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Pre-Monsoon Cyclogenesis Over Bay of Bengal

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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 noCoriolis 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.

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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 gate 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 coasts 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.

Masato Sugi, 2009[11]. Sumesh et al., 2013[12] mentioned about the simultaneous occurrence of El-Nin˜o 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) over the 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 to7 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.rsmcnewdelhi .imd.gov.in), Hazra A., 2017[16]. The number of cyclones passing different states in the EC of India from 1891 to 2013e 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]. Mallik 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, ENE 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:

About80-90 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 (VSCS) 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.

Bay CDs using Saffir–Simpson scale	Organization	Beaufort scale	Wind speed Kts	Wind speed Kmph	≈Wave ht. (m)	Δ hPa(mbar)	Sea condition
LPA/ WML	IMD (3mnt)	0-4	< 17	<31	<1.5	<4	Calm-mod
Depression(D) Sustained wind	NHC/CPHC/JTWC(1mnt)	5 to7	<32	<59			Mod –rough
	IMD (3minutes)	5 to 6	17 to27	31to 49	0-3	4-6	Mod-rough
	WMO/JMA/MF/BOM /FMS(10mnts)	5 to 7	<28	<52			Mod –rough
Deep depression (DD)	NHC/CPHC/JTWC (1mnt)	7	33–37	61–69			very rough
	IMD (3minutes)	7	28to 33	50to 61	<6m	6-10	very rough
	WMO/JMA/MF/BOM /FMS(10mnts)	7	30-33	56-61			very rough

Cyclonic (CS)/ Tropical storm (TS)	NHC/CPHC/JTWC (1mnt)	9 to 11	38–54	70–101			Mod.- high waves edges of crests break into spin drift; foam blown is seen
	IMD (3minutes)		34-47	62 to 88	<9m	10-15	
	WMO/JMA/MF/BOM /FMS(10mnts)		34–47	62–88			
Severe Cyclonic SCS)/Severe Tropical storm (VTS)	NHC/CPHC/JTWC	11 to 12	55–63	102–117			Exceptional high waves, foams cover and low visibility, Cause wide spread damage
	IMD (3minutes)		48-71	89-118	9-4m	15-20	
	WMO/JMA/MF/BOM /FMS(10mnts)		48–55	89–102			
Very Severe Cyclonic(VSCS) /Severe Tropcal storm (VSTS)	NHC/CPHC/JTWC	>11	72-97	133-180			
	IMD (3minutes)		64 to 90	118 to 167	>14m	20-66	
	WMO/JMA/MF/BOM /FMS(10mnts)		64-85	119-157			
Extreme Severe Cyclonic(ESCS) /Severe Tropcal storm (ESTS)	NHC/CPHC/JTWC		98-129	181-240			Phenomenanal, The air is filled with foam and spray; sea is completely white with driving spray; visibility least, vast devastation
	IMD (3minutes)	12+	91-119	168 to221	>14m	67-79	
	WMO/JMA/MF/BOM /FMS(10mnts)		86-113	159-209			
Super Cyclone(SC) /Super Tropcal storm (VSTS)	NHC/CPHC/JTWC		64-90	>241			
	IMD (3minutes)	12+	>120	>222	>14m	>80	
	WMO/JMA/MF/BOM /FMS(10mnts)		>130	>211			

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, Sources: Chaudhuri et al., 2013[31], Mishra S.P. 2014[30], https://en. Wiki pedia.org/wiki/Tropical cyclone, https://pdfs.semantic scholar.org/bceb/750c4aefb0fb0d5ca753ee3509ef7de32ad3.pdf, Dvorak, V. F., 1975[3]

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 (98numbers) in the decade 1991-2000 and the lowest (38) in the year 1981-1990 (Wiki data updated) Fig -1.

