

# Cyclonic Storm Landfalls in Bangladesh, West Bengal and Odisha, 1877–2016

## A Spatiotemporal Analysis

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## Abstract

Recurrent cyclonic storms in the Bay of Bengal inflict massive losses on the coastal regions of Bangladesh and India. Information on occurrences and severities of cyclones is necessary for understanding household and community responses to cyclone risks. This paper constructs a georeferenced panel database that can be used to obtain such information for Bangladesh, West Bengal, and Odisha. Cyclone strike locations and impact zones are analyzed for several historical periods between 1877 and 2016. The findings indicate that although the median location has

shifted eastward, there is a marked variability in location, especially after 1960. Impacts also have varied considerably within and across zones over time, with the highest-impact zones in northern Odisha and the Sundarbans region of West Bengal. The pronounced spatial and temporal variation in cyclone impacts will provide robust controls for comparative research on household and community adaptation to cyclones in the study region. The methodology developed in the paper is general and could be expanded to an arbitrarily large set of coastal locations.

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# **Cyclonic Storm Landfalls in Bangladesh, West Bengal and Odisha, 1877–2016 A Spatiotemporal Analysis**

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## 1. Introduction

Recurrent cyclonic storms in the Bay of Bengal inflict massive losses on the coastal regions of Bangladesh and India. Extensive research has investigated the incidence, power and impacts of cyclones in Bangladesh (Ali 1999; Dasgupta et al. 2014; Hoque 1992; Khalil 1992), India (Mishra 2014; Srivastava et al. 2000) and the Bay of Bengal more generally (Bhaskar Rao 2001; Dash et al. 2004; Mandke and Bhide 2003; Mooley and Mohile 1983; Mooley 1980; Muni Krishna 2009; Rao 2002; Yu and Wang 2009). This paper attempts to extend the previous work in several ways.

First, we focus on the historical frequency and locations of cyclone strikes to inform household- and community-level research on adaptation to past and expected future cyclones. Previous studies of coastal community adaptation in the region have focused on responses to specific cyclones or generally-defined coastal hazards (Brouwer et al. 2007; Khalil 1993; Khan et al. 2015; Mallick et al. 2011; Mallick and Vogt 2013; Shameem and Momtaz 2014; Siddiqui et al. 2013; Sultana and Mallick 2015). With the notable exception of Dasgupta et al. (2016), these studies have seldom used household-level data to assess the impacts of past cyclones on communities and households, as well as their role in the formation of expectations about future impacts.

Such research requires construction of a georeferenced panel database that specifies the dates of cyclonic storms, their coastal landfall points, subsequent interior paths, and measures of relative power. Construction of an appropriate spatial panel has therefore been a primary objective of this exercise. To support ongoing research, we focus on the coastal regions of Bangladesh and two contiguous Indian states -- West Bengal and Odisha. However, our approach could easily be extended to cover an arbitrarily-large set of coastal regions.

The second distinctive feature of this exercise is its incorporation of compatible data from different sources. For the period since 1960, we use georeferenced track information on major cyclones striking Bangladesh from the Bangladesh Meteorological Department (BMD). Equivalent information for the Indian coastal region comes from the India Meteorological Department (IMD). For cyclones prior to 1960, we add information from the IBTrACS database maintained by the Global Data Center for Meteorology, operated by the US National Oceanic and Atmospheric Administration. The IBTrACS data for the Indian Ocean have been provided by meteorological institutions in the region. We also use them for a few post-1960 cyclones that are not included in the data available to us from BMD and IMD. We ensure cross-source compatibility by using WMO standards for the two commonly-available measures of storm strength: maximum wind speed (measured in knots (kt)) and radial distance from a storm's center to its zone of maximum wind speed. We employ a standard IMD storm classification based on maximum wind speed intervals in kt: (Cyclonic Storm (CS) [34-47 kt]; Severe Cyclonic Storm (SCS) [48-63]; Very Severe Cyclonic Storm (VSCS) [64-119] and Super Cyclonic Storm (SuCS) [120+]. We have excluded all storms rated as tropical depressions because their maximum wind speeds are below 34 kt.

The third distinctive feature of our exercise is use of the constructed database to explore temporal and spatial patterns in cyclone impacts that can provide the context for future household-level research on adaptation by coastal communities. Our analysis is aggregative in this paper, but the source database can provide high-spatial-resolution cyclone incidence and impact measures for households and communities in both coastal and interior locations.

We should introduce a cautionary note at the outset. During the past 140 years, technical support for cyclone tracking has evolved from land-based telegraphy in the 19th century, through

ship-to-shore radio after 1900, aircraft observation after 1940, and satellite observation after 1960. Measurement error has undoubtedly fallen over the years, but we cannot judge whether earlier technologies imparted any systematic bias to the recording of cyclone occurrences, track locations, wind speeds and storm radii. If historical observations have been unbiased estimates of storm characteristics, then the aggregative estimates in this paper should be also be regarded as unbiased, but with significantly-decreasing variance over the 140-year period.

The remainder of the paper is organized as follows. Section 2 provides a technical discussion of database construction. Section 3 employs the database to investigate trends in the incidence and power of Indian Ocean cyclonic storms from 1877 to 2016. Section 4 focuses on trends in the spatial distribution of cyclone landfalls in Bangladesh, West Bengal and Odisha, while Section 5 broadens the analysis to impact zones around cyclone landfalls. Section 6 summarizes and concludes the paper.

## **2. Georeferenced Database Construction**

We combine data from BMD, IMD and IBTrACS to document all recorded cyclonic storms in the Indian Ocean region from 1877 to 2016. We construct a panel database; the component for each storm includes a unique identification number; year and month of occurrence<sup>1</sup>; maximum wind speed (kt); radial distance (km) from storm center to zone of maximum wind speed; IMD storm classification derived from wind speed; time indices for successive observation points<sup>2</sup>; and latitude/longitude for each point.

We use ArcGIS to construct individual storm-track polylines by interpolation from time-indexed latitude/longitude observations for each storm. Then we determine maximum-impact

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<sup>1</sup> The first month for storms that occur in two months.

<sup>2</sup> Incommensurate day/time tracking in the three databases (BMD, IMD, IBTrACS) could be addressed in a more complete exercise. For our purposes, identifying successive observations by cardinal units [1,2,3, ...] is sufficient for constructing GIS polylines that trace individual storm tracks.

zones by constructing a buffer around each storm polyline whose width is the storm's radial distance from center to the zone of maximum wind speed.

