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On the occurrence of tornadoes and their distribution in India

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ABSTRACT. Eight cases of tornadoes and one case of a waterspout were examined since the time upper air soundings have become available. Meteorological conditions associated with their occurrence have been studied. It was found that the mesoscale lows formed along lines of discontinuity in the lower tropospheric levels are the preferred areas for their occurrence.

44 cases of tornado occurrence in record with India Met. Dep. and 113 cases of strong winds collected from press reports quoted in *Weekly Weather Reports* from 1951 onward were used to prepare the maps for distribution of tornadoes and expected maximum winds on Fujita scale.

1. Introduction

Seven cases of tornadoes, one case of water-spout, one case of a squall of tornado violence have been (listed in Table 1) taken. They are the cases of tornado occurrence during the period for which upper air soundings are available. In this paper radiosonde soundings and wind profiles of the nearest Radiosonde/Rawin and Pibal stations were critically examined in order to assess the instability and wind field criteria associated with the tornadoes in India. A study of the antecedent synoptic charts has also been made to evaluate their forecasting probability. In addition 113 cases of strong winds marked for their severity were collected from *Weekly Weather Reports* starting from 1951 and used for constructing the probability distribution maps for tornadoes and strong winds for India.

2. Evaluation of wind and stability data

The total index, Showalter's stability index and George's airmass instability index were computed for 00 and 12 GMT soundings of nearest representative radiosonde stations. The values of the three instability indices so computed have been presented in Table 2. Gauhati (19 April 1963), Calcutta (12 May 1976), Calcutta (20 March 1969) and New Delhi (17 March 1978) ascents for 00 and 12 GMT and the computed indices therefrom, give impression of significant convectional state of atmosphere over the area in which tornadoes have occurred. In the case of Gauhati ascent greater instability was noticed at 00 than at 12 GMT whereas the evening ascent taken between 1640 and 1720 IST, when the funnel cloud was seen at Cooch Behar about 120 miles to the upstream at 1700 IST was actually the more representative ascent in space and time. In case of Delhi the evening ascent taken between 1645-1730 IST when the tornado occurred over Delhi at 1805 IST was the closest proximity sounding (taken within 50 km) in space and time. It gave higher value of instability factor at 12 than at 00 GMT. Instability indices of Lucknow (13 May 1967), Bhubaneswar (16 April 1978) and Calcutta (18 April 1978) do not give much indication about the convectional state of atmosphere.

3. Evaluation of ground inversion

Analysis of the radiosonde ascents representing seven of the reported tornadoes was made. An inversion layer starting from ground with varying depths from surface upto 950 mb and 850 mb was observed in the morning ascents for tornadoes occurring in the evening. Morning ground inversion is a general feature in northeast India during pre-monsoon months due to night cooling. However, on the days of occurrence of severe weather phenomenon accompanied by tornadoes, a significant rise of moisture with height is

TABLE 1

Details of tornadoes under study

Date	Place of occurrence	Estimated wind reported (kmph)	Nearest RS/RW station	Approx. distance from the place of occurrence
19 Apr 1963	Contiguous district of Cooch Behar & Golpara in Assam	160	Gauhati	200 km east
13 May 1967	Kanpur	200	Lucknow	100 km northeast
21 Mar 1969	Diamond Harbour	100	Calcutta	60 km north
7 Nov 1969	Kolleru Lake in Krishna District	—	Gannavaram	20 km northwest
10 Mar 1975	Ludhiana City	—	Patiala	75 km south soutwest
12 May 1976	Balasore District	—	Calcutta	160 km northeast
17 Mar 1978	New Delhi	160	New Delhi	—
16 Apr 1978	Keonjargarh District (Orissa)	200–400	Bhubaneswar	120 km south
18 Apr 1978	Nadia District (W.B.)	—	Calcutta	— 100 km south

