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On forecasting the time of incidence of Nor'westers at Calcutta

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ABSTRACT. The speed of travel of the downdrafts from regenerative Nor'wester sequences in southwest Bengal has been investigated by analysing data of times of their outbreak at Calcutta, Asansol and Hazaribagh. This is found to lie roughly between 30 and 40 mph. There are scarcely any thundersqualls at Calcutta before 1600 IST caused by parental storms at interior stations. Thunderstorms so generated are most frequent during 1700 to 1900 IST at Calcutta. The highest gust speeds in Nor'wester squalls also appear to be confined to this period. Thunderstorms occurring during 1100-1200 IST at Hazaribagh or 1400-1500 IST at Asansol produce squalls reaching 60-90 mph at Calcutta. From these results, simple rules for forecasting the time of incidence and speed likely to be attained in Nor'wester squalls at Calcutta have been deduced.

1. Introduction

The Nor'wester is the most serious of all the hazards to which aviation is exposed at Calcutta. It is, therefore, of considerable practical importance to provide accurate forecasts of the time of incidence of this hazard to aviation interests at the busy international airport at Dum Dum adequately in advance for diverting incoming aircraft to alternate aerodromes and for adoption of necessary precautionary measures for the protection of parked or moored aircraft. The available literature on the speed of propagation of the impulse generating the chains of Nor'westers in Bengal is, however, meagre. The only available information appears to be what has been yielded by the project of the India Meteorological Department to investigate the problem of the Nor'westers in Bengal during the period April and May 1941, with a dense network of observing stations (*India met. Dep. Tech. Note*, 1944). This investigation has shown a definite sequence in the most frequent times of occurrence of thunderstorms, similar to that at the cold fronts of middle latitudes. Such a sequence is clearly perceptible in southwest Bengal, with a definite NW-SE movement between 30 and 40 mph. As a large mass of data of Nor'westers at and in the neighbourhood of Calcutta is now available, it has been felt desirable to undertake a study of the problem of the speed of propagation of the trigger generating the Nor'wester sequences. The results of such a study are presented in this paper.

2. Data utilised

In considering the speed of approach of a Nor'wester towards Calcutta, it is important to bear in mind the restricted aerial extent of the phenomenon, as a result of which it may pass undetected in between two or more observing stations, if the density of the network of these stations is small. With the commencement of weather observations at the Barrackpore airfield (about 10 miles to the northwest of Dum Dum) in 1952 and the existence of a class I observatory at Alipore (about 12 miles to southwest of Dum Dum), the chances of a Nor'wester, directed towards Dum Dum, passing away to the north or south of that place without affecting either of the other two stations would be small. The present study has, therefore, been confined to the years 1952, 1953 and 1954, and the period 1 March to middle of June, when Nor'westers are generally experienced at Calcutta. All the available records of Nor'westers at Barrackpore, Dum Dum and Alipore (representing Calcutta) on the one hand and of Asansol, Hazaribagh, Patna and Gaya (representing the area where the thunderstorm cells first develop) on the other, have been collected from the Current Weather

and Pocket Registers, Monthly Meteorological Registers and the autographic charts of Dum Dum and Alipore. The data have been tabulated with reference to the times of occurrence of Nor'westers, the speed of the squalls recorded and the prevailing upper winds. The corresponding synoptic charts have also been scrutinised with a view to classifying the Nor'westers in accordance with the scheme proposed in the *India met. Dep. Tech. Note*, 1944, which embodies the main results of the investigation conducted in 1941.

3. The causes of the observed time sequence

The most predominant type of Nor'westers of Bengal is the one classified as Type A (1944), which originates in West Bengal and Chota Nagpur in the afternoon and proceeds in a southeasterly direction, ultimately affecting Calcutta. The number of these approaching Calcutta from other directions is small as shown by Desai and Mull (1938). Thunderstorms of this type, from which the name Nor'wester is itself derived, show a definite shift of the most frequent time of occurrence towards later hours of the evening as one proceeds from Hazaribagh towards the southeast. Desai (1950) has dealt with the factors which, singly or jointly, are responsible for the time sequence shown by Nor'westers. The primary cause is the incursion of moist air from the Bay of Bengal into the hills of Chota Nagpur and neighbourhood under favourable synoptic conditions. The primary or parent thunderstorm in the interior is triggered off by insolation in the early afternoon. In such a thunderstorm, the descending air is from the higher levels where westerly to northwesterly winds prevail, causing a squall from some northwesterly direction. The uplift provided by the cold downdraft outflowing from the parent thunderstorm generally spreads in some southeasterly direction and provides the requisite vertical displacement for another thunderstorm, further to the southeast. Thus a whole series of thunderstorms—secondary, tertiary, quaternary etc—is generated, propagating the thunderstorm activity against the direction of inflow of moist air at lower levels. It is this mechanism of formation of Nor'westers that results in the observed time sequence.

