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The environment associated with significant tornadoes in Bangladesh

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ABSTRACT

This paper investigates the environmental parameters favoring significant tornadoes in Bangladesh through a simulation of ten high-impact events. A climatological perspective is first presented on classifying significant tornadoes in Bangladesh, noting the challenges since reports of tornadoes are not documented in a formal manner. The statistical relationship between United States and Bangladesh tornado-related deaths suggests that significant tornadoes do occur in Bangladesh so this paper identifies the most significant tornadic events and analyzes the environmental conditions associated with these events. Given the scarcity of observational data to assess the near-storm environment in this region, high-resolution (3-km horizontal grid spacing) numerical weather prediction simulations are performed for events identified to be associated with a significant tornado. In comparison to similar events over the United States, significant tornado environments in Bangladesh are characterized by relatively high convective available potential energy, sufficient deep-layer vertical shear, and a propensity for deviant (i.e., well to the right of the mean flow) storm motion along a low-level convergence boundary.

1. Introduction

Bangladesh experiences its severe thunderstorm season between March and May, resulting in property damage, injuries and deaths each year (Yamane et al., 2010a). During the pre-monsoon season, the ingredients for severe thunderstorms may develop including low-level moisture from the Bay of Bengal, a relatively hot and dry air mass from the Indian Subcontinent and relatively strong flow at mid- to upper-levels to provide sufficient vertical wind shear for organized convection (e.g., Petersen and Mehta, 1981; Yamane and Hayashi, 2006; Yamane et al., 2010a). These ingredients can lead to an elevated mixed layer above a moist air mass where a capping inversion suppresses convection and allows instability to build with daytime heating until localized convergence along a dryline triggers deep convection (Carlson and Ludlam, 1968). Akter and Ishikawa (2014) noted this mechanism in a case study over Bangladesh as being similar to convective initiation along the dryline in the Great Plains of North America.

Past studies have investigated tornado events across Bangladesh (Afrose et al., 1981; Ono, 1997), however as noted by Yamane et al. (2010a), the definition of tornadoes in these studies is based on arbitrary thresholds of wind speeds so that non-tornadic events may have been included in previous climatologies. The critical limitation in studying tornadoes over Bangladesh lies in the fact that the Bangladesh Meteorological Department (BMD) does not formally document tornado reports (except for a few significant events that cause extensive damage).

Yamane et al. (2010b) studied the environment of severe local convective storms which included tornadoes in addition to reports of wind, hail and lightning. Discriminating between tornadic and non-tornadic events is not generally possible if one is interested in all tornado events due to the absence of tracking tornado reports. However, by beginning with a database of tornadoes similar to Afrose et al. (1981) or Ono (1997) and only considering the most significant of these events, we will likely have a dataset associated with the most significant tornadoes. Given the dearth of formal tornado documentation, this study represents the best possible effort to follow a study similar to Cohen (2010), which was done over the U.S., in assessing the environment associated with significant tornadic storms over Bangladesh.

When assessing environmental conditions, it is important to note that the only available rawinsonde data in Bangladesh is the morning (0600 Bangladesh Standard Time) observation from Dhaka. These data are not generally representative of the environment of tornadic storms that typically occur during the afternoon and evening hours. One method of addressing the limited upper-air observational data is to use reanalysis data, numerous studies have used reanalysis data for assessing the severe thunderstorm/tornado environment (e.g. Brooks et al., 2003b; Grünwald and Brooks, 2011; Romero et al., 2007; Kaltenböck et al., 2009). Yamane

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and Hayashi (2006) utilized the European Centre for Medium-Range Weather Forecasts (ECMWFs) re-analysis (ERA-40) dataset available every 6 h on a 2.5° by 2.5° grid. As in Yamane et al. (2010b), the focus was on severe local convective storms (not solely tornadoes). However, the coarse resolution of these data precludes a suitable assessment of the near-storm environment of tornadic thunderstorms. Akter and Ishikawa (2014) examined a case study of a tornadic event in Bangladesh with 50 km horizontal resolution and 6 hourly temporal resolution reanalysis data and remarked on the need for higher temporal resolution data. Since the focus of this study is to quantify the near-storm environment of significant tornadoes, the need for high-resolution (3-dimensional) data during the afternoon and evening hours is critical. In order to provide the best possible solution given data limitations, we make use of short-term simulations using the Weather Research and Forecasting (WRF) — Advanced Research WRF (ARW) dynamical core numerical weather prediction (NWP) model (Skamarock and Klemp, 2007).

The remainder of this article is organized as follows. A climatology of probable tornadoes and associated deaths is presented in Section 2. From this initial dataset, a subset of only the most significant tornado events is considered for simulating the near-storm environment. Section 3 presents the results of ten selected numerical modeling case studies, along with a comparison to similar studies from the United States (U.S.). Conclusions are given in Section 4.