TABLE 2

Instability indices for the nearest radiosonde stations

Date	RS/RW stations	Total index		Showalter index		George's instability index	
		00GMT	12GMT	00GMT	12GMT	00GMT	12GMT
19 Apr 1963	Gauhati	16	52	—9.5	—5.0	43	34
13 May 1967	Lucknow	41	45	4.0	1.2	14	28
20 Mar 1969	Calcutta	—	54	—	—3.4	—	29
21 Mar 1969		48	—	—0.4	—	31	—
12 May 1976	Calcutta	49.0	50.0	—4.0	—5.0	34.0	37.0
17 Mar 1978	New Delhi	54.6	61.2	—1.7	—7.9	32.0	36.4
16 Apr 1978	Bhubaneswar	43.8	—	2.0	—	26.0	—
18 Apr 1978	Calcutta	47.0	33.6	—1.1	0.7	19.9	27.1

TABLE 3

Summary of the vertical wind shears

Date	Time (GMT)	Nearest RW station	Mid/lower tropospheric wind max. (deg./kt)		Wind at lower levels		Shear wind between these levels (A-B)
			Level A (mb)	Wind (kt)	Level B (mb)	Wind (kt)	
19 Apr 1963	00	Gauhati	600	280/60	850	250/35	310/38
	12	Gauhati	700	270/50	850	240/35	310/27
13 May 1967	12	Lucknow	600	266/50	850	225/14	270/40
20 Mar 1969	12	Calcutta	600	266/52	850	273/06	263/45
7 Nov 1969	00	Gannavaram	0.9 km	006/42	Ground	315/12	019/34
10 Mar 1975	06	Ambala	0.9 km	138/46	Ground	090/14	156/38
12 May 1976	00	Calcutta	600	325/58	850	211/16	282/50
	12	Calcutta	650	324/26	850	282/06	337/22
17 Mar 1976	00	New Delhi	700	319/50	850	177/12	233/43
16 Apr 1978	12	Bhubaneswar	500	310/38	850	256/10	326/33
18 Apr 1978	12	Calcutta	850	317/62	Ground	323/34	303/29

observed in the lower layer of the atmosphere in which case the dry bulb temperature and dew point temperatures were found running parallel in the ground inversion layer on the morning soundings. This occurs due to moisture convergence by advection from the Bay of Bengal under certain favourable conditions. The morning inversion is not present in the evening ascent and a general increase in moisture is observed at all levels due to convection.

4. Vertical wind structure

Two wind maxima one in the middle (sometimes descending to lower troposphere) and the other at some upper tropospheric level were observed over the area in 5 cases on the day of occurrence of tornadoes. In the case of Ludhiana tornado which occurred ahead of an intensifying western depression and the kolleru waterspout which occurred ahead of a severe cyclonic storm striking the coast, strong winds varying from 40 to 50 kt were observed at 0.9 km over the area. However, the middle and upper tropospheric levels did not exibit strong winds in cases of tornadoes which occurred in Balasore and Keonjargarh districts.

Strong wind shears were observed between the mid-tropospheric wind maxima and 850 mb level. Strong wind shears were again observed in the lower troposphere in the cases of Ludhiana tornado and Kolleru waterspout and also in case of Nadia district tornado where the lower wind maxima descended to 850 mb level (Table 3). This suggests that baroclinicity or baroclinic instabilities may be present in the lower and middle tropospheric levels in areas affected by tornadoes or severe thunderstorm activity at a sub-synoptic scale, which may not be discernible in otherwise quasi-barotropic atmosphere of tropics with the available network of Radiosonde stations.

5. Discussion of synoptic conditions

An examination of the synoptic situation in which tornadoes occurred has been made for all the nine cases. The Kolleru lake waterspout occurred in the right front quadrant of a severe cyclonic storm while striking the south Andhra Coast near Masulipatnam. Hurricane spawned tornadoes are most frequent in USA which occur within 100 nm of the shore when hurricanes strike the coast and undergo rapid filling. The Ludhiana tornado occurred in the forward sector of a western depression over area when it was still undergoing intensification.

