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Climatology of Tornadoes of India and Bangladesh

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With 1 Figure

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Summary

On the basis of 51 tornadic events reported since 1835, the climatology of tornadoes across the Indian Subcontinent is elucidated. Tornadoes are most likely to occur during the late afternoon of the pre-monsoon months in northeast India or Bangladesh. A secondary maximum exists for the post-monsoon transitional period in the Northeast; moreover, tornadoes have been reported in a corridor extending to the northwest toward Pakistan. The characteristic weather patterns favoring the pre-monsoon severe storms are described. It is speculated that cycles of tornado years may be correlated to periods of reduced tropical cyclone activity.

Zusammenfassung

Klimatologie der Tornados in Indien und Bangladesch

Auf Grund von Berichten über 51 Tornados seit 1835 wird eine klimatologische Beschreibung dieser Wirbelstürme über dem indischen Subkontinent erstellt. Diese Stürme treten am häufigsten am Spätnachmittag während der Vormonsunmonate in Nordostindien und Bangladesch auf. Ein sekundäres Häufigkeitsmaximum existiert während der postmonsunalen Übergangsjahreszeit im Nordosten Indiens. Überdies wurden Tornados aus einem Korridor berichtet, der sich nordwestwärts gegen Pakistan hin erstreckt. Die charakteristischen Wetterlagen der Vormonsunmonate, welche das Auftreten von Tornados fördern, werden beschrieben. Tornadozyklen scheinen mit Perioden reduzierter tropischer Zyklonenaktivität korreliert zu sein.

1. Introduction

Tornadoes are relatively rare meteorological phenomena; however they do occur at numerous locations across the globe. Fujita [16] combined records of tornadoes for the period 1963–1966 with estimates of tornado activity to produce a map of expected tornado occurrence around the world. Japan,

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Australia, New Zealand, Europe, South Africa, Argentina and India are the most frequented regions outside of the United States.
Although accounts of tornadic storms are scattered through the literature, detailed studies on the nature and characteristics of tornadoes for regions

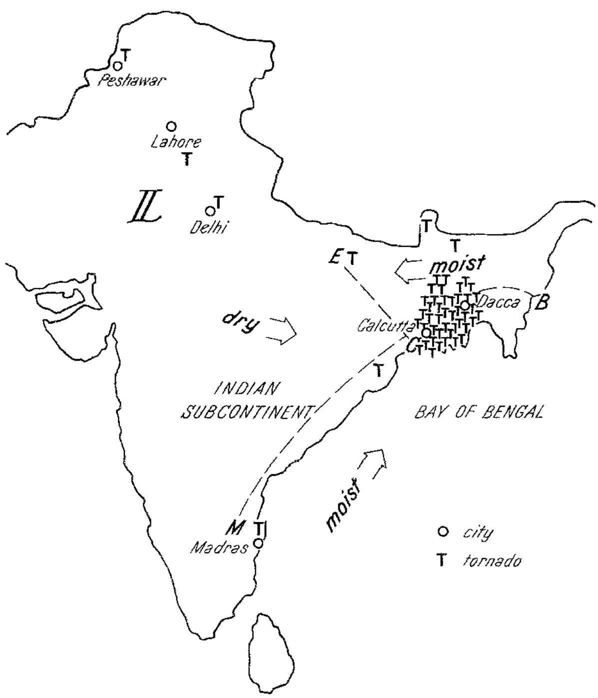

Fig. 1. Map of Indian Subcontinent. Major cities mentioned are shown by open circles. Locations of reported tornadic events are indicated by T's. Typical weather features characteristic of the pre-monsoon period include a low (L) near Delhi and troughs extending from E to C, from B to C and from M to C which separate the flow of dry and moist air masses (arrows)

beyond the United States are quite uncommon and not widely disseminated: e.g., Argentina [1], Austria [34], New Zealand [42], Europe as a whole [46]. Saha [41] has briefly noted outstanding tornado events in India, but a climatology of tornadoes there has not appeared. Across the Indian Subcontinent (Fig. 1) areas of high population density are subject to the hazard of tornadoes. Furthermore, the relatively long period of meteorological observation and commentary has generated a source of information which allows the compilation of a provisional climatology of tornadoes.

