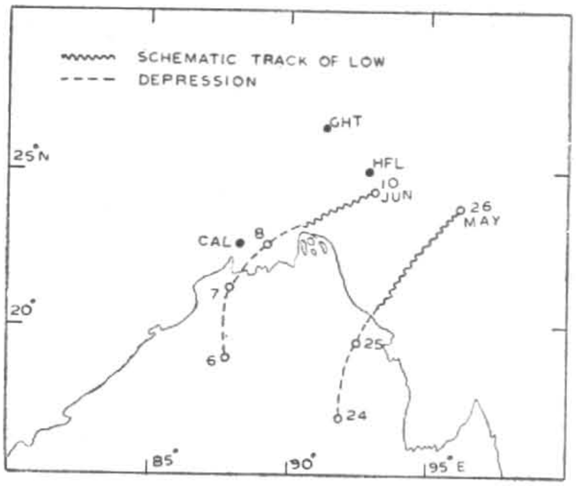


Fig. 2. Low pressure systems from the Bay of Bengal which influenced the weather over the catchment of the *Brahmaputra* in May and June 1962

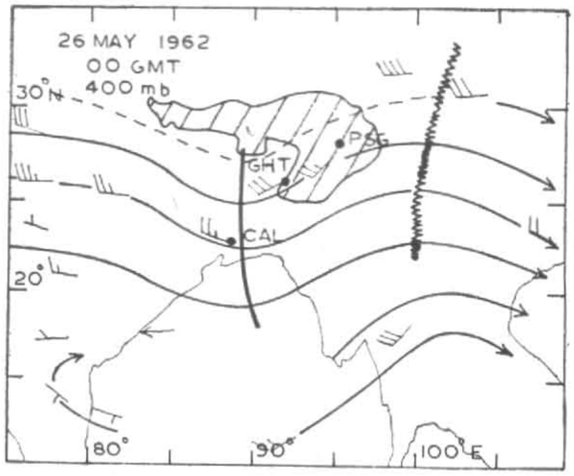


Fig. 3. Upper air flow pattern over and near India at the 400 mb level at 00 GMT on 26 May 1962.

[Continuous thin lines are stream-lines. The catchment of the *Brahmaputra* upto Pandu (Gauhati) and of the *Tsangpo* have also been roughly indicated (hatched area) in the diagram. Note that the *Brahmaputra* upto Pandu and the eastern half of the *Tsangpo* lie in the area where high-level divergence in the sinusoidal wave-pattern would be a maximum.]

RAINFALL (cm)

PASIGHAT (28°06', 95°23')	2·0	3·0	11·8	39·0	96·0	17·2	17·2
MOHANBARI (27°29', 95°01')	3·4	6·0	10·4	32·1	8·9	15·9	89·5
N. LAKHIMPUR (27°14', 94°07')	0·0	0·4	15·6	34·6	53·6	95·2	70·4
TEZPUR (26°37', 92°47')	0·0	0·0	6·6	80·6	37·4	17·8	5·0
MAJBAT (26°45', 92°21')	0·0	0·0	95·0	235·0	45·2	6·6	0·0
KOHIMA (25°38', 94°10')	39·9	30·6	101·0	26·7	3·1	26·6	49·8
HAFLONG (25°10', 93°01')	56·2	99·1	128·8	12·4	11·4	11·8	8·9

Fig. 4. Time-section of the winds over Gauhati and of rainfall at representative stations in the catchment of the *Brahmaputra* during the period 5 June to 12 June 1962