All the other seven tornadoes occurred on lines of wind discontinuities observed in the lower tropospheric levels of 0.3, 0.6, 0.9 km and 1.5 km over area of convergence between moist current from south and southeast and dry current from west and northwest. Lows at mesoscale were observed to have formed in these areas of convergence and moved over area where tornadoes occurred. The tornado history suggested that severe weather occurred only after several hours of substantial pre-existing moisture convergence. A general rise of dew points and minimum temperature was observed over the area. The mesolows were mostly found to form in areas of maximum pressure fall (isallobaric lows) otherwise on many occassions they were not noticed on the surface charts. Mesolows moved from west to east in the cases of Cooch Behar, Kanpur, Delhi, Balasore, Keonjargarh and Nadia district tornadoes. They moved from southwest to northeast in other cases.

Westerly troughs with embedded jet streams were found to influence six out of eight tornadoes (excluding the case of Kolleru waterspout where the upper air wind field would be easterly). In many cases upper air wind maxima lay over the areas of tornado occurrence with a second wind maxima underneath at some mid-tropospheric levels. This supplied the upper air divergence crucial for generation of convergence in lower tropospheric layers and subsequent formation of induced mesolows. The upper air divergence is generally associated with positive vorticity advection (PVA) ahead of the upper air troughs. However, it was not possible to find PVA in case of Balasore and Keonjargarh district tornadoes.

In Fig. 1(a & b) we present the case study of Diamond Harbour tornado. Thuderstorm and rain were noticed at 12 GMT chart of 20 March 1969 over the area specified in figure just southwest of Calcutta. A mesoscale low was noticed at 0.3 km and 0.6 km at 18 GMT of 20 March 1969. It moved northeastward giving tornado over Diamond Harbour in the early morning hours of 21 March 1969. The occurrence of tornado when the mesolow came underneath the mid-tropospheric wind maxima of 50 kt over Calcutta again testified the added effect of baroclinic as well as shear instabilities

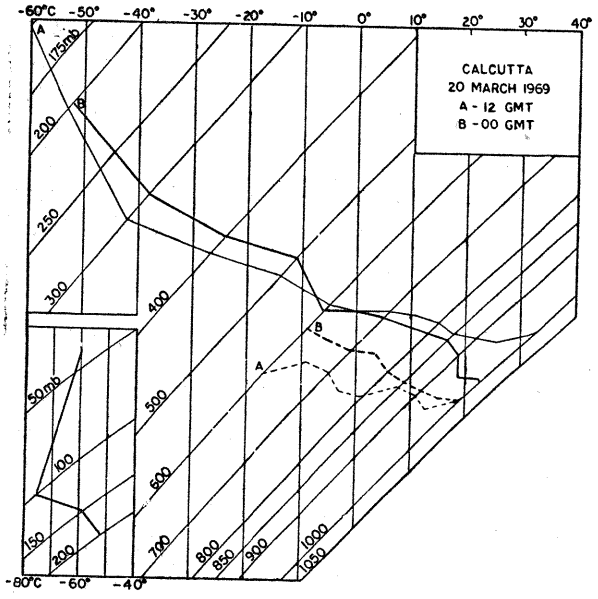

Fig. 1 (a). Calcutta tephigram of 12 GMT of 20 March 1969 and 00 GMT of 21 March 1969

