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SPATIO-TEMPORAL DYNAMICS OF BAY OF BENGAL TROPICAL CYCLONES: 1972-2015

Doctoral Dissertation Abstract (2019)

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Tropical Cyclones (TCs) are non-frontal low-pressure systems of synoptic scale with organized convection over tropical and sub-tropical waters. These TCs are among the most powerful and disastrous weather events, which often cause extreme socio-economic impacts in the coastal areas due to strong winds, intense rainfall and high storm surges resulting coastal inundation. Therefore, various researchers have extensively examined the TCs occurrence for different ocean basins world over particularly in the North Atlantic, the western and eastern North Pacific and the Australian region.

The North Indian Ocean, including the Bay of Bengal (BoB) and the Arabian Sea, accounts for just 7 per cent of global TCs. About 80 per cent of North Indian Ocean TCs originating in the BoB, tend to be the deadliest of any TCs around the globe. Adjoining coastal countries including Bangladesh, India and Myanmar have reported more than 75 per cent of the casualties caused by BoB TCs. However, studies on the BoB TCs are not well documented in comparison to other ocean basins. Also, the available studies are restricted to small time period, particular season and few parameters of the BoB TCs. None on the study has provided a meticulous and comprehensive analysis about spatial and temporal variations of the BoB TCs comprising their frequency, intensity, duration, accumulated cyclone energy (ACE), power dissipation index (PDI), genesis location, track and landfall. Also, the influences of different modes of climate variability such as El Niño-southern oscillation (ENSO) and Madden Julian oscillation (MJO) over the BoB TC activity have not been well documented. Besides, no study has been attempted to identify the areas under the high risk of TCs extreme winds in the BoB. Therefore, to fill this research gap, the present study has been attempted to investigate the spatio-temporal dynamics of Bay of Bengal tropical cyclones.

Objectives of the Study

Major objectives of the study are:

- to study the climatological characteristics of TCs in the BoB during the period 1972-2015;
- to identify the influence of ENSO on the BoB TCs and associated alterations in the environmental conditions;
- to investigate the impact of MJO on the BoB TCs and related modulations

in the atmospheric and oceanic conditions and

- to estimate the frequency, return period and probability of BoB TCs extreme wind speed.

Database and Methodology

For this study, TCs data have been acquired from the Joint Typhoon Warning Center for the period 1972-2015 (44-years). This dataset is appropriate and reliable for the long-term climatological study of the BoB TCs. The Oceanic Nino Index data have been acquired from the website of National Oceanic and Atmospheric Administration, Climatic Prediction Center to identify the ENSO events. The daily real-time multivariate MJO index data have been acquired from the website of Bureau of Meteorology, Australia to identify the phases and amplitude of the MJO. Data related to various atmospheric and oceanic variables have been obtained from the website of National Centers for Environmental Prediction-National Center for Atmospheric Research reanalysis. Several suitable and reliable methods and techniques have been applied for the analysis on this data. Subsequently, derived results have been summarized in the form of tables, graphs and maps. The maps of TCs genesis location and tracks have been prepared using ArcGIS 10.2. The spatial plotting of various environmental parameters has been done by means of GrADS.