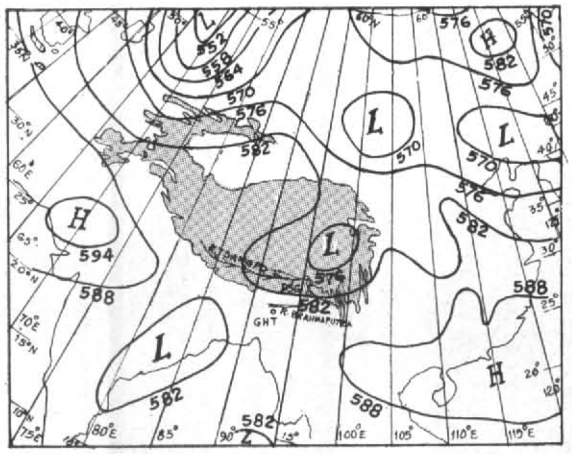


Fig. 5. 500 mb chart (12 GMT) of 22 June 1962 (Japanese charts)

[Through the courtesy of Japan Meteorological Agency, Tokyo]

the catchment of the river (Fig. 3). Consequent on this, the monsoon advanced over the area of the catchment on 26 May, one week earlier than the "normal" date (first week of June) and caused very heavy rainfall.

(b) *Strong monsoon in June 1962 in association with another Bay of Bengal depression*

Fig. 2 shows the track of another depression which developed in north Bay of Bengal and entered lower Assam as a 'low'. This system further activated the monsoon over the Brahmaputra basin.

An examination of the tracks of cyclonic storms and depressions in the Bay of Bengal during the 80-year period 1891-1970 (India Met. Dep. 1964, 1972) shows that this was *one of the two exceptional instances in which two cyclonic systems in the Bay of Bengal influenced, one after the other, the development of weather over the Brahmaputra catchment within a period of 14 days.*

Fig. 4 shows a time-section over Gauhati beween 5 and 12 June 1962 and the daily 24 hours rainfall at representative stations in the Brahmaputra basin. The strong easterlies below 850 mb level associated with the second 'low' from the Bay of Bengal referred to above and the heavy rainfall caused by this low is clearly brought out by the time-section. The area of occurrence of heavy rainfall is also consistent with the fact that the Bay of Bengal low influenced the rainfall much more in the lower than in the upper reaches of this river.

(c) *Spell of strong monsoon in the upper reaches of the river between 22 and 28 June 1962*

Fig. 5 shows the 500 mb contours over southeast Asia on 22 June 1962. These have been reproduced from printed charts published by the Japan Meteorological Agency at Tokyo. The contour have been drawn by the Japanese meteorologists at 60-metre intervals. It is interesting to see that there is a deep low over the southeast corner of the Tibetan plateau. The position of Pasighat and the course of the *Tsangpo* with reference to this deep low over the southeast of the Tibetan plateau may be particularly noted. As this cyclonic system to the southeast of the plateau will frequently be referred to in the later sections, we shall, for the sake of brevity refer to this as the cyclonic lee-vortex or simply as a "lee-vortex". We may mention even at this stage that, in certain situations, a closed vortex does not exist but instead, only an open-trough. We shall refer to the latter as a "lee-trough". The genesis of the lee-vortex and lee-trough will be discussed in detail in one of the later sections.

The lee-vortex seen in Fig. 5 caused very heavy rainfall over the Pasighat region and possibly over the eastern half of the *Tsangpo* also. Fig. 5 also shows a deep trough in the westerlies on 22 June with its axis near 70°E. This trough later moved eastwards, increased in amplitude over the Tibetan plateau (as is to be expected) and moved as a weak system over the Tsangpo and Arunachal Pradesh.

Fig. 6 shows a time-section of the winds over Gauhati and of the heavy rainfall which occurred over Pasighat, North Lakhimpur and Majbat during the period 22 to 28 June. The precipitation between 22 and 24 June was caused by the lee-vortex seen on the 500 mb chart in Fig. 5. The heavy rainfall between 24 and 28 June was caused by the successive movement of the two troughs in the westerlies seen in Fig. 6 and on the 500 mb charts of the corresponding dates (not reproduced in the paper). There was no clear evidence to indicate