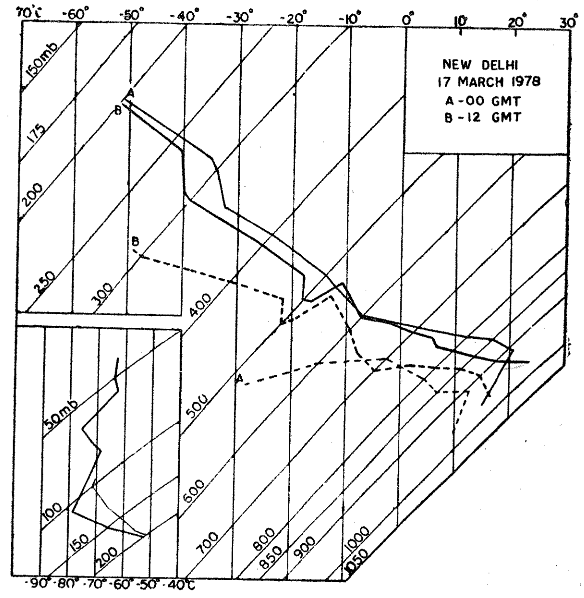

Fig. 2(a). New Delhi tephigram of 17 March 1978

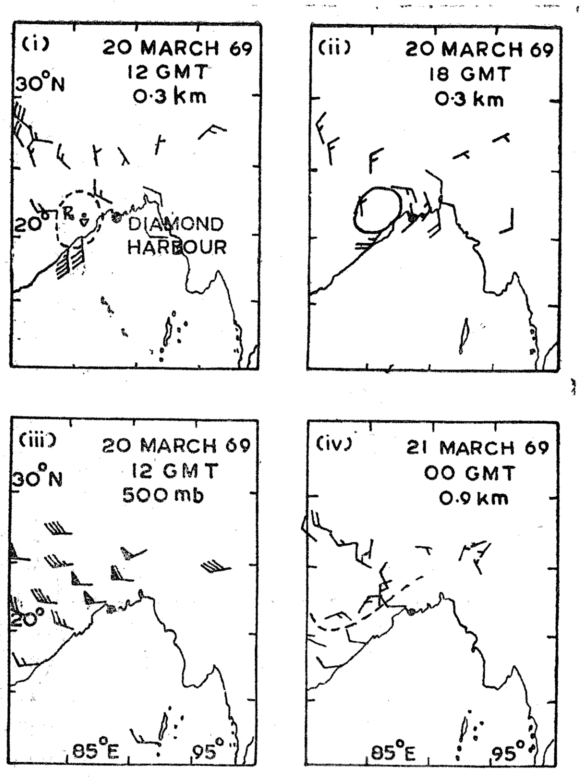

Fig. 1 (b). Diamond Harbour tornado of 20 March 1969 (description given in text)

in the lower and mid-tropospheric levels in the occurrence of Diamond Harbour tornado. Tephigrams of Calcutta (12 GMT of 20 March and 00 GMT of 21 March) indicated considerable latent instability. A significant increase of moisture depth is noticed at 00 GMT of 21 March.

The Fig. 2(a & b) present the case study of Delhi tornado of 17 March 1978. The 12 GMT tephigram of Delhi indicated considerable increase in latent instability and moisture depth over that of 00 GMT. An induced meso-scale low was observed to form at 06 GMT west of Delhi in a trough extending southeastward from a western depression lying over north Pakistan, Punjab and Jammu and Kashmir. The western depression had weakened into a low by 12 GMT and lay over Himachal Pradesh and neighbourhood. Delhi experienced the tornado at 1230 GMT of the same day. It occurred by the movement of 06 GMT meso-scale low over the area, was supported by the 0.9 km wind charts of 06 and 18 GMT. The mid-tropospheric wind maxima of 223/85 kt and vertical wind shear (500 mb-850 mb) of 235/80 signify the possible existence of baroclinic and shear instabilities at meso-scale in addition to upper air divergance associated with jet stream embedded in westerly trough.

