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On the Forecasting of Nor'westers in Gangetic West Bengal

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ABSTRACT. A comparative study has been made of the upper air data based on radiosonde ascents at Calcutta and Allahabad, in relation to two distinct classes of days, namely, those of widespread nor'westers of the pre-monsoon season over Gangetic West Bengal and those altogether free from such storms. It is seen that the most important contributory factors to the genesis of well developed nor'westers are, increased humidity resulting in suitable distribution of wet bulb temperatures in the first two kilometres and cyclonic convergence in the lower moist air field to provide the initial impulse for upward convection, and that the advection of colder air at higher levels is not an essential criterion.

A nomogram using dry bulb and dew point temperature values at 850-mb level in the morning has been suggested to serve as an empirical, but quite a useful, tool for the forecasting of nor'westers over Gangetic West Bengal during the pre-monsoon season.

1. Introduction

The problem of issuing timely warnings about nor'westers in Bengal and adjacent areas during the pre-monsoon season has received careful attention of meteorologists in India for a long time. A number of workers have made a detailed study of this subject and suggested techniques to enable one to locate in time the genesis of these storms and forecast their future progress or movements. In this paper an attempt is made to judge the relative importance of the temperature and humidity distribution at lower levels and the kinetics of air flow in these layers when compared to the temperature conditions prevailing at 700-mb level and above as suggested in some recent studies, in the forecasting of nor'westers.

2. Analysis of radiosonde data of Calcutta in relation to nor'westers over the area under study

Incidence of thunderstorms at nine meteorological observatories (Calcutta, Dum Dum, Krishnagar, Berhampur, Asansol, Burdwan, Midnapore, Contai and Saugar Island) in Gangetic West Bengal and three other observatories, *viz.*, Balasore, Jamshedpur and Naya Dumka lying very close to the western border of Gangetic West Bengal have been considered for purpose of this study. Occasions on which 50 per cent or more of these 12 stations reported thunderstorms have been classified as widespread nor'wester days, while the term non-nor'wester days applies to those occasions when none of these stations had a thunderstorm. The vertical structure of the atmosphere over Calcutta as represented by the dry bulb and dew point temperatures at various levels for the two classes of days, namely, those of widespread nor'westers and with no nor'wester respectively, has been studied in some detail. The period examined is April and May, the two main nor'wester months, during the six years 1948 to 1953. In all, during this period, there were 98 days of widespread nor'westers and 133 non-nor'wester days. As it is hardly possible to discuss all the cases individually, the averages of dry bulb and dew point temperatures have been worked out for the various standard pressure levels, separately for the two classes of days in each of these two months during the six years under study. Incidentally, this process of averaging also helps to eliminate possible errors of observation on individual days and makes the comparison more effective. The averages based on ascents at 0300 and 1500 Z of the day are shown in Tables 1 and 2 respectively. As no evening ascent data are available for Calcutta for the year 1948, Table 2 gives data for five years only. Also,

TABLE 1

Average dry bulb and dew point temperatures (°C) over Calcutta at 0300 GMT on (a) non-nor'wester and (b) widespread nor'wester days

