INCREASING VULNERABILITY OF RICE FARMING TO CYCLONIC STORM SURGES IN MYANMAR'S AYEYARWADY DELTA

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ABSTRACT: Storm surge is one of the deadliest parts of a tropical cyclone. Unlike Bangladesh, which has repeatedly and notoriously been hit by major cyclones, its immediate neighbor to the southeast—Myanmar has been less frequently visited by cyclones due to its geographical setting in relation to most likely cyclone tracks in the Bay of Bengal. Yet, 2008 Cyclone Nargis of category 4 with peak winds of over 165 km/h took an unusual track eastward and swept into the low-lying Ayeyarwady delta in central Myanmar, which is the most vulnerable and densely populated part of the country. It caused the catastrophic damage to human lives and properties. It should equally to be noted that it devastated the rice farming community in the delta region. By using the database of archived global cyclone tracks—International Best Track Archive for Climate Stewardship (IBTrACS) managed by the National Oceanic and Atmospheric Administration (NOAA) of the USA, I generated the spatial distribution of cyclone track frequency map summarized by 1 degree grid and found that more cyclones tracked eastward in the last 20 years (1996–2015) as compared to the previous counterpart (1976–1995). This tendency agreed with a reported result from an atmospheric model experiment. The deadly path of Cyclone Nargis was considered one of those very rare cases in the history. However, combined with the observed sea-level rise and the conversion of mangrove forests to agricultural lands, rice farmers—particularly smallholders sitting just 3 meters above sea-level will face the increasing vulnerability to cyclonic storm surges as more cyclones are likely to head eastward to Myanmar.

1. INTRODUCTION

1.1 Tropical Cyclones in the Bay of Bengal

Tropical cyclones (TCs) are powerful hydro-meteorological hazards and storm surge is one of the deadliest parts of a tropical cyclone. With continued climate change, coastal areas are subject to undesirable situations in the form of sea-level rise and associated storm surge (Islam *et al.*, 2015). Almost all TCs in the Bay of Bengal are formed in the north Indian Ocean. Studies have shown the apparent intensification of TCs in the north Indian Ocean in recent years (Singh, 2007; Wang *et al.*, 2013; Balaguru *et al.*, 2014). Most of the severe cyclones in the Bay of Bengal usually move northward or northwestward and strike coasts of India and Bangladesh (Singh *et al.*, 2000).

Bangladesh is considered to be one of the most seriously affected countries in the world by climate change due largely to its high population, flat topography of its coastal areas, low relief of sediments, funnel shapes and the relative shallowness of the Bay of Bengal all leading to adverse outcome of cyclonic storm surges. The severity of such vulnerabilities was characterized in the cases of 2007 Cyclone Sidr and 2009 Cyclone Aila (Islam and Chik, 2011). Meanwhile, its immediate neighbor to the southeast—Myanmar has been less frequently affected by cyclone damage. This was because of Myanmar's geographical location in relation to most likely cyclone tracks. However, the severe 2008 Cyclone Nargis of category 4 with peak winds of 165 km/h took an unusual track eastward and made landfall on the Ayeyarwady delta in central Myanmar. The catastrophic damage in both human lives and properties caused by the cyclonic storm surge immediately forced the world to recognize that Myanmar was equally vulnerable to cyclone risk.

Although the track of Cyclone Nargis characterized by an eastward movement toward Myanmar after a recurvature over the Bay of Bengal was considered one of those very rare cases (Yamada *et al.*, 2010), some numerical simulation based on an atmospheric model experiment reported future favorable conditions for TCs to grow and to track eastward toward Myanmar (Wang *et al.*, 2013).

1.2 Rice Production in Myanmar

At 676,552 km^2, Myanmar is the second largest country in Southeast Asia, only after Indonesia (Myanmar Statistical Yearbook). The country as a whole can be divided into three main agro-ecological zones: i) central dry, ii) coastal, and ii) hilly zones. These zones can be further subdivided into eight physiographic regions: i) northern hilly, ii) central dry, iii) Rakhine coastal, iv) western hilly, v) eastern hilly, vi) Ayeyarwady delta, vii) Yangon deltaic, and viii) southern Myanmar coastal regions (Myanmar Government, 2012).