TABLE 1

Frequencies of thunderstorms of different types at Calcutta during March to middle of June (1952-1954)

Year	Type A	Type B	Type C	Type D	Local heat	All types
1952	10	4	4	3	6	27
1953	9	3	0	2	2	16
1954	2	2	0	1	1	6
All years	21	9	4	6	9	49

4. Frequencies of different types of Nor'westers

In Table 1 are shown the frequencies of thunderstorms of the different types, which affected one or more of the Calcutta stations during the years 1952-54. These have been differentiated into types A, B, C and D in accordance with the classification adopted in *Tech. Note*, No. 10 (1944).

It is seen from the above Table that of the 49 thunderstorms which affected Calcutta during the Nor'wester season in the years 1952-1954, 43 per cent are of Type A. This is in good agreement with the frequency of 45 per cent for this type of Nor'westers at all Bengal stations put together, during the period March-April 1941, as given in *Tech. Note*, 10. Next in order of importance are those of Type B, which form 18 per cent of the total. Thunderstorms of a local character, *i.e.*, those which did not appear to have been generated by the outflowing downdraft from any earlier thunderstorm in the interior, have about the same frequency as those of Type B.

5. Time sequence in Type A Nor'westers

The topographical features of the area where the thunderstorm cells initially develop are shown in Fig. 1. The stations, Patna, Gaya, Hazaribagh, Asansol and Calcutta are shown in this map together with the ground contours of 200 and 500 metres. At the top of these stations are marked the distances in miles of each of these from

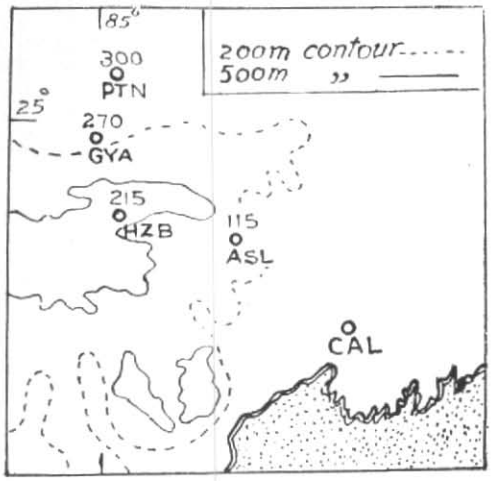

Fig. 1. Topographical features of the source region of Nor'westers of Type A

Calcutta. It will be noticed that Hazaribagh is located at a higher elevation and is nearer to Calcutta than Patna and Gaya. In the hilly plateau, over which Hazaribagh is located, a valley runs from near this place towards the southeast. This topographical feature appears to be of some importance in favouring the outflow of the downdrafts from thunderstorms forming here in the southeasterly direction.

On comparison of the data of Patna and Gaya with those of Hazaribagh, it has been found that the origin of the Nor'westers at Calcutta is traceable much more frequently to Hazaribagh than to the other places. Data of Patna and Gaya have, therefore, been left out of the discussion in the following pages.

The relationship subsisting between Nor'westers at Calcutta and the earlier thunderstorms at Asansol and Hazaribagh is brought out in Table 2, in which are shown the number of occasions of thundersqualls at Calcutta preceded by earlier ones in the interior together with those not so preceded. Similar frequencies for Type B Nor'westers are also reproduced in this table for comparison.

It is seen from Table 2 that two-thirds of the 21 Nor'westers of Type A, which affected Calcutta were preceded earlier by thunder-

TABLE 2

Thundersqualls at Calcutta associated with those experienced earlier at Hazaribagh and Asansol during March to middle of June (1952-54)

Type	No. of occasions when thunderstorm sequences was experienced by			Total No. of occasions of thundersqualls at Calcutta
	Hazaribagh, Asansol and Calcutta	Asansol and Calcutta only	Calcutta only	
A	13	8	0	21
B	1	3	5	9

storms both at Hazaribagh and Asansol and all the rest by earlier outbreak of thunderstorms at Asansol. There was not a single case of a Nor'wester at Calcutta, the origin of which was not traceable to earlier thunderstorms either at Asansol or at Hazaribagh. It may, therefore, be inferred that every Type A thunderstorm at Calcutta was without exception caused by the outflowing downcasts from primary thunderstorms developing at stations to the northwest of Calcutta. Of the 21 Nor'westers, which affected Calcutta during the period of study, 8 were preceded by thunderstorms at Asansol without any thunderstorms occurring on the occasions at Hazaribagh. All the rest were preceded earlier by thunderstorms both at Hazaribagh as well as Asansol. Asansol, therefore, appears to provide an advance clue to the outbreak of a Nor'wester at Calcutta.