2. Severe Thunderstorms Across the Indian Subcontinent

The worldwide distribution of severe thunderstorms has been illustrated by Ludlam [24]; within India they are known as "andhis" and "nor'westers". In northwest India (west of 83°E long.) the thunderstorms develop under very warm unstable but rather dry conditions. The resulting high-based storms yield little precipitation; however the evaporatively cooled downdrafts from the largely scattered storms darken the skies with spreading walls of dust (included in the term "andhi"). As early as 1850 these events are vividly described from the vicinity of Lahore by Baddeley [33].

To the east of 83°E long. the severe storms are fueled more abundantly by low-level moisture. Squall lines advancing from the northwest (nor'westers) with locally heavy rain are most characteristic; however they may be accompanied by hail, high winds and tornadoes. (A local term, "Kal-Balsakhi" refers to their severity during the spring season, "Balsakh".)

While thunderstorms may occur through much of the year, the most violent storms are witnessed during the pre-monsoon months. Ramaswamy [35] augmented statistics on squalls with winds of over 18 m/s compiled by Ramakrishnan and Rao [37], showing that Delhi (to the west) and Calcutta (to be east) both average about ten thundersqualls during the March–May period. Storm winds within this zone in excess of 45 m/s have been recorded [39].

From the Northwest to the Northeast, the incidence of hail is highest near the mountainous border regions [36]. Relatively frequent storms are recorded within the severe storm corridor; in the Bengal, the highest frequency is during the pre-monsoon period [15].

3. Synoptic Setting During the Pre-monsoon Period

On the average, the low-level features of the pre-monsoon period may be related to a pattern of troughs (Fig. 1). From east of an area of lowest pressure near Delhi, a trough (EC) extends southeast to near Calcutta. From that point, one trough (CM) parallels the east coast to west of Madras, while another trough (CB) stretches eastward across Bangladesh. The easterly flow in the northeast sector is relatively moist; the south to southwesterly flow in the southeast quadrant is warm and quite moist; the west to northwesterly flow in the southwest sector is dry. The dry line along CM may play a role in the outbreak of severe storms [47] similar to that across the High Plains of the United States [7].

Ramaswamy [35] noted that while southwest to westerly flow might exist at the 300 mb level, the flow often does not uniformly veer with height from the lowest levels. The roughly north-south trough (CM) tilts eastward with height, so that at 1–1.5 km elevation northwest flow may be present above the sea-level trough. Quite commonly on storm days this trough may tilt eastward through the 500 mb level.

4. Tornado Climatology

In the United States, the annual number of reported tornadoes has increased markedly over the last several decades, due undoubtedly to changes in communication and public awareness [27]. Within the Indian subcontinent it is still difficult however to gather information on the many severe storms which occur [25]. Many reports do not go beyond local newspapers; on the other hand, the most notable storms may be mentioned in the international press and eventually be detailed in the scientific literature e.g. [4, 8, 10, 16, 23, 24, 45].

Especially after the founding of the Asiatic Society of the Bengal in the nineteenth century, exceptional weather (duststorms, hailstorms, tornadoes, etc.) across the Indian subcontinent began to be rather well documented. Subsequently, the Meteorological Department issued many reports on special specialized subjects.

For the purpose of this study, all known available references to Indian tornadoes have been gathered; the 51 tornadic events identified span 142 years (Table 1). In order to minimize the possibility that storm features (duration, damage swath width, etc.) be confused with those due to a tornado, the original descriptive accounts have been obtained for this study. As may be noted in the references, papers from the previous century were more exhaustive in their descriptions of events based on the information at hand; this is an aid in the determination of the nature of the events. The report by Hill [19], for example, refers to tornado-like violence, but the details related do not seem to be tornadic in scale; these unprecedented hailstorms to the east of Delhi therefore are omitted from this tornado climatology.