Agriculture is the main source of livelihood of the Myanmar people. Rice is the major agricultural commodity grown in almost 50% of the country's cultivated area. The Ayeyarwady delta, central dry zone, Yangon deltaic, and Rakhine coastal areas are the major rice producing physiographic regions.

The Ayeyarwady delta, the rice bowl of Myanmar, covers 35,032 km^2 and is home to 21 million people. The delta has a monsoonal climate which delivers an average annual rainfall of 1,500–2,000 mm in the north, increasing to 2,500 mm in the southeast and 3,500 mm in the southwest. More than 90% of the rain falls between mid-May and mid-November (Driel and Nauta, 2015). It was this region that was hit the hardest by the storm surge caused by Cyclone Nargis in 2008. The catastrophic loss due to storm surge was associated with the low flat coastal terrain and the funnel shape of the bay (Yamada *et al.*, 2010). The damage was further amplified because of the historical conversion of mangrove forests to agricultural lands along the coastline. Most rice farmers in the delta—particularly smallholders sitting just 3 meters above sea-level were particularly at risk. No major agricultural damage caused by cyclonic storm surges has been reported since Cyclone Nargis.

1.3 Objective of this Study

In view of the economic importance of rice production in Myanmar, particularly in the major rice producing coastal zone including the Ayeyarwady delta, it is worthwhile shedding light on the recent trend of TC tracks in the context of cyclonic storm surge risk. The aim of this study is to visually and statistically evaluate the frequency of TC visits to see if there is any significant pattern over time.

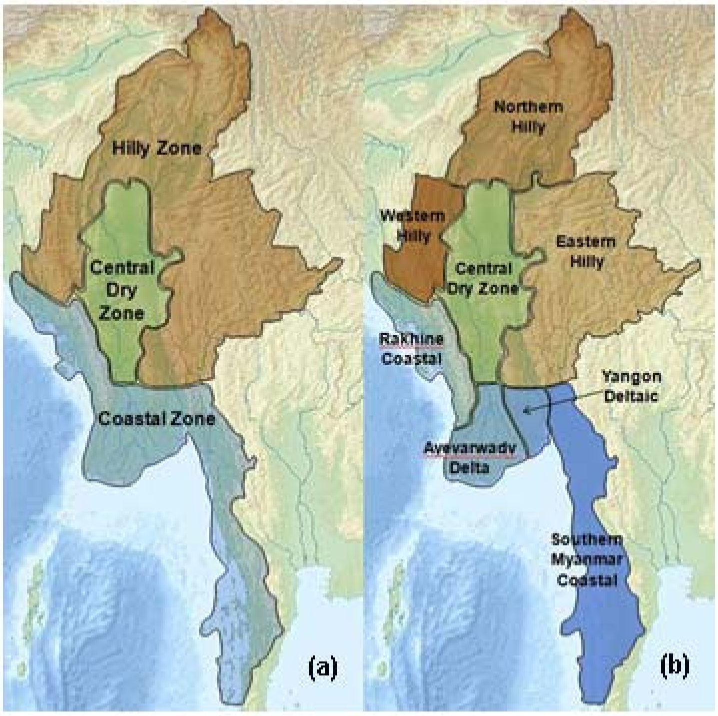

Figure 1. Map of Myanmar's agro-ecological zones (a) and physiographic zones (b). (Adapted from Myanmar Government, 2012)

2. DATA AND METHODS

2.1 TC Track Data Set

The International Best Track Archive for Climate Stewardship (IBTrACS)—a global database of archived TC tracks managed by the National Oceanic and Atmospheric Administration (NOAA) of the USA—was used to generate the spatial distribution of cyclone track frequency map in this study. There are several TC track databases in the world and they are archived and managed by different international and regional meteorological organizations. Most of such TC data worldwide include the best estimates of storm position and intensity at 6-hour intervals—commonly termed as best track data. The IBTrACS data set was used as the primary input for cyclone track frequency computation because this data set is particularly unique in terms of combining track and intensity estimates from many sources to provide a centralized platform for complete global climatology. Detailed description of the IBTrACS can be found in (Knapp *et al.*, 2010) and the data set is freely available for download at <www.ncdc.noaa.gov/oa/ibtracs/>. Like many other TC track data sets, the IBTrACS data can date back as early as 1940's. For this study, I primarily used the data since 1976, a time when reliable satellite observation became available (Reynolds *et al.*, 2002), to focus on the assessment of the interdecadal variability of TCs in the context of recent climate change.