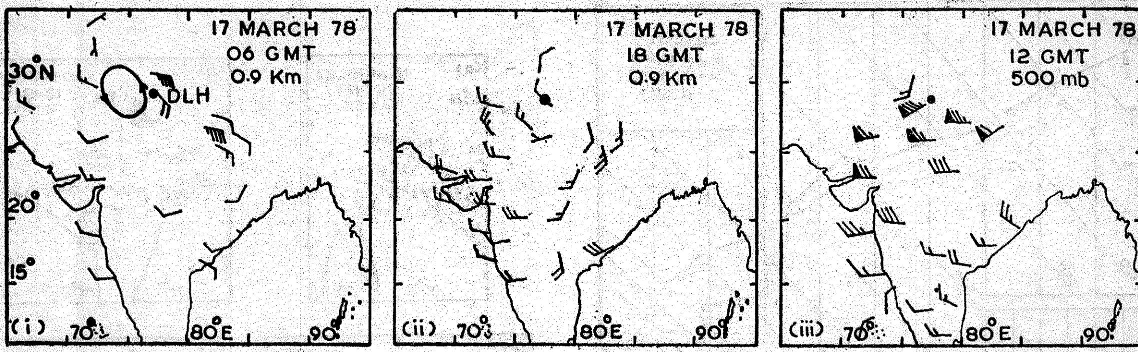

Fig. 2(b). Delhi tornado of 17 March 1978

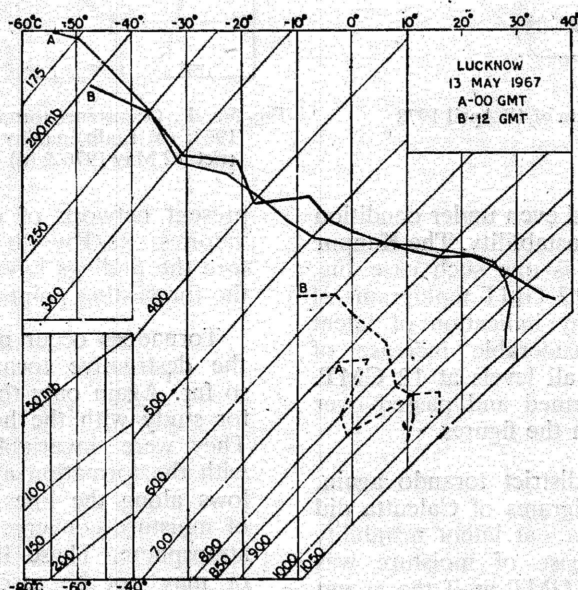

Fig. 3(a). Lucknow tephigram of 13 May 1967

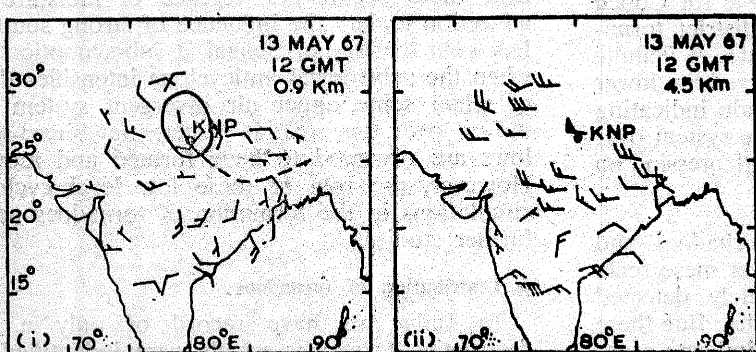

Fig. 3(b). Kanpur tornado of 13 May 1967

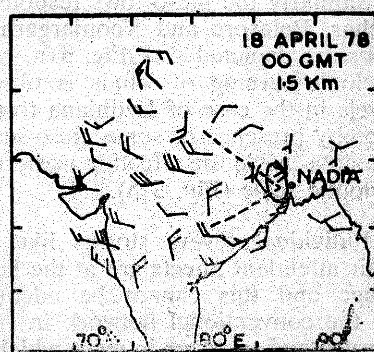

Fig. 4(a). Nadia district tornado of 18 April 1978

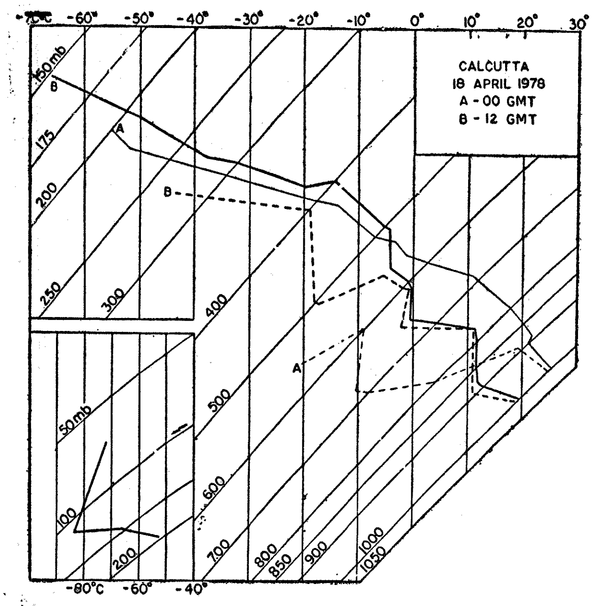

Fig. 4(b). Calcutta tephigram of 18 April 1978

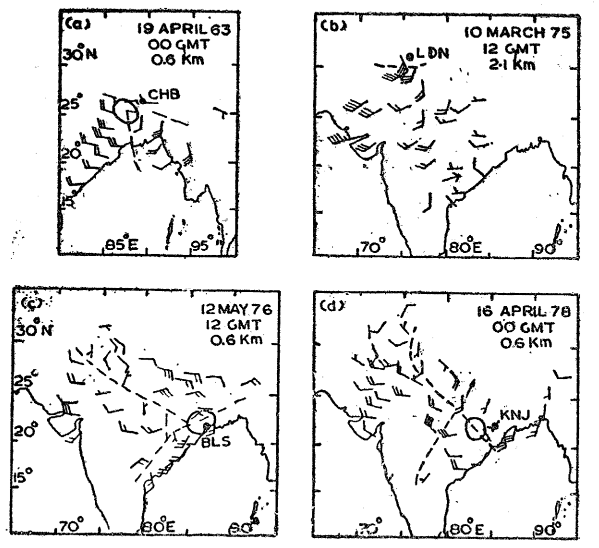

Fig. 5(a–d). Occurrence tornadoes in : (a) cooch Behar, 19 April 1963; (b) Ludhiana city, 10 Marcn 1975; (c) Balasore district, 12 May 1976 & (d) Keonjargarh district, 16 April 1978

Tornodoes have occurred even under condition of relatively neutral latent instablility. The Kanpur tornado (13 May 1967) is one such case Fig. 3(b). The 00 as well as 12 GMT tephigrams of Lucknow did not give any indication of latent instability. However, considerable increase of moisture was observed at all levels at 12 GMT. A meso-scale low had formed and passed over the area, was obvious from the figures.

In the case of Nadia district torando again, the 00 and 12 GMT tephigrams of Calcutta did not give much indication about latent instability though considerable increase of moisture was noticed at all levels at 12 GMT as if the ascent had passed through some *Cb* cloud, Fig. 4(b). However, the formation and movement of a meso-scale low over the area giving tornado could be observed from the lower tropospheric wind charts Fig. 4(a).

Similarly the meso lows responsible for Cooch Behar, Balasore and Keonjargarh district tornadoes are depicted *vide* Fig. 5(a, c, d). A definite cyclonic turning of winds is observed in lower levels in the case of Ludhiana tornado indicating thereby presence of some meso-scale system over the area inside the affecting western depression on synoptic scale (Fig. 5 b).

Individual severe storms like tornadoes and their attendant affects are at the lower meso-scale range and this cannot be adequately detected by the conventional network in India. But these storms tend to occur in ways which indicate organisation on meso-scale with upper limits which can be detected with the available data from the present network of conventional surface observatories, Rs/Rw/Pb and radar stations. Therefore the findings have valuable implications from the forecasting point of view.