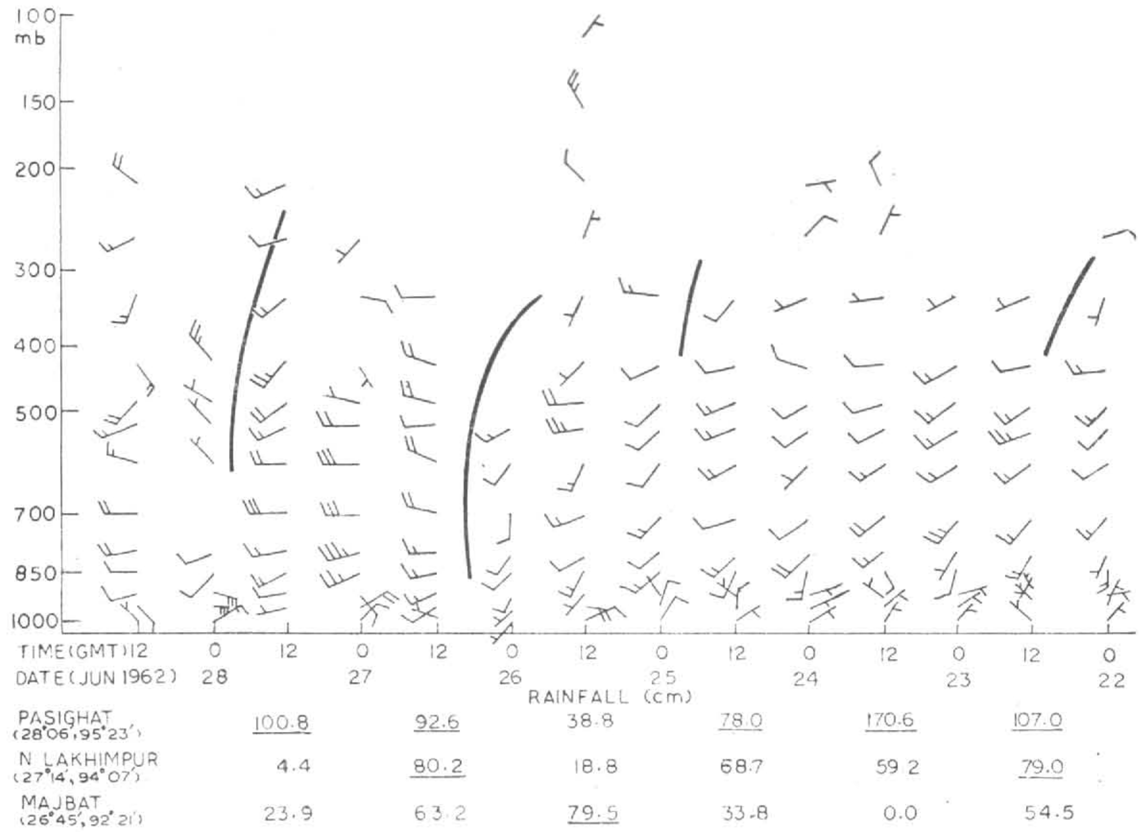


Fig. 6. Time-section of the winds over Gauhati and rainfall at representative stations in north Brahmaputra basin during the period 22 June to 28 June 1962

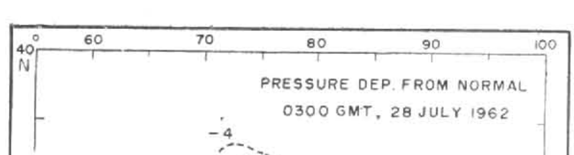


Fig. 7. Pressure-departures from normal over the Indian sub-continent at 0300 GMT on 28 July 1962

[Note the large negative pressure-departures along the foot of the Himalayas. Note also the positive anomalies over the western half of Peninsular India. The isopleths are for whole millibars]