Major Findings

A total of 144 TCs have formed in the BoB during the 44 years of study period. On an average, 3.27 TCs have formed without significant increasing or decreasing trend. Similarly, non-significant increasing or decreasing trends have been observed in their ACE and PDI values. The TCs have formed in all parts of the BoB and made their landfall over the coasts of India, Bangladesh, Myanmar and Sri Lanka. The genesis locations and tracks of the BoB TCs have mostly followed the northward and southward shifting of the Sun. The mean genesis location of TCs shifts northward from the month of January to July and then it moves southwards continuously. Majority of the TCs have travelled a distance between 1000 to 2500 km, while the mean distance travelled by post-monsoon season TCs has been found higher than pre-monsoon season. Of the total, approximately 38 and 12 per cent TCs have been found to be intensified and rapidly intensified. Further, a unique bimodal pattern has been observed in monthly occurrence of TCs, ACE and PDI. The first peak has been witnessed in the month of May (0.5 TC/year), while second in the month of November (1 TC/year). The maximum number of TCs have formed during post-monsoon season, while lowest during winters. The mean annual duration of TCs has been observed to be 232.2h. The duration of maximum number of TCs lie between 12 to 114 h, whereas the long-lasting cyclones are rare. Interestingly, the number of cyclonic storms and their ACE and PDI values have shown a slightly non-significant increasing trend. Conversely, number of intense cyclonic storms have shown a slightly non-significant decreasing trend with constant trend in their ACE and PDI values. This constant trend in ACE and PDI values of intense cyclonic storms can be attributed to the increasing trend in severity of TCs in terms of maximum sustained wind speed. Also, a significant negative correlation has been observed between annual minimum sea level pressure and maximum sustained wind speed.

ENSO significantly controls the TC activity over the BoB. Niño 3.4 sea surface temperature anomalies have been found negatively associated with the TC activity. The mean number and intensity of TCs have been observed more during La Niña than El Niño years. The mean ACE, PDI and lifetime of TCs have been found significantly higher during La Niña than El Niño years (significant at 95% confidence level). Genesis locations of TCs have shifted towards east (west) of 89°E longitude with a tendency to make landfall towards northward during La Niña (El Niño) years, which has exhibited the more recurving nature of the tracks of TCs in La Niña than El Niño years. These variations in the TCs characteristics are attributed to ENSO forced alteration in the large-scale environmental conditions over the BoB. Outgoing longwave radiation anomalies have been noticed negative (more convective activity) over the eastern and south-eastern BoB, the Andaman Sea and the Gulf of Thailand in La Niña years, which can be attributed to the rising limb of Walker circulation. However, this region of high convective activity shifts eastward in El Niño years. Negative anomalies have been found only over a small south-western part of the BoB. The higher convective activity over the western and south-western parts of the BoB leads to a westward shift in TCs genesis during El Niño years. Besides, high moisture transport to the mid-tropospheric level, which is attributed to the rising branch of Walker circulation, is essential for TCs formation and intensification during La Niña years. Low-level winds have shown the anticyclonic (cyclonic) circulation pattern, which is unfavourable (favourable) for the genesis of TCs over the north BoB during El Niño (La Niña) years. Presence of cyclonic flow has formed the low-level cyclonic vorticity during La Niña years, while anticyclonic flow has created the anticyclonic vorticity over the BoB. The sinking motion related with the falling limb of Walker circulation is responsible for the anomalous high pressure over this region which inhibits the TC activities during El Niño conditions. The vertical wind shear has been found relatively low (high) in cold (warm) conditions, which has contributed to the enhanced (reduced) TC activity over the BoB. Overall, it can be said that the large-scale atmospheric and oceanic conditions have provided the favourable environments for the genesis and strengthening of TCs in La Niña than El Niño years. Apart from this, TCs frequency has been observed above normal in some El Niño years owing to relatively high convective activity and relative humidity, cyclonic circulation pattern and low vertical wind shear in spite of the prevalence of warm conditions whereas these conditions have been found reverse in several El Niño years. Similarly, above normal TCs frequency is the result of high convective activity, more relative humidity, high sea surface temperature and cyclonic circulation pattern during some La Niña years, whereas these conditions have found to be reversed in few La Niña years in spite of cold conditions over the BoB.

