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Orographical influence on the air flow over Brahmaputra Valley

A. K. MUKHERJEE and S. K. GHOSH

Meteorological Office, Gauhati Airport

(*Received 28 July 1961*)

ABSTRACT. Airflow over Assam during different seasons has been examined. It has been shown that except during the monsoon, easterly air at the lower levels originates from the Himalayas. These are more marked during winter. Similarly it has been shown that there is a tendency for air to flow towards Himalayas during monsoon. Basing on this tendency the distribution of fog in winter over the whole valley has been explained. The effect of this air on the formation of thunderstorm activity over Brahmaputra valley has also been indicated.

1. Introduction

To study the weather over a particular place, the air flow over it should be clearly understood. From synoptic charts we get the idea about the pressure distribution and the resulting air flow over a vast area in a broad way. Over the Brahmaputra valley the air flow in the lower levels is not generally consistent with the pressure distribution as can be seen from the Climatological Atlas (India met. Dep. 1943). It follows, therefore, that the prevailing wind over the valley is the result of super-imposition of local factors on the air flow resulting from the existing pressure distribution.

The Brahmaputra valley has the Himalayan range and the Tibetan plateau to the north, Garo-Khasi-Jaintia and Naga hills to the south and the mountains of Yunan to the east. The average heights of these barriers are 4 km, 1 to 1·5 km, and 3 km respectively. The river Brahmaputra flows along the whole length of the plain enclosed by the hills. The river is 4 km wide on the average, the minimum and the maximum widths being 1 km and 8 km respectively. The Brahmaputra valley is 550 km long and 70 km wide. As stated the local relief has a profound influence on the wind over a place or an area. To understand the air flow over the valley we should, therefore, know the relief of the valley and the neighbourhood. "The Tibetan Plateau has roughly the shape of an ellipsoid. Its major axis is over 3000 km long and its minor axis over 1400 km. Connected with the adjacent plateau, the Sinkiang-Mongolian Plateau, their latitudinal width can be compared with that of the westerlies and their extension can be compared with the wave length of the long waves. Its average height is over 4 km occupying more than a third of the troposphere. Such a huge intrusion in the westerlies will no doubt have a profound dynamic influence on the general circulation. Considering it as a radiating body well high in the atmosphere it will also have a thermal influence on the circulation" (Academica Sinica 1958). Rai Sircar and Patil (1961) have found that the thermal condition over the Himalayas and the Tibetan plateau may have a considerable influence on the northward progress of the monsoon current. Presumably these thermal conditions are due to the existence of the Tibetan plateau. Thus the Tibetan plateau, which has influence on the large scale circulations of the atmosphere is expected to have considerable influence on the local circulation also.

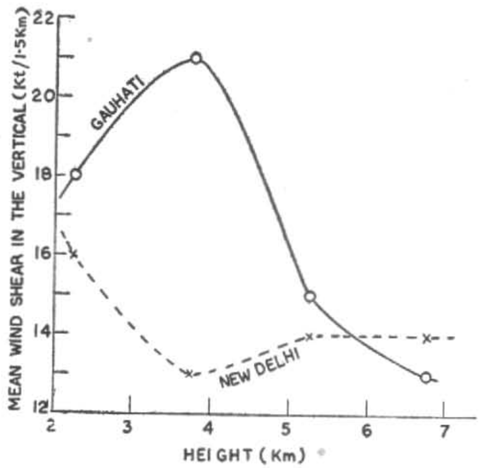

Fig. 1

In the present paper the air flow over the Brahmaputra valley has been studied and the possible orographical influence, particularly the influence of the Tibetan plateau on the air flow over this valley, has been investigated.

2. Observations for winter

In the winter north India is generally free from weather except in association with the western disturbances. In view of this, winter has been considered as the best season to understand the influence of the local factors.

2.1. *Easterlies in the lower levels*

The first peculiarity in the lower levels that can be observed is that the easterlies blow over the valley during the winter. These easterlies gradually decrease in speed as we go up and between 1·5 and 3·0 km a.s.l. the flow changes to westerlies (Krishnan, Pant and Ananthakrishnan 1961). There is, therefore, a region of light variable winds between 1·5 and 3·0 km a.s.l.