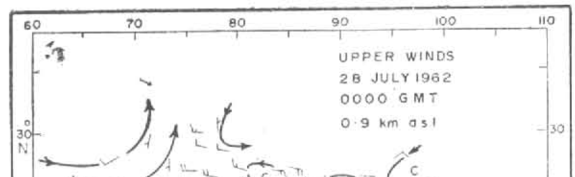


Fig. 8. Upper winds and streamlines at 0.9 km asl over the Indian sub-continent at 0000 GMT on 28 July 1962

TABLE 2

Rainfall (mm) over north Brahmaputra basin (in India) between 15 and 23 August 1962

(Peak-discharge at Gauhati — 24 August 1962)

Date (Aug 1962)	PSG	DBH	LKR	SBG	TZP	GHP	GLT	MJT	TNL	GHT
15	7·0	2·1	3·1	0·4	8·8	0·0	0·0	9·2	4·2	0·0
16	**122·0**	57·1	22·0	0·5	5·1	14·4	4·4	21·2	0·0	6·4
17	**320·8**	38·6	13·9	22·0	15·6	41·4	8·6	16·4	6·4	4·0
18	**311·6**	30·1	62·9	7·2	44·6	18·8	8·2	40·0	9·0	11·8
19	**259·7**	50·0	53·0	14·0	22·6	25·0	0·0	72·6	49·5	6·0
20	**105·8**	38·2	8·3	0·5	7·5	2·2	0·0	30·5	25·5	13·2
21	**76·6**	Trace	12·2	4·3	1·8	12·6	42·0	6·4	0·0	6·4
22	2·8	8·2	5·6	4·1	0·0	6·2	0·0	28·0	0·0	9·0
23	0·4	0·0	10·6	0·0	0·0	0·0	6·8	0·0	0·0	0·0

that either of the weak troughs in the westerlies merged with the lee-vortex at any stage.

(d) *Fairly active monsoon in the upper reaches of the river in the first week of July 1962*

Fairly active monsoon conditions prevailed over and near the Pasighat region in the first week of July. The Japanese charts show that lee-troughs at the 500 mb level contributed mostly to the development of the fairly active monsoon conditions.

(e) *Active monsoon over the catchment of the river in the last week of July 1962*

Fig. 7 shows a typical chart showing the departure of sea-level pressure from normal over the Indian subcontinent in the last week of July 1962. The distribution of rainfall over India on this day (diagram not reproduced in this paper) reminds us of break-conditions in the monsoon in the sense that the rainfall was heavy along and near the foot of the Himalayas with little or no rain in the central parts of the country and scanty rainfall over the west coast of Peninsular India. We could not, however, classify this situation as a " break in the monsoon" in view of the fact that easterlies prevailed at 0·9 km asl along the foot of the Himalayas (Ramamurty 1969). Fig. 8 which shows a series of cyclonic vortices at 0.9 km on 28 July is relevant in this connection. We therefore prefer to refer to this situation as a "quasi-break condition". It may be mentioned that the Pasighat region lay during this spell at the periphery of a "lee-vortex" at the 500 mb level on several days. The existence of the lee-vortex became more conspicuous when the contours were drawn by us at 40-metre intervals (instead of at 60-metre intervals as drawn by the Japanese scientists).

The lower tropospheric systems referred to above aided by the quasi-break situation and the lee-vortex at the 500 mb level were mainly responsible for active monsoon over the Brahmaputra basin in the last week of July 1962.

(f) *The monsoon during the first two weeks of August 1962*

The activity of the monsoon over the Brahmaputra basin between 1 and 9 August 1962 was subdued. This was because a low pressure system from the north Bay of Bengal was moving west-northwestwards into the interior of the country, and during such periods, the monsoon is normally feeble over extreme northeast India. As the Bay of Bengal low pressure system moved away west-northwestwards, the southeasterlies over northeast India veered to southerlies over Assam. In such situations, the monsoon becomes generally more active over Assam. The schematic flow patterns of type B in July and August published by one of us (Ramaswamy 1972) is relevant in this connection. The rainfall over Assam between 10 & 14 Aug was consequently heavier than between 1 & 9 Aug.