Nor'westers of the Type B, on the other hand, do not provide any positive earlier indication at Asansol or Hazaribagh, presumably because these places are far removed from and are not in the path of the travel of the trigger of this class of thunderstorms. Of the 9 thunderstorms of this class at Calcutta during the period of study, the majority were definitely not preceded by earlier thunderstorms at Asansol or Hazaribagh.

In Table 3 are shown the mean intervals of time in minutes that elapsed from the time of outbreak of the parent thunderstorm at Hazaribagh or Asansol till the time of

TABLE 3

Time lapse and mean speed of travel of Nor'westers of Type A between Hazaribagh, Asansol and Calcutta

(based on data for the years 1952-54)

Hour (IST) of incidence of thunderstorm at latter station	Hazaribagh—Asansol (100 miles)		Asansol—Calcutta (115 miles)		Hazaribagh—Calcutta (215 miles)	
	Time (min)	Speed (mph)	Time (min)	Speed (mph)	Time (min)	Speed (mph)
1300-1359	200(1)	30	..	..	..	..
1400-1459	208(4)	29	195(1)	35	..	..
1500-1559	201(4)	30	..	..	..	..
1600-1659	228(2)	26	205(1)	34	405(1)	32
1700-1759	225(1)	27	169(5)	41	355(2)	36
1800-1859	265(1)	23	182(7)	38	395(6)	33
1900-1959	..	..	225(3)	31	448(2)	29
2000-2059	..	..	225(3)	31	410(1)	31
2100-2159	..	..	210(1)	33	475(1)	27
Weighted mean irrespective of hour	214	28	194	36	405	32

incidence of each Nor'wester of a later generation at Calcutta during all the days of the season from 1952-1954 together with the number of observations, on which each value is based. For this purpose, the occurrence of a thunderstorm at one or more of the three observing stations at Calcutta has been treated as single event. These data are dispersed against hourly intervals from 1300 to 2200 IST, the period to which all the Nor'westers of Calcutta appear normally to be confined (Sohoni 1931). The mean speeds of travel of the trigger between Hazaribagh and Asansol, Asansol and Calcutta and Hazaribagh and Calcutta are also shown in the table.

The following inferences can be drawn from Table 3—

(1) The speed of travel of the Nor'wester trigger lies roughly between 30 and 40 mph from Asansol or Hazaribagh to Calcutta.

(2) A thunderstorm sequence starting from Hazaribagh is likely to reach Calcutta within a period of about 7 hours without reference to the time of origin. Similarly its travel from Asansol to Calcutta is completed within about 3 hours.

(3) Except for an isolated case, there are scarcely any thunderstorms at Calcutta before 1600 IST, the development of which is attributable to prior outbreak of the primary thunderstorms at interior stations.

(4) The time interval for travel of the trigger from Hazaribagh to Calcutta is not identical with the algebraic sum of the corresponding intervals of time for travel from Hazaribagh to Asansol and from Asansol to Calcutta.

It is useful to distinguish the speed of travel of the Nor'wester trigger from the speed of travel of individual thunderstorm cells. By 'speed' is implied here the rate of propagation or growth around the edges of a thunderstorm due to the formation of new cells. The speed of movement of an individual cell within the general current may have a component in the direction of propagation of thunderstorm activity. The speed of such translation, however, rarely exceeds 10 mph (Byers and Braham 1949). The speed of movement of a thunderstorm sequence is more or less within the limits of speed of the upper winds between 10,000 and 15,000 ft, which is normally about 30-40 mph.

6. Maximum gust speed in Nor'wester squalls in relation to time of incidence at Calcutta

It is of considerable practical importance to investigate whether there is any variation with time of the highest gust velocities in Nor'wester squalls at Calcutta. In Fig. 2 are shown the highest speeds reached in individual Nor'wester squalls during different hours of the day. In this scatter diagram is also shown a curve joining the points representing the maximum observed gust speed at different hours. The Beaufort Scale is also shown to provide a ready indication of the magnitude of the squall speeds.

