Meteorological Characteristics of Tornadoes in Bangladesh

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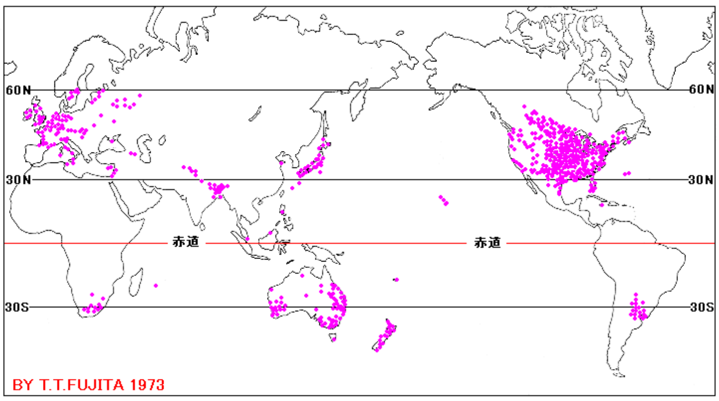
ABSTRACT: Severe local storms including tornadoes frequently occur in Bangladesh in the pre-monsoon season from March to May and kills and injures several thousands peoples in a year. Therefore, severe local storm is one of the most important natural hazards in Bangladesh. This paper presents meteorological characteristics of severe local storms including tornadoes.

KEYWORDS: Tornado, Severe local storm, Bangladesh,

1. INTRODUCTION

Bangladesh is located in the depths of the Bay of Bengal with the area of 143,998km^2. This country has been attacked frequently by severe cyclones and serious floods. For example, several hundreds thousands people were killed by the cyclone of 1970 and more than a hundred thousand by that of 1991. On the other hand, severe local storms of meso-scale phenomena such as tornadoes and downbursts also have occurred frequently in the northeastern Indian subcontinent including Bangladesh as shown in Figure.1 (Fujita[1], 1973). However, comprehensive research of the severe local storms is very few and several climatological and case studies were only reported (Peterson and Metha[2,3], 1981, 1995).



世界のトルネード(地上たつまき)分布。毎年約1000個のたつまきが地球上に発生している。
発生回数のトップはアメリカ。日本、ヨーロッパ、オーストラリアなどの温帯国にもしばしばおこるが、
熱帯には少なく、寒帯にはほとんどない。

図1　世界で発生したトルネードの分布

[出典]藤田哲也:たつまき－上　渦の驚異、共立出版(1973),表紙裏

Figure 1. The distribution of tornadoes over the world (Fujita, 1973).

In this paper, the evaluation method of tornadoes is introduced following the Fujita scale and the Enhanced Fujita scale. The climatology and evaluation of forecast skill of convective parameters for severe local storms in Bangladesh are also presented. The occurrence of the local severe storms concentrated in the pre-monsoon season in March, April and May in Bangladesh every year and is called as "Nor'wester" in local name or "Kalbaishaki" in Bangla. The damages by the single sever local storm is located in the very small area compared with those in the cyclones and floods. However, as the occurrence frequency of the severe local storms is much larger than that of cyclones and floods, the total damage amount cannot be negligible. The field research results of Tangail in May of 1991, one of the severest tornado disasters in Bangladesh, are also reported.

2. CLIMATOLOGY OF SEVERE LOCAL STORMS IN BANGLADESH

This chapter presents climatology of severe local storms on the basis of Yamane et al. (2009a)[4]. We produced a database of severe local stoms in Bangladesh based on the survey of storm reports published in the local literature (mostly media-based literature). In this study, we included severe weather accompanied with deep convection (e.g., tornado, lightning, hail and gust wind). In Bangladesh, tornadoes are confused with cyclones in the literature. In our database the exclusion of wind damage reports associated with tropical cyclones by using the best track data made available by the Joint Typhoon Warning Center (JTWC). The database constructed in the present study contains date, location (district and upazila[1]), duration, type of phenomena (e.g., hail and lightning) and the damage to property. The district of occurrence is identified for most reports, and the upazila is also identified in some events. The occurrence time is identified for some events. Details of damage (e.g., the number of deaths and injuries, the damage to buildings and crops) are also included in the database. In this study, we collected 2,324 SLCS events from 1990 to 2005 in Bangladesh. There were more events and the period of analysis is longer than those of previous studies.