(g) *Vigorous monsoon over Pasighat region and the eastern half of Tsangpo during the third week of August 1962*

The third week of August is the crucial period in the activity of the monsoon over the Pasighat region and the eastern half of the *Tsangpo*. It was the activity during this period which contributed most to the peak-discharge at Gauhati (Pandu) on 24 August. We shall, therefore, go into this situation a little more in detail.

TABLE 3

Rainfall (mm) in 24 hours ending at 0300 GMT in August 1962

Date (Aug 1962)	West coast			East Rajasthan			Deccan plateau	Central parts of country			East coast	
	BMB	RTN	MNG	JPR	JLR	KTA	HYD	NGP	AKL	SNI	KND	VSK
16	5·1	18·5	84·6	0·0	51·6	2·0	0·0	36·0	4·1	28·7	68·0	0·0
17	16·9	4·6	69·9	0·8	3·6	3·0	1·3	20·3	1·0	61·4	116·0	8·3
18	0·2	10·4	12·2	0·0	0·0	1·6	0·6	0·1	20·4	6·6	—	0·4
19	10·6	10·2	43·0	16·6	14·8	1·4	0·0	0·0	2·6	0·4	5·2	10·4
20	0·9	6·2	3·8	0·0	0·0	5·0	1·2	2·5	0.7	0·0	0·0	0·0
21	5·0	8·2	0·0	0·0	0·0	0·0	1·4	0·0	0·0	2·2	0·0	22·3
22	7·6	8·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	41·8	0·0
23	0·6	2·4	1·1	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	7·1

Additional comments:

03 GMT 18th — Barmer and Jodhpur in the arid zone in West Rajasthan had reported respectively 61·5 mm and10 mm of rain.

Ajmer in East Rajasthan was having continuous slight rain at 03 GMT.

03 GMT 19th — Jodhpur in West Rajasthan had reported 1·6 mm of rain.

Table 2 shows the rainfall over the north Brahmaputra basin (*i.e.*, along the foot of the Himalayas) as recorded at the India Met. Dep. observatories during the period 15 to 23 August both days inclusive. Rainfall exceeding 75 mm (in 24 hours) has been printed in the table in thick print.

Table 2 clearly shows the following :

(*a*) Rainfall exceeding 75 mm occurred only in Pasighat;

(*b*) Rainfall abruptly *increased* over Pasighat on 16th and reached a maximum on 17th and 18th;

(*c*) There was a sharp *decrease* in rainfall at almost every station after the 19th.

Table 3 shows the 24-hour rainfall (in mm) at representative stations on the west coast of the Peninsula, in the Deccan plateau, East Rajasthan, the central parts of the country and the east coast of the Peninsula between 16 and 23 August 1962.

Table 3 and the additional information given at the bottom of the table clearly show that almost all the stations had significant rainfall upto the morning of 19th and that the amounts sharply decreased on the 20th. The additional comments about other stations given at the bottom of the table may also be noted.

Now, the generally-accepted criteria for declaration of a "break in the monsoon" are :

(*a*) sharp decrease in the rainfall over the central parts of the country ;

(*b*) significant decrease in rainfall on the west coast and the northern half of the Deccan plateau ;

(*c*) no rainfall in semi-arid areas like East Rajasthan and certainly no rainfall in an arid zone like West Rajasthan ;

(*d*) disappearance of easterlies at the surface and below 1·0 km over the Gangetic plain.