The occurrence of tornadic events by decades (Table 2) reveals a general increase in reports from the 1830's to 1890. Thereafter, none have been found until the decade of the thirties of this century. Since that time, the numbers have been relatively constant, until the last decade. Presumably, these large changes have a non-meteorological origin; however, such factors (policy shifts within journals, retirement of interested meteorologists, departmental reorganizations, etc.) have not been identified.

In the United States, a high proportion of the reported tornadoes last only a minute or so [21]; few of these are ever described in the literature. For those across the Indian subcontinent, the lifetimes have averaged much

Table 1. *Tornadic Events Reported Across the Indian Subcontinent.* The dates and locations are given for tornadoes (T), funnels (F) and waterspouts (W) reported by the sources (listed in the reference list). Multiple occurrences are indicated by doubling the letter designators

Date	Location	Event	Source
8 April 1838	24-Parganas	T	12
29 May 1852	Darjiling	F (multiple)	43
27 Sept. 1855	Calcutta	W	43
24 Sept. 1856	Howrah	W	43
7 Oct. 1859	Dum Dum	WW	43
11 Aug. 1860	Dum Dum	WW	43
28 Oct. 1860	Calcutta	F	43
5 May 1865	Pundooah	T	32
April 1871	Nadiá	T	48
15 April 1872	24-Parganas	T	48
25 April 1872	24-Parganas	T	48
Sept. 1872	Nadiá	T	48
11 Feb. 1874	Nadiá	T	48
16 Sept. 1874	Nadiá	T	48
26 March 1875	Mymensingh	T	11
31 March 1875	Mymensingh	T	41
27 March 1888	Jessore	T	32
27 March 1888	Dacca	T	32
7 April 1888	Dacca	TT	10, 32
27 April 1888	Hooghly	T	32
15 April 1889	Madhanagar	T	41
5 April 1933	Peshawar	T	44, 45
14 Feb. 1936	Bay of Bengal	WWW	8
8 Oct. 1945	Madras	W	39
26 June 1946	Dum Dum	F	8
10 July 1949	Hooghly	F	2
20 March 1951	Diamond Harbour	F	6
3 Oct. 1952	Bay of Bengal	W	3
14 Sept. 1956	Bamrauli	T	39
19 April 1963	Cooch-Behar	T	30
21 March 1969	Diamond Harbour	T	29
14 April 1969	Dacca	T	18
1 April 1972	Mymensingh	T	9
20 April 1972	Dacca	T	9
27 April 1972	Jessore	T	9
29 April 1972	Dacca	T	9
19 May 1972	Mymensingh	T	9
28 May 1972	Bogra	T	9
17 April 1973	Dacca	T	5, 18
11 April 1974	Bogra	T	5
10 March 1975	Punjab	T	26
10 April 1976	Madaripur	T	5
9 May 1976	Narayanganj	T	20
1 April 1977	Madaripur	T	4
17 March 1978	Delhi	T	17, 11, 22
16 April 1978	Orissa	T	13

Table 2. *Number of Tornadic Events Reported per Decade over the Indian Subcontinent, 1830–1978*

1831–40	1		1931–40	4
1841–50	0		1941–50	3
1851–60	5		1951–60	3
1861–70	4		1961–70	3
1871–80	8		1971–78	14
1881–90	6	Total	1831–1978	51

Table 3. *Duration of 25 Tornadic Events by Percentage (Number) Within Intervals*

1–5 min	6–10 min	11–30 min	31–50 min	51–100 min	> 100 min
12% (3)	28% (7)	44% (11)	8% (2)	0	8% (2)

Table 4. *Percentage (Number) of 14 Tornadic Events by Path Length Intervals*

1–5 km	6–10 km	11–20 km	21–50 km	51–100 km	> 100 km
14% (2)	21% (3)	36% (5)	21% (3)	0	7% (1)

Table 5. *Percentage (Number) of 15 Tornadic Events by Path Width Intervals*

21–50 m	51–100 m	101–200 m	201–500 m	501–1000 m	> 1 km
20% (3)	13% (2)	27% (4)	13% (2)	7% (1)	20% (3)

longer (Table 3); 72% (of those with estimated durations) lasted 6–30 minutes. In like manner, the reported path lengths (Table 4) and widths (Table 5) are rather large. Since these generally represent the more significant events, it is quite likely that many other funnels and tornadoes of shorter duration go unreported.