For high-resolution location of landfalls, we construct a coastal boundary polyline for Bangladesh, West Bengal and Odisha. Then we convert the coastal polyline into points spaced evenly at intervals of .001 decimal degrees (approximately 100 meters). The resulting set of ordered points along the coastline is numbered successively from 0 (southern tip of the Odisha coastline) to 11,327 (southern tip of the Bangladesh coastline). For each storm track, we identify the landfall as the closest ordered point where the track first intersects the coastline.<sup>3</sup> To guard against exclusion bias from regional bounding, we include intersecting storm tracks within 20 km of the southernmost coastal points in Odisha and Bangladesh. We identify a storm's coastal impact zone as the set of ordered coastal points within the radius-buffered storm track polygon at its first coastal intersection.

### **3. Aggregate Results**

#### **3.1 Trend in Cyclonic Storm Incidence, 1877-2016**

Although we focus on the northern coast of the Bay of Bengal, our database includes all recorded tracks for the Bay of Bengal and Arabian Sea. This provides a very large regional sample: 525 cyclonic storms recorded from 1877 to 2016. For a trend analysis, we divide the data into seven periods: 1877-1900, 1901-1920, 1921-1940, 1941-1960, 1961-1980, 1981-2000 and 2001-2016.

Table 1 and Figure 1 provide two trend measures for cyclonic storm frequencies since 1877: storms/year for each period, and the two-period moving average of storms/year. The first measure displays no trend through 1960, a large increase during the period 1961-1980, and a decline from

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<sup>3</sup> Some storm tracks that approach at oblique angles intersect the coastline two or more times.

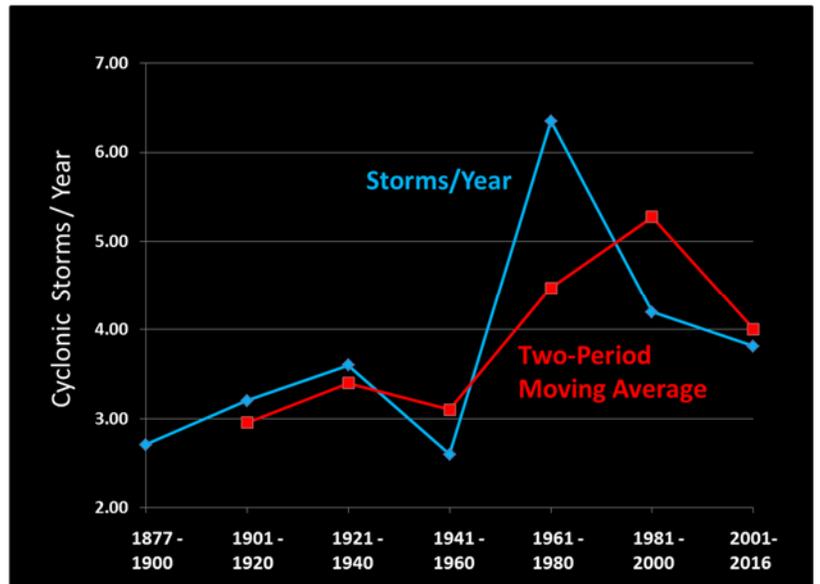
that peak during 1981-2016. The long trend is better-captured by the two-period moving average (MA), which strongly suggests a trend break around 1960: All three MAs for 1961-2016 are significantly higher than any MA for 1877-1960. The most informative view may be a comparison between endpoints, since the MA for 2001-2016 excludes the influence of the incidence surge in 1961-1980. The MAs for 1877-1920 and 1981-2016 are 2.95 and 4.01, respectively. From these benchmarks, we infer that the yearly incidence of cyclonic storms in the Arabian Sea and Indian Ocean has increased by about 35.9% during the past century.

**Table 1: Incidence by period, 1877- 2016:**  
525 cyclonic storms,  
Arabian Sea and Bay of Bengal

Period	Cyclonic Storms	Years in Period	Storms/Year	2-Per. MA
1877-1900	63	24	2.71	
1901-1920	63	20	3.20	2.95
1921-1940	73	20	3.60	3.40
1941-1960	49	20	2.60	3.10
1961-1980	127	20	6.35	4.48
1981-2000	84	20	4.20	5.28
2001-2016	66	16	3.81	4.01

Sources: BMD, IMD, IBTrACS

**Figure 1: Incidence by period, 1877-2016:**  
525 cyclonic storms,  
Arabian Sea and Bay of Bengal



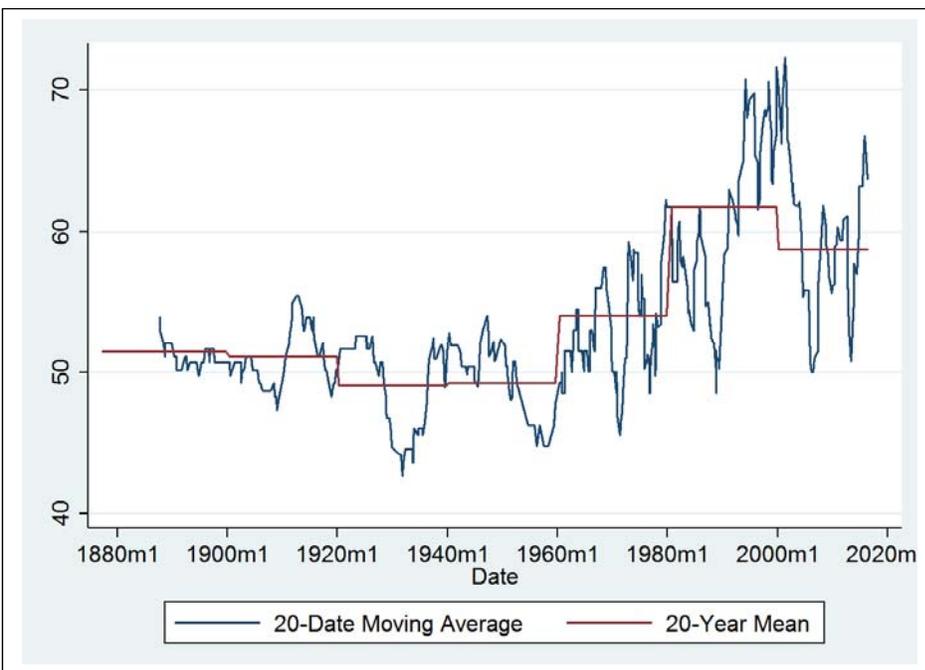
### 3.2 Trend in Maximum Wind Speed, 1877-2016

Maximum wind speed is the consistently-reported measure of storm power in our database. We compute two measures for a trend analysis. First, we order all 525 storms by date and compute the 20-date moving average (MA) for maximum wind speed. This is similar to a conventional moving average, which uses evenly-spaced dates. Storm incidence in our database varies by season and year, but we believe that our MA measure is informative because year-to-year

variations in incidence are a relatively minor factor in a series that spans 140 years. Our second, more conventional, measure is mean maximum wind speed during each of the seven periods.