			No. of occasions	Heights (mb) 1000 TT	1000 T_d	1000 T_d	900 TT	900 T_d	900 T_d	800 TT	800 T_d	800 T_d	700 TT	700 T_d	700 T_d	600 TT	600 T_d	600 T_d	500 TT	400 TT	300 T	T
1948	April	(a)	17	26	24		25	11		19	4		9	−3		−2	−9		−11	−23	−36	
				(15)	(15)		(15)	(15)		(15)	(15)		(15)	(14)		(15)	(13)		(14)	(14)	(14)	
		(b)	5	28	25		24	20		21	10		12	5		0	−2		−12	−23	−35	
				(5)	(5)		(4)	(4)		(4)	(4)		(4)	(4)		(4)	(4)		(3)	(2)	(2)	
	May	(a)	8	29	26		26	18		24	6		14	−3		+3	−7		−3	−15	−27	
				(4)	(4)		(8)	(8)		(8)	(8)		(7)	(6)		(7)	(6)		(3)	(4)	(3)	
		(b)	14	29	25		25	18		21	10		12	3		2	−6		−7	−15	−27	
				(11)	(11)		(11)	(11)		(11)	(11)		(11)	(11)		(10)	(10)		(9)	(9)	(9)	
1949	April	(a)	7	28	24		23	12		18	4		10	−3		0	−15		−8	−16	−30	
				(7)	(7)		(7)	(7)		(7)	(7)		(7)	(7)		(7)	(4)		(7)	(5)	(5)	
		(b)	14	28	24		23	15		19	7		10	1		0	−10		−9	−19	−32	
				(14)	(14)		(14)	(14)		(14)	(14)		(14)	(14)		(14)	(10)		(12)	(12)	(9)	
	May	(a)	3	29	25		23	19		21	11		14	3		4	−4		−3	−12	−23	
				(2)	(2)		(3)	(3)		(3)	(3)		(3)	(3)		(3)	(3)		(3)	(2)	(1)	
		(b)	11	29	25		23	19		19	12		12	3		3	−6		−4	−14	−28	
				(10)	(10)		(10)	(10)		(10)	(9)		(11)	(11)		(11)	(11)		(10)	(10)	(9)	
1950	April	(a)	25	30	21		25	8		18	0		8	−4		−1	−14		−9	−20	−35	
				(24)	(24)		(24)	(24)		(24)	(24)		(23)	(23)		(24)	(21)		(24)	(22)	(20)	
		(b)	2	31	20		26	10		18	8		8	3		−4	..		−15	−27	−38	
				(2)	(2)		(2)	(2)		(2)	(1)		(2)	(1)		(2)	..		(2)	(1)	(1)	
	May	(a)	5	31	26		26	17		22	6		12	−1		1	−10		−9	−20	−35	
				(5)	(5)		(5)	(5)		(5)	(5)		(5)	(5)		(5)	(5)		(5)	(5)	(4)	
		(b)	12	30	26		22	18		19	8		12	1		−1	−8		−11	−20	−32	
				(12)	(12)		(12)	(12)		(12)	(11)		(10)	(10)		(12)	(9)		(12)	(12)	(11)	
1951	April	(a)	14	30	20		25	4		15	0		4	−5		−5	−9		−13	−23	−35	
				(14)	(14)		(13)	(13)		(13)	(12)		(14)	(11)		(14)	(6)		(12)	(11)	(8)	
		(b)	2	28	22		20	17		13	9		5	3		−5	−1		−12	−20	−34	
				(2)	(2)		(2)	(2)		(2)	(2)		(2)	(2)		(2)	(1)		(2)	(1)	(1)	
	May	(a)	14	32	26		26	10		17	3		7	−2		−3	−4		−10	−20	−35	
				(14)	(14)		(14)	(14)		(12)	(12)		(12)	(12)		(11)	(4)		(10)	(9)	(9)	
		(b)	9	31	24		23	15		17	8		8	1		−2	−8		−11	−20	−34	
				(9)	(9)		(9)	(9)		(8)	(8)		(8)	(8)		(8)	(7)		(8)	(8)	(8)	
1952	April	(a)	9	30	24		26	8		18	2		6	−3		−4	−9		−11	−23	−36	
				(9)	(9)		(9)	(8)		(9)	(8)		(9)	(9)		(9)	(6)		(9)	(9)	(7)	
		(b)	9	29	24		23	16		17	6		9	1		−2	−4		−13	−22	−37	
				(9)	(9)		(9)	(9)		(9)	(9)		(9)	(7)		(8)	(3)		(8)	(7)	(7)	
	May	(a)	5	32	26		23	18		19	8		10	−1		−1	−9		−9	−19	−31	
				(5)	(5)		(5)	(5)		(5)	(5)		(5)	(5)		(5)	(4)		(5)	(4)	(3)	
		(b)	11	31	26		25	17		20	9		10	2		1	−11		−9	−18	−32	
				(10)	(10)		(10)	(9)		(10)	(9)		(10)	(9)		(10)	(7)		(10)	(10)	(10)	
1953	April	(a)	17	32	22		27	11		21	0		11	−3		1	−11		−8	−17	−32	
				(15)	(15)		(13)	(11)		(13)	(13)		(15)	(13)		(14)	(7)		(12)	(10)	(9)	
		(b)	3	30	25		25	16		22	7		14	2		4	−5		−6	−17	−34	
				(3)	(3)		(3)	(3)		(3)	(3)		(3)	(3)		(3)	(2)		(3)	(3)	(2)	
	May	(a)	9	32	27		26	17		21	9		11	4		2	−4		−5	−14	−28	
				(9)	(9)		(8)	(6)		(8)	(7)		(8)	(7)		(8)	(4)		(8)	(8)	(6)	
		(b)	6	30	27		25	19		20	12		12	4		3	−12		−4	−14	−27	
				(6)	(6)		(6)	(5)		(6)	(5)		(6)	(4)		(5)	(1)		(5)	(5)	(6)	
Averages for the six-year period 1948-1953	April	(a)	89	30	22		25	9		18	1		8	−3		−2	−11		−10	−21	−35	
				(84)	(84)		(81)	(78)		(81)	(79)		(83)	(77)		(83)	(57)		(78)	(71)	(63)	
		(b)	35	28	24		23	15		18	7		10	2		−1	−6		−11	−20	−34	
				(35)	(35)		(34)	(34)		(34)	(33)		(34)	(31)		(33)	(20)		(30)	(26)	(22)	
	May	(a)	44	31	26		25	15		20	6		11	0		0	−7		−7	−17	−31	
				(39)	(39)		(43)	(41)		(41)	(40)		(40)	(38)		(39)	(26)		(34)	(32)	(26)	
		(b)	63	30	25		24	18		19	10		11	2		1	−8		−8	−17	−30	
				(58)	(58)		(58)	(56)		(57)	(53)		(58)	(53)		(56)	(45)		(54)	(54)	(53)	

NOTE—Figures within brackets indicate the number of occasions on which the averages are based

TABLE 2

Average dry bulb and dew point temperatures (°C) over Calcutta at 1500 GMT on (a) non-nor'wester and (b) widespread nor'wester days