2.1 Monthly Frequency

Figure 2 shows the monthly frequency of severe local storms in Bangladesh from 1990 to 2005. Severe local storms occurs frequently during the pre-monsoon season from March to May. The peak was found in April, with 829 events, which is 36% of the total number of events. The frequency decreases sharply in the monsoon season. From September in the late monsoon season to October, the frequency slightly increases. SLCS is rare during the winter season (December-February).

2.2 Hourly frequency

Figure 3 shows the hourly frequency of the occurrence of severe local storms. The frequency has two peaks. One is between 16 Bangladesh Standard Time (BST) and 17

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[1] Bangladesh is divided into 64 districts. Moreover, each district is divided into an upazila

(sub-district)

BST with 21 events, and the other is between 20 BST and 21 BST with 22 events. The frequency is large in the evening and small at midnight and early morning. The minimum of the frequency is between 4 BST and 5 BST with no event.

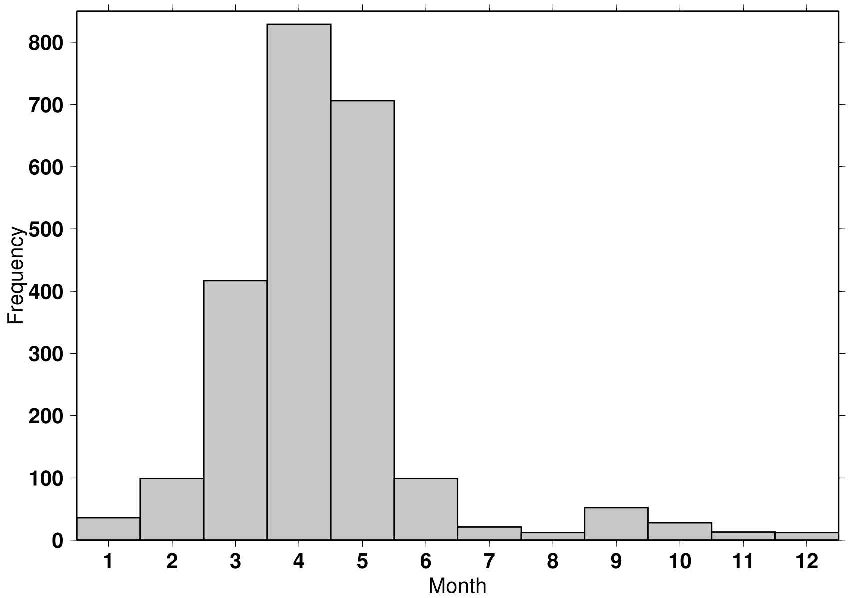

Figure 2. Monthly frequency of severe local storms in Bangladesh from 1990 to 2005 (Yamane et al., 2009a).

