Pre-Monsoon Cyclogenesis Over Bay of Bengal

Siba Prasad Mishra, Kumar Charan Sethi, Durga Prasad Mishra, Mohammed Siddique

Abstract: Cyclonic disturbances in the Bay of Bengal are natural, recurrent, and a regular devastator to the east coasts of Ceylon and India (especially to Odisha coast), Bangladesh and Myanmar. The destruction depends upon the frequency, intensity, place of formation, life span in Bay, SST, ENSO, El Nino Modoki, Indian Ocean Dipole, boreal summer atmospheric phenomena, Madden–Julian oscillation and the climatology of India’s mainland. The effective management of these vulnerable storms can reduce fatalities, degradation to environment and socio-economic consequences. The investigation to decadal trend of pre-monsoon bay disturbances for last 129 years reveals that the decadal distributions of cyclonic disturbances in BOB were irregular. From last 30 years pre-monsoon landfall data (1990 to 2019) divulges that frequencies of CS in BOB are increasing during La-Nina Modoki years than normal La-Nina years. The frequencies of SCS increase during warm, strong La-Nina years than La-Nina Modoki years and particularly during negative ONI events, La Nada, Strong ENSO, high PIOD events. Individually the events may not be conclusive regarding conceive strong pre-monsoon cyclonic storms but they become severe when taken in combination.

Index Terms: Pre-monsoon, ENSO, NIO, Cyclones, Bay of Bengal, Odisha Coast.

I. INTRODUCTION

Cyclonic disturbances (CDs) in the Bay of Bengal (BOB) are natural and cause widespread damage to the coastal ecosystem including loss of lives, and immense impairment to property and infrastructures on landfall. About 68% storms formed in the North Indian Ocean (NIO) move to BOB basin and ≈30% to Arabian Sea (AS) basin and rest dissipate within the sea (1891-2007), Mohapatra M.M. 2013[1]. The frequency of CDs in the BOB are more than the AS, because of the dry air blowing from the Middle East desert, disapprove (culminating) wind shear to form and intensify. Stratification, timing, temperature (threshold ≥ 280 C) and vertical shear are the major factors that make cyclones proactive and intense in BOB. India combated 317 severe cyclonic storms (SCS), out of which 73% (230) were spawned in the BOB (updated from 1891 to 2019 IMD data). State wise, out of total BOB CDs 44% slam Odisha along east coast and 85% hit Gujarat coast from AS storms (data 1891-2005) Tyagi et al, 2009[2]. The BOB extends from ≈ 5° to 22° N Lat. and 80° to 90° E. long. is covering area in South Asia of about 2,173,000 km2, average depth, 2600m and the maximum depth is ≈ 4694 m.(Encyclopedia Britannica). Between 50N to 50S latitude, the North Indian Ocean (NIO) is calm and has no Coriolis Effect/ trade winds (doldrums area). The area is not conducive for cyclogenesis. Cyclone season in the BOB starts from March (rare), April and May (MAM months), called Pre-monsoon, with SW trade winds (monsoon flow in JJAS months) and ceases during October, November-December (the Post monsoon, with NE trade winds flow). The coastal states of India are West Bengal (WB), Odisha, Andhra Pradesh (AP), Puducherry and Tamil Nadu (TN) lies along east coast (EC) of India.

A. Review of literature:

A satellite method to estimate intensity of tropical cyclone was done empirically by Dvorak, 1975[3], establishing a relationship between current intensity, maximum sustained wind speed and a T number to a storm. Mooley D. A., 1980[4], reported that major percentage of CDs (depression (D) and above) initiated in BOB had intensified into severe cyclones within 1965–77 whereas the hit to coast was less. Veeraraghavan K. et al. 1983[5], noted about the increase in frequency of cyclones in BOB in the 2nd half of 19th century than the 1st half and the rate of intensification of LOPAR to intense tropical cyclones (TCs: Cyclonic storms and above) in BOB was highest (77%) in the month of Nov followed by Dec (63%) and May (61%), Mohanty U. C. 1994[6]. The utmost susceptible months for CDs in BOB are May, Oct and Nov for Bangladesh, May for Myanmar, June, Aug and Sept for WB, Odisha and AP coasts in India and OND months for AP and TN in south EC of India. Total pre-monsoon storms are 20.99% (MAM months) and 54.32% during OND months, Alam et al 2003[7]. The conducive areas for cyclogenesis of Cyclonic storms (CS) in tropics were observed mainly between 15.0° N to 22.5° N Lat. and 86.0° E to 92.0° E Long. over the BOB (data 1891-2004) with significant increase in intensity of SCS and above in May, Oct, and Nov month during 19th Century Singh C., et al., 2005[8] and Singh O P., 2007[9]. Fritz, H.M., 2009[10] reported that there is ≈ 4:1 ratio in number of CDs distributed between the BOB and AS. The numbers of CDs formed in the BOB and slammed the BOB storms from 1974 to 1999 (26yrs) were 202 and intensified to CS and above were 99. Among the 17 pre-monsoon TCs in BOB, 29.41% slammed Myanmar coast, 52.94% crossed BD coast, and rest 29.41% hit EC of India. The projection of cyclonic disturbances as per IPCC is uncertain qualitatively and quantitatively.

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Masato Sugi, 2009[11]. Sumesh et al., 2013[12] mentioned about the simultaneous occurrence of El-Niño Modoki and positive Indian Ocean Dipole (IOD) events are favourable for the formation of TCs over NIO.

Panda J., 2016[13] mentioned that the CDs over NIO comprises of ±35% amplify to (CS), ±16% to SCS, and ±7% intensify to VSCS (very severe cyclonic Storms). The trend is increase in cyclogenesis in post monsoon than monsoon with frequency/intensity is the maximum in November, Mishra A, 2014[14]. The % of frequency of tropical cyclones (TCs) in NIO is less in comparison to other oceans. About 80 TCs cause an average 20,000 fatalities and average (av.) total pecuniary loss of $6 to 7 billion/year. Mohanty et al., 2015[15]. Cyclone e-Atlas, IMD shows that from 1891 to 2015 (124 years), there were total 682 D. 280 CS and 227 SCS have been formed over BOB, AS and Indian hinter lands respectively. Above 60% of cyclones forming over BOB slam east coast of India, ≈30% strike the BD and Myanmar coast and the rest 13% dissipate within BOB (http://www.rsmnceedelhi.imd.gov.in), Hazra A., 2017[16]. The number of cyclones passing different states in the EC of India from 1891 to 2013 were 69, 104, 83, 62 along WB, Odisha, AP and TN. Nitu S., 2012[17] and Mishra A., 2014 updated[14] Mishra S P. 2014[18].