			No. of occasions	Heights (mb) 1000 TT	1000 T_d	1000 T_d	900 TT	900 T_d	900 T_d	800 TT	800 T_d	800 T_d	700 TT	700 T_d	700 T_d	600 TT	600 T_d	600 T_d	500 TT	400 TT	300 TT
1949	April	(a)	7	27	24		23	16		17	—2		6	—8		—4	—29		—15	—28	—43
				(6)	(6)		(6)	(6)		(5)	(5)		(5)	(4)		(5)	(1)		(4)	(2)	(2)
		(b)	14	27	22		21	15		17	5		7	—2		—4	—15		—13	—24	—39
				13)	(13)		(13)	(13)		(13)	(13)		(13)	(13)		(12)	(7)		(11)	(10)	(9)
	May	(a)	3	28	25		24	19		19	10		11	0		1	—6		—5	—15	—32
				(2)	(2)		(3)	(3)		(3)	(3)		(3)	(3)		(3)	(2)		(3)	(3)	(2)
		(b)	11	26	24		24	19		19	13		11	4		2	—1		—6	—17	—32
				(8)	(8)		(9)	(9)		(9)	(9)		(8)	(8)		(8)	(7)		(8)	(7)	(7)
1950	April	(a)	25	29	22		29	7		20	0		9	—5		1	—14		—8	—20	—35
				(23)	(22)		(23)	(22)		(24)	(23)		(23)	(23)		(23)	(17)		(22)	(21)	(18)
		(b)	2	27	21		25	11		16	4		6	2		—7	..		—16	—27	—40
				(2)	(2)		(2)	(2)		(2)	(2)		(2)	(2)		(2)	..		(2)	(2)	(2)
	May	(a)	5	29	25		26	16		22	7		12	—1		1	—5		—7	—18	—28
				(4)	(4)		(4)	(4)		(4)	(4)		(5)	(5)		(5)	(3)		(5)	(5)	(3)
		(b)	12	28	23		25	17		20	8		10	—3		1	—5		—8	—16	—32
				(11)	(11)		(12)	(12)		(12)	(12)		(11)	(11)		(11)	(10)		(11)	(11)	(9)
1951	April	(a)	14	28	22		28	8		19	3		8	—2		—3	—7		—10	—22	—35
				(14)	(14)		(13)	(13)		(13)	(13)		(13)	(13)		(12)	(9)		(13)	(11)	(8)
		(b)	2	25	21		24	10		16	0		7	—4		—3	..		—10	—18	—30
				(2)	(2)		(2)	(2)		(2)	(2)		(2)	(2)		(2)	..		(2)	(2)	(2)
	May	(a)	14	31	26		28	12		21	2		11	—2		6	—9		—6	—19	—24
				(14)	(14)		(14)	(14)		(14)	(14)		(14)	(14)		(13)	(10)		(13)	(13)	(11)
		(b)	9	28	22		23	15		18	10		9	5		0	—2		—9	—18	—31
				(9)	(9)		(8)	(7)		(8)	(7)		(8)	(8)		(8)	(4)		(7)	(6)	(4)
1952	April	(a)	9	30	23		28	10		20	4		9	—2		0	—2		—9	—22	—37
				(9)	(9)		(9)	(9)		(9)	(8)		(9)	(8)		(9)	(3)		(9)	(9)	(7)
		(b)	9	26	21		21	14		13	7		5	2		—5	—3		—14	—25	—39
				(9)	(9)		(9)	(9)		(7)	(7)		(7)	(7)		(6)	(2)		(5)	(4)	(3)
	May	(a)	5	30	26		24	17		19	4		11	—1		2	—6		—6	—17	—31
				(5)	(5)		(5)	(5)		(5)	(5)		(5)	(5)		(5)	(5)		(5)	(5)	(5)
		(b)	11	27	23		25	16		19	9		12	2		1	—6		—9	—18	—30
				(10)	(10)		(10)	(10)		(10)	(10)		(10)	(10)		(10)	(7)		(10)	(10)	(8)
1953	April	(a)	17	29	24		27	10		19	4		9	—1		1	—7		—8	—18	—31
				(17)	(17)		(16)	(16)		(16)	(16)		(16)	(16)		(16)	(13)		(16)	(14)	(14)
		(b)	3	28	23		26	13		20	9		12	5		2	—5		—8	—14	—25
				(3)	(3)		(3)	(3)		(3)	(3)		(3)	(3)		(3)	(2)		(3)	(2)	(2)
	May	(a)	9	31	27		28	18		22	9		13	2		3	—4		—5	—15	—29
				(9)	(9)		(8)	(8)		(9)	(9)		(9)	(8)		(9)	(9)		(9)	(8)	(8)
		(b)	6	26	21		26	13		21	10		13	5		4	—1		—5	—13	—25
				(5)	(5)		(4)	(4)		(4)	(4)		(4)	(4)		(5)	(3)		(5)	(5)	(4)
Averages for the five-year period 1949-1953	April	(a)	72	29	23		27	9		9	2		9	—3		—1	—10		—9	—20	—35
				(69)	(68)		(67)	(66)		(67)	(65)		(66)	(64)		(65)	(43)		(64)	(57)	(49)
		(b)	30	26	22		22	14		6	5		7	0		—3	—11		—12	—23	—37
				(29)	(29)		(29)	(29)		(27)	(27)		(27)	(27)		(25)	(11)		(23)	(20)	(18)
	May	(a)	36	30	26		27	15		1	5		11	—1		1	—6		—6	—17	—32
				(34)	(34)		(34)	(34)		(35)	(35)		(36)	(35)		(35)	(29)		(35)	(34)	(29)
		(b)	49	27	23		25	17		19	10		10	2		1	—3		—8	—16	—30
				(43)	(43)		(43)	(42)		(43)	(42)		(41)	(41)		(42)	(31)		(41)	(39)	(32)

NOTE—Figures within brackets indicate the number of occasions on which averages are based

TABLE 3

Average temperatures (°C) over Calcutta on evenings previous to widespread nor'wester and non-nor'wester days respectively