Tornadoes occur much less in India and only the destructive tornadoes have been recorded so far. Again only the nine cases were available for study with the help of upper air soundings. They were invariably found to be associated with the formation and movement of meso-scale lows along the lines of discontinuities in areas of moisture convergence in the lower layers of atmosphere. These lines of discontinuities may or may not be associated with some synoptic scale system like the western depression or pre- and post-monsoon cyclonic storm. The lines of discontinuities forming in the lower atmosphere north of 20 deg. N and running west to east during pre-monsoon season signify the areas of convergence at synoptic scale. Superposed over this, there occurs convergence of moisture by advection under the influence of strong southerlies from the Bay of Bengal at sub-synoptic scale when the subtropical anticyclone intensifies there or when some upper air divergent system has moved over the area. It is here that meso-scale lows are observed to have formed and moved. However, the role of these low level cyclonic circulations in the formation of tornadoes needs further studies.

6. Distribution of tornadoes

In India we have record of only a few destructive tornadoes which were indentified by the type of destruction left behind by them mostly by Meteorological Observers. The practice

TABLE 4

Monthly distribution of the reported tornadoes in record with India Met. Dep.

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
—	—	7	17	9	2	1	—	4	1	1	—	42

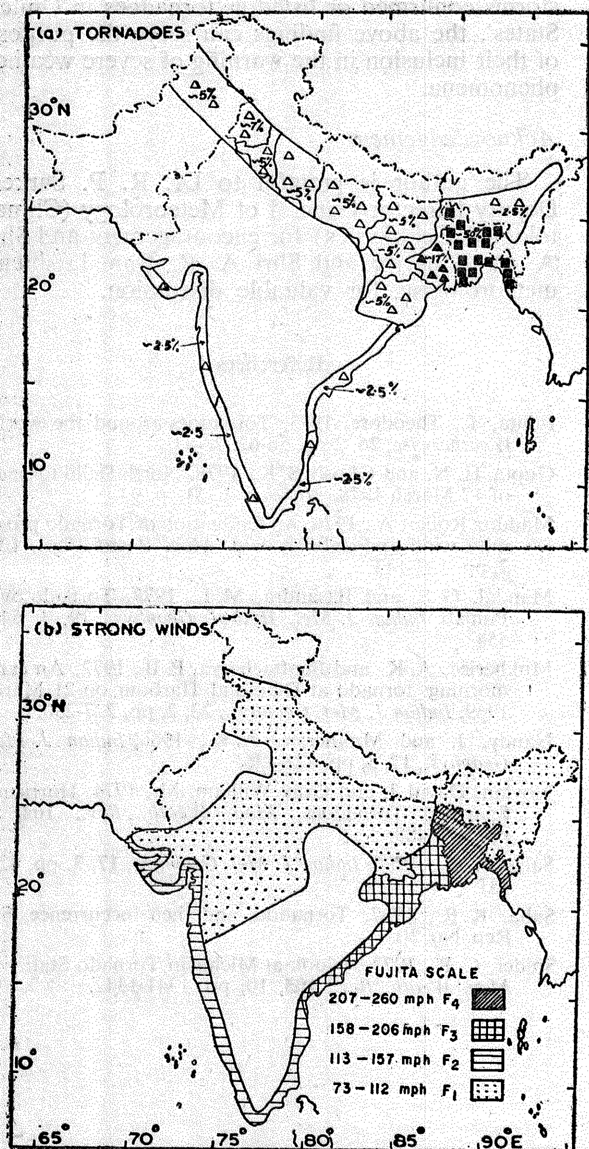

Fig. 6(a-b). Areas of occurrence over India

of reporting them in press was practically non-existent till recently.