The storms in BOB strongly targets coastal districts of Odisha followed by AP, TN, and WB respectively Sahoo B. P. et al 2015[19]. The duration of LPs has increased in the 2nd half of the 20th century. Jadav et al., 2009[20]. Malik et al., 2016[21] mentioned from the Landfall BD coast data (1981 -2014, 33yrs) that the CDs striking BD coast is decreasing mostly during pre-monsoon. Studies have reported that the MJO events on TC activity under El Niño and La Niña phases of ENSO has impact on the CS activity over NIO, Liebmann et al., 1994[22]; Madden R et al., 1994[23]; Kikuchi and Wang, 2010[24]. The 30-60 days MJO has impact on tropical cyclone activity, vertical wind shear, vertical motion, and sea level pressure (SLP), Philip J. Klotzbach, 2013[25]. Balaguru et al 2016[26] reported that beyond SST and ENSO anomalies, the strong warming in the NIO and the meridional dipole during pre-monsoon have influence on TC genesis over BOB. The CDs has increased at high rate(≈+1.67%/ annum) and C.S. is more over BOB than over AS. Strong monsoon prohibits the genesis of C.S. increases with the increase of Global Sea Surface Temperature (GSST) Banerjee et al 2016[27]. The NE moving / curving of CS that landfall BD and Myanmar are common during the pre-monsoon (MAM months). Mohanty U C 2019[28].IOD coupled with El Niño Modoki can develop TC genesis in NIO, Aurora K, et al., 2019[29].

B. Objective of the study:

The history reveals that the cyclones in pre-monsoon (MAM months) generally starts over SW Bay and move E, EN, or NE and slams coasts of Bangladesh (BD) and Myanmar. The ESCS FANI is an exception as a pre-monsoon cyclone heating Odisha in East Coast of India. The rare CD, Fani, life period from 25th April – 4th May, 2019, intensified to an extreme severe cyclonic storm (ESCS) with sustained wind speed of 175-185 km/h gusting to 205 km/h and eye pressure dropping to 937hPa with heavy devastation in Odisha has instigated for studying the cyclogenesis of bay disturbances in Bay of Bengal in North Indian ocean.

Classification of cyclonic disturbances:

About 80-90 numbers of CDs/year are forming in different oceans around the globe out of which ≈45-50 numbers are of CS and above/year. In an average 4-5 numbers of CS & above year form in BOB, Alamet.al, 2003[7], Needham H F 2015[42]. The CDs (above depression) occur in the tropics (00to 350Latitude) are called tropical cyclones and elsewhere as extra-tropical cyclones. In Indian Ocean it is called cyclonic storms and Hurricanes in the Atlantic or Eastern Pacific, and typhoons over western North Pacific. Thereafter the storms in BOB were classified mainly to four categories adding very severe cyclonic storms (VSCL) Mooley et al 1980[4]. The name supper cyclone (SuCS) was started from the date, 29th Oct, 1999 (Paradeep cyclone, Odisha), when the wind speed measured by Cyclone Warning Center, PDP was ≈260Km/h (>222 km/h) and the central pressure was 912 hPa. The term extreme severe cyclonic storm (ESCS) was probably introduced after the CS Phailin hitting Odisha, in 2013 with wind speed 205Km/h (168 - 221Km/h) and eye pressure 940 hPa. The various orders of CDs are in Table 1.

<table>
<thead>
<tr>
<th>Bay CDs using Saffir–Simpson scale</th>
<th>Organization</th>
<th>Beaufort scale</th>
<th>Wind speed Kts</th>
<th>Wind speed Kmph</th>
<th>≈Wav ht. (m)</th>
<th>Δ hPa(mbar)</th>
<th>Sea condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>LPA/ WML</td>
<td>IMD (3mnt)</td>
<td>0-4</td>
<td>&lt;17</td>
<td>&lt;31</td>
<td>&lt;1.5</td>
<td>&lt;4</td>
<td>Calm-mod</td>
</tr>
<tr>
<td>Depression(D)</td>
<td>NH/C/PH/JTWC(1mnt)</td>
<td>5 to 7</td>
<td>&lt;32</td>
<td>&lt;59</td>
<td></td>
<td></td>
<td>Mod–rough</td>
</tr>
<tr>
<td>Sustained wind</td>
<td>IMD (3minutes)</td>
<td>5 to 6</td>
<td>17 to 27</td>
<td>31 to 49</td>
<td>0-3</td>
<td>4-6</td>
<td>Mod–rough</td>
</tr>
<tr>
<td></td>
<td>WMO/IMA/MF/BOM/FMS(10mmts)</td>
<td>5 to 7</td>
<td>&lt;28</td>
<td>&lt;52</td>
<td></td>
<td></td>
<td>Mod–rough</td>
</tr>
<tr>
<td>Deep depression (DD)</td>
<td>NH/C/PH/JTWC (1mnt)</td>
<td>7</td>
<td>33–37</td>
<td>61–69</td>
<td></td>
<td></td>
<td>very rough</td>
</tr>
<tr>
<td></td>
<td>IMD (3minutes)</td>
<td>7</td>
<td>28 to 33</td>
<td>50 to 61</td>
<td>&lt;6m</td>
<td>6-10</td>
<td>very rough</td>
</tr>
<tr>
<td></td>
<td>WMO/IMA/MF/BOM/FMS(10mmts)</td>
<td>7</td>
<td>30-33</td>
<td>56-61</td>
<td></td>
<td></td>
<td>very rough</td>
</tr>
</tbody>
</table>
### Decadal statistics NIO:

The number of TCs formed in the NIO, BOB and AS during the last 28 years (1991–2019) were 795. The highest number of TCs formed (98 numbers) in the decade 1991–2000 and the lowest (38) in the year 1981–1990 (Wiki data updated) Fig-1.

### Historical pre-monsoon storm records:

The data series of pre (MAM months) and post monsoon (OND months) reveals that out of 711 TCs (1891 to 2019 May) in the NIO System, the depressions were (38.25%), deep depression (27%), CS (16.32%), SCS (8.86%), VSCS (6.05%), ESCS & SuCs (3.52%) respectively.

### Abbreviations:
- Tropical cyclone (TS): Lopar and above, CDs: cyclonic disturbances (depression and above), TC: tropical cyclone (CS and above), MSW: Max sustainable (surface) wind, MSLP: Minimum sea level pressure.

### Table: Frequency of Cyclonic Disturbances in the NIO

<table>
<thead>
<tr>
<th>Category</th>
<th>Data Source</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>TC: tropical cyclone (TS)</td>
<td>1.3394x10^5 + 16.116x4.4267x + 11.618x0.0818x + 0.6218x</td>
<td>34-47</td>
</tr>
<tr>
<td>Severe Cyclonic SCS) (VTS)</td>
<td>55-63</td>
<td>102–117</td>
</tr>
<tr>
<td>Very Severe Cyclonic (VSCS) /Severe Tropical storm (VSTS)</td>
<td>72-97</td>
<td>133-180</td>
</tr>
<tr>
<td>Extreme Severe Cyclonic (ESCS) /Severe Tropical storm (ESTS)</td>
<td>98-129</td>
<td>181-240</td>
</tr>
</tbody>
</table>


### Figure 1: Decadal CDs above CS in BOB and AS (1891 to 2019) (source data: Wiki & IMD)

The decay data series of pre (MAM months) and post monsoon (OND months) reveals that out of 711 TCs (1891 to 2019 May) in the NIO System, the depressions were (38.25%), deep depression (27%), CS (16.32%), SCS (8.86%), VSCS (6.05%), ESCS & SuCs (3.52%) respectively.