None of the criteria given above were satisfied upto 19 August. *We therefore arrive at the important conclusion that large-scale break-situation developed over the country only on and after the morning of 19 August.*

Turning our attention again to Table 2, we are of the opinion that if a break-situation had been responsible for heavy rainfall over Pasighat, the rainfall over that station and other stations in Table 2 should have *increased* after the 19th. It was, however, *just the opposite*, showing thereby that the exceptionally heavy rainfall over the Pasighat region and the significant amounts of rainfall at other stations in the North Brahmaputra basin, between 16th and 19th were not associated with break-conditions in the monsoon but with some other system. What this other system was, may be seen in the12 GMT 500 mb Japanese chart for 17 August in Fig. 9. It will be seen from this diagram that there was a west to east oriented lee-vortex over the southeast of the Tibetan plateau on 17th. The course of the *Tsangpo* and the position of Pasighat with reference to this "lee-vortex" may be noted.

As stated on an earlier occasion, the Japanese scientists have drawn the contours at 60-metre intervals. We would point out that the lee-vortex could be indentified at the 500 mb level on the 16th (previous day) as well as on the 18th (next day) on the 12 GMT charts by drawing contours at less than 60-metre intervals. The position of the lee-vortex on the 18th was somewhat northeastward of its position on 17th.

The trough in the westerlies with its axis between 65°E and 70°E on 17 August *vide* Fig. 9 began to move eastwards as a separate entity. The main system moved to the north of the Tibetan plateau. But a "low" developed to the south of the Tibetan plateau on 18 August, moved eastwards along the foot of the Himalayas and crossed Arunachal Pradesh on 20 August. This low was responsible for the rainfall of 76·6 mm reported by Pasighat on the morning of 21 August *vide* Table 2. The above analysis is supported by the charts prepared at the Weather Forecasting Office at Safdarjung, New Delhi and also by the 500 mb charts published by Japan Meteorological Agency at Tokyo.

It is interesting to note that the Japanese charts for the 500 mb level did not contain even a feeble indication of a lee-vortex or a lee-trough over or near the Pasighat region on the 12 GMT charts of 21st. This is considered as significant because the rainfall over Pasighat region sharply decreased after the morning of 21st.

We conclude from the above analysis that the factor which contributed most to the exceptionally heavy rainfall over Pasighat between 16th and 20th was the lee-vortex and that the wave in the westerlies and the break-situation in the monsoon played a very secondary role in the production of very heavy rainfall over the Pasighat region. We also infer from this analysis that the very heavy rainfall which had occurred between 16th and 20th would have considerably swollen the eastern half of the *Tsangpo* river and the *Brahmaputra* near Pasighat where the river was already in high flood. These remarkable developments would have led to the observed peak-discharge at Gauhati (Pandu) on 24 August.

5. Genesis of the lee-vortex to the southeast of the Tibetan plateau

In a very interesting paper published in the January-February 1977 issue of *Scientia Sinica* a group of 10 Chinese scientists (Li Kuo-Ching *et al.* 1977) have reported on an experimental simulation of the atmosphere over and near the Chinghai-Tibetan plateau. They have simulated atmospheric motion by fixing a model plateau inside a body of rotating fluid, heating the model-plateau wholly or in different parts, using different Rossby numbers and controlling the rate of motion of the rotating fluid. Their findings are briefly summarised below so far as they are relevant to our present investigation :

(*a*) In the case of a non-heated model plateau and high Rossby numbers, only lee-troughs form to the southeast of the model plateau. No vortices form under such conditions.

(*b*) As the plateau is progressively heated but below a certain limit, there is a greater and greater tendency for the formation of lee-vortices to the southeast of the model-plateau. These vortices are not ordinary heat-lows as they are not formed over the heating source and are much smaller than the heat-lows.

(*c*) With low Rossby numbers, lee-troughs extend westwards to form a WSW-ENE oriented tilted trough which may reach as far as north Bay of Bengal as in the actual weather charts prepared in China. Along this tilted trough, vortices are frequently formed.

(*d*) The value of the Rossby number is of great importance in determining the formation of lee-vortices and their structure.

(*e*) The vortices are more pronounced with weak basic westerlies than with strong basic westerlies over and around the plateau. Consequently, the lee-vortices are more pronounced in conditions corresponding to June than in April or January.