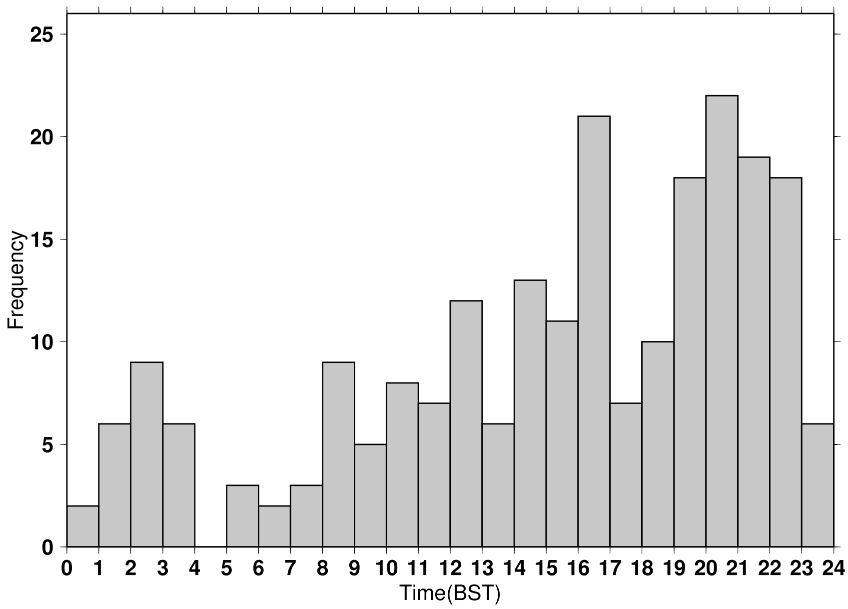

Figure 3. Hourly frequency of severe local storms in Bangladesh from 1990 to 2005 (Yamane et al., 2009a).

2.3 Geographical distribution

Figure 4 shows the geographical distribution of severe local storms across Bangladesh. A dot locates at the headquarters of a district, and the shade and size of the dot indicate the magnitude of the frequency for each district. Severe local storms occurs most frequently in Dhaka (90.3 °E and 23.7°N (indicated as "D" in Figure 4)) with 111 events. In addition, SLCS occurs more frequently in Netrakona (90.7°E and 24.8°N (indicated as "N" in Figure 4)) with 109 events, Tangail (89.9°E and 24.2°N (indicated as "T" in Figure 4)) with 90 events, Sirajganj (89.6°E and 24.0°N (indicated as "S" in Figure 4)) with 83 events, Comilla (91.1°E and 23.4°N (indicated as "C" in Figure 4)) with 83 events. Thus, severe local storms occur most frequently in the central part of Bangladesh. On the contrary, severe local storm is rare in the southwestern and eastern hill regions.

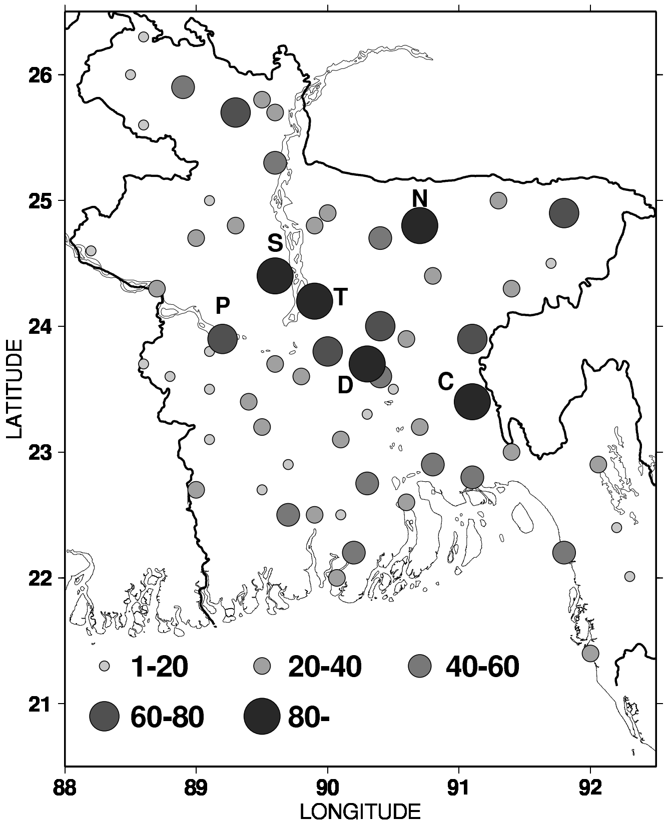

Figure 4. Geographical distribution of severe local storms in Bangladesh from 1990 to 2005 (Yamane et al., 2009a).