### Figure 2: Decadal trend of CDs in BOB (dep. & above) hitting EC India (1891 to 2019)
IMD was established in 1875 and the updated records of CDs over BOB are made available by IMD from 1891 onwards. However literature reveals about some major historical storms in BOB during pre-recorded period in BOB. Considering RSMC data up dated (1891-2019) study has been made to find the decadal trend in TCs in BOB. It is observed that the trend in numbers of Deep and SCS and above category is increasing whereas the middle order CS-Category is reducing Fig–2. Past literatures reveals that, ≈ 60 had affected EC coast, BD and Myanmar out of which only seven were pre-monsoon storms that slammed Odisha coast from 1804 to 1890. Some important historical pre-monsoon storms before1890 are given in Table 2.

**Table 2: The pre-monsoon & Holocene TCs in BOB slammed EC of India up to 1890**

<table>
<thead>
<tr>
<th>#</th>
<th>Year</th>
<th>Period</th>
<th>Surge/intesity</th>
<th>Place/ types</th>
<th>Damages</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>SCS, BD</td>
<td>May-June 1797</td>
<td>Hurricane wind</td>
<td>Chittagong coast</td>
<td>All kachha sheds lost. 2 ships sunk Chittagong Port</td>
<td>BD Met.Dept. wikipedia.org/wiki/List_of_BD_tropical_cyclones</td>
</tr>
<tr>
<td>3</td>
<td>SCS IND</td>
<td>27th May, 1823</td>
<td>10km, inland. storm surge.</td>
<td>Strong wind. heavy rain</td>
<td>Some ships, villagemissin g.</td>
<td>Chhitebabu et al 2004</td>
</tr>
<tr>
<td>4</td>
<td>CS BD</td>
<td>2 June 1823</td>
<td>NA</td>
<td>Chittagong coast</td>
<td>NA</td>
<td>F.Henderson. 1979</td>
</tr>
<tr>
<td>5</td>
<td>CS, IND</td>
<td>May, 1833</td>
<td>NA</td>
<td>Balesore dist.</td>
<td>Flooding</td>
<td>Chhitebabu et al 2004</td>
</tr>
<tr>
<td>6</td>
<td>SCS, Ind</td>
<td>1834</td>
<td>NA</td>
<td>Odisha coast</td>
<td>wind damage</td>
<td>Chhitebabu et al 2004</td>
</tr>
<tr>
<td>7</td>
<td>SCS, IND</td>
<td>Apr 27–May 1, 1840</td>
<td>vsccs</td>
<td>Chilika coast, South of Puri.</td>
<td>Puri, Cuttack &amp;Balasore Dist.</td>
<td>Tripathy S. 2011</td>
</tr>
<tr>
<td>8</td>
<td>CS, BD (Gale)</td>
<td>11 May 1844</td>
<td>NA</td>
<td>Chittagong coast</td>
<td>Noakhali and Chittagong coast</td>
<td>By F. Henderson, 1979</td>
</tr>
<tr>
<td>9</td>
<td>CS, BD</td>
<td>12–13 May 1849</td>
<td>NA</td>
<td>Chittagong coast</td>
<td>NA</td>
<td>F. Henderson,1979</td>
</tr>
<tr>
<td>10</td>
<td>SCS</td>
<td>23–28 April, 1850</td>
<td>High surge</td>
<td>False Pt. PDP-DP</td>
<td>Surge in S-RekhaRiver mouth</td>
<td>Chhitebabu et al 2004</td>
</tr>
<tr>
<td>11</td>
<td>SCS</td>
<td>12–15 May 1852</td>
<td>NA</td>
<td>63 km, Calcutta(E)</td>
<td>NA</td>
<td>F. Henderson.1979</td>
</tr>
<tr>
<td>12</td>
<td>CS</td>
<td>13–17 May 1869</td>
<td>NA</td>
<td>Cape Negrais, Myanmar</td>
<td>crossed the Bengal coast</td>
<td>F. Henderson. 1979</td>
</tr>
<tr>
<td>13</td>
<td>CS-</td>
<td>26th May, 1887</td>
<td>0.61 m</td>
<td>False Point to Sagar Island</td>
<td>776 drowned. Worst sea tragedy</td>
<td>Chhitebabu et al 2004</td>
</tr>
</tbody>
</table>

Other historical pre-monsoon storms crossed BD are on 11 May 1844 (Noakhali), 12–13 May 1849 (Chitagong) and 16th May 1869 (Pusur), and 1941, Washington D.C. 20523 – by F. Henderson


Causes of cyclogenesis in NIO Basins:

NIO has two major basins namely BOB and AS. The number occurrence of CDs in BOB are more than the AS. It is due to weak vertical mixing in BOB due to huge perennial fresh water influx from Himalayan Rivers, basin rainfall and sluggish wind in comparison to the AS. Cyclogenesis in NIO is due to transfer of water vapour and heat from the higher SST zone to the upper air in sea. The rising warm air expands and cools rapidly and become saturated and release the latent heat retained by the warm vapour. The air column in the core of the intensifying CDs is heated under decreased pressure and moistened. The outer surfaces have more wind velocity depending upon the strength of the CD. The ΔT between the hot and the cool air in surrounding make rising air to become more floating and increase its upward motion. During drive, if the system receives moist air or influenced by adjoining disturbances, it intensifies. Volcanic eruptions (Natural), nuclear explosions and over consumption of fossil fuel (Anthropogenic) inject a huge quantity of aerosols particles to the atmosphere. These charged active particles chemically react with solar emission and triggers climate changes globally. The intensity and frequency of meteorological extreme events are governed by these aerosols in air since 3 to 4 decades can be a cause of TCs. The high tropospheric temp (7Km to 20Km above earth’s surface), trade wind and 26.50 C temp (considered thresholds SST) are encouraging for the BOB disturbances for initiating onvection between the sea surface and the troposphere. The land surface heats up and cools down rapidly than the water surface. The temperature difference caused by this variable cooling and heating of land and ocean creates LPA indicating less air mass within the system than the surrounding. Winds blow from high towards LPAs and energize the system into higher order CD depending on the evaporation in the region that can feed sufficient moisture to the circling winds.

Manifestation of BOB storms:

BOB is one of the potential areas of formation to≈7% of CDs of the globe and these CDs are highly devastating. The basic causes of cyclone genesis in BOB are due to effect of suitable Coriolis force vector (depending on NH or SH), Stratospheric +ve relative viscosity as initial turbulence, low tropospheric upright wind shear, appropriate SST (threshold >26.50 C) up to 60m depth, atmospheric instability and sectional temperature gradient, and mid tropospheric relative humidity (RH),Gray W. M. (1975)[32,1979[33]). Insufficient knowledge about cyclone genesis, intensification mechanisms, in adequacy in situ observations within sea and eye of the CDs at times lead to forecasting errors of the trajectory, storm surges, point of curvature and its dissipation. Detailed and accurate data of the season of formation (timing), orientation, the place of origin, associated climatic condition for intensification or dissipation, the SST and allied energy, the trajectory, the wind vector within the domain, cloud pattern, UACYCIR, positioning of ITCZ is essential to forecast the track and landfall point considering ENSO, MJO, POID, El Nino and Modoki and BSISO events.