(*f*) The lateral extent of the simulated lee-vortices is 400-1000 km at the 700 mb level. Thus, they are of the same order of magnitude as have been actually observed on the Chinese synoptic charts.

(*g*) Simulated vortices which form to the west of the Tibetan plateau get decelerated as they move eastward. They also become diffuse and lose their identity by the time they cross the model plateau. However, when these vortices to the west of the plateau are deep enough, they can cross the plateau and then they regenerate over and near the Hengtuan range.

(*h*) As the experiments are still of a preliminary nature, it would be incorrect to assume at this stage that the simulated motion would agree in all respects with the motion actually observed in the atmosphere over and around the Chinghai-Tibetan plateau.

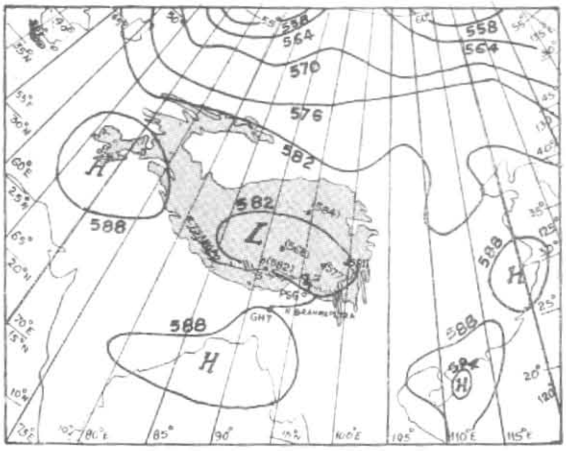


Fig. 9. 500 mb chart (12 GMT) of 17 August 1962 (Japanese charts)

[Through the courtesy of Japan Meteorological Agency, Tokyo]

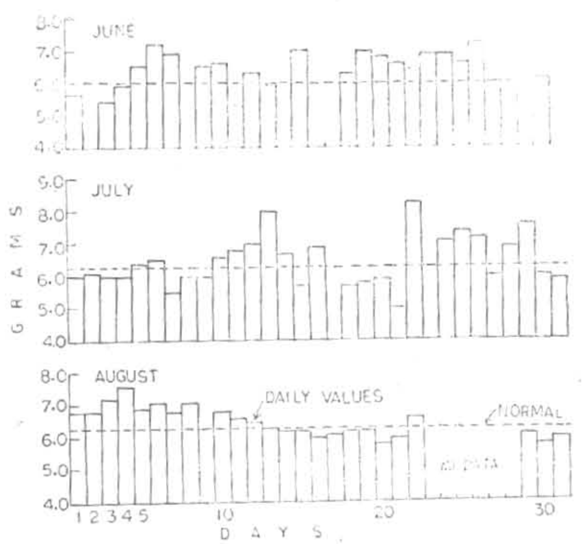


Fig. 10. Daily variation of total precipitable water over Gauhati during the period June to August 1962

6. Importance of the lee-vortex in the development of floods in Brahmaputra basin

The laboratory experiments performed by Li Kuo-Ching *et al.* (1977) and the schematic patterns published by these Chinese scientists of the simulated vortices are of great interest to us from the point of view of the development of heavy rainfall over and near the Pasighat region and further upstream, *i.e.*, over the river *Tsangpo.*

From the literature referred to above and from our study of the 500 mb charts* published by the Japan Meteorological Agency and of the charts for the Indian subcontinent prepared in the India Met. Dep. we arrive at the following general conclusions :

(*a*) The lee-vortices actually observed at the 500 mb level to the southeast of the Tibetan plateau are quasi-stationary in

*The 500 mb charts published by the Japan Meteorological Agency cover the whole of Asia and even northern Africa. The 700 mb charts are however much more restricted west of 100° E. We have based our conclusions from a study of the 500 mb charts.

character. The mean position of the centre of the lee-vortex at the 500 mb level in June, July and August 1962 is 31°-32°N and 97°-98°E. Their lateral extent at the same level is about 400 to 1000 km, *i.e.*, of the same order of magnitude as that found by the Chinese scientists in their laboratory experiments.