It is seen from Fig. 2 that the highest speed is reached during the period 1700 to 1900 IST, the epoch of maximum temperatures and shortly thereafter, when storm winds exceeding B.F. No. 11 (64-72 mph) had been recorded. Squalls occurring before 1700 IST never exceeded the stage of B.F. No. 9 or strong gale. The maximum speeds of squalls occurring after 1700 IST show a rapid rise with time of occurrence till 1730 IST. Those occurring after 2000 IST never showed speeds exceeding strong gales (47-54 mph). Classifying squalls with speeds exceeding storm wind as severe, one may expect that thunderstorms occurring during 1100-1200 IST at Hazaribagh or 1400-1500 IST at Asansol, which cause Nor'westers of Type A at Calcutta during 1700-1900 IST can lead to squalls with hurricane winds (above 73 mph) at the latter place, other conditions remaining favourable. One can also rule out the risk of such squalls at Calcutta following an earlier or later outbreak of thunderstorms at Hazaribagh and Asansol than during the periods mentioned above.

7. Forecasting probable time and speed of Nor'wester squalls at Calcutta

From the above discussion relating to the speed of travel of the trigger for Nor'westers and the highest gust speeds in the squalls caused at Calcutta, it is possible to formulate simple rules to assist a forecaster to gauge the probable time of incidence and strength of the squall for issuing airfield warnings. With this object in view, the maximum,

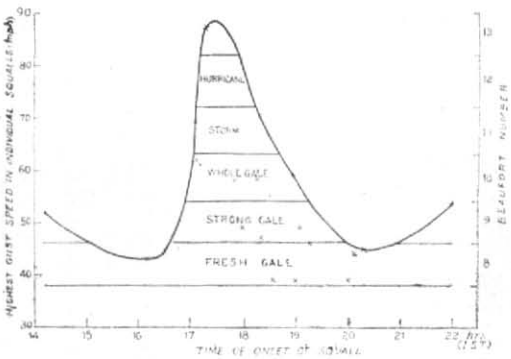

Fig. 2. Dispersion with time of onset of speeds of highest gusts in individual Nor'wester squalls during the years 1952-54

minimum and mean gust speeds in squalls at Calcutta during the different hours of the day have been worked out from the available data on Nor'westers of Type A during the period of study. These data are shown in Table 4 together with the hours of outbreak of the parent thunderstorms at Hazaribagh and Asansol. The number of observations, on which each of the values is based, is shown in brackets in the last column.

The results in Table 4 will help in issuing timely warnings regarding the time of incidence as well as the intensity of Nor'wester squalls at Calcutta. For example, if an M5 report is received from Hazaribagh at Dum Dum at 1300 IST that a thunderstorm had commenced at 1200 IST, one can issue a warning for the Calcutta airfields six hours in advance to the effect that a thundersquall is likely during 1900-2000 IST when winds may attain a maximum speed of 40-50 mph in the squall. Confirmation of this expectation should normally be forthcoming in the shape of a subsequent M5 report from Asansol during 1500-1559 IST.

Although the results shown in Table 4 are self-explanatory, certain features of the table call for special emphasis. Thunderstorm impulses from Asansol take about 3 hours to reach Calcutta, if their travel commences before 1400 IST; thereafter the time taken is 4 hours. As regards the severity of squalls, it is the thunderstorms that originate during

TABLE 4

Times of incidence of and highest gust velocities in Nor'westers of type A at Calcutta

Hours of occurrence of thunderstorm at			Highest gust velocity in Nor'wester at Calcutta (in mph)		
Hazaribagh	Asansol	Calcutta	Maximum	Minimum	Mean(n)
..	1100—1159	1400—1459	52	..	52(1)
..	1200—1259	1500—1559	..	..	..
1000—1059	1300—1359	1600—1659	44	..	44(1)
1100—1159	1400—1459	1700—1759	87	58	63(5)
1100—1159	1400—1459	1800—1859	70	39	54(7)
1200—1259	1500—1559	1900—1959	49	39	44(3)
1300—1359	1600—1659	2000—2059	45	39	43(3)
1400—1459	1700—1759	2100—2159	53	..	53(1)

the hour 1100-1159 at Hazaribagh and 1400-1459 at Asansol, which cause severe squalls at Calcutta during 1700-1859 IST. Of these, the squalls during the hour 1700-1759 are the most severe, with a minimum wind speed equalling or exceeding B.F. No. 10. After 1800 IST at Calcutta, both the upper and lower limits of the squall speeds are apt to be lower; the later the time of occurrence of the squall the less the speed.

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