Timing: CDs usually do not form over BOB during Jan to March may be termed as “passive period” for cyclone genesis. The pre-monsoon cyclones are only 27.6% of total in MAM months in NIO. The climatic factors for formation of BOB disturbances are most conducive during July to September (monsoon season) but the numbers of higher order CS, are least (<10%) but the vulnerability rate of CS formation is very high (≥54,5%) in post monsoon period reported by Mohanty U. C. et al 1994[40]. There were ~35 MAM TCs were recorded from 1891 to 2019, and EC India received 8 landfalls (4 along AP coast, 3 slammed Odisha coast and 1 along TN coast). The pre-monsoon BOB storms which slammed EC, during April and May (1891-2019) were given in Table3.

Table 3: The list of pre-monsoon BOB TCs slammed EC of India (Mar to May), 1891-2019

<table>
<thead>
<tr>
<th>#</th>
<th>Name of Cyclone</th>
<th>Date</th>
<th>Death</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>SCS</td>
<td>May 23–26, 1893</td>
<td>NA</td>
<td>Heavy rain over BLS, PRI, CT, cyclones in May in the BOB in 25 years,5000 house damaged.</td>
</tr>
<tr>
<td>2</td>
<td>SCS, BD storms Barisal SCS</td>
<td>May 1898</td>
<td>Lost: 40000, 100,000 cattle</td>
<td>NA</td>
</tr>
<tr>
<td>3</td>
<td>Noakhali CS</td>
<td>17-19 May 1948</td>
<td>1200</td>
<td>NA</td>
</tr>
<tr>
<td>4</td>
<td>East &amp; west Meghana estuary</td>
<td>16-19 May, 1958</td>
<td>870 death 14,500 cattle</td>
<td>NA</td>
</tr>
<tr>
<td>5</td>
<td>SCS,Bagerhat&amp;Khu lna</td>
<td>5th-9th May 1961</td>
<td>11468(Cha Alexander)</td>
<td>2.44-3.05m, 161Kmph.</td>
</tr>
<tr>
<td>6</td>
<td>SCS Chittagang</td>
<td>28-29th, May, 1963</td>
<td>11,520 lives and 32,617 cattle lost</td>
<td>4.3-5.2m &amp; max wind 203 km/h</td>
</tr>
<tr>
<td>7</td>
<td>VSCS Barisal CS 2B</td>
<td>11-12 May 1965</td>
<td>19279</td>
<td>3.7m/ 162 km/hr</td>
</tr>
<tr>
<td>8</td>
<td>SCS, Bhola</td>
<td>9-12th May, 1975</td>
<td>05 killed,</td>
<td>96.5 to 112.6Km/h</td>
</tr>
<tr>
<td>9</td>
<td>CS-1976</td>
<td>Apr 29-May 2,</td>
<td>95Kmph</td>
<td>Between Nellore and Kavali</td>
</tr>
<tr>
<td>10</td>
<td>CS Khulna</td>
<td>9-12 May 1977</td>
<td>NA</td>
<td>112.63 km/h</td>
</tr>
<tr>
<td>11</td>
<td>SCS Ongle-Bapatla</td>
<td>05 - 13 May 1979</td>
<td>700 lives, 30000 cattle</td>
<td>Fall bet. Ongole&amp;Bapatla</td>
</tr>
<tr>
<td>No.</td>
<td>cyclone</td>
<td>date</td>
<td>year</td>
<td>description</td>
</tr>
<tr>
<td>-----</td>
<td>---------</td>
<td>------</td>
<td>------</td>
<td>-------------</td>
</tr>
<tr>
<td>12</td>
<td>SCS, Chittagong</td>
<td>24-25 May, 1985</td>
<td>1985</td>
<td>11069 lives, 1350 33 bovines</td>
</tr>
<tr>
<td>14</td>
<td>SuCS Machhli-patnam</td>
<td>04 - 09 May 1990</td>
<td>1990</td>
<td>967 deaths</td>
</tr>
<tr>
<td>16</td>
<td>SuCs (CS 02B), Timemaz.’Gorky’</td>
<td>Apr. 24- May 2nd, 1991 (Cat - 4 Cyclone.)</td>
<td>1991</td>
<td>138,866 died &amp; 139054 injured.</td>
</tr>
<tr>
<td>17</td>
<td>CS BOB 01</td>
<td>May 30 – June 3, 1991</td>
<td>1991</td>
<td>No fatalities</td>
</tr>
<tr>
<td>18</td>
<td>CS BOB 02</td>
<td>May 15-19, 1992</td>
<td>1992</td>
<td>27lives, 19missing</td>
</tr>
<tr>
<td>19</td>
<td>Bangladesh VSCS ESCS BOB 2</td>
<td>April 24 - May 2, 1994</td>
<td>1994</td>
<td>285people</td>
</tr>
<tr>
<td>20</td>
<td>Bangla Des(wiki) ESCS</td>
<td>May 14-20, 1997</td>
<td>1997</td>
<td>1296 died,9663 injured</td>
</tr>
<tr>
<td>21</td>
<td>SCS BOB 1(01B)</td>
<td>May 13-17 1998</td>
<td>1998</td>
<td>35died, 504 injured,</td>
</tr>
<tr>
<td>22</td>
<td>CS BOB 01</td>
<td>March 27-30, 2000</td>
<td>2000</td>
<td>No advisories</td>
</tr>
<tr>
<td>23</td>
<td>VSCS, BOB 01 (01B), Sri Lanka</td>
<td>May 10 – 20, 2003</td>
<td>2003</td>
<td>254 deaths</td>
</tr>
<tr>
<td>24</td>
<td>VSCS, BOB 01</td>
<td>May 16 – 19, 2004</td>
<td>2004</td>
<td>236 deaths</td>
</tr>
<tr>
<td>25</td>
<td>ESCS, Mala</td>
<td>April 25th-29th, 2006</td>
<td>2006</td>
<td>37 lives</td>
</tr>
<tr>
<td>26</td>
<td>CS Akash, BOB 1B -2007</td>
<td>13th - 15th May 2007</td>
<td>2007</td>
<td>14 direct, 100missing</td>
</tr>
<tr>
<td>27</td>
<td>ESCS, Nargis, Myanmar</td>
<td>May 24th, 2008</td>
<td>2008</td>
<td>84500 lives</td>
</tr>
<tr>
<td>28</td>
<td>CS, BOB Bijli,Trop. Cyclone1B</td>
<td>14-17 April 2009</td>
<td>2009</td>
<td>75Kmph, 996mbar</td>
</tr>
</tbody>
</table>
| 29  | SCS:Aila (JTWC: 02B) | May 26-27, 2009 | 2009 | 339 total lives | 110 km/h, 968 hPa,

The SST anomaly of BOB is one of the key causes for materialization of CD's and increasing intensification of TCs in BOB. Environmental conditions, including the SST of 300°C to 310°C, are conducive for intensifying the SCS into an ESCS within 12 hours. Asymmetry has been observed with ENSO forcing and upsurge in the frequency of El Niño events in the BOB cause for rise in temperature Roxy et al 2015[32].