Of the 42 cases of tornado occurrence, 9 listed by Saha (1969) and 34 by Ghosh and Gupta (1978), 20 (48 per cent) occurred in Bangladesh and 2 (5 per cent) in Pakistan. Out of the remaining 20 cases, 7 (17 per cent) occurred in West Bengal, 3 (7 per cent) in Punjab, 2 (5 per cent) each in Haryana, east U.P. and Orissa and one (2.4 per cent) in Assam. One tornado (2.4 per cent) occurred along the coast of Maharashtra, Kerala and Tamilnadu each. Besides, one water-spout (Kolleru lake) occurred in south Andhra Pradesh.

In addition 113 cases of strong wind associated with severe weather phenomena which caused large scale damage in terms of human life and property were also collected from the Press reports quoted in the *Weekly Weather Reports* of India Meteorological Department from 1951 onwards.

For preparing map showing distribution of tornadoes in India, following points are worth consideration:

(1) Most of the tornadoes occurred in the pre-monsoon season of the later half of March, April and May (Table 4).

(2) With the exception of three tornadoes and one waterspout which occurred along the Coastal Peninsula, all the other tornadoes occurred North of 20 deg. N under the regime of upper air westerlies.

(3) In northwest India tornadoes may occur associated with western depressions.

(4) Most of the tornadoes occurred in northeast India along wind discontinuities appearing in the lower tropospheric levels. Migratory meso-scale lows formed on these lines are the preferred areas for their occurrence. They have again occurred in maximum number in Bangladesh a land of rivers and lakes which make an additional source of moisture besides the moist current from the Bay.

Tornadoes occurring south of 20 deg. N, are rather weak (Fujita 1973). Keeping all the above facts in view and giving them proper weight, a map is prepared showing the distribution of tornadoes in India (Fig. 6a). The rugged hilly terrain of west Uttar Pradesh, Himachal Pradesh, Jammu and Kashmir will have lesser probability for tornado occurrence even though they may fall on the path of passing western disturbances (Snider 1977).

Besides, attempt is made to prepare a map of strong wind phenomena (Fig. 6b). They are one category lower in India than in US on Fujita Scale (loc. site).

7. Conclusions

(1) Over 72% of the reported tornadoes have occurred in northeast Indian subcontinental regions of Bangladesh, West Bengal, Assam and north Orissa. Around 22 per cent were reported from northwest regions of Pakistan, Punjab, Haryana and east Uttar Pradesh. Most of these tornadoes occurred in the pre-monsoon season of March, April and May. Tornadoes and water-spouts have also occurred along coastal India, though their occurrence is very rare.

(2) Dry bulb temperature and dew point curves were found running parallel in the ground inversion layers on the morning soundings over the tornadoes affected area. There was erosion of the capping inversion and deepening of moist layer in the evening soundings.

(3) Tornadoes were found to occur in areas with scattered TS activity at synoptic scale of motion. Meso-scale lows formed in areas of moisture convergence along the wind discontinuity lines at 0.3, 0.6, 0.9 and sometimes extending to 1.5 or 2.1 km levels, were favourable for the formation of tornadoes. They were mostly reflected as isallobaric lows on the surface change charts.

(4) Troughs in the upper air westerlies with embedded jet stream, provided the areas of upper air divergence in most of the cases.

(5) Two wind maxima were found to occur one at some upper tropospheric level and the other at some mid/lower tropospheric level in many of the cases. Their super-position was often observed on upper air-charts over the areas, on the day of tornado occurrence.

(6) Strong vertical wind shears were observed between the mid/lower tropospheric wind maxima and 850 mb/surface wind.

(7) Tornadoes have occurred in northwest India associated with western depressions.

(8) Tornadoes/waterspouts have occurred in the right front sector of a severe cyclonic storm striking the coast and undergoing rapid filling.

Though in India the occurrence of tornadoes is a rare phenomenon as per Fujita statement loc. site) who quotes the number of destructive tornadoes is no more than a fraction of all storms confirmed or listed as tornadoes in United States', the above findings can serve the purpose of their inclusion in the warning of severe weather phenomena.

Acknowledgement

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