2.2 Synopsis of Historical TCs in the Bay of Bengal

The most straightforward presentation of the synopsis of historical TCs is to draw them all on a map. In order to depict the historical distribution of TCs in the Bay of Bengal, I converted all recorded cyclone tracks (1945–2015) in the IBTrACS data set (Version: v03r08) into geographic information system (GIS) format, and plotted them on a regional base map. For GIS operations, ESRI® ArcGIS™ for Desktop 10.3.1 software was used.

2.3 Spatial Distribution of TC Track Frequency around Myanmar

To examine the pattern of distribution of TC track frequency around Myanmar in a geographical context, I summarized the frequency of TCs in grid cells of one-degree resolution covering 9–29 degrees north latitude and 91–102 degrees east longitude. This boundary roughly encompassed the entire Myanmar territory and vicinity. One way to identify patterns across the area in a GIS is to display the values on a map. For a visual comparison, I prepared two maps showing the numbers of TCs crossing each one-degree grid cell for two consecutive time period of 20 years (1976–1995 and 1996–2015). The two time periods were meant to represent the first and the second half of the temporal data after 1976.

2.4 Statistical Measure to Compare Patterns of TC Track Frequency over Time

Using statistics to measure patterns is more accurate than identifying patterns by simply looking at a map. Gi* (G-i-star) statistics were computed for the two respective time periods in order to measure the degree of clustering for either high values or low values and to compare the patterns over time. Gi* statistic was first introduced by (Getis and Ord, 1992) as a quantitative measure to evaluate the spatial association of variable and is commonly used to identify clusters of high values and low values—hot spots and cold spots—across the area of interest. In ArcGIS™ used in this study, computation of Gi* statistic is implemented in "Hot spot analysis (Getis-Ord Gi*)". Hot spots, if identified, should indicate areas of high vulnerability while cold spots should indicate areas relatively safe against cyclone attacks.

The input data I prepared were polygons of one-degree cells with attribute data values, where values were the number of TCs that crossed the particular grid cell over the two time periods of interest: 1976–1995 and 1996–2015. In most hot spot analyses, some kind of "distance" is chosen for conceptualization of spatial relations—which essentially means what features qualify as neighbor to any given feature. Using distance works fine and makes a lot of sense when working on points. However, in case of polygons like in this study, distance is not as straightforward as in case of points. I used "contiguity" which is one of the typical ways when working with polygons as a means of defining neighborhood. Polygons that touched one another qualified as neighbors. To be generous, I accepted both edges and corners for polygon contiguity. The program computed the statistics and produced the p-values and the z-statistics as well as visualization of the output.

3. RESULTS AND DISCUSSION

3.1 Synopsis of Historical TCs in the Bay of Bengal

A major concentration of all 71 years of TC tracks (1945–2015) was evident along and near the coasts of India and Bangladesh (Figure 2). The generally likely paths of TCs, indicated by yellow arrow, agreed well with the reported pattern by (Singh *et al.*, 2000). It was also evident that coastlines south of 20 degree latitude have been less frequently visited by TCs. Such coastlines included most Myanmar coastal zones indicating less vulnerability to cyclone attacks in the past.