Figure 2 and Table 2 display our results, which indicate the same trend break as Figure 1: After remaining roughly constant from 1877 to 1959, both measures of wind speed rise rapidly after 1960.

**Figure 2: Maximum cyclonic storm wind speed (kt), 1877-2016:  
Bay of Bengal and Arabian Sea**



**Table 2: Maximum wind speed, 1877-2016  
525 cyclonic storms, Arabian Sea and Bay of Bengal**

<b>Period</b>	<b>Cyclonic Storms</b>	<b>Years in Period</b>	<b>Mean Max Wind Speed (kt)</b>	<b>2-Period Mvg. Avg</b>
<b>1877-1900</b>	<b>65</b>	<b>24</b>	<b>51.3</b>	
<b>1901-1920</b>	<b>64</b>	<b>20</b>	<b>51.6</b>	<b>51.4</b>
<b>1921-1940</b>	<b>72</b>	<b>20</b>	<b>48.9</b>	<b>50.2</b>
<b>1941-1960</b>	<b>52</b>	<b>20</b>	<b>49.4</b>	<b>49.1</b>
<b>1961-1980</b>	<b>127</b>	<b>20</b>	<b>53.3</b>	<b>51.4</b>
<b>1981-2000</b>	<b>84</b>	<b>20</b>	<b>63.3</b>	<b>58.3</b>
<b>2001-2016</b>	<b>61</b>	<b>16</b>	<b>58.6</b>	<b>61.0</b>

Sources: BMD, IMD, IBTrACS

For long-run trend analysis, the most informative view may be a comparison of two-period MA end points in Table 2 (column 5): 51.4 kt in 1901-1920 vs. 61.0 kt in 2001- 2016. From these benchmarks, we infer an increase of 18.5 % in maximum wind speed during the past century.

For overall perspective, we posit a rough composite index of storm power within a period as the product of storm incidence and mean wind speed. During the past century, the incidence and speed components of this index have increased by 35.9% and 18.5%, yielding an increase of 54.4% in the composite index.

#### **4. Spatial Landfall Dynamics in Bangladesh, West Bengal and Odisha**

As we noted in the Introduction, we have constructed the cyclone database to support research on household- and community-level adaptation to cyclone risks. These risks may affect coastal population dynamics in at least two ways. In the long run, the number and size of coastal communities may be affected by the long-run frequency and power of cyclone strikes. Other things equal, we would expect areas that have been largely cyclone-free for many years to be more populous than frequently-impacted areas. Shorter-term, if impact-intensive zones shift over time,

we would expect accelerated outmigration from newly-impacted communities and, perhaps, deceleration in communities where cyclone strikes have declined. These changes would reflect both damage from actual impacts and revised expectations about future impacts.

In this context, robust tests of expectations formation have two requirements. The first is a georeferenced panel database of the type assembled for this exercise. The second is significant temporal and spatial variation in cyclone impacts, which enable them to serve as effective statistical controls in multivariate analyses of household and community changes over time.

To determine whether our data meet the second requirement, we perform an intertemporal assessment using the seven previously-defined periods for 1877-2016. Within each period, we consider the full set of spatially-ordered coastline points numbered 0 (the southernmost coastal point of Odisha) to 11,327 (the southernmost coastal point of Bangladesh). We register each coastal landfall at the closest point of initial strike and compute distribution statistics for spatial order numbers. Figures 3 and 4 display our results for the landfalls of 178 cyclonic storms from 1877 to 2016.

Figure 3 provides a geographical perspective by mapping median landfall points for each period. Two conclusions are immediately clear. First, the locus of cyclone landfalls has been far from stable during the past 140 years. The seven median landfall locations in Figure 3 are distributed in a broad arc from the central coastline of Odisha to the western coastline of Bangladesh. Second, the inter-period variation has been far from random: Median landfalls are in Odisha from 1877 to 1920, the Odisha/West Bengal border area from 1921 to 1960, and the West Bengal/Bangladesh border area from 1961 to 2016.

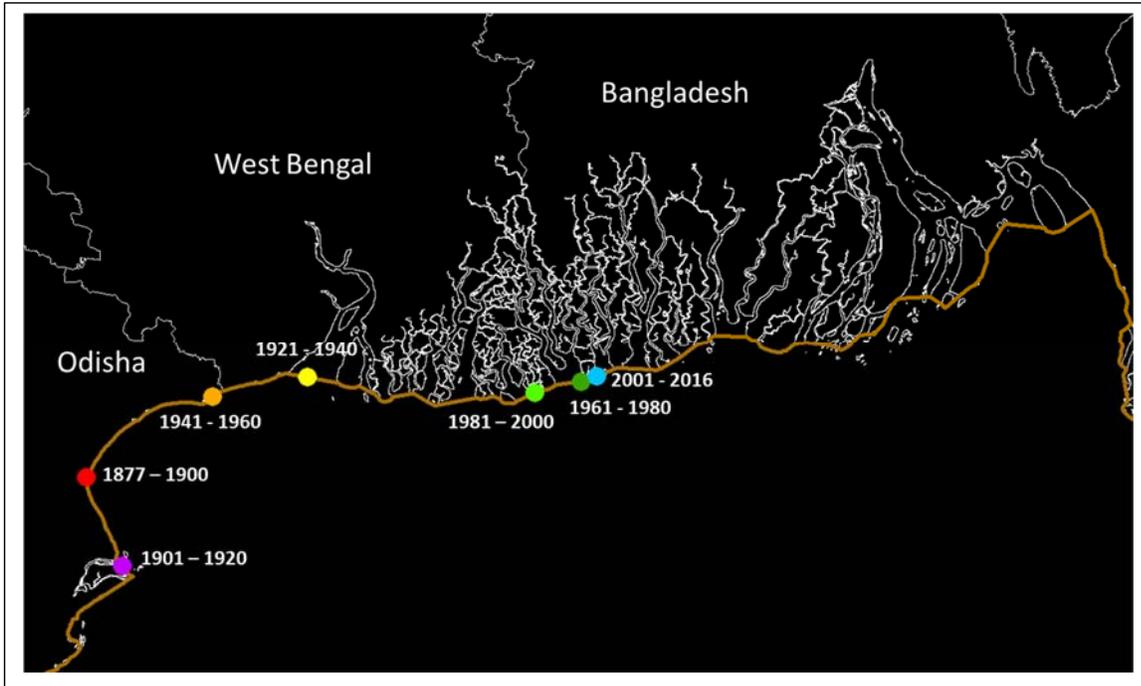
Figure 4 provides statistical perspective, with coastal point order numbers configured on the y-axis from 0 (southernmost coastal Odisha) to 11,327 (southernmost coastal Bangladesh). The