The geographical distribution of reported tornadoes (Fig. 1) indicates that for most of the Indian subcontinent, the phenomenon is an unknown event. Certainly, the "severe storm corridor" extending from Peshawar to Bangladesh is subject to hail, high winds and blowing dust from severe thunderstorms; but 82% of the reported tornadoes have been within a radius of 175 km centered just west of Dacca.

Table 6. *Percentage (Number) of 19 Tornadic Events Resulting in Death Totals*

1–5	6–10	11–20	21–50	51–100	101–200	201–500	501–1000
26% (5)	0	16% (3)	16% (3)	11% (2)	11% (2)	16% (3)	5% (1)

Table 7. *Monthly Distribution of 51 Tornadic Events Across the Indian Subcontinent by Percentage and Number*

Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	month
0	8	16	39	10	2	2	4	10	10	0	0	%
0	4	8	20	5	1	1	2	5	5	0	0	#

Table 8. *Percentage (Number) of 22 Tornadic Events by Direction of Origin*

ENE–E	ESE–SE	SSE–S	SSW–SW	WSW–W	WNW–NW	NNW–N
5% (1)	5% (1)	9% (2)	18% (4)	5% (1)	41% (9)	18% (4)

Over the years, tornadoes in India have come under investigation in part because of the associated large toll in lives (Table 6); several hundreds have died in single events. For the United States only a handful of tornadoes (e.g. the Tupelo tornado, 1936, the Waco tornado, 1953) have dealt such blows. It may be anticipated that large loss of life will be repeated for tornadoes in India. Bangladesh has a population (1979 estimate) of 83 million with a rural population density over 700/km^2; Dacca is 2–3 million and Calcutta is the eighth largest metropolitan area in the world with 10–12 million.

As a prelude to more detailed studies of the conditions favoring the occurrence of tornadoes, it is noteworthy that of the total number of tornadoes, 65% have occurred during March–May, with 39% in April alone (Table 7). Four have come during the monsoon period, while 20% have occurred during the post-monsoon period (September–October). Moreover, for reports including a direction of origin, 82% have indicated between south-southwest and north; none have moved from the northeast (Table 8). Translational speeds up to 90 km/hr have been reported; the more rapid speeds tend to occur in March and early April, while those later in the season are more sluggish.

A set of photographs has been published portraying the life cycle of the tornado near Peshawar [45] in the Northwest; in the northeast though only one photograph [2] and a few sketches [38] have illustrated the reports. In part, this dearth may result from the time of occurrence (Table 9); the greatest number of tornadoes have developed near and after sunset. With abundant low-level moisture, low cloud bases and scud may often obscure the tornado funnels as well.

Within the United States, tornadoes are often spawned within a tropical cyclone circulation as it makes landfall [31]. The Bay of Bengal is noted for its severe tropical cyclones which wreak great havoc ashore [14]. No

Table 9. *Number of 36 Tornadic Events According to Local Time of Occurrence to the Nearest Hour*[1]

LST	1	2	3	4	5	6	7	8	9	10	11	12 h
Nr.	–	–	–	1	–	–	–	–	–	–	–	3
LST	13	14	15	16	17	18	19	20	21	22	23	24 h
Nr.	2	–	7	–	7	9	4	2	–	1	–	–

[1] For times reported as "afternoon" ("evening") the time was uniformly set at 1500 (1800) local time.

tornadoes have been reported however with these storms; it is quite difficult though to distinguish a tornado swath amid widespread tropical cyclone damage. Without overlooking the data limitations, it is still of interest to note several features mentioned by Frank and Husain [14]. The severe tropical cyclones develop primarily between 15 April–15 June and 15 September–15 December. Moreover, a bar graph of severe cyclones for each decade up to 1970 reveals an inverse relationship to the decade reports of tornadoes; few cyclones 1830–1890, many for 1890–1930, etc.