3. EVALUATION OF FORECAST SKILL OF CONVECTIVE PARAMETERS FOR SEVER LOCAL STORMS

In this section, we present the evaluation of forecast skill of the convective parameters using a skill score on the basis of Yamane et al. (2009b)[5]. The skill score used in this study is the Heidke Skill Score (HSS). The HSS is a skill score based on a contingency table and defined as

$$HSS = 2(ad - bc)/\{(a+b)(b+d)+(a+c)(c+d)\},$$

where a is the number of correct nonevent forecasts, b is the number of false alarms, c is the number of events not detected, and d is the number of correct event forecasts. While the HSS gives a score of 1 for no incorrect forecasts, it gives a score of -1 for no correct forecast. The HSS takes into account the number of correct random forecasts. The HSS gives credit for a correct forecast on a nonevent and takes into account the number of correct random forecasts. Thus, we utilized the HSS for evaluation of the forecast skill of convective parameters.

In this study, we calculated various convective parameters to quantify the environmental conditions in the outbreak of severe local storms. The convective parameters investigated were the K Index (KI), Total Total (TT), Showalter Stability Index (SSI), Precipitable Water (PW), Convective Available Potential Energy (CAPE), Mean Shear (MS), the magnitude of the vector difference between the winds at the surface and the level of 500 hPa (hereinafter, referred to as SHEAR0-500hPa for simplicity), Storm Relative Environmental Helicity (SREH), Vorticity Generation Parameter (VGP), Energy Helicity Index (EHI), and Bulk Richardson Number (BRN). MS, SHEAR and SREH are measures of vertical wind shear of the atmosphere. The vertical wind shear is important for organization of convection (supercell and multicell). Supercells and multicells have greater potential to produce severe weather such as tornadoes than ordinary cells. VGP, EHI and BRN are combinations of the thermal instability and vertical wind shear parameters and common indicators of the formation of supercells and tornadoes. VGP is calculated between the surface and 1 km Above Ground Level (AGL), 2km AGL, 3km AGL and 4km AGL (referred to as VGP0-1km, VGP0-2km, VGP0-3km and VGP0-4km, respectively). Detailed definitions of these parameters are described in Yamane et al. (2009b)[5].

We determined the statistical significance between convective parameters on severe local storm days (SLSD, days with the reports of severe weather) and non-severe local storm days (NSLSD, days without any report of severe weather). The result indicates that all thermodynamic parameters and combination parameters except for the TT and the BRN have statistical significance with the confidence level of 99%. However, all dynamic parameters have no statistical significance with the level of 99%. The SLSD identified in this study include various severe convective weather events. If we can discriminate between supercell and non-supercell, or tornado and non-tornado, dynamic parameters may be able to differentiate between these two categories. Therefore, the result in the present study does not necessarily indicate that the vertical wind shear is not important for the formation of tornadoes and supercells during the pre-monsoon season in Bangladesh. In this study, we focus on convective parameters with the statistical significance of the level of 99% between SLSD and NSLSD.

The method of evaluation conducted in this study is as follows. First, a threshold was set for a convective parameter, and the categorical forecast was performed using the threshold. Then, the HSS was obtained for the threshold. This procedure was continued until the threshold yielding the best HSS was obtained. In this study, we evaluated the HSSs for the convective parameters that can distinguish between SLSD and NSLSD with the statistical significance of the 99% confidence level. Table 1 shows the best HSSs and the thresholds yielding the best HSS for each convective parameter. This table shows that the HSSs for the LI and PW are better among all parameters. The HSSs for the LI and PW are 0.29 and 0.29, and the thresholds for them are -2.6 K and 31.9 kgm^{-2}. The value of the HSS for the CAPE is also relatively high. The values of the HSS and threshold for the CAPE are 0.24 and 1121 Jkg-^{1}. In contrast, the values of the HSS for the EHI, VGP0-3km and VGP0-4km are relatively worse among all parameters (0.17, 0.17 and 0.12, respectively). The HSSs of the combination parameters are relatively low. This may be because we cannot distinguish between tornado and non-tornado or supercell or non-supercell in our database as mentioned before. If we can discriminate among these categories, we could determine higher value of the HSS of the combination parameters.

Tabale 1. Heidke Skill Score (HSS) and thresholds yielding the best HSS for each convective parameters (Yamane et al., 2009b).