It becomes evident from the streamlines and also from the pressure distribution over Indo-Pakistan sub-continent as given in the climatological charts that these easterlies do not conform to the pressure distribution.

2.2. *Strong westerly shear in the vertical near 4·0 km a.s.l.*

It can be seen cn the climatological charts that at 4·0 km a.s.l. strong westerlies blow over the valley. This indicates the presence of strong westerly wind shear in the vertical near that level. In the northern hemisphere, particularly during winter, ambient temperature at any level below the tropopause decreases as we go north. This means that there should always be westerly wind shear in the vertical.

The presence of easterlies in the lower level and strong westerlies at 4·0 km a.s.l. over the valley suggests the presence of a stronger shear than is expected. To check this upper wind, observations of a station on the Brahmaputra valley have beem compared with those of a station west of it. For analysis of wind data over the valley, Gauhati observations have been taken as rawin observations are available for this station only. New Delhi has been selected as a station west of the valley.

The wind shear along the vertical for the period 16 December to 15 January for the three winter seasons, 1957-58, 1958-59 and 1959-60 were compared. Mean of the daily shear of the westerly components of the wind has been found out. Wind shear has been calculated for every 1·5 km from 1·5 km a.s.l. The result of the comparison has been shown graphically in Fig. 1. It is apparent from the graph that the maximum wind shear of 21 kt per 1·5 km in the vertical over Gauhati is at 3·75 km a.s.l. and there is no such pronounced wind shear at New Delhi. Rough comparison of wind shear over Allahabad and Jodhpur with that over Gauhati also brings out similar difference.

2.3. *Strength of the westerlies*

In the climatological charts isotachs are drawn. It is found that at 4·0 km over north India westerlies are strongest over the Brahmaputra valley. To show that winds near this level is strongest over the valley winds at 4·5 km a.s.l. over Gauhati with those of Allahabad were compared for January and December from December 1957 to January 1960 and the results of comparison are shown in Table 1.

3. Explanation of the observations

To explain the above observations, we have to understand the influence of the local factors. In Sec. 2.1 it has been stated that easterlies in the lower levels over the Brahmaputra valley do not conform to the prevailing pressure distributions. The high pressure area over northwest India and West Pakistan cannot cause an easterly flow. The Siberian 'High' causes easterly winter monsoon over China. "The Himalayas to the north and mountains of Yunan and Burma to the east prevent these easterlies from reaching India" (Byers 1959). Hence these easterly winds appear to be local winds.

Accepting them to be local winds, we can now construct the local wind system, as suggested above, blowing over the valley. As is well known there is a downslope or katabatic wind on a diurnal scale resulting from the cooling of hills or mountains during night. Any land mass over northern hemisphere loses heat during winter. It is reasonable to expect that due to extra cooling on a seasonal scale (winter), the katabatic wind may blow over a favourably situated place.

It is suggested that these easterlies over the Brahmaputra valley are katabatic winds on a seasonal scale as no other local

TABLE 1

		Time (GMT)	n	D_n	V_R
ALLAHABAD (4·5 km a.s.l.)					
1957	Dec	03	23	275	29·0
		12	28	277	28·3
1958	Jan	00	28	277	27·1
		12	30	275	29·7
	Dec	00	28	288	24·6
		12	30	283	24·7
1959	Jan	00	30	271	31·2
		12	30	272	32·7
	Dec	00	31	275	27·5
		12	30	277	28·7
1960	Jan	00	29	270	27·2
		12	31	274	29·3
GAUHATI (4·5 km a.s.l.)					
1957	Dec	00	31	275	41·6
		12	30	275	43·8
1958	Jan	00	30	275	37·7
		12	31	277	38·3
	Dec	00	31	278	28·2
		12	31	273	30·0
1959	Jan	00	29	275	39·0
		12	31	271	42·5
	Dec	00	31	270	35·4
		12	29	268	40·8
1960	Jan	00	31	260	33·1
		12	31	273	35·2

n=Number of observations, D_n = Direction of resultant wind in degrees, V_R = Mean resultant wind in knots