The Eye and Pressure Difference: The radius of outermost closed isobar (ROCI), pressure fall in the eye of the cyclone (∆P) of the CDs is calculated in hectopascals (hPa) from standard ambient atmospheric pressure at MSL as 1013.2 hPa (millibar). The higher the rate of the pressure drop, the TC is stronger. The pressure difference (∆hPa) within the eye of the cyclonic storms of different category of CDs is given in Table 1. Life span of CS in BOB: Normally, the life spans of the CDs in BOB are for three to seven days. The monsoon storms move NW-ly and commonly slam in northern parts of EC (East Coast of India) and BD (Bangladesh) coast. The pre-monsoon CS tends to be intense and devastating when their life over the marine area is longer. In the process they intensify and gain high momentum by capturing more moisture and energy. Some storms generated in BOB do not intensify due to unfavorable atmospheric conditions and become stagnant, weaken and dissipate in BOB.

Place of Formation: The formations of CDs in Bay generally occur within 0 to ±10 degree Lat. depending on position of ITCZ during pre and post-monsoon seasons. Studies reveal that that the highest number of TCs formed in SE bay (66), SW bay (52), West coast and East coast bay (49 each), NW Bay (43) and North Andaman Sea (35) during pre-monsoon. The other cyclone origin areas like NE Bay and south Andaman Sea which reported 15 and 12 numbers of CDs respectively during 1981-2019 (Fig 3a & 3B). but are presently declining below 50 Lat (Ex:Fani)

The Pre-monsoon CS trajectory, BOB: It is recorded that the trajectory of each CD in BOB is unique. Generally the pre-monsoon cyclones initiated originating in the southern and adjoining central bay, move initially either NW-ly or N-ly, and curve to the NE direction en-route before landfall at BD or Arakan coast (Fig 4). Some CS in the MAM months move NWN to NE directions and landfall AP, Odisha or WB coast and cause heavy devastation. But majority of CDs storms in monsoon/post monsoon move in W, WNW, NW and NNW directions but mainly in NW direction. Post monsoon storms are intense and form mostly below 200 lat and few of them curve on their move or dissipate en-route.
land from the high’s, to the system allow it to intensify and move either north or NE direction to hit BD or Myanmar coast triggered by favorable El Nino Modoki events, boreal summer intra-seasonal oscillation, MJO, ENSO and IOD events.

**Intensification and dissipation:**
The BOB disturbances become intense when its motion is sluggish and have a long stay over the ocean or aided by external factors. Above 50% of the Bay disturbances that form in the pre and post monsoon months intensify into D/DD. The probabilities of intensification of a CDs to depression is maximum in April followed by May and November in case of depression to CS are in the month of May followed by April and November and in case of depressions to SCSit is in the months of MAY and November (IMD) http://www.Rsmcnewdelhi.imd.gov.in/index.php?option=com_content&view=article&id=52&Itemid=200&lang=en.The weakening of TCs in ocean occurs when cyclone penetrates and stir deeper from sea surface (>≈60m depth), and reach cooler ocean waters where supply of thermal energy is reduced. After landfall the supply of energy to the CS becomes zero and as a result TCs weakens rapidly.

**Type of track**
The trajectory and movement TCs in BOB may be straight, slow, rapid or changing direction in an obtuse or acute angle. Accordingly cyclones can be classified as SM: Slow movement, RM: Rapid movement, SCD: Slow change in direction, SCD: Sudden change in direction and SM/SCD: Slow moving and sudden changing in direction (Mohapatra M. M., IMD). The list of slamming/ dissipating pre-monsoon tracks of TCs in BOB from 2000 -19 are given Table 4

Table 4: List of pre-monsoon TCs, the type of track, origin and landfall place from 2000 – 2019

<table>
<thead>
<tr>
<th>Date/year</th>
<th>Type of BOB CS &amp; above</th>
<th>Type of track</th>
<th>Landfall/w eaken CS</th>
<th>Direction Of curvature</th>
<th>Place of form</th>
<th>Place of land fall/</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mar 27–30,2000</td>
<td>CS</td>
<td>SM</td>
<td>Landfall</td>
<td>NNE</td>
<td>SE Bay</td>
<td>Chennai</td>
</tr>
<tr>
<td>May 10-19, 2003</td>
<td>VSCS</td>
<td>SCD</td>
<td>Land fall</td>
<td>NW–N –NE</td>
<td>SE Bay</td>
<td>West Myanmar</td>
</tr>
<tr>
<td>May 16-19, 2004</td>
<td>SCS</td>
<td>SCD</td>
<td>Land fall</td>
<td>NE track</td>
<td>EC Bay</td>
<td>Myanmar(Sittwe)</td>
</tr>
<tr>
<td>April 25-29, 2006</td>
<td>VSCS (Mala)</td>
<td>RM</td>
<td>Land fall</td>
<td>N –ly</td>
<td>SE Bay</td>
<td>Myanmar Rakhine</td>
</tr>
<tr>
<td>May 13-16, 2007</td>
<td>CS ((Akash))</td>
<td>RM</td>
<td>Land fall</td>
<td>N-ly</td>
<td>EC Bay</td>
<td>BD-Myanmar</td>
</tr>
<tr>
<td>Apr 27-3rd May 08</td>
<td>VSCS Nargis</td>
<td>SCD</td>
<td>Land fall</td>
<td>NE-ly</td>
<td>EC Bay</td>
<td>southern Myanmar</td>
</tr>
<tr>
<td>April 14-17, 2009</td>
<td>CBijli</td>
<td>RM</td>
<td>Land fall</td>
<td>WNW–NE-NW</td>
<td>WC-Bay</td>
<td>Chittagong, BD</td>
</tr>
<tr>
<td>May23–26 2009</td>
<td>SCS (Aila)</td>
<td>RM</td>
<td>Landfall</td>
<td>N-ly</td>
<td>EC Bay</td>
<td>Sagar IslandWB</td>
</tr>
<tr>
<td>May 17-21 2010</td>
<td>SCS (Laila)</td>
<td>SM/SCS</td>
<td>Landfall</td>
<td>NW- NWN</td>
<td>SE Bay</td>
<td>Bapatla, AP Ind</td>
</tr>
<tr>
<td>May 10-17, 2013</td>
<td>Viyaru, Mahasen</td>
<td>SM/SLCD</td>
<td>Landfall</td>
<td>NW – NE ly</td>
<td>SE Bay</td>
<td>Chittagong, BD</td>
</tr>
<tr>
<td>May 17-22, 2016</td>
<td>CS, Roanu</td>
<td>SCD</td>
<td>Landfall</td>
<td>NE-ENE</td>
<td>SW Bay</td>
<td>BD-Chittagong</td>
</tr>
<tr>
<td>April 15-17,2017</td>
<td>CS Marutha</td>
<td>RM</td>
<td>Landfall</td>
<td>NE</td>
<td>SW Bay</td>
<td>M yan mar coast</td>
</tr>
<tr>
<td>May 28-31 2017</td>
<td>SCS Mora,</td>
<td>SLCD</td>
<td>Landfall</td>
<td>E-NNE</td>
<td>SE Bay</td>
<td>BD,Chittagong</td>
</tr>
</tbody>
</table>

About 14 TCs had formed in BOB in past 20yrs and none from them dissipated en-route. Two of them slammed EC, India. The ESCS, Fani had landfall at Puri in central EC of India, a SLSMCD causing catastrophe in coastal Odisha in 2019. The other was RM type SCS (Aila) had landfall near Sagar Island , WB.