			Heights (mb)				
			700	600	500	400	300
1949	April	(*a*)	+ 4	—6	—17	—27	—44
		(*b*)	+ 7	—3	—12	—24	—40
	May	(*a*)	+13	+4	— 3	—13	—29
		(*b*)	+12	+3	— 6	—17	—31
1950	April	(*a*)	+ 9	+1	— 9	—21	—35
		(*b*)	+ 7	—5	—13	—21	—33
	May	(*a*)	+11	0	— 9	—19	—34
		(*b*)	+11	0	—10	—16	—30
1951	April	(*a*)	+ 7	—2	—11	—22	—35
		(*b*)	+ 3	—7	—15	—27	—40
	May	(*a*)	+11	0	— 7	—19	—34
		(*b*)	+ 9	0	— 8	—19	—33
1952	April	(*a*)	+ 9	0	— 9	—21	—36
		(*b*)	+ 6	—4	—13	—24	—39
	May	(*a*)	+11	+2	— 6	—15	—28
		(*b*)	+11	0	— 9	—19	—32
1953	April	(*a*)	+10	+1	— 8	—18	—31
		(*b*)	+13	+4	— 5	—14	—23
	May	(*a*)	+13	+4	— 4	—12	—27
		(*b*)	+12	+4	— 4	—15	—27
Averages for the five-year period 1949-53	April	(*a*)	+ 8	0	— 9	—21	—34
		(*b*)	+ 7	—3	—12	—23	—37
	May	(*a*)	+12	+2	— 6	—16	—31
		(*b*)	+11	+1	— 8	—17	—31

(*a*) Refers to days previous to non-nor'wester days, (*b*) Refers to days previous to widespread nor'wester days

dew-point temperatures above freezing level, being not sufficiently dependable as a rule, have not been included in the tables above 500-mb level. The figures within brackets below each average value gives the number of observations on which the average is based.

From Table 1 it is seen that, except for the month of April 1950, when widespread nor'westers occurred on two days only and the dry bulb temperatures were 3° to 7°C lower than those at corresponding levels on days without nor'westers, the average temperatures of air at upper levels show little difference from one type to another. In fact, in some of the months temperatures on widespread nor'wester days were somewhat higher than those on non-nor'wester days. Had the presence of colder air aloft been a really significant criterion for the occurrence of widespread nor'westers over the area, the differences between the two sets of averages should have been more marked. On the other hand, Td Td at lower levels (below 700 mb) is higher for widespread nor'wester days than on days of the other class, confirming the view that sufficient moisture content in the lower layers of air, particularly between 900-and 800-mb levels, constitutes an important factor associated with development of nor'westers over the area. Table 2 showing the averages based

TABLE 4

Average temperatures (°C) over Allahabad on evenings previous to widespread nor'wester and non-nor'wester days respectively

			Heights (mb)				
			700	600	500	400	300
1949	April	(a)	+ 9	+ 1	—13	—26	—40
		(b)	+ 7	— 3	—12	—24	—46
	May	(a)	+11	— 1	— 9	—23	—35
		(b)	+12	0	—10	—22	—35
1950	April	(a)	+ 8	— 2	—13	—24	—39
		(b)	+ 2	—11	—21	—34	—45
	May	(a)	+12	0	—13	—26	—36
		(b)	+10	— 2	—13	—25	—32
1951	April	(a)	+ 7	— 4	—13	—25	—38
		(b)	+ 6	— 2	—12	—23	—38
	May	(a)	+10	+ 1	— 9	—22	—37
		(b)	+12	+ 1	— 9	—20	—34
1952	April	(a)	+ 7	— 4	—12	—23	—40
		(b)	+11	— 1	—12	—24	—41
	May	(a)	+12	0	—12	—20	—33
		(b)	+12	0	— 9	—20	—38
1953	April	(a)	+ 9	0	—11	—22	—35
		(b)	+13	+ 1	—10	—20	—34
	May	(a)	+12	+ 3	— 6	—17	—29
		(b)	+13	+ 1	— 8	—19	—31
Averages for the five-year period 1949-53	April	(a)	+ 8	— 2	—12	—24	—38
		(b)	+ 8	— 2	—12	—24	—40
	May	(a)	+11	+ 1	— 9	—21	—34
		(b)	+12	0	—10	—21	—35

(a) Refers to days previous to non-nor'wester days, (b) Refers to days previous to widespread nor'wester days

on 1500 GMT data show more or less the same kind of difference but in a smaller degree. The averages in Table 1 are also presented in the form of T-ϕ curves in Figs. 1 and 2. The continuous lines refer to widespread nor'wester days while the dotted lines represent days without nor'westers. It is seen that, on the average, the T-ϕ curves for the higher levels for the two types of days are practically coincident and also show similar trend with regard to lapse rates. Comparing, however, the dew point curves in the lower layers it is seen that the two curves are widely separated, the T_d T_d values being much higher on days of widespread nor'westers than on occasions of non-nor'westers.

3. Comparison of upper air temperatures at different levels over Allahabad with those over Calcutta at 1500 GMT, as recorded on the days previous to the two types of days under study

With a view to finding out how the distribution of temperatures at higher levels over Allahabad and Calcutta on the evenings previous to the days of occurrence of widespread nor'westers over Gangetic West Bengal compares with that on evenings prior to days of no nor'westers, Tables 3 and 4 have been added showing the mean values of TT at different levels over these two stations for the two months April and May during the period under examination. It is seen that as in the case of Tables 1 and 2, the two classes of days show little difference

TABLE 5

Differences between the average temperatures (°C) of Allahabad and of Calcutta on evenings previous to days of widespread nor'westers and non-nor'westers