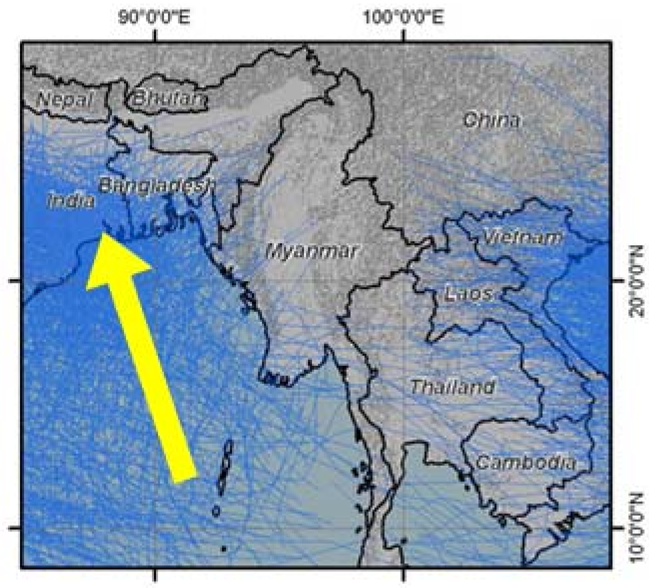

Figure 2. Historical TC tracks in the Bay of Bengal (1945–2015)

3.2 Spatial Distribution of TC Track Frequency around Myanmar

Visual comparison of maps showing the numbers of TCs crossing each one-degree grid cell between 1976–1995 and 1996–2015 hinted that there were slight increase in the instances of TCs in the southern areas, particularly along the Myanmar's coastal zone (Figure 3). The observed tendency may be justified by the reported simulation result in (Wang *et al.*, 2013). However, the fact that most grid cells in the Myanmar's coastal zone received values—numbers of TC visits—only between 0 and 2 during the first and second 20-year periods, the strength of the observed pattern could be subtle.

3.3 Statistical Measure to Compare Patterns of TC Track Frequency over Time

Hot spot analysis based on Gi* statistic identified statistically significant hot spots and cold spots with different level of confidence (Figure 4). The statistical analysis highlighted the significant increase in TC occurrences in the area just off coast of Ayeyarwady delta. Mere cyclone visits alone don't necessarily ensure major coastal damage by TCs. However, the Ayeyarwady delta with its flat and low terrain, densely cultivated rice fields, deforested coastal mangroves, and funnel-shaped river mouths is likely subject to cyclonic storm surges when hit by severe TCs.

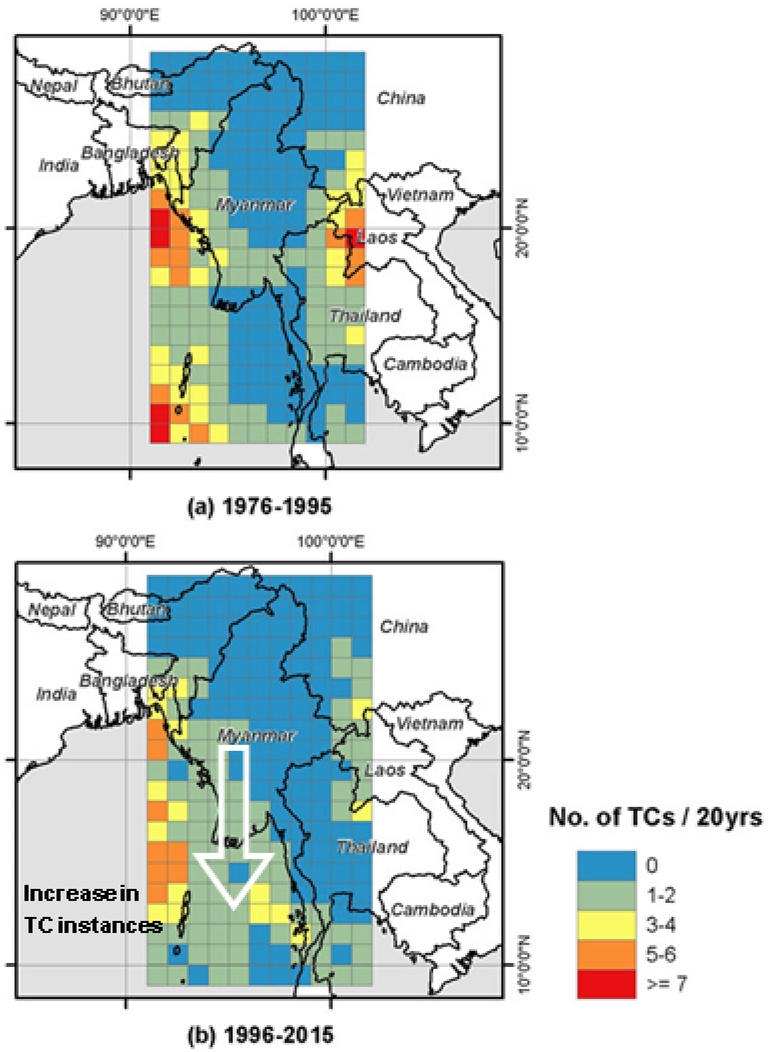

Figure 3. Spatial distribution of the numbers of TCs around Myanmar (1976–1995; 1996–2015).