figure displays first quartiles, medians and third quartiles of cyclone strike locations using coastal point order numbers by period, along with the coastal point order numbers of state and national boundaries. In 1877-1920, the distribution overlaps the Odisha/West Bengal border with the majority of locations in Odisha. For 1921-1960, the interquartile range remains approximately constant while the median location shifts to the Odisha/West Bengal border. For 1961-2016, two major changes are evident. First, the median location shifts to the West Bengal/Bangladesh border area. Second, the interquartile range becomes much larger. In the most extreme period, 1981-2000, the first-quartile location is well into Odisha, the median location is in West Bengal, and the third quartile location is far into Bangladesh.

We summarize by considering the potential significance of these results for empirical analysis of spatial adaptation by coastal households and communities. For contrast, suppose that coastal cyclone strikes during the past 140 years exhibited a stable distribution, with a roughly-constant median location and a relatively narrow range of variation. Then, other things equal, we might well expect community adaptation and expectations formation to produce a long-run inverse relationship between coastal community sizes and nearby strike intensities. On the other hand, suppose that cyclone history exhibited substantial instability in both the median and variance of coastal strike locations. Then long-run uncertainty could prevail, and expectations formation might contract in time; communities' spatial dynamics might respond only to recent strikes.

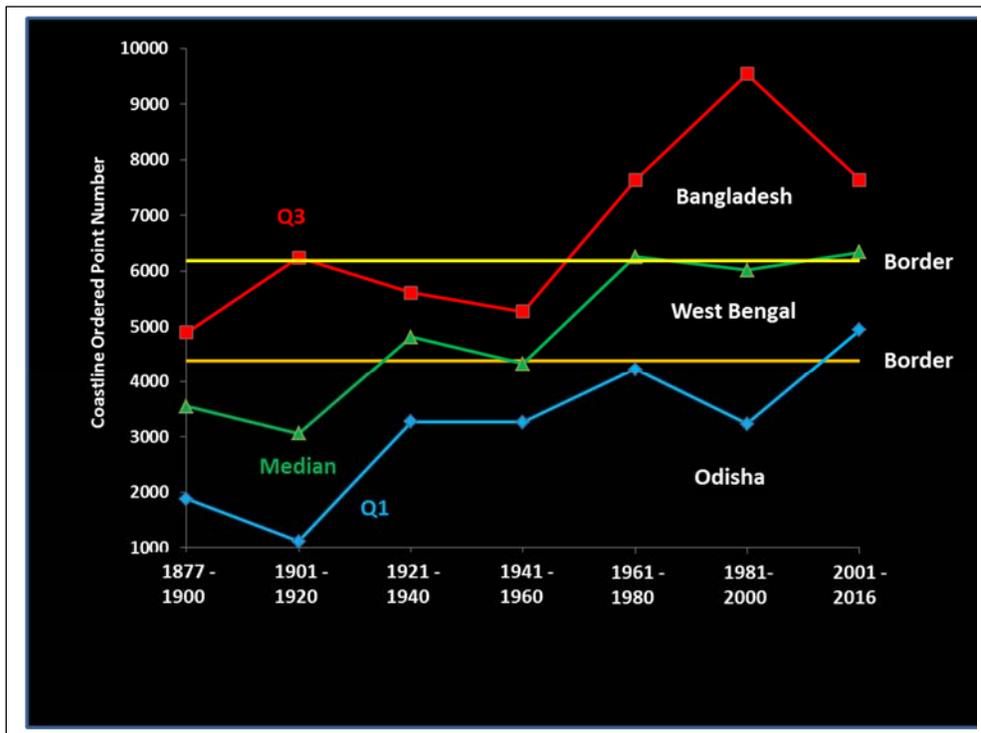
The results displayed in Figures 3 and 4 suggest that the coastal region has been closer to the latter scenario, but two major issues remain unexplored: First, cyclonic storms impact entire

**Figure 3: Coastal cyclone landfalls in Bangladesh, West Bengal and Odisha: Median locations by period, 178 cyclonic storms, 1877-2016**



Sources: BMD, IMD, IBTrACS

**Figure 4: Coastal cyclone landfalls in Bangladesh, West Bengal and Odisha: Distribution of locations by period, 178 cyclonic storms, 1877-2016**



Sources: BMD, IMD, IBTrACS

areas, not just single landfall points. What patterns emerge when we incorporate this factor? Second, adaptive expectations formation may be highly sensitive to strike proximity, and the broad coastal strike patterns in Figures 3 and 4 may mask substantial local variation within generally “high-intensity” or “low-intensity” zones. How important is this factor in practice? We address these questions in the following two sections.

## **5. Coastal Distribution of Impact Zones, 1877-2016**

### **5.1 Impact Measurement**

For each cyclonic storm, we specify the primary coastal impact zone as the set of ordered coastline points that lie within the cyclone’s radius from centroid to zone of maximum wind speed. Then we compute cyclone strike frequency and mean maximum wind speed for each ordered point, by period and for all 140 years. As Table 3 shows, correlation coefficients for the two measures are both weak and inconsistent across periods: Their 140-year correlation is -0.16 and their period correlations vary from -0.48 to +0.54. Sample sizes are also of interest because they indicate the number of coastal points that lie within at least one impact zone. The table’s last column provides a scaled estimate that adjusts for different period lengths by multiplying strikes/year by period years (Scaled N). The results reflect the period variations in the spatial strike distribution displayed in Figure 4: Increased spatial variance after 1960 translates to larger numbers of coastal points impacted by at least one cyclone.