			Heights (mb)				
			700	600	500	400	300
1949	April	(*a*)	5	7	4	1	4
		(*b*)	0	0	0	0	0
	May	(*a*)	—2	—5	—6	—10	— 6
		(*b*)	0	—3	—4	— 5	— 4
1950	April	(*a*)	—1	—3	—4	— 3	— 4
		(*b*)	—5	—6	—8	—13	—12
	May	(*a*)	1	0	—4	— 7	— 2
		(*b*)	—1	—2	—3	— 9	— 2
1951	April	(*a*)	0	—2	—2	— 3	— 3
		(*b*)	3	5	3	4	2
	May	(*a*)	—1	1	—2	— 3	— 3
		(*b*)	3	1	—1	— 1	— 1
1952	April	(*a*)	—2	—4	—3	— 2	— 4
		(*b*)	5	3	1	0	— 2
	May	(*a*)	1	—2	—6	— 5	— 5
		(*b*)	1	0	0	— 1	— 6
1953	April	(*a*)	—1	—1	—3	— 4	— 4
		(*b*)	0	—3	—5	— 6	—11
	May	(*a*)	—1	—1	—2	— 5	— 2
		(*b*)	1	—3	—4	— 4	— 4
Averages for the five-year period 1949-53	April	(*a*)	0	—2	—3	— 3	— 4
		(*b*)	1	1	0	— 1	— 3
	May	(*a*)	—1	—1	—3	— 5	— 3
		(*b*)	1	—1	—2	— 4	— 4

(*a*) Refers to days previous to non nor'wester days, (*b*) Refers to days previous to widespread nor'wester days

from the point of view of the mean temperatures at the 700-mb level or above, suggesting that coldness of air at higher levels alone apparently plays not so significant part in the development or otherwise of nor'westers over the area in question. Also, judging from the temperature differences between Allahabad and Calcutta at levels of 700 mb and above (*vide* Table 5), it does not appear that the upper air to the north-west of Calcutta area was colder on days preceding widespread nor'westers than on those before no nor'westers. A general survey, as has been attempted in this note, of the upper air temperature features associated with the two fundamentally different classes of days from the point of view of incidence of nor'westers, makes it clear that the advection of colder air at levels such as 700 mb and above does not chiefly govern the development of thunderstorms over the area.

4. Study of meteorological features on a few individual days of widespread nor'westers and no nor'westers

An examination of the day-to day data shows that although the existence of sufficient moisture or the proper distribution of wet bulb temperatures at the lower levels undoubtedly constitutes the necessary conditions, this by itself is not always sufficient for the full development of nor'westers over an area. An initial perturbation or trigger, in some form or other is necessary for the realisation of the energy of latent instability,

and experience has shown that, normally, insolation alone is not sufficient to provide the trigger required. According to Roy, convergence as indicated by cyclonic curl in the moist air field at the lower levels is one of the most important factors for providing the initial impulse for the growth of a prominent *Cb* cell and its subsequent development into a nor'wester. The present study seems to confirm this view, as it is seen that out of the 98 cases of widespread nor'westers examined, as many as 90 occasions were associated with cyclonic circulation of the moist air streams over Chota Nagpur and adjoining regions. On the other hand, in a number of cases it is seen that despite favourable wet bulb temperature distribution in the lower levels no nor'westers developed, chiefly because the moist streams were predominantly translatory or was undergoing an anticyclonic circulation. Tables 6 and 7 give the values of dew point temperatures at lower levels up to 800 mb and dry bulb temperatures at the higher levels as recorded at Calcutta in the morning and the evening on some of the individual days of widespread nor'westers and no nor'westers respectively. The figures within brackets indicate departures from the corresponding mean values based on data of the 5-year period 1949-53. It is seen from Table 6 that the temperatures at higher levels over Calcutta were mostly higher than what occur normally. On the other hand, despite the lower-than-normal temperatures on days included, in Table 7, no nor'westers occurred. With a view to finding out in what other respects the meteorological features differed in these two sets of days, though more or less similar from the point of view of distribution of T_dT_d values, the flow pattern at 3000 and 5000 ft levels on all these days was examined carefully from the point of view as suggested by Roy (1949). It is seen that the main difference lay in the presence or absence of cyclonic vorticity in the moist air field across Gangetic West Bengal on these two sets of days. As illustrations, the streamlines of winds at 3000 and 5000-ft levels on 8 May and 29 April 1953 (two days of widespread nor'westers) and on 16 April 1950 and 22 April 1951 (days without nor'westers) have been shown in Figs. 3 to 6. As will be seen from Tables 6 and 7, the wet bulb temperatures at lower levels on all these days were favourable, and temperature conditions at the upper levels were more helpful on the latter two days than on the former. Yet, nor'westers did not occur on the last two days mentioned, presumably due to the absence of cyclonic convergence in the moist air stream over the area under consideration.

5. A simple nor'wester prediction diagram

It is seen from the tephigrams in Figs. 1 and 2 (p. 30) that the values of $TT—T_dT_d$ at 900 and 800-mb levels on widespread nor'wester days differ substantially from those on days of no nor'westers. The element $(TT—T_dT_d)$ at the mean level of 850 mb should thus serve as a useful parameter for preparing a simple dot diagram for prediction of nor'westers. This element, together with another variable, *viz.*, dry bulb temperature (TT) at 850-mb level over Calcutta has been used for preparing a diagram to provide an empirical aid for the forecasting of nor'westers in Gangetic West Bengal. The diagram is shown in Fig. 7. The crosses, the hollow circles and the solid circles represent non-nor'wester, scattered nor'wester (less than 50 per cent stations reporting thunderstorms) and widespread nor'wester days respectively. On occasions when $TT—T_dT_d$ and TT values of different days correspond to the same point they have been plotted very close to the point which they actually represented. A line has been drawn on the diagram, separating the nor'wester days (scattered and widespread) from the non-nor'wester days as far as possible. It is seen that about 76 per cent of the points on the right hand side of the above line correspond to non-nor'wester days and hence, if on a particular day the point represented by TT and $TT—T_dT_d$ falls on the same side of the line, the possibility of occurrence of nor'wester on that day is rather small. It is further noticed that about 80 per cent of the points on the left

TABLE 6

Some instances of widespread nor'westers over Gangetic West Bengal with warmer air aloft