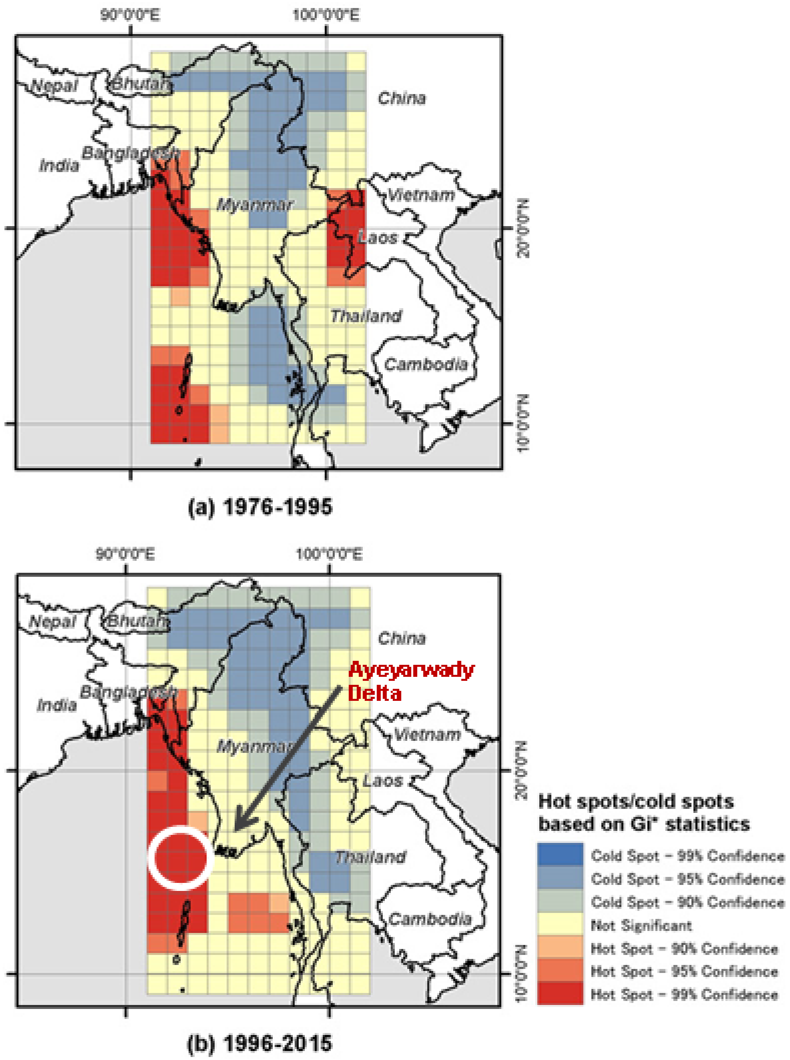

Figure 4. Spatial distribution of hot spots/cold spots of TCs around Myanmar (1976–1995; 1996–2015).

4. CONCLUSIONS

Based on the statistical assessment of TC frequencies, it's safe to draw a conclusion that the Ayeyarwady delta, the rice bowl of Myanmar, is likely to become more subject to cyclonic storm surges and the rice farmers in the area will be more vulnerable to such events. Although the area has not frequently experienced such damages except in the case of catastrophic 2008 Cyclone Nargis, the patterns of TC tracks and dynamics are changing with continued climate change. Combined with the observed sea-level rise and the conversion of mangrove forests to agricultural lands, rice farmers—particularly smallholders sitting just 3 meters above sea-level will face the increasing vulnerability to cyclonic storm surges as more cyclones are likely to head eastward to Myanmar. The knowledge acquired from this study forms the basis for developing future adaptation measures against climate change in this region.

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