2. Climatology of significant tornadoes

2.1. Tornado database formulation

The methodology begins with the development of a comprehensive climatology of tornado reports based on past studies and historical Bangladesh media reports. Knowing that some non-tornadic events have been included in historical media reporting, only the most significant events are retained for the purposes of simulating the near-storm environment (see Section 3). Previous studies of tornado climatologies in the region (Petersen and Mehta, 1981, 1995; Afrose et al., 1981; Ono, 1997) listed tornado events according to an arbitrary definition of a tornado due to the absence of a formal tornado reporting system. The climatology compiled here is generally restricted to the area from 85° to 93°E and from 21° to 27°N (mostly Bangladesh but a portion of eastern India as well) for the period 1838–2005. The sources of information include scientific journal articles and newspaper reports. Articles were queried for only the March to May time period since that is the primary severe thunderstorm season over the Bengal region (Yamane et al., 2010a). Other sources of information include the Office of U.S. Foreign Disaster Assistance, the Centre for Research on the Epidemiology of Disasters, and the British Association for Immediate Care. The sources were scanned for information reporting on storm-related damage/fatalities that provides evidence of a tornado based loosely on Fujita (1971).

The thresholds used to determine if the event was tornadic are the following: 1) specific information such as width and path length, sharp gradients in damage or damage intensity, or description of the actual funnel or roaring sound was provided that would be indicative of a tornado, 2) heavy objects, people or animals thrown long distances, 3) flying debris such as corrugated iron sheets caused lacerations, decapitation, or loss of limbs, 4) description of catastrophic damage (e.g., entire villages reduced to rubble and/or photos showing tornadic damage), and 5) at least 15 deaths occurred inland that can be documented as unrelated to tropical cyclones. At least one of these criteria needs to be met for tornado classification. Given the lack of detailed storm surveys in Bangladesh, these types of thresholds are necessary for the development of a relatively objective tornado climatology. Unless there were at least 15 deaths, additional evidence was required to label an event as a tornado. Even if at least 15 people were killed, an event was not classified as a tornado if the documentation suggested the presence of widespread straight-line winds. High winds associated with a land-falling, tropical cyclone cannot be distinguished from the accompanying tornadoes, especially since the term cyclone was used for tropical cyclones and tornadoes. Therefore, tornadoes associated with land falling tropical cyclones were excluded altogether.

Since the housing structure is predominantly frail in Bangladesh, people are often killed by straight-line winds. For example, collapsing of roofs and capsizing of ships have been responsible for many deaths at times. In addition, weaker tornadoes are often indistinguishable from straight-line wind events since documentation for such events is extremely limited. Newspapers tend to ignore events that are less than catastrophic. Since it is very difficult to differentiate less than catastrophic tornadoes from straight-line winds, this climatology focuses primarily on the deadliest and most catastrophic events that tend to be associated with significant and violent tornadoes.

The unique aspect of this tornado climatology compared with past studies in the region (Petersen and Mehta, 1981, 1995; Afrose et al., 1981; Ono, 1997) is the blending of scientific articles, reports from the BMD, multiple newspapers and other sources over a long time period (1838–2005) as listed in Appendix A. Petersen and Mehta (1981) used scientific journals and BMD reports from 1838 to 1978. Ono (1997) used one newspaper source between 1990 and 1994. Afrose et al. (1981) considered tornado and nor'wester events between 1975 and 1979. Utilizing a blend of multiple sources to collect tornado reports has been employed in similar studies of tornadoes over Europe (e.g., Gayá, 2011; Brazdil et al., 2012; Taszarek and Kolendowicz, 2013; Simeonov et al., 2013). In addition, at least one of five criteria was used to determine if the event was tornadic (note Appendix A lists the criteria met with numerous events associated with multiple criteria).

The analysis yielded 84 tornado events from 1838 to 2005, with details for each tornado listed in Table A1 of Appendix A. Most of the events (81) denoted the number of deaths. A summary of the tornado climatology is shown via the location with the number of deaths by category (Fig. 1). The data were binned into 10-day periods to illustrate the time period during the pre-monsoon season when tornadoes tend to occur most frequently (Fig. 2). The maximum occurs in mid-April (specifically April 11–20) which agrees with the peak of severe local storms from Yamane et al. (2010a). This climatology serves as a foundation for the dataset on significant tornadoes in Bangladesh, which is the primary focus of this study. Although some tornado events are undoubtedly missed in this climatology, it is highly unlikely that a significant tornado event is missed because of the high population density.

2.2. Determination of threshold for significant tornado events

The number of deaths by event from the Bangladesh tornado climatology is shown as a cumulative distribution function in Fig. 3. In order to determine the most significant events to retain for the numerical simulations, we compare the distribution of deaths to tornado-related deaths in the U.S. where reporting of tornadoes and tornado-related deaths is much more comprehensive than Bangladesh. The dataset used for analysis is the number of tornado-related deaths in the U.S. from 1950 to 2013. There is a strong relationship between the damage rating and number of deaths. For example, all events with greater than 20 tornado related deaths were caused by a tornado associated with a damage rating of (E)F-3 or greater. Table 1 shows the percentage of U.S. killer tornado events by damage scale and further categorized for events with 10 and 20 or more tornado-related deaths. These results indicate that events with relatively large numbers of deaths are associated with tornadoes at the higher end of the E(F) damage scale. For the category of tornado events with 20 or more tornado related deaths, 92.8% of these events were associated with violent tornadoes (i.e., a damage rating of E(F) 4 or 5). Using a similar period of record, Ashley (2007) found that tornadoes with a damage rating of (E)F-4 or 5 were responsible for 67.5% of all tornado deaths in the U.S., despite accounting for only 2.1% of all tornadoes.