**Table 3: Cyclone strike frequency vs. mean maximum wind speed**

Period	Corr.	N	Years	Scaled N
1877 - 2016	-0.1559	11,328	140	11,328
1877 - 1900	-0.1846	7,916	24	6,597
1901 - 1920	0.3095	8,832	20	8,832
1921 - 1940	-0.4839	10,435	20	10,435
1941 - 1960	0.1024	7,904	20	7,904
1961 - 1980	0.1304	11,140	20	11,140
1981 - 2000	0.0378	10,207	20	10,207
2001 - 2016	0.5376	7,796	16	9,745

## 5.2 Impact Index Construction

Given the quasi-independence of strike frequency and maximum wind speed, we compute three impact indices: (1) **Strike intensity:** We count the number of times a point has fallen within a cyclone impact zone. The total count is the overall strike intensity for 1877-2016. We also compute period strike intensities as period counts divided by years within periods.

(2) **Cyclone power:** For each point, we compute mean maximum wind speed by period and for 140 years. (3) **Cyclone impact:** We weight a strike occurrence by the cyclone's maximum wind speed. For each period and all 140 years, we compute total weights for all impacted points and divide by the maximum weight in the point set to produce an impact index bounded by [0 100].

## 5.3 Strike Intensity

Figure 5 displays color-coded maps of cyclone intensity -- cyclone strikes per year -- in each of the seven periods. These maps corroborate Figures 3 and 4, while offering additional insights into the spatiotemporal distribution of strikes. In particular, they highlight the substantial variation in coastal areas where strikes have been concentrated. The maps for 1877-1900 and 1901-1920 show why the median coastal strike location was in Odisha during this era. Both periods feature Odisha coastal stretches in the highest intensity class (0.30 - 0.80 strikes/year), with more moderate intensities in the mid-coastal region and lower intensities for most of the Bangladesh coastline. At

the same time, the Odisha coast includes substantial intensity variation and the mid-coastal area exhibits the full range of strike intensities.

In the following era (1921-1940, 1941-1960), Odisha's area of greatest intensity contracts northward while the mid-coastal region exhibits generally-higher but varied intensities. Intensities generally remain in the lower ranges on the Bangladesh side. The following period (1961-1980) provides a striking spatial illustration of the structural trend break that is evident in Figures 1, 2 and 4. High-intensity zones dominate the entire coastal region, with exceptions only in the extreme west and east. Intensities generally recede in 1981-2000, but remain high for a stretch of the Bangladesh coastline and a smaller stretch in Odisha (this bifurcation accounts for the relatively high variance for the period displayed in Figure 4). The decline from 1981-2000 continues in 2001-2016, with relatively high intensities dominating the central Bangladesh coast.

Figure 8a condenses this historical experience into composite strike intensities for 1877-2016. Over 140 years, the highest-intensity zones have been in West Bengal and northern Odisha, with a relatively clear pattern of incremental intensity decline in both directions.

#### **5.4 Mean Maximum Wind Speed**

Assessing the significance of a cyclone strike requires information about the storm's power, which is measured by maximum wind speed in our database. Figure 6 shows that mean maximum wind speeds are generally highest in sections of the mid-coastal region during 1877-1900 and 1901-1920. Conditions vary considerably during the next three periods. During 1921-1940, higher wind speeds appear in Odisha, the mid-coastal region and Bangladesh's eastern coast. Wind speeds generally decline in 1941-1960, with notable cyclone-free areas in southern Odisha, the central coastal region, and eastern Bangladesh. Conditions reverse during