TABLE 2

Number of days of occurrence of fog

Average for January and December

(December 1957 to January 1960)

South bank		North bank	
Station	No. of days	Station	No. of days
Gauhati	35	Rupsi	16
Jorhat	44	Tezpur	10
Mohanbari	36	North Lakimpur	9
		Pasighat	1

wind system is conceivable from the geography of the place. The Himalayan range and the Tibetan plateau to the north constitute the highest orography. We can, therefore, assume that the Himalayan range and the Tibetan plateau cools down excessibly during winter and katabatic wind starts flowing from them.

This wind should blow along the valley. As this valley slopes down from east to west, these winds should be easterlies. These easterlies should be stronger at the lower levels and gradually weaken as we go up. This is what is actually observed and is mentioned in Sec. 2.1. Easterlies should have blown upto 4·0 km, the mean height of the Tibetan plateau. In absence of orography northwesterlies should have blown over the valley as is expected from the pressure distribution over India. Thus the westerlies will try to exert themselves against the local wind system. This is why the westerlies appear over 2·0 km a.s.l. as the katabatic wind is expected to be weak at higher levels. Between 1·5 and 3 km a.s.l. we get region of light variable winds where those two wind systems try to exert themselves between each other. This explains the observations mentioned in Sec. 2.1.

As in all mountain wind systems there should be a counter current in this case also. The katabatic winds here are easterlies and hence the counter current blowing at the southern edge of Tibetan plateau should be westerlies and should blow at 4·0 km a.s.l. The normal westerlies over the valley are likely to get laterally mixed with this westerly counter current. Whereas the westerlies below 4·0 km are opposed by the katabatic winds those above 4·0 km are accentuated causing a pronounced wind shear in the vertical. This is why wind shear in the vertical over Gauhati (21 kt) is stronger than that over New Delhi (13 kt) at 3·75 km a.s.l. This explains the observations mentioned in section 2.2.

The counter currents accentuate the westerlies. No cause for accentuation of westerlies is known to be present over any other place at the corresponding height over northern India. The counter currents in a mountain wind system are expected to be shallow. Thus the effect of accentuation should vanish after a certain height. That is why strong westerlies are found at 4·0 km a.s.l. and are not found at and above 6·0 km a.s.l. This explains the observations mentioned in Sec. 2.3.

3.1. *Associated Weather*

The main weather over the valley is fog. Fog is formed by two conditions, *viz.*, (*a*) sufficient moisture in the lowest level of the atmosphere and (*b*) sufficient cooling. In northern India cooling seems to be sufficient over most places but the low moisture content prevents the formation of fog. In Brahmaputra valley the amount of moisture available seems to be high and that is why fog occurs very frequently. Accepting that the easterlies at lower levels are mountain winds we have to admit that the available moisture at the lowest level comes from local sources. In the present case, the river Brahmaputra may be supposed to be the local moisture source for the valley. The mountain wind should blow along the valley.

Since this is heavy and blows under the action of gravity, it should take a course usually taken by the rivers. As such it should blow along the Brahmaputra. As the katabatic wind originates from the north it is also expected that the winds along the valley should have a northerly bias. Thus winds blowing along the river will evaporate moisture during its travel and this moisture should be carried to both banks of the river. If the winds have a northerly bias more moisture should be carried to the south than to the north bank. This would mean that the frequency of fog will be higher on the south bank than on the north bank of the river Brahmaputra. Frequency of fog given in Table 2 brings out the same.

4. Pre-monsoon

During the pre-monsoon season the pressure distribution over India changes resulting in certain changes in the air flow over the valley. The orographical influences on the air flow during this season have been discussed in the following paragraphs.