Parameter	HSS	Threshold
LI	0.29	-2.6
PW	0.29	31.9
CAPE	0.24	1121
SSI	0.24	0.7
VGP0-2km	0.23	0.67
KI	0.21	29.6
VGP0-1km	0.20	0.77
VGP0-3km	0.17	0.70
VGP0-4km	0.17	0.13
EHI	0.12	0.01

4. EVALUATION OF SEVER LOCAL STORMS

The affected area of the severe local storm and the damaged region is concentrated in the very small region. Therefore, the meteorological data such as pressure and wind cannot be obtained because the weather observatories are not distributed in a fine spatial resolution. Fujita[6] (1971) introduced the estimating scale of severe local storms, especially tornadoes, applying the tornado damages in the past of reports of NOAA, USA. This scale was made up on the basis of relationship between the wind speed and the damage in the tornadoes. This Fujita scale is utilized for the estimation of the intensity of the tornadoes in USA and other counties. However, this scale is different in each countries and local regions. Therefore, the Fujita scale in Bangladesh version is necessary to complete on the basis of the original Fujita scale for the development of research and the official use.

4.1. Fujita scale

Typical Fujita scale is summarised in Table 1.

Table 2. Fujita scale

Scale	wind speed mph	wind speed km/h m/s	Relative frequency	Damage Path Width (meters)	Potential damage
F0	40-72	64-116 18-32	38.90%	10 - 50	Light damage. Some damage to chimneys; branches broken off trees; shallow-rooted trees pushed over; sign boards damaged.
F1	73-112	117-180 32-50	35.60%	30 - 150	Moderate damage. The lower limit is the beginning of hurricane wind speed; peels surface off roofs; mobile homes pushed off foundations or overturned; moving autos pushed off the roads; attached garages may be destroyed.
F2	113-157	181-253 50-70	19.40%	110 - 250	Considerable damage. Roofs torn off frame houses; mobile homes demolished; boxcars overturned; large trees snapped or uprooted; highrise windows broken and blown in; light-object missiles generated.
F3	158-206	254-332 70-92	4.90%	200 - 500	Severe damage. Roofs and some walls torn off well-constructed houses; trains overturned; most trees in forest uprooted; skyscrapers twisted and deformed with massive destruction of exteriors; heavy cars lifted off the ground and thrown.
F4	207-260	333-418 92-117	1.10%	400 - 900	Devastating damage. Well-constructed houses leveled; structures with weak foundations blown away some distance; cars thrown and large missiles generated. Skyscrapers and highrises toppled and destroyed.
F5	261-318	419-512 117-142	<0.1%	1100 ~	Total damage. Strong frame houses lifted off foundations and carried considerable distances to disintegrate; automobile sized missiles fly through the air in excess of 100 m (109 yd); trees debarked; steel reinforced concrete structures badly damaged; incredible phenomena will occur.

5. TANGAIL TORNADO ON 13 MAY 1996

A tornado occurred in Tangail district of Bangladesh in the evening of around 16LST(local Standard Time) on May 13th, 1996. The number of death amounted 525 (SMRC[7], 1996, Hayashi[8], 1996). The Japanese research team in Disaster Prevention Research Institute of Kyoto University carried out the filed research of damages for clarifying the damages of this tornado form June 27 to July 2, as the case study.

5.1 Meteorological condition

Figure 5 shows the surface weather chart at 09LST on May 13, 1996, when the tornado happened. The trough was just over the middle of Bangladesh, which connected between the lows of 996 hPa in the northeast India and 1000hPa in the east of Bangladesh. The clod flow from the Himalaya and the warm flow from the Bay of Bengal converged in the upper layer over Bangladesh. The wind system in the middle west shows the appearance of the small low.

The aerological (Radio Sonde) observation at 06LST in Dhaka of that day is shown in Figure 6 for the vertical profiles of air temperature and dew point temperature. The difference of those two temperatures is very small up to 600 hPa from the surface.