Figure 5: Coastal strike intensities (strikes/year), 1877-2016

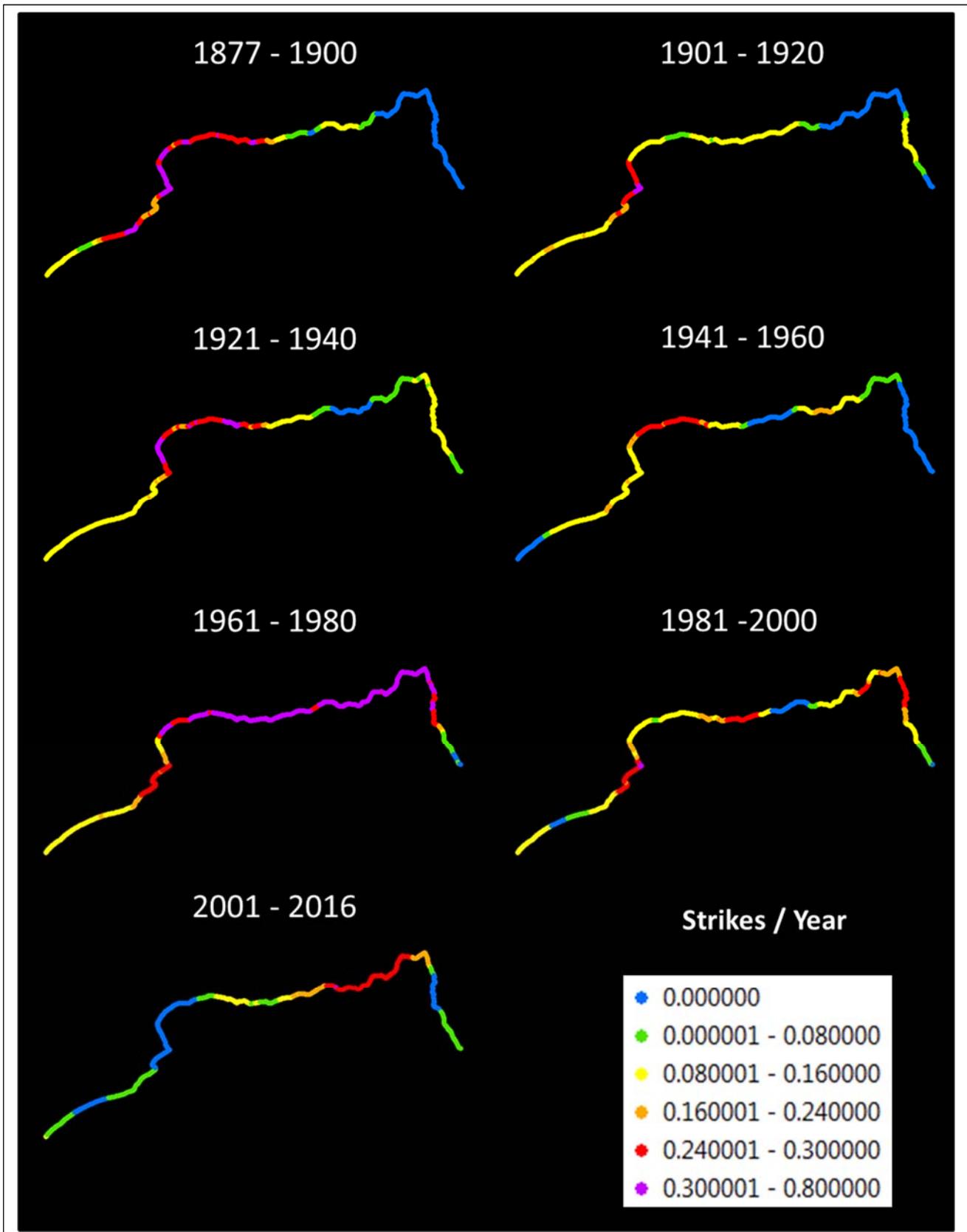
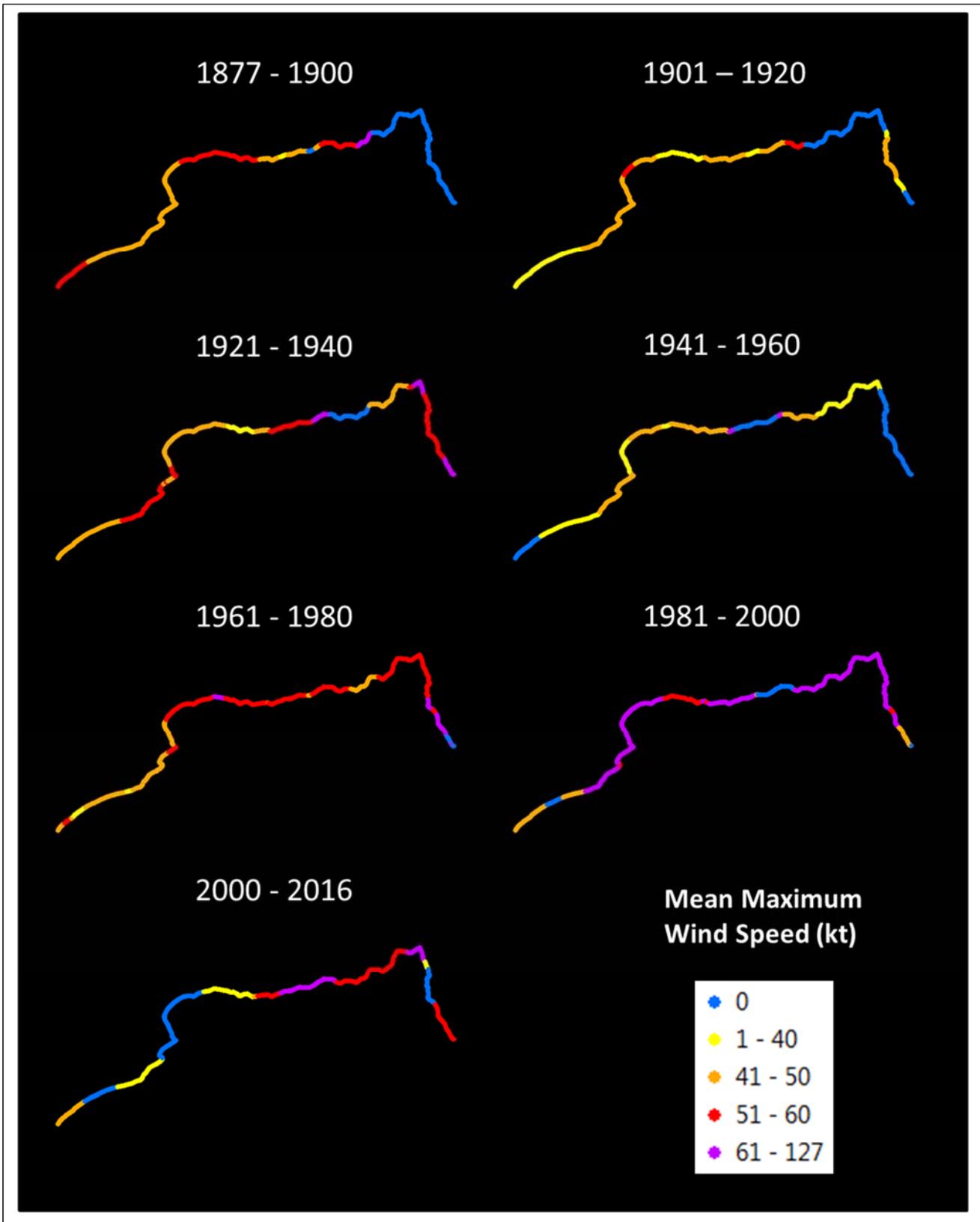


Figure 6: Coastal mean maximum wind speed (kt), 1877-2016



1961-1980, with the reappearance of higher wind speeds in the Odisha/West Bengal border region, the mid-coastal area, and eastern Bangladesh. Another change is evident in 1981-2000, with generally-higher speeds in Odisha, West Bengal and Bangladesh. The final period exhibits considerable variation, with high wind speeds shifting away from Odisha to the mid-coastal region and eastern Bangladesh.

Figure 8b summarizes the historical record for 1877-2016, showing why the overall correlation with cyclone strike intensity is negative. While northern Odisha and West Bengal have had more cyclone strikes, the highest mean wind speeds have occurred in the eastern coastal area of Bangladesh.

### **5.5 Composite Impact**

The spatial distributions of strike intensity and mean maximum wind speed have been largely independent during the past 140 years. We therefore compute a composite index -- the product of the two measures -- for a summary assessment. Figure 7 displays the results by quintile, along with a separate color code for areas that lay outside primary impact zones in each period. The results generally resemble the spatial distribution of strikes, which is more highly varied than the distribution of mean wind speeds.

Figure 8c provides a summary view for the past 140 years. Comparison with Figures 8a and 8b confirms that the composite index distribution resembles the cyclone strike distribution much more closely than the wind speed distribution. This difference stems essentially from differences in spatial variance, which is huge for cyclone strikes (ranging from 2 to 37) and more modest for mean maximum wind speeds (varying from 43 to 63 kt). As Figure 8c clearly shows, the composite cyclone impact measure is generally highest in separate coastal zones of northern Odisha and West Bengal.