4.1. *Easterlies in the lower levels*

After accepting that the easterlies over the Brahmaputra valley during winter are mountain winds on a seasonal scale we now proceed to the easterlies in the pre-monsoon season. Once the easterlies set in during winter they should continue to prevail till the Tibetan plateau and the Himalayan ranges get sufficiently heated up to make up the difference of their temperature from that of the adjacent air over the valley. The Tibetan plateau may get heated up in two processes, *viz.*, insolation and the transport of heat by air flowing over it. As the Tibetan plateau is mostly snow covered during winter it will reflect back most of the solar energy incident on it. The little portion of the energy that will be absorbed will be used up as latent heat in converting snow into water. The Tibetan plateau slopes down gradually from west to east. The prevailing westerlies will have a long travel over the western side of the plateau before reaching its part to the north of the Brahmaputra valley. These westerlies will have contact with the snow covered surface for a long time and will, therefore, be considerably cooled before reaching the part of the plateau with which we are concerned. The Brahmaputra valley on the other hand will absorb more solar radiation. There is no cooling process operating on the westerlies reaching the Brahmaputra valley at the level of the plateau. It follows, therefore, that the Tibetan plateau will continue to remain colder than the air over the Brahmaputra valley at the corresponding level. Hence the easterlies over the valley, shown to be mountain winds on a seasonal scale, will continue to blow during the pre-monsoon season.

4.2. *Southerlies entering the valley*

"The main seasonal feature over north India in April and May on the lower level charts upto 3000 ft (0·9 km) is the existence of a trough of low pressure over Uttar Pradesh and north Bihar, with its axis or troughline running in a WNW—ESE direction. Around this trough, WSW/W-ly current normally blows over Assam in the lower levels. With the passage of western disturbances or otherwise, the seasonal trough often gets accentuated and extends southeastwards into the Gangetic West Bengal and neighbourhood or eastwards into north Bengal causing incursion of moist southwesterly to southerly air from the Bay of Bengal into Assam. Quite often from extreme northeast Assam, ENE/E-ly current, which is relatively dry and somewhat cooler blows westwards across the foot of the Himalayas" (Sen and Basu 1961). That these easterlies should be dry and cooler in comparison to the southerlies can be understood from the theory of origin of the easterlies at the lower levels, as given in the preceding paragraphs. The southerlies approaching the Brahmaputra valley originate from the Bay of Bengal; so they are warm and moist. On the contrary, as mentioned earlier, the easterlies originate from the

Tibetan plateau and are, therefore, cool and dry.

We now propose to discuss how the presence of Naga-Khasi-Jaintia-Garo hill range influences the air flow over the Brahmaputra valley. This range runs from east to west from 95°E to 90°E longitudes between 25°N and 26°N latitudes. On its east, run the mountains of Burma almost perpendicular to it. Southerlies approaching the Brahmaputra valley, are, therefore, obstructed by these ranges. The easterlies originating from the Tibetan plateau and blowing over the Brahmaputra valley are also protected from mixing with the southerlies. As the average height of the range is less than 1·5 km a.s.l., this sort of protection should be confined to a level not more than 1·5 km a.s.l. It is normally supposed that "the existence of these ENE/E-ly air over the extreme north Assam and warm moist southwesterly to southerly air from the south results in an E-W line of wind discontinuity over upper Assam" (Sen and Basu, *loc. cit.*). As explained earlier, the wind discontinuity is apparent on the chart by the separation of two air currents of different origin by the Naga-Khasi-Jaintia-Garo range. Strong southerlies can, however, cross over the barrier at levels 1.5 km and above. These are expected to remain above the easterlies over the Brahmaputra valley as these are warmer and more moist (with the progress of the summer season easterlies are likely to weaken) and should not normally descend unless forced by some mechanism to do so. One possible mechanism to bring down the warm moist southerlies on the Brahmaputra valley is suggested below. At night, when the Garo-Khasi-Jaintia hills cool down more rapidly than the plains katabatic wind blows down the slope towards the valley. This, in turn, brings down the moist air on the valley. There will, therefore, be a front like structure during night, having two different types of air on either side. This is probably the reason why the pre-monsoon thunderstorms occur over the Brahmaputra valley mostly during night.