Date	Station	Time (GMT)	Dew point temperature (°C)			Dry bulb temperature (°C)				
			1000 mb	900 mb	800 mb	700 mb	600 mb	500 mb	400 mb	300 mb
17-5-49	Calcutta	0300	..	..	..	14 (3)	3 (1)	—2 (4)	—12 (4)	—25 (4)
		1500	26 (1)	22 (5)	18 (9)	12 (0)	3 (1)	—2 (4)	—12 (4)	—24 (7)
27-5-49	Calcutta	0300	27 (1)	21 (3)	12 (2)	13 (2)	6 (4)	—2 (4)	—10 (6)	—30 (—1)
		1500	..	23 (6)	16 (7)	16 (4)	6 (4)	—3 (3)	—10 (6)	—24 (7)
31-5-50	Calcutta	0300	..	20 (2)	17 (7)	10 (—1)	2 (0)	4 (10)	—11 (5)	—23 (6)
		1500	..	19 (2)	16 (7)	13 (1)	7 (5)	—2 (4)	—10 (6)	—24 (7)
28-5-51	Calcutta	0300	24 (—2)	11 (—7)	13 (3)	9 (—2)	0 (—2)	—4 (2)	—15 (1)	—29 (0)
		1500	24 (—1)	..	..	12 (0)	4 (2)	—7 (—1)	—16 (0)	—28 (3)
22-5-52	Calcutta	0300	26 (0)	20 (2)	16 (6)	15 (4)	8 (6)	—2 (4)	—17 (—1)	—30 (—1)
		1500	25 (0)	18 (1)	10 (1)	12 (0)	3 (1)	—3 (3)	—14 (2)	—26 (5)
28-4-53	Calcutta	0300	25 (2)	16 (4)	7 (3)	15 (6)	6 (8)	—6 (4)	—19 (2)	..
		1500	24 (1)	21 (9)	17 (14)	14 (6)	4 (5)	—5 (5)	—16 (5)	—25 (10)
29-4-53	Calcutta	0300	25 (2)	17 (5)	8 (4)	11 (2)	3 (5)	—3 (4)	—17 (4)	—31 (3)
		1500	20 (—3)	14 (2)	10 (7)	12 (4)	2 (3)	—5 (5)	—12 (9)	—25 (10)
8-5-53	Calcutta	0300	26 (0)	16 (—2)	11 (1)	12 (1)	2 (0)	—3 (3)	—12 (4)	—23 (6)
		1500	23 (—2)	20 (3)	16 (7)	14 (2)	7 (5)	—1 (5)	—13 (3)	—26 (5)
14-5-53	Calcutta	0300	28 (2)	16 (—2)	11 (1)	15 (4)	..	..	..	—24 (5)
		1500	20 (—5)	13 (—4)	11 (2)	15 (3)	5 (3)	—4 (2)	—12 (4)	—25 (6)

NOTE—Figures within brackets indicate the departures from mean values based on data of 5 years from 1949-53

TABLE 7

Some instances of non-occurrence of nor'westers in Gangetic West Bengal with colder air aloft

Date	Station	Time (GMT)	Dew point temperature (°C)			Dry bulb temperature (°C)				
			1000 mb	900 mb	800 mb	700 mb	600 mb	500 mb	400 mb	300 mb
6-4-49	Calcutta	0300	21 (—2)	12 (9)	4 (0)	8 (—1)	—3 (—1)	—12 (—2)	—22 (—1)	—33 (1)
		1500	23 (0)	13 (1)	1 (—2)	2 (—6)	—10 (—9)	—22 (—12)	—35 (—14)	—49 (—14)
16-4-50	Calcutta	0300	27 (4)	17 (5)	5 (1)	7 (—2)	—2 (0)	—8 (2)	—16 (5)	—38 (—4)
		1500	26 (3)	19 (7)	10 (7)	6 (—2)	1 (0)	—10 (0)	—23 (—2)	—41 (—6)
23-5-50	Calcutta	0300	27 (1)	11 (—7)	..	13 (2)	2 (0)	—12 (—6)	—25 (—9)	—37 (—8)
		1500	..	21 (4)	14 (5)	15 (3)	0 (2)	—7 (—1)	—19 (—3)	..
22-4-51	Calcutta	0300	12 (—11)	8 (—4)	0 (—4)	6 (—3)	—3 (—1)	—14 (—4)	—25 (—4)	—39 (—5)
		1500	25 (2)	13 (1)	11 (8)	6 (—2)	—4 (—3)	—13 (—3)	..	..
24-4-51	Calcutta	0300	24 (1)	..	..	8 (—1)	—3 (—1)	—7 (3)	—19 (2)	—34 (0)
		1500	26 (3)	12 (0)	5 (2)	6 (—2)	—6 (—5)	—11 (—1)	—24 (—3)	..
9-4-52	Calcutta	0300	17 (—6)	2 (—10)	1 (—3)	4 (—5)	—5 (—3)	—14 (—4)	—30 (—9)	..
		1500	21 (—2)	12 (0)	6 (3)	5 (—3)	—5 (—4)	—14 (—4)	—25 (—4)	—42 (—7)
15-4-53	Calcutta	0300	15 (—8)	3 (—4)	10 (6)	14 (5)	..	..	..	..
		1500	26 (3)	16 (4)	9 (6)	7 (—1)	—2 (—1)	—11 (—1)	—22 (—1)	—36 (—1)
26-5-53	Calcutta	0300	27 (1)	17 (—1)	11 (1)	9 (—2)	2 (0)	—6 (0)	—16 (0)	—30 (—1)
		1500	27 (2)	20 (3)	17 (8)	11 (—1)	2 (0)	—8 (—2)	—18 (—2)	—24 (7)