Figure 7: Coastal wind impact quantiles, 1877-2016

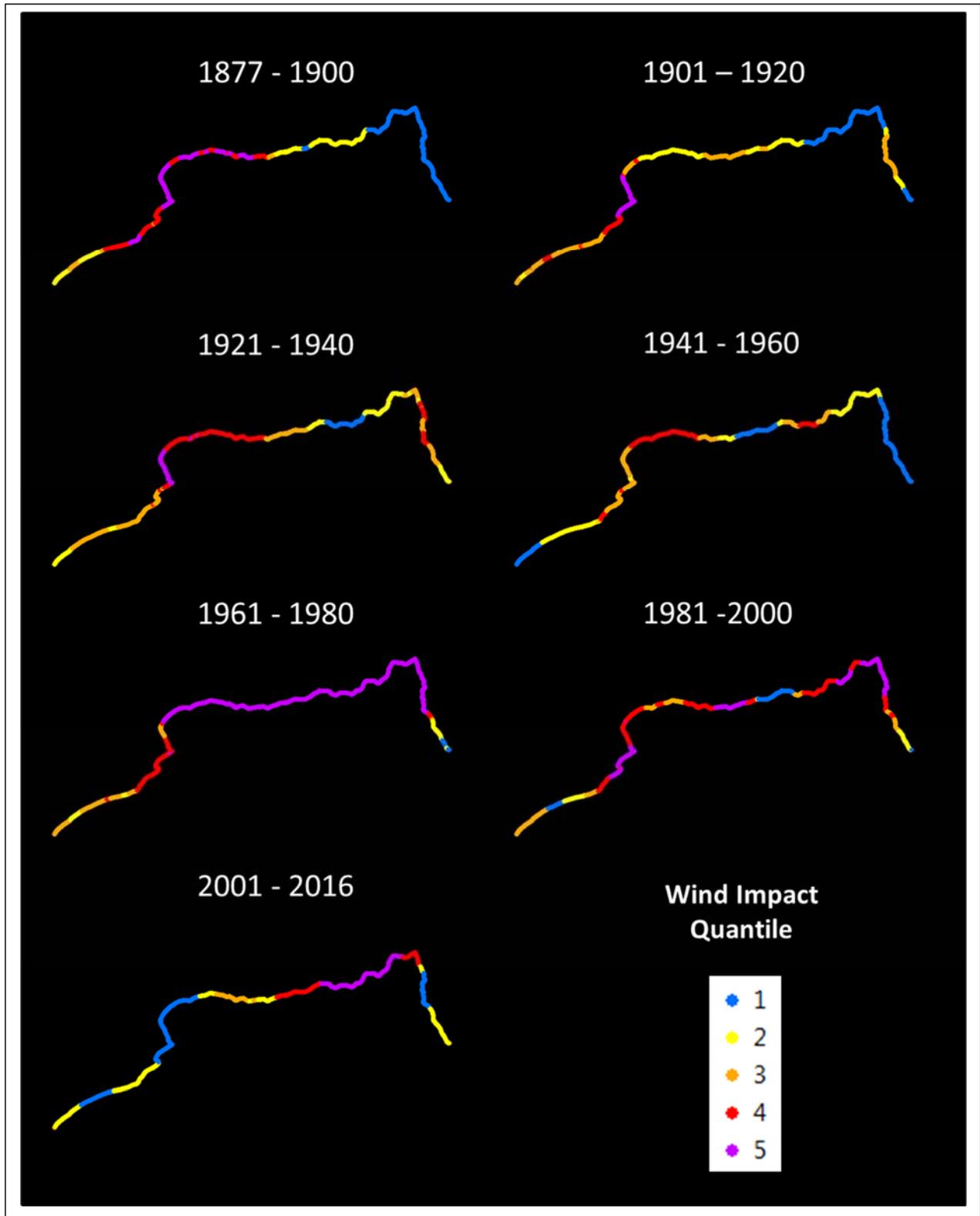


Figure 8a: Cyclonic storm strikes, 1877-2016

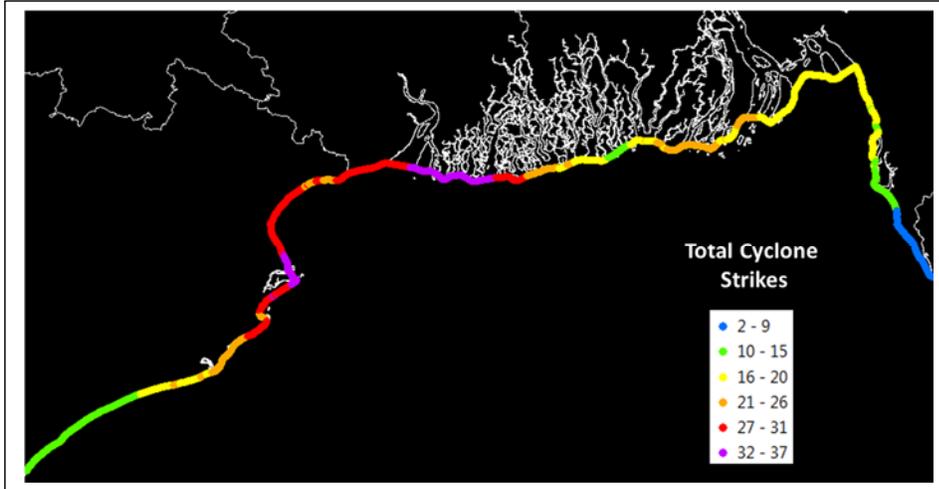


Figure 8b: Mean cyclone maximum wind speeds (kt), 1877-2016

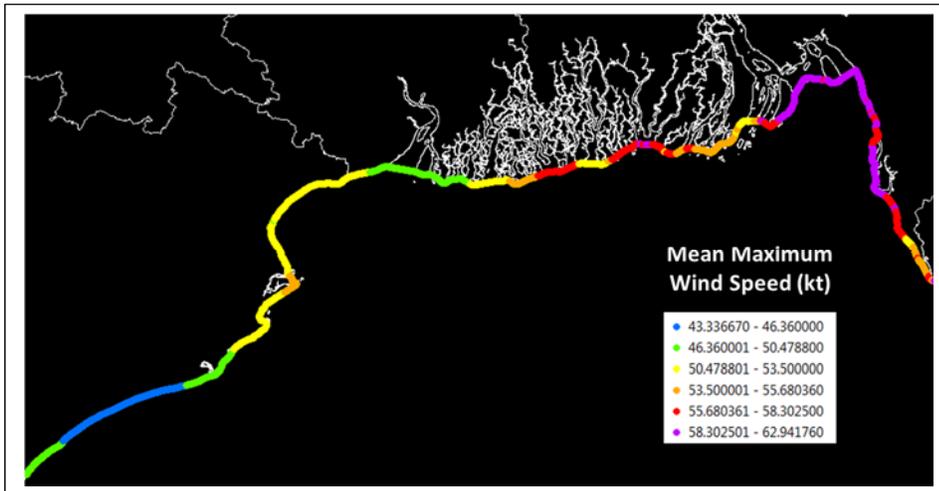
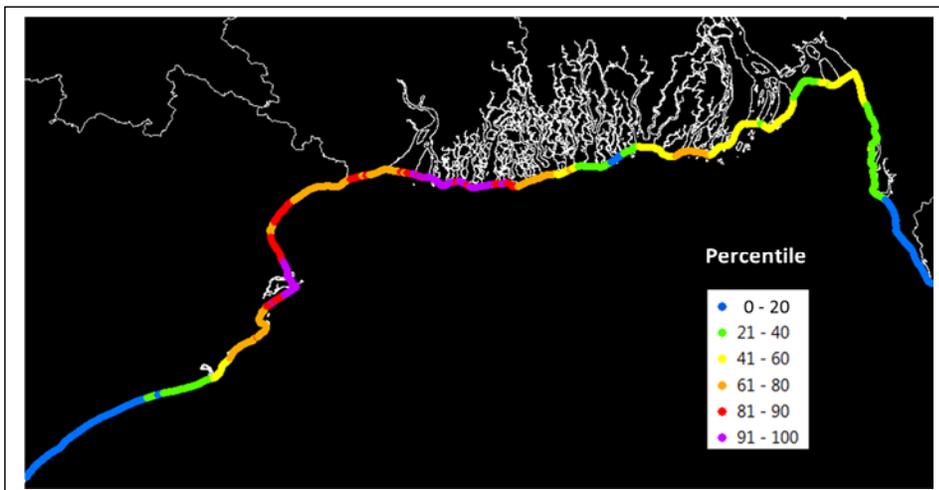


Figure 8c: Cyclonic wind impact quantiles, 1877-2016



## 6. Summary and Conclusions

In this paper, we have constructed a spatial panel database of cyclone tracks and coastal landfalls in Bangladesh, West Bengal and Odisha. For 1960-2016, our tracking data come from the Bangladesh Meteorological Department (BMD) for cyclones with Bangladesh landfalls and the India Meteorological Department (IMD) for cyclones with landfalls in West Bengal and Odisha. For storms before 1960, our data come from country reports in the global IBTrACS database maintained by the Global Data Center for Meteorology of the US National Oceanic and Atmospheric Administration. We determine each storm's landfall as its first intersection with an ordered line of coastline points, spaced at .001 decimal degrees (approximately 100 meters). We identify each cyclone's primary coastal impact zone as the set of coastline points lying within the cyclone's radial distance from its landfall point to its zone of maximum wind speed. Although we confine our exercise to Bangladesh and the two Indian coastal states, our methods are general and could be expanded to an arbitrarily-large set of coastal locations.

We use the database for an analysis of cyclone strike locations and impact zones in seven historical periods: 1877-1900, 1901-1920, 1921-1940, 1941-1960, 1961-1980, 1981-2000 and 2001-2016. Although we believe that our results have independent interest, we highlight their implications for socioeconomic analysis of household and community responses to cyclonic storm risks. Episodic, short-run responses to some individual storms are well-documented. Such anecdotal evidence certainly provides many useful insights, but georeferenced panel data are required for systematic comparative research on coastal adaptation.

In this context, robust assessment of causal factors requires significant variation in cyclone impacts, both across coastal areas and over time. The results of our seven-period analysis indicate that such variation characterizes the coastal zone. During each 20-year period, some areas have

high impact intensity and others have none. The first and second moments of the spatial impact distribution also change over time: The median landfall location shifts eastward from northern Odisha to the Bangladesh/West Bengal border area, while locational variance increases markedly after 1960.

We also consider the overall distribution of impacts during the 140-year period covered by our database. Despite pronounced period-to-period shifts in impact locations, the overall distribution is far from uniform. We find the highest impact zones in northern Odisha and the Sundarbans region of West Bengal, with somewhat lower impacts in the zone between those two areas and a pattern of decline from the high-impact zones to the southern coastline boundaries of Odisha and Bangladesh. We should note that these boundary results are not artifacts of our methodology: We have also incorporated cyclone strikes in proximate areas south of the end points. Finally, despite the pronounced bimodality of the spatial distribution, we also find significant variation within zones. For example (Figure 8c), western coastal Bangladesh, generally a mid-impact zone, also has significant stretches of coast that have very low historical impacts.