**Wind Speed:**
IMD use Saffir–Simpson scale (SSHWS) for predicting the type of BOB disturbances considering wind as major criteria, http://www.rsmcnewdelhi.

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imd.gov.in/index. The different met centers consider the sustained wind as the average wind speeds of different time spans. The Tropical numbers (T-numbers) are assigned as T-scale (after Dvorak) is Very weak, pre-genesis tropical CDs=T1.0 (Tnum =1.0). Minimal tropical storm intensity (MSW of 35 kts)=T2.5. Minimal hurricane intensity (65 kt)=T4.0, T5.0 = 90 kt, T6.0 = 115 kt, and T7.0 = 140 kt. The rareT8.0 = 170 kts is the top of the scale and rare. The SSHWS Scale was followed in India to categorize TCs with 3mnt av wind speed in m/s are T-1 (33-42m/s), T-2 (43-49m/s), T-3 (50-58m/s), T-4 (59-69m/s), T-5 (>70m/s) with minimal, moderate, extensive extreme and catastrophic damages.

**Storm surges:**

Maximum inundation due to storm surges and coastal flooding and their impact along east coast, is Ganga-Brahmaputra delta and Myanmar coast, Ali A., 1979[35], Murty T. S. et al, 1986[36], Das P. K. , 1994[37], Dube S. K. et al, 1997[38], Chittibabu P. 1999[39], 2004[39], Gayatri R. et al, 2015[40], Sahoo B et al, 2017[41], High tides (full moon). The BOB in the NIO has reports of world’s highest surges, @ five times surges ≥5 m/10years and has storm tide levels reaching 13.7 m Needham et al 2015[42], AGU, Reviews of Geophysics, https://doi.org/10.1002/2014RG000477. The Hurricane Katrina’s storm 2005 had the tide + surge of 13m. East coast delta between 150 N upto 250N is well stretched and shallow containing huge deltaic coastal area in comparison to southern coast of India. The delta is wider with mild gradient of 1:5000 to even 1:10000 and creates vast low lying areas up to ≈100Km. During storms these areas act as funnels to absorb high surges for long period causing huge crop loss and salinity intrusion. Explained in Table 3

**Pre-monsoon CDs in BOB:**

NIO covers both Southern and Northern Hemisphere. Frequency of TCs NIO (CS and above with wind speed >64 Km/h IMD 3mnts average) over the BOB, AS and inland in Indian subcontinent during the pre-monsoon months (wiki data) were analyzed and found that from 1891 to 2019 the CS and above disturbances formed during pre-monsoon months (MAM) were 131 in number out of which 97 over BOB and 34 over AS. From the statistics (1891 to 2019 May) reveals that there was highest number of D/DD CDs in BOB were 11 in the decade 1940-49, CS was highest (8 numbers)1920-29 and CDs higher than CS, SCS and above were 9 during 1960-69 Fig 7. The statistics [1891 to 2019(May)] of post monsoon CS in BOB reveals that the highest numbers D/DD, CS, and CDs higher grade than CS were 1950-59 (23numbers), both 1920-29 and 1940-49 (15numbers) and 1960-69 (21 numbers). The numbers of CDs were highest 49 in the decade 1960-69 Fig 6.

**Naming of Cyclones in Indian Ocean**

The naming process to cyclones started in Atlantic during World War II by the military meteorologists. They initially tried with several naming strategies to name hurricanes after their girlfriends. But by 1953, meteorologists had begun using alphabetical ordered female names. In 1979, male names were added Kalila M., 2018[43]. Today, the WMO maintains six lists of alphabetical ordered male and female names. They name rotationally for each TC. But the extreme devastating hurricane is named as retired (like Nargis, Camille and Katrina). Greek letters were used when the list got exhausted within a season. If a hurricane forms beyond the usual season, it is titled after the date of occurrence. The systematized naming was started from Sept.2004. After Fani (BOB), the TCs to follow are the Vayu, AS (in force), the other CS in pipe line are Kikaa, Kyarr, Maha, Bulbul, Soba, Amphan and the names given by the countries are Maldives, Myanmar, Oman, Pakistan, Sri Lanka and Thailand respectively and the list shall be exhausted. Mishra S. P. et al. 2014[44]

**Pre-monsoon Cyclones are in-situ origin in BOB**

The duration between months of January to March is rare period for cyclone genesis over the BOB, AS. NIO storms initiated in the months April or May, ends in Oct. and November. A big difference between the strengths of cyclones in MAM and ONM months are that the former originate in situ in the BOB itself,
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a few hundred kilometers from the landmass. Besides cyclones in Oct. to Dec. formed in Andaman sea, usually remnants of typhoons of in the Pacific Ocean, but manage to enter to the BOB. Afterwards the energy is restored and gathers momentum as they join the BOB from Andaman Sea indicates cyclones in the BOB in April-May are in situ systems.

**Strengthening of Cyclones:**
The cyclones originating over BOB become strong when the low-level relative vortices, mid-tropospheric RH, vertical wind shear are favourable. During monsoon, strong zonal (latitudinal) wind in the form of a jet at lower levels which reduces the vertical shear between lower and upper troposphere occur. The SST gears in a rising trend which favour for Cyclogenesis during monsoon i.e. the rise in TC intensity are due to increased SST, upper air heat content over ocean and convective instability induce cyclone genesis. TC intensification occur in BOB being influenced by extrinsic environmental oscillatory systems that includes some like La Nina, ENSO, Equatorial Indian Ocean Oscillation, MJO, Indian Ocean Dipole effect (IOD effect) and El Nino Modoki events. As such the longer the duration of stay for cyclones over the BOB the stronger they become. Extrinsic systems that initiate/energies BOB/NIO CDs: The major extrinsic systems that regulate NIO CDs are El Nino, El Nino Modoki, Indian Ocean Dipole effect (IOD effect) and boreal summer intra seasonal oscillation (BSISO) and Madden-Julian oscillation (MJO). The El Nino Southern Oscillation (ENSO) determines a warm phase, La Nina a cold phase and a neutral phase as La Nada. During El Nino events, the vertical shear in troposphere increases and inhibit tropical cyclone genesis and intensification occur within the 200mb (upper troposphere) with permitting strong Westerly winds Gray W.M., 1984[45]. La Nina events (ENSO cold phase) enhances cyclone genesis activity. The Walker circulation occurs during normal Years (La nada years). Southern Oscillation, is an inter-annual flux of atmospheric pressure over the tropical Indo-Pacific region and El Nino when match (frequently occur) is called ENSO. The ONI, Oceanic Nino Index (+ for El Nino and -ve for La Nina) is further considered with SST anomaly as Weak (with a 0.5 to 0.9), Moderate (1.0 to 1.4), Strong (1.5 to 1.9) and Very Strong (≥ 2.0) events.


![20th century, WIO warming, reaching the SST of warm pool, BOB, weakening the SST gradient](http://www.climate.rocksea.org/research/indian-ocean-warming)
El-Nin’o Modoki years compared to the only El-Nin’o years


atmospheric pressure between BOB and AS, found from IO dipole mode Index (DMI).