NOTE—Figures within brackets indicate the departures from mean values based on data of 5 years from 1949-53

hand side of the line refer to nor'wester days and about 90 per cent of the total nor'wester days are located on this side. Thus, most of the nor'wester days during the six-year period under study could have been forecasted with a fairly high degree of reliability with the help of this diagram alone. The method has been tested by the data of April and May of 1946 and 1947. No radiosonde ascents were made at Calcutta during the first half of May 1946 due to the failure of ground equipment. Data were also missing on some more occasions during the above period. It is, however, seen from the remaining available

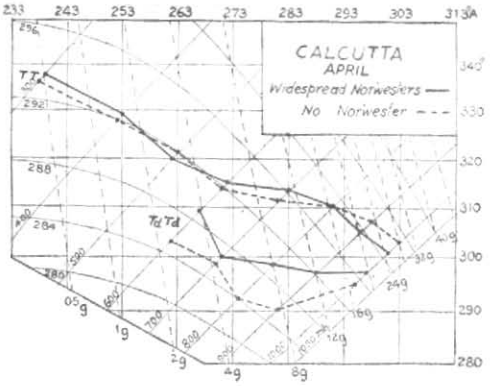

Fig. 1. Average dry bulb and dew point temperature curves at 0300 GMT on widespread nor'wester and non-nor'wester days

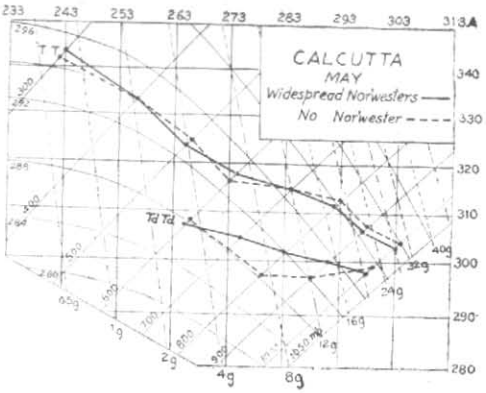

Fig. 2. Average dry bulb and dew point temperature curves at 0300 GMT on widespread nor'wester and non-nor'wester days

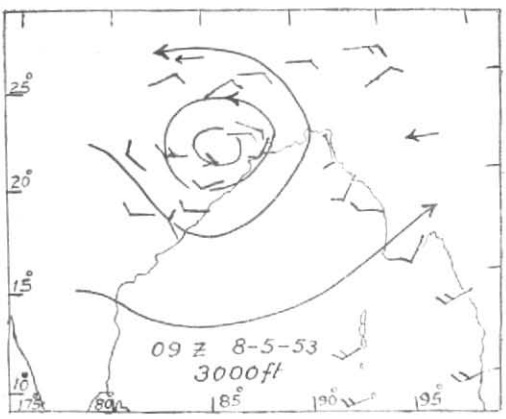

Fig. 3(a)

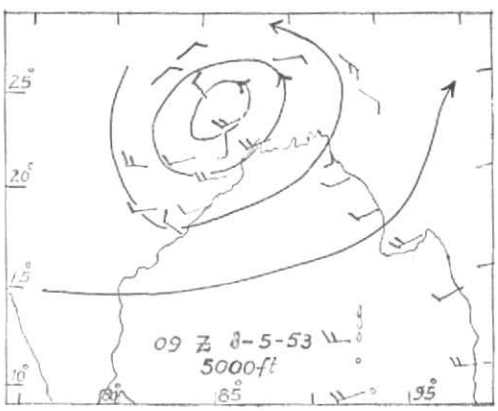

Fig. 3(b)

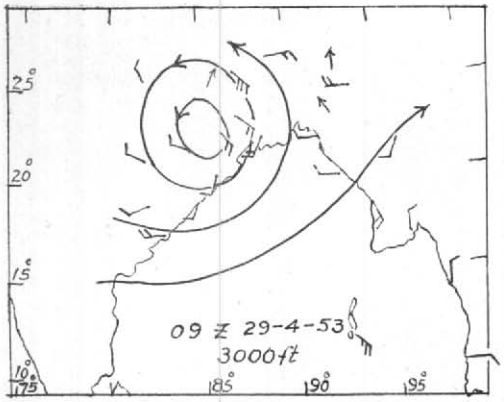

Fig. 4(a)

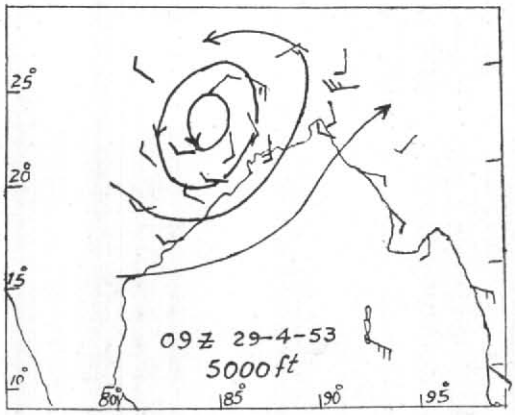

Fig. 4(b)

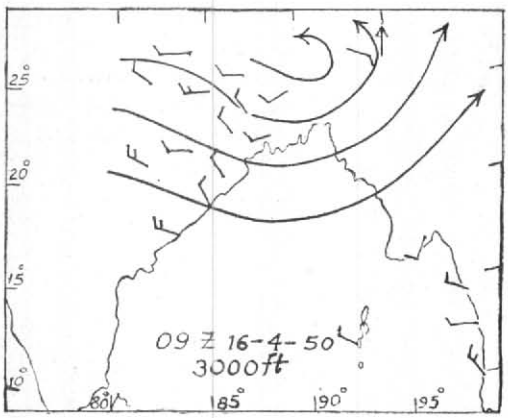

Fig. 5(a)