To summarize, our focal coastline area has witnessed highly-varied long- and short-term distributions of cyclonic storm impacts during the past 140 years. Our database therefore incorporates three major elements that are important for research on expectations formation and adaptation: pronounced long-term impact clustering; highly-varied clustering over 20-year periods; and a pronounced west/east trend. As previously noted, such variation is necessary for using cyclone impacts as effective statistical controls in comparative adaptation studies. We conclude that our panel database can make a significant contribution to household- and community-level studies that also incorporate social, economic, demographic and political variables from the relevant regions of India and Bangladesh.

Several important questions can be addressed with these data. The first relates to locational stability: What are the permanent and transient components of household and community responses to long- and short-run cyclone clustering, and to the power of recent cyclones? Outright relocation will be part of the response, but so will relocation of prime-age household members to less-impacted inland areas where their earnings and residence will offer financial insurance and a potential safe harbor from future cyclones. The size and speed of the response will depend critically on expectations about future cyclone strikes, which can be inferred from the highly-varied data in our cyclone panel.

Other questions of interest can also be explored once cyclone-related controls are introduced. For example, how much coastal outmigration reflects the “pull” of urban opportunities, and how much reflects the “push” of cyclone-related hazards? How do disaster mitigation policies affect responses to these hazards? Some coastal zones in our study area invest significant resources in damage prevention via polder construction and other measures, while others offer compensation once cyclone-related damage has occurred. Incorporation of controls from our cyclone panel database may permit more accurate estimation of the timing and magnitude of responses to these differences.

To conclude, we believe that the coastal cyclone experiences of Bangladesh, West Bengal and Odisha also offer potentially-valuable lessons for the global community. Our overall findings for the Indian Ocean are consistent with the view that ocean warming from climate change has increased the frequency and average power of regional cyclone storms. Since 1960, a composite index of cyclone frequency and power has increased by about 50%. Since our focal study area is one of the world’s most cyclone-prone, its experience can provide important clues for understanding the potential future of other cyclone-affected areas. In this context, studies that

incorporate our long-run panel of cyclone data may contribute important insights about climate change adaptation on the coastal “front line”.

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