The Madden-Julian Oscillation (MJO)

Madden R. and Julian P. (1971)[23] reported that the TC genesis like relative vortices, divergence, vertical motion and wind shear, growth/decay of CD’s, trajectory, and intensity in the NIO region are substantially modulated by the MJO, particularly during El Niño conditions Kikuchi K et al 2010[24] and Klotzbach P. J., 2013[25]. The phenomenon is the major fluctuation in tropical weather on weekly to monthly timescales. The MJO can be characterized as an eastward moving ‘pulse’ of cloud and rainfall near the equator that typically recur every 30 to 60 days or 40-50daysinterval butless the periodicity betters the monsoon in India. MJO is apt to be very active during ENSO neutral years, and frequently absent in moderate-to-strong El Niño and La Niña events. Warm and cold years: Fig 9(a) is the Global averaged Sea Surface Temperature Anomalies of NOAA Extended Reconstruction Sea Surface Temperature (ERSST) v4 joint average (black line) and operational production (dashed red line) and the shaded region represents the 95% confidence interval due to total quantified uncertainty in ERSST v4 (Contributed by Boyin Huang at NOAA NCDC). The WIO (western Indian Ocean) was normally cool, whereas the NIO and SIO was a warm pool region with SST > 28.0°C during summer but presently, the WIO is warm, getting up to the SST of NIO and SIO and depleting the SST gradient. This warming contributes to the ocean surface warming globally Roxy et al, 2015[32].
Based on the ONI and Saunders sorted the years as warm (>0.3 ONI) and cold (<−0.3 ONI), in between as normal year. The threshold should satisfy for a min. of 5 consecutive months (Feb, Mar, Apr, May, and June) during TC initiating season Saunders et al. 2000[51]. Continuous warming of WIO and reaching the warm pool of BOB and depletion of thermal gradient contribute to Global ocean surface temperature and conducive for pre-monsoon CS distractions. Present study is conducted for the grouping pre-monsoon (MAM months) Less BOB storms in Pre-monsoon:

Table 5: The total number of CDs above depression and status of ENSO, MJO, IOD and La Nina events in NIO in the pre-monsoon months golden spike period of the Anthropocene

<table>
<thead>
<tr>
<th>Year</th>
<th>D+ DD</th>
<th>≥C S</th>
<th>Total</th>
<th>Warm/Cold/rend(FMAM J)</th>
<th>El Nino Event</th>
<th>ONI MAM</th>
<th>ENSO events</th>
<th>IOD yrs&amp;type/ MJO</th>
<th>CDs in BOB, Pre-monsoon</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990</td>
<td>17 7 24</td>
<td>Normal(Inc)</td>
<td>La Nada</td>
<td>0.3</td>
<td>Passive</td>
<td>Neutral</td>
<td>SuCS BOB 01 02B</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1991</td>
<td>13 7 20</td>
<td>Warm</td>
<td>St. Nino, Mod</td>
<td>0.5</td>
<td>Strong</td>
<td>Neutral</td>
<td>CS 01A ,CS BOB02</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1992</td>
<td>24 11 35</td>
<td>Warm (de)</td>
<td>Lanada, Modoki</td>
<td>1.1</td>
<td>Strong</td>
<td>NIOD</td>
<td>CS BOB01</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1993</td>
<td>9 6 15</td>
<td>Warm (Inc)</td>
<td>La Nada</td>
<td>0.7</td>
<td>Strong</td>
<td>Neutral</td>
<td>No CDs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1994</td>
<td>10 9 19</td>
<td>Normal (Inc)</td>
<td>EL Nino, Mod</td>
<td>0.4</td>
<td>Moderate</td>
<td>PIOD</td>
<td>BOB1B(D),ESCSBOB2,</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1995</td>
<td>14 8 22</td>
<td>Warm (dec)</td>
<td>La-Nina</td>
<td>0.1</td>
<td>Strong</td>
<td>Neutral</td>
<td>BOB 01, 02 &amp; 03</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1996</td>
<td>18 12 30</td>
<td>Cold (Inc)</td>
<td>-0.3</td>
<td>Passive</td>
<td>NIOD</td>
<td>DD BOB (01B)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1997</td>
<td>16 7 23</td>
<td>Warm (Inc)</td>
<td>V. st. El Nino</td>
<td>0.8</td>
<td>Very st.</td>
<td>PIOD</td>
<td>ESCS BOB 01 01B</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1998</td>
<td>23 15 38</td>
<td>Warm (dec)</td>
<td>St. La Nina</td>
<td>0.5</td>
<td>Strong</td>
<td>NIOD</td>
<td>CS BOB 01 (01B)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1999</td>
<td>18 14 32</td>
<td>Cold (Inc)</td>
<td>St. La Nina</td>
<td>-1.0</td>
<td>Moderate</td>
<td>Neutral</td>
<td>CS, BOB 01 weak</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2000</td>
<td>13 11 24</td>
<td>Cold (dec)</td>
<td>Weak LaNina</td>
<td>-0.8</td>
<td>Weak</td>
<td>Neutral</td>
<td>CS, BOB 01</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2001</td>
<td>11 7 18</td>
<td>Cold (dec)</td>
<td>La Nada</td>
<td>-0.3</td>
<td>Passive</td>
<td>Neutral</td>
<td>No CDs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2002</td>
<td>14 5 19</td>
<td>Normal (Inc)</td>
<td>Modoki El Nino</td>
<td>0.2</td>
<td>Moderate</td>
<td>Act. MJO</td>
<td>No CDs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2003</td>
<td>12 7 19</td>
<td>Warm (Inc)</td>
<td>La Nada</td>
<td>0.0</td>
<td>Passive</td>
<td>Neutral</td>
<td>DD, BOB 01, DD</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2004</td>
<td>17 9 26</td>
<td>Warm (cons)</td>
<td>Modoki El Nino</td>
<td>0.2</td>
<td>Weak</td>
<td>Neutral</td>
<td>VSCS, BOB 01 B</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2005</td>
<td>19 3 22</td>
<td>Warm (dec)</td>
<td>WeakLaNina</td>
<td>0.4</td>
<td>Weak</td>
<td>Neutral</td>
<td>ESCS, BOB 1,</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2006</td>
<td>18 7 25</td>
<td>Cold (de)</td>
<td>Weak El Nino</td>
<td>-0.3</td>
<td>Weak</td>
<td>PIOD</td>
<td>ESCS, Mal,</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2007</td>
<td>19 11 30</td>
<td>Normal (de)</td>
<td>St. La Nina</td>
<td>-0.2</td>
<td>Strong</td>
<td>Neutral</td>
<td>BOB 01D,CS Akash</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2008</td>
<td>17 7 24</td>
<td>Cold (Inc)</td>
<td>WeakLaNina</td>
<td>-0.9</td>
<td>Weak</td>
<td>Neutral</td>
<td>ESCS, Myanmar</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2009</td>
<td>14 5 19</td>
<td>Normal (In)</td>
<td>ModokiElNino</td>
<td>-0.2</td>
<td>Moderate</td>
<td>Neutral</td>
<td>CS Bjiil, SCS Aila</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2010</td>
<td>14 12 26</td>
<td>Warm (dec)</td>
<td>St. La Nina Mod</td>
<td>0.4</td>
<td>Strong</td>
<td>St. NIOD</td>
<td>SCS Laila</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2011</td>
<td>16 4 20</td>
<td>Cold (In)</td>
<td>Mod La Nina</td>
<td>-0.6</td>
<td>Moderate</td>
<td>Neutral</td>
<td>BOB 1 (D)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2012</td>
<td>10 2 12</td>
<td>Cold (In)</td>
<td>La Nada</td>
<td>-0.4</td>
<td>Passive</td>
<td>PIOD</td>
<td>No CDs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2013</td>
<td>16 13 29</td>
<td>Normal (de)</td>
<td>La Nada</td>
<td>-0.2</td>
<td>Passive</td>
<td>Neutral</td>
<td>CS Viyar, BOB 2D</td>
<td></td>
<td></td>
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<tr>
<td>2014</td>
<td>13 9 22</td>
<td>Normal (In)</td>
<td>Weak El ino</td>
<td>0.1</td>
<td>Weak</td>
<td>NIOD</td>
<td>BOB 1(D), BOB 2D</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2015</td>
<td>21 10 31</td>
<td>Warm (In)</td>
<td>V. st.ElNino, Modoki</td>
<td>0.8</td>
<td>Very St.</td>
<td>PIOD</td>
<td>No CDs Pre-monsoon</td>
<td></td>
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<tr>
<td>2016</td>
<td>15 6 21</td>
<td>Warm (de)</td>
<td>ModokiWeakLa Nina</td>
<td>1.0</td>
<td>Weak</td>
<td>NIOD</td>
<td>CS Roanu,</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2017</td>
<td>16 6 22</td>
<td>Nor (In)</td>
<td>WeakLa Nina</td>
<td>0.3</td>
<td>Weak</td>
<td>Neutral</td>
<td>CS Maruth, SCS Mora</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2018</td>
<td>23 16 39</td>
<td>Cold (In)</td>
<td>WeakELNino</td>
<td>-0.4</td>
<td>Weak</td>
<td>PIOD</td>
<td>BOB 01 (DD)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2019</td>
<td>4 5 9</td>
<td>Warm Const</td>
<td>Weak El ino</td>
<td>0.8</td>
<td>Weak</td>
<td>progress</td>
<td>ESCS Fani</td>
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</table>