Figure 7 shows the satellite (GMS-5) photo at the time of tornado occurrence. The clear and solid cumulonimbus can be recognized in this figure and this cloud is considered as the mother cloud of this tornado. Figiure 8 shows the time series of the details photo of the cloud system over Bangladesh. The cumulonimbus (T_{bb} is less then -70 ℃) highly developed in the middle of Bangladesh from 15LST and covered mostly the main area of middle Bangladesh at 17LSt and 18LST. Bangladesh was in the unstable weather condition and, thunder and lightening was found in Dhaka in the evening of May 13 and hail fell down in Chittagong on May 14.

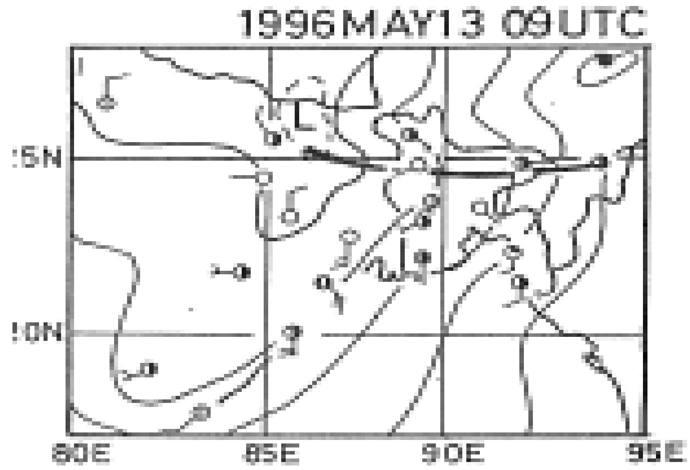

Figure 5. Surface weather chart at 06LST on May 13,1996

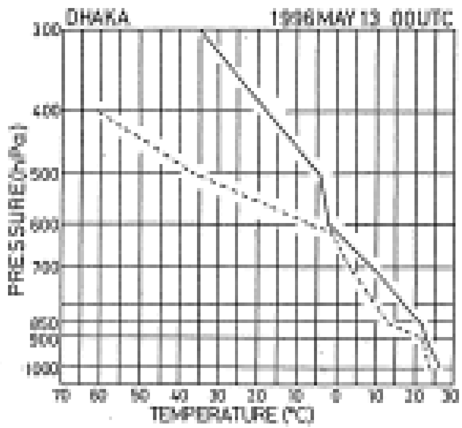

Figure 6. Aerological observation in Dhaka at 06LST on May 13, 1996

5.2 Damages in tornado

The damages in this tornado are summarized in Table 3. The dead amounts 525, the injured 32,601, the affected persons 84100 and the destroyed houses 35,691. The most seriously damaged regions are Goparpur, Kalihatti and Bashail tanas in Tangail district, where is located in the distance of 120km north from Dhaka. The first damaged area is in the south end of Jamalpur district next to the Tangail district. The damaged path was traced southward running through the Tangail district and the moving direction changed southwestward in the southern end of this district as shown in Figure 8. The total lenghth of damaged area extended about 80km and the width was about 3km in maximum. The time of occurrence of damages was estimated from 16:30LST to around 18LST, then the time duration of this severe local storm was one hour and half. The traveling speed is calculated as 53kmh^{-1} on average. Several witnesses told that they identified a funnel during this severe local storm. The damaged area by the tornado was estimated 20km long and 500km wide in maximum.

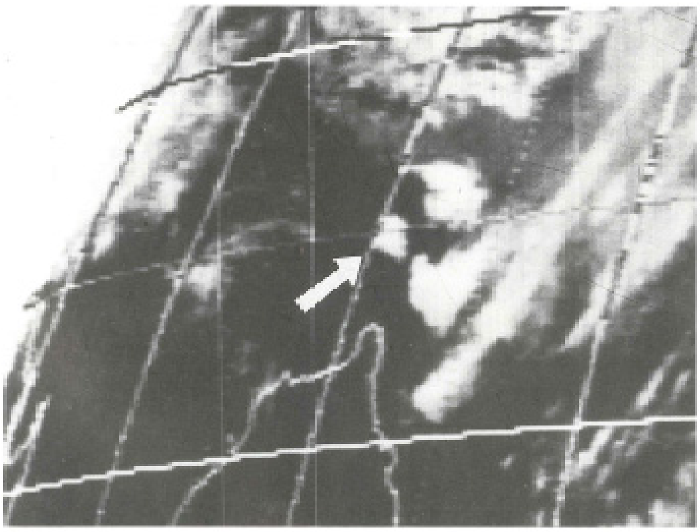

Figure 7. Satellite image at tornado occurrence on May 13,1996, white arrow shows the mother cloud of the tornado