5. Monsoon

Wind circulation over the Brahmaputra valley during the monsoon is generally consistent with the prevailing pressure distribution. The prevailing winds over the Brahmaputra valley are easterlies in the lower levels. But these easterlies will be quite different from those during winter and pre-monsoon. In the latter case the easterlies originate from the Tibetan plateau as has been explained earlier. Towards the end of the pre-monsoon, the snow over Tibet melts and the plateau gradually warms up, katabatic winds should cease to blow. Thus the mountain winds which blow during winter and pre-monsoon, should not prevail during the monsoon.

5.1. *Seasonal valley wind*

It has already been shown that mountain winds blow on a seasonal scale. It is probable, therefore, that a valley wind will also blow on a seasonal scale under favourable conditions, *viz.*, when the Tibetan plateau becomes more heated than the air over the Brahmaputra valley at the corresponding level. July is the hottest month in the Northern Hemisphere. Over the Brahmaputra valley, August is found to be hottest. The Tibetan plateau is also expected to be hottest during the period July and August. After the snow in the plateau has melted, the temperature starts rising rapidly. With the advent of monsoon, clouding and precipitation increase, checking the rise in temperature. The valley wind, if any, is likely to be delayed due to the slower rate of heating. Moreover, after the onset of monsoon over the Brahmaputra valley, stronger monsoon current prevails. Valley wind will, therefore, have to establish itself against this strong current. Hence valley wind should take a longer time to appear and should be light. However, when the monsoon current weakens, valley winds should be found on charts. Climatologically this wind (light southwesterly) is found in the lower levels over the Brahmaputra valley in September. It does not conform to the prevailing pressure pattern. On day-to-day charts southwesterly winds are observed under the following condition in the lower level over the valley even when it is not a "break monsoon" condition. When monsoon depressions, which form over Head Bay and subsequently move inland and weaken or move away westwards from Bengal, thereby loosening their grip on the wind circulation over Bengal and Assam, southwesterlies appear over the Brahmaputra valley. These southwesterlies are caused by either the thermodynamic influence of the Tibetan plateau or by the dynamic influence of the orientation of hills and mountains or both. The thermodynamic influence has been explained above. The dynamic influence is explained below. The southerly monsoon air is obstructed both by the Garo hills and by the Himalayan range and is deflected anticyclonically and blows as a southwesterly current along the valley. These southwesterlies carry enough moisture with them and flow unchecked to the extreme northeast Assam causing widespread rain there.

6. Post-monsoon

After the monsoon recedes in the early October, the sky over the Tibetan plateau and Assam clears and with the approach of winter the Tibetan plateau starts losing heat rapidly. Thus the condition for setting in of the flow of the katabatic winds on a seasonal scale becomes favourable. Consequently the easterly mountain winds again appear in the lower levels over the Brahmaputra valley. These dry cool easterlies may give 'trigger action' to the relatively warm prevalent air which may also be moist due to the residual moisture and ultimately give rise to development of thunderstorm.

7. Thermal pattern

In the above discussions it has been suggested that the air flow over the Brahmaputra valley in the lower levels is highly influenced by the orography and that the winds are mainly mountain and valley winds blowing on a seasonal scale. On a diurnal scale these winds blow due to differential heating or cooling of mountains and valleys. For such winds to blow on a seasonal scale we can similarly expect to find differential heating and cooling of mountains.

Normal temperatures based on evening radiosonde data from 1956 to 1960 for all Indian stations were plotted for 700-mb level. It was found that from November to April Tibetan plateau represents the coldest region. During these months lowest temperature was obtained over Gauhati. Again the warmest region was found over the Tibetan plateau during the monsoon months July, August and September. The change takes place during May and June and again during October. The difference in temperature between Gauhati and Calcutta during November to February is — 4 to — 5°C and during July is + 3°C. Thus the normal thermal patterns suggest the possibility of seasonal mountain and valley winds.

8. Conclusion

From the present study we conclude that the Tibetan plateau acts as a cold mass during winter and warm mass during monsoon. As a result katabatic and anabatic winds blow in the lower levels on a seasonal scale over the valley.

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