The Positive Indian Ocean Dipole (PIOD) along with El Nino Modoki events alters the influence of the cyclogenesis over BOB and AS in comparison to a pure El Nino Modoki year. This cyclogeic circulation is influenced by several coupled ocean-atmospheric phenomena such as El Nino, El Nino Modoki, Indian Ocean Dipole and Madden Julian Oscillation. It may be concluded by observing last 30 years pre monsoon landfall data (1990 to 2019),
that frequencies of CDs in BOB are of increased trend during La-Nina Modoki years than normal La-Ninã years. The frequencies of severe cyclonic storms are more during strong La-Nina years than La-Ninã Modoki years. Over BOB, there is less numbers of CDs during La Nina Modoki years due to less low level convergence, than La-Ninha years. At times strong vertical wind shear and adverse MJO status of BOB, CDs inhibit rapid intensification and give a storm of an unusual tract like Maruth -2017 in BOB during pre-monsoon.

**Discussion and conclusion:**

BOB coast is funnel shaped. The EC India has major six curved pockets at the estuaries, shoreline curves. They are the catastrophic risk zone for land fall of the CDs at the curves. The TCs cause the maximum damage when they reach the northern half of the EC India depending upon intensity and direction of slamming. The host states mostly affected are AP, Orissa, West Bengal, and the country Bangladesh coasts in the periphery. The damages occur due to huge low flat terrain (from the Subarnarekha delta to the Krishna delta), high density of population and structurally unsafe houses. Surprisingly from 1999 onwards the coastal areas from Sirkakulam to Paradeep has been struck by more than 20 cyclonic storms ranging from low to high intensity.

BOB Cyclones travel at speeds of 5 to 10 km/hr at initial stage with wind speed clocking up to 40 km/hr at intensified state and then at reduced speed of @ 20 to 30 km /hr at fag end. A pre-monsoon cyclone follows the direction of the UACYCR current of the cyclones and move NW initially and then curves ENE to ESE direction under climatic strategies. But the trajectories are unique for each storm and never identical. Cyclones are accompanied by heavy rains and storm surges (high under high tides period) causing most of the damage to life and property.

The year, 2018 may be considered as the storm year (14 CDs) for NIO in the first part of 21st century as seven consecutive intensive CDs are formed in NIO. The pre-monsoon CDs above DD are CS Sagar (May 16-20), ESCS Mekunu (May 21-27) and the post monsoon storms were Lumban (Oct 6-15) in AS hitting WCoF India. The other five CDs above CS are Daye (Sept 19th – 22nd, AP coast), VSCS Titili (Oct 8 – 12, Wind speed 150kmph), SCS Gaja (Nov 10-13 slammed TN) and SCS Pethai (Dec 13-18) in NE India. The number of fatalities due to these 14 disturbances on NIO is 343 lives and including financial loss of $4.33 billion. The cyclonic storms account for 76% of fatalities in Asia due to disaster i.e. estimated to be 9.15 lakh. Mortalities were caused by meteorological extremes in Asia and 6.95lakhs are due to TCs (The report–Atlas of Mortality and Economic Losses). The conducive strategies for creation of CDs over NIO basins are ENSO, La Nina, the, boreal summer intra-seasonal oscillation (BSISO) mainly during pre-monsoon. TC genesis and intra seasonal oscillation (ISO) plays important role in pre-monsoon CS formation in BOB and tends to move the system NW-ly. Inter annual variation of genesis potential index (GPI) constructed by Kekkuchi et al, 2010[24], shows that pre-monsoon TC genesis in the year 2007 (one), 2008 (one) and 2009 (2) numbers of CS were formed in BOB when the GPI was strong. The US Govt. has conducted experiments in the Atlantic by spraying silver iodide in the region minimize the high wind speed zone. It was very promising, but remained unsettled fearing diversion of track of storm. The chance that those cyclones change their track and move towards another direction could not be eliminated. The other method tried to prevent the formation and reduce the severity of tropical cyclones is to cover the probable area of sea surface using Nano technology for reducing evaporation. The apprehension of sea surface pollution stopped the experiment to be undertaken. Natural and Anthropogenic signatures due to the tropical cyclone and climate change initiatives were discussed in International Workshop on Tropical Cyclones-VI (IWT-C-VI). The conclusion was abated though the recent increase in societal impact from tropical cyclones is large due to population explosion along coastal areas.

Tropical cyclone wind-speed, place of origin, the trajectory and the zone of slamming coast has changed dramatically over the last few decades leading to difficulties in determining accurate trends of cyclogenesis. The short term and long term multi-decadal variability of tropical cyclones over BOB are yet to be finalized whether solely natural, anthropogenic or amalgamated result of both. Global warming, corresponding MSL rise, PIOD, climate change and increase in SST (AR IPCC 2007, AR IPCC 2014[52]) rather agreed upon but that the frequency of CDs in BOB have not abruptly changed. But the number of intensified storms hitting the east coast has changed the frequencies, uncertain place of impact, place of landfall and intensities.

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