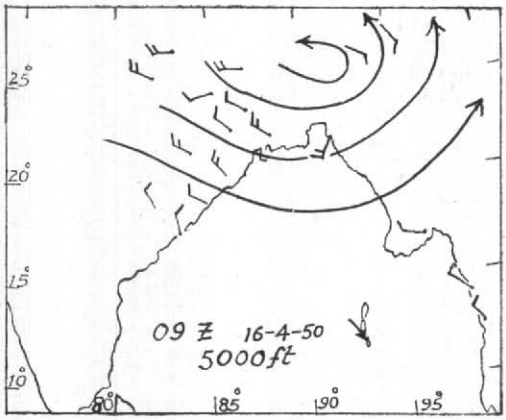

Fig. 5(b)

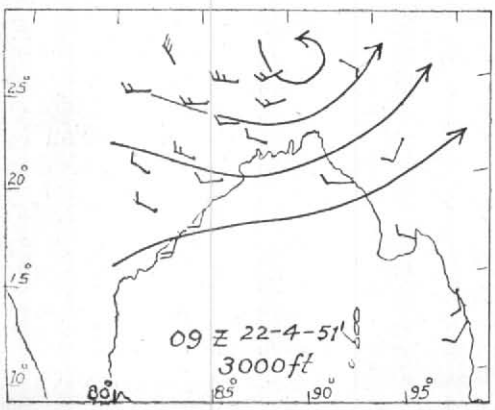

Fig. 6(a)

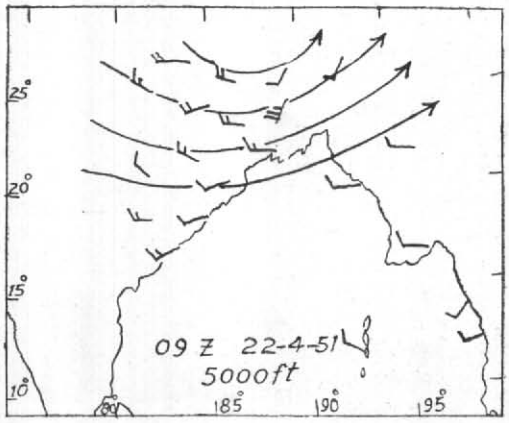

Fig. 6(b)

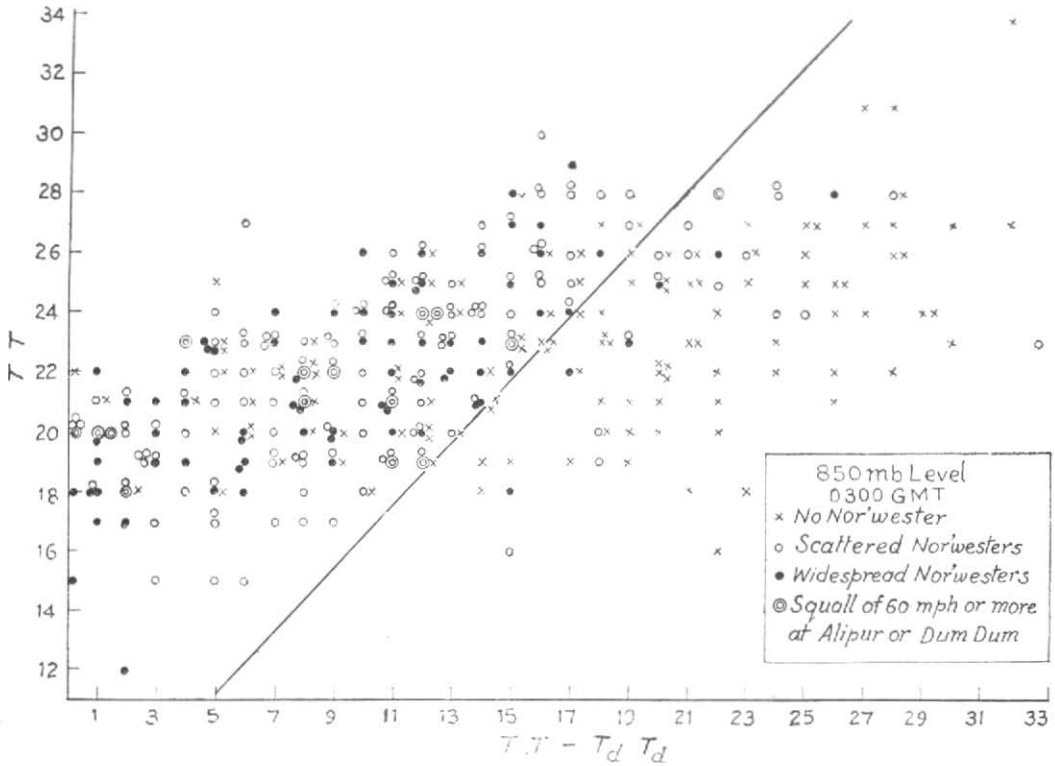

Fig. 7. Nor'wester prediction diagram

data that about 73 per cent of the points lying on the left hand side of the line were nor'wester days and about 80 per cent of the total nor'wester days were on this side. During the 6-year period 1948-53, nor'-wester with speed of 60 mph or more occurred at Dum Dum on 10 occasions and at Alipore on 6 occasions, the dates of occurrence of such nor'westers at the two stations being different except on one day. It is seen that these nor'westers (except on one occasion on which the dew-point temperature data appeared extremely doubtful) could be predicted on the basis of this diagram. All these occasions are shown in the diagram by double circles.

6. Acknowledgement

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