(*b*) The lee-vortex is not always seen on the printed Japanese charts. It is, however, to be remembered that, in the Japanese charts, contours have been drawn at the 500 mb level at 60-metre intervals. It is, therefore, difficult to keep track of the vortices from day to day, when they begin to weaken. Sometimes, they appear only as lee-troughs at the 500 mb level. However, they have also occasionally become more deep at the 500 mb level when they consist of 2 closed contours (drawn at 60-metre intervals).

(*c*) The lee-vortices play an important role in the development of weather over the Pasighat region and the eastern half of the *Tsangpo* when they are in the appropriate position.

7. Total precipitable water over the catchment of the *Brahmaputra*

Fig. 10 shows the total precipitable water (in grams) over Gauhati upto 500 mb level, daily between 1 June 1962 and 31 August 1962. For purposes of comparison, the monthly mean precipitable water (upto 500 mb level) over Gauhati in June, July and August (Mokashi 1971) have been shown on the respective graphs for June, July and August 1962. The precipitable water has been computed by the same method as was done by Mokashi (1971).

We can safely assume that the figures of precipitable water computed with the radiosonde data of Gauhati, would be reasonably valid for the area of Pasighat which is 450 km to the northeast of Gauhati. We immediately note from Fig. 10, that an increase in rainfall over Pasighat does not depend upon an increase in the amount of precipitable water in the atmosphere. In particular, it may be seen that the precipitable water between 16 and 20 August 1962 was actually less than the mean precipitable water on some days. This is presumably due to the fact that lower temperature in the atmosphere on account of rain-cooling was responsible for the smaller amount of precipitable water-vapour in the atmosphere. We thus conclude that it is not dearth of water vapour which led to smaller amount of rainfall on any particular day. It is the variation in the potency of the mechanism responsible for lifting the air-parcels which determines whether there would be lesser or greater amount of rainfall on any particular occasion.

8. Conclusions

Based on the above detailed study, we arrive at the following conclusions :

(*a*) The very large floods which occurred in the *Brahmaputra* in August 1962, were due to exceptionally heavy rainfall over the extreme northeast of Arunachal Pradesh and (by inference) over the eastern half of the *Tsangpo*.

(*b*) The lee-vortex observed by us at the 500 mb level, is essentially the same as the one generated to the southeast of the Tibetan plateau in the simulation experiments of the atmosphere, conducted by Chinese scientists.

(*c*) The lee-vortex contributed far more to the development of heavy rainfall over the Pasighat region and the eastern half of the *Tsangpo* in the monsoon season of 1962 than any other single factor such as quick succession of northeastward-moving low pressure systems from the Bay of Bengal, eastward moving waves in the westerlies and break-situation in the monsoon.

(*d*) A study of the large-scale synoptic systems to the north and northeast of Arunachal Pradesh on a day to day basis is "a must" if we are to issue reasonably accurate forecasts of heavy rainfall which have their origin in the upper reaches of the *Brahmaputra* and over the *Tsangpo*. In particular, the synoptic climatology of the above-mentioned region at the 700 and 500 mb levels with special reference to weather over the Brahmaputra basin, must be developed and used in day-to-day synoptic practice.

(*e*) While we do not under-estimate the importance of the synoptic systems which led to the antecedent precipitation during the 30-day period prior to the peak-discharge on 24 August, we are of the opinion that weather systems right from the time of onset of the monsoon must have played a role, however minor in the development of very high floods in the *Brahmaputra* in August 1962.

(*f*) In Arunachal Pradesh and elsewhere in Assam, there is enough precipitable water to cause very heavy rainfall over those areas during the southwest monsoon period.

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