5. Conditions for Tornadogenesis on the Indian Subcontinent

The origin and characteristics of nor'westers have been investigated in numerous papers [25]; andhis have not received so much attention. Moreover, only Ramaswamy [35] and Livingston [23] have focussed on conditions leading to severe thunderstorms. Compositing the data from 80 days of severe storm activity for the pre-monsoon months of 1952–1954, Ramaswamy concluded that there is little correlation between the storm outbreaks and low-level features, or even cold-air advection aloft. The dominant forcing mechanism appears to be the presence of upper-level divergence in the subtropical jet.

Using sounding for Calcutta and Tinker Air Force Base (Oklahoma) from May 1968–1970, Livingston compared the mean profiles and the composite soundings on storm days. Several factors appear to be responsible (in May) for the smaller incidence of severe weather in northeast India. Over Calcutta there is much more low-level moisture and greater instability, even on the morning sounding. Vertical wind shears though are characteristically smaller; moreover, baroclinic disturbances are rare.

The hypothesis emerges that forcing capable of initiating convection is weaker in the northeast India sector than in Oklahoma. With little vertical wind shear and with reduced evaporative cooling (due to the high relative humidity), the likelihood of asymmetric, supercell organization of storms is reduced. Storms then tend to be self-destructive, less frequently producing high winds, hail and tornadoes than in Oklahoma.

On the other hand, the occasional presence of pronounced northwesterly flow at mid-levels with subsidence could more effectively cap the lower level instability during the morning hours. With sufficiently strong horizontal divergence at upper levels and insolation, instability could eventually be released explosively in the afternoon. These severe storms would then tend to move with the mid-level flow from the northwest.

6. Storm Damage Investigations

Over the years most of the published damage reports have emphasized the destruction of houses and the uprooting of trees. Of these, the most exhaustive account dealt with the 1888 tornado through Dacca [10]. From one end of the swath to another, the effects on houses, barracks, walls, temples and river steamers are described, accompanied by detailed sketches of the damage track. Another tornado in 1889 [41] derailed a moving train.

Recent accounts are replete with damage photographs. A tornado in 1963 reportedly scoured the ground and deposited scraps of metal 50 km from the source [30].

Estimates of windspeeds within the tornadoes have ranged up to 150–200 m/s [41]. More recently, several occurring in Bangladesh (1972–1977) have been thought to have winds 50–100 m/s [5, 9].

Few of these windspeed estimates have been accompanied by supporting analyses. A report of water raised one meter by the passage of a tornado led Saha [40] to infer a pressure deficit of $\sim$ 100 mb; with the assumption of cyclostrophic balance, a tangential windspeed of 92 m/s was deduced. (While such a conclusion is not unreasonable, the original report may be regarded with some suspicion.) The failure of two radio transmission towers was analyzed [22], yielding estimates of 90–97 m/s. (The credibility of such results has been assessed by Mehta [28] in a review of wind-speed estimates derived from damage analysis.)

7. Conclusions and Recommendations for Further Study

On the basis of published accounts several often-mentioned characteristics of tornadoes across the Indian Subcontinent have been given quantitative support. The typical notable tornado occurs near sunset in April in the Bengal, travelling rapidly from the northwest.

The available studies of upper-level conditions during the storm period have focussed on May, whereas this study has shown that the preponderance of tornadoes occur in April. Studies for April similar to those of Ramaswamy and Livingston should be carried out; in addition, however, case studies for storms in that month should be pursued since features critical for storm formation can be lost in the averaging process. These should incorporate available radar and satellite data; to date, these have not contributed significantly to the published studies.

Another intriguing study would seek relationships between the occurrence of severe storms and the time of onset of the southwest monsoon; perhaps, the development of severe tropical cyclones is related to this aspect as well.

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