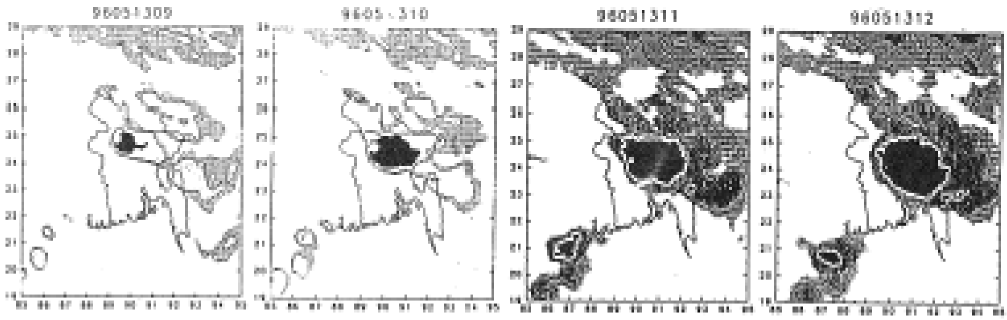

Figure 8. Time series of visible images of GMS-5 From 15LST to 18LST on May 13, 1996

Table 3. Main damage statistics in the outbreak of the tornado in Tangail on 13 May 1996.

Personal Damage	Dead		525
	Injured		32,601
	Affected		84,100
Damaged Structures	Houses		35,691
	Schools	Completely damaged	16
		Partially damaged	34
Damaged Water	Public well		500
	Private well		1,000
Damaged Food			15% of the whole crops
Damaged Cattle	Cow		2,800
	Sheep		14,100
	Hen & Cock		404,000

Figure 9. Typical view of the rural village area in Bangladesh

The ordinal scene in the rural region in Bangladesh is shown in Figure 9, where paddy rice field is extending flatly and the villages of a small community with several houses are constructed in the heights. This rice field is completely covered with water in the monsoon season except small lanes. After passing of the tornado, most of trees on the heights were broken as shown in Figure.10. The severest damage is shown in Figure 11, which is the school building in Milkpur. This building was reinforced concrete and its beams and columns are fully strong for the high wind. The maximum wind speed is estimated as more than 70ms-1 from this damage and corresponding to F3 of the Fujita scale. In the developing countries such as US and Japan, the F3 tornadoes sometimes did not make more than 500 dead persons. What is the reason of such terrible damages? The typical and traditional houses in the rural area in Bangladesh are made with straw roofs and bamboo walls (Figure 12). Recently the house with tin board roof and walls are prevailing (Figure 13). This house is keeping good for the water proof condition during heavy rainfall in the monsoon season. However, when the high wind blows in the severe local storm in the pre-monsoon season, those tin boards are flown away immediately and become dangerous knives to cut and kill a body. Many persons were injured by these flying tin boards in this severe storm.

Figure 10. Damaged village

Figure 11. The severest damage of the school building in Milkpur

Figure 12. Traditional rural house

Figure 13. Tin roof and wall house

6. SUMMARY

This paper presents meteorological characteristics of severe local storms including tornado in Bangladesh comprehensively on the basis of our studies. In the future, we need to promote research of severe local storms further for the purpose of forecasting of severe local storms and mitigating damages. Database of severe local storms needs to be renewed continuously in the future. In these days, efficient observation such as radar system has been established in Bangladesh. Case studies by using these observational data and numerical model should be performed vigorously for the purpose of clarifying mechanism of occurrence and development of severe local storms. In addition, filed survey should be conducted further to clarify damages in detail.

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