The results of this study have also displayed a strong influence of the MJO on the BoB TC activity. During April-June, TCs formation has significantly enhanced and suppressed over the BoB when MJO is located in phases 3-4 and 8, respectively. Normalized ACE and PDI values have been found significantly higher in phases 2-4 and lower in phases 7-8. The MJO does not show a significant modulation of TCs frequency during October-December, however, it significantly modulates the duration of TCs and their ACE and PDI values. ACE and PDI values during October-December are significantly enhanced in phases 2, 4-5 and suppressed in phases 1, 7-8. From this, it can be inferred that TC activity has significantly enhanced (suppressed) over the BoB when the convectively active phase of the MJO has positioned over the eastern Indian Ocean, the Maritime Continent and the western Pacific (the Western Hemisphere and Africa). The genesis locations and tracks have also been modulated by the MJO. These modulations in TC activity have been mainly triggered by the MJO-driven alterations of large-scale oceanic and atmospheric conditions. Overall, the combination of more convective activity, higher relative humidity, lower sea level pressure, increased cyclonic vorticity, upper-level easterly winds and reduced vertical wind shear have provided supportive circumstances for the TCs formation and strengthening in the BoB in phases 2-5. Conversely, in phases 7-8, reduced convective activity, lower relative humidity, higher sea level pressure, anomalous upper-level westerly winds and higher vertical wind shear have suppressed TC activity over the BoB.

A probabilistic analysis of TCs extreme wind speed has been carried out by three methods. These methods have provided almost similar estimations for TCs of low intensities (≤90 kt), however, variations have increased with an increase in intensity (>90 kt). The analysis has shown that the exceedance probability falls from the low to high intensity of TCs. The exceedance probability of cyclonic storms occurrence has been observed to be about 99 per cent, whereas it has been found very low (less than 15 per cent) for ≥ super cyclonic storms (SupCSs). The most probable annual maximum TCs intensity estimated by these methods for whole basin, region 1, 2 and 3 have been observed approximately 69, 43, 53 and 51 kt, respectively. The most probable maximum intensity of TCs in region 1 has been relatively less than regions 2 and 3 as TCs of region 1 get intensified after travelling some distances on the sea and subsequently reach in the region 2 and 3. The annual expected number of CSs has been observed as 3.5 in the BoB. This annual expected number of CSs has been found nearly similar to the mean number of TCs (3.27) during 44 years period. The annual expected number of cyclonic events has decreased from CSs to ≥ SupCSs intensity. Similarly, the mean return period of TCs of low intensity has been found very small than extremes. The mean return period of CSs has been about 0.27 years, whereas it has been found about 6-years for SupCSs and 12 to 14 years for TCs of 140 kt intensity in the BoB. In past 44 years, the BoB has experienced 10 SupCSs. In these 10 SupCSs, 4 have intensified up to the speed of 140 kt. Therefore, the results of estimated return period of SupCSs and TCs of 140 kt occurrence have been observed to be reliable. Also, with the increase in return period time, the spatial extension of areas affected by TCs of higher intensities will increase. With the 20 years return period, the large parts of the eastern India, entire Bangladesh and adjacent Myanmar coasts are expected to be affected by extremely severe cyclonic storms, while some parts of the central-northern BoB can experience the SupCSs. The occurrence probabilities of TCs of low intensity are high, whereas chances of occurrence of SupCSs is relatively far less. The occurrence probability of very severe cyclonic storms has been observed more than 90 per cent and it has been found about 70 per cent over the coastal areas of India, Bangladesh and adjacent Myanmar and larger parts of the BoB for 20 years return period. Overall, the results of this study have shown that the northern and western coastal areas of the BoB are at high risk of TCs extreme winds.

It is assumed that the findings of the present study may update the current knowledge and may be of importance for the scientific community as well as academicians, and others who have an interest in tropical atmospheric science. The findings may also shed new light on the intraseasonal and interannual variability of TCs in the BoB. Moreover, the findings of this study may enable the meteorologists and scientists to make seasonal and short-term prediction of the BoB TCs and disaster managers to strengthen the TCs disaster risk management works. Finally, this study may provide improved awareness and knowledge about TCs to policy makers and ultimately to the people living in the coastal areas of BoB who are the most vulnerable to these deadly events for taking necessary precautions to avoid human casualties and minimizing the losses to infrastructure.

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