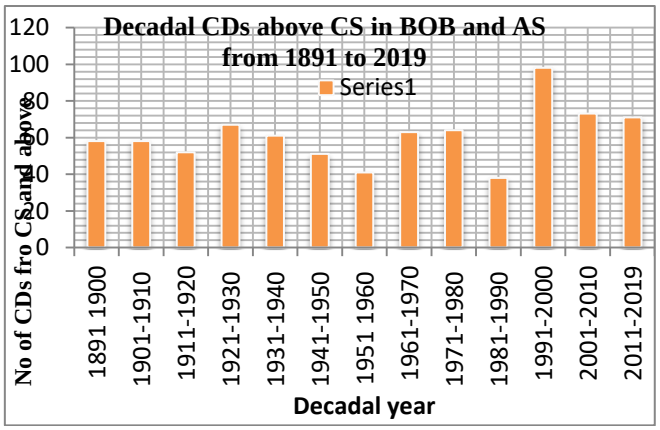

Fig 1: Decadal CDs above CS in BOB and AS (1891 to 2019) (source data: Wiki & IMD)

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.

Historical pre-monsoon storm records:

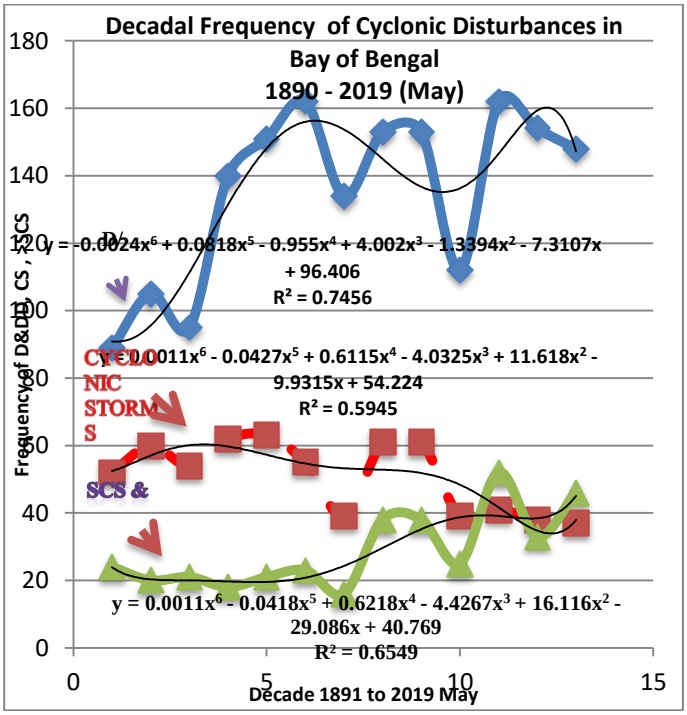

Fig 2: Decadal trend of CDs in BOB (dep. &above) hitting EC India (1891 to 2019)

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

#	Year	Period	Surge/intesity	Place/ types	Damages	Reference
1	SCS, BD	May-June 1797(date NA)	Hurricane wind	Chittagong coast (LF)	All kachha sheds lost. 2 ships sunk Chittagong Port	BD Met.Dept. wikipedia.org/wiki/List_of_BD_tropical_cyclones
2	SCS, BD	May, 1822	NA	(L.F.)Barisal, BD	40000 lives, 1lakh cattle,lost collector records	Jr. of Asiatic SOC., BOB, Vol. 46, Part II, pp 332- H.F. Blandford
3	SCS IND	27th May, 1823	10km, inland. storm surge.	Strong wind. heavy rain	Some ships, villagemissing.	Chhitebabu et al 2004
4	CS BD	2 June 1823	NA	Chittagongcoast	NA	F.Henderson. 1979
5	CS, IND	May, 1833	NA	Balesore dist.	Flooding	Chhitebabu et al 2004
6	SCS, Ind	1834	NA	Odisha coast	wind damage	Chhitebabu et al 2004
	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					
7	SCS, IND	Apr 27–May 1, 1840	vscs	Chilika coast, South of Puri.	Puri, Cuttack &Balasore Dist.	Tripathy S. 2011
8	CS, BD (Gale)	11 May 1844	NA	Chittagong coast	Noakhali and Chittagong coast	By F. Henderson, 1979.
9	CS, BD	12–13 May 1849	NA	Chittagong coast	NA	F. Henderson,1979.
10	SCS	23–28 April, 1850	High surge	False Pt. PDP-DP	Surge in S-RrekhaRiver mouth	Chhitebabu et al 2004
11	SCS	12–15 May1852	NA	63 km, Calcutta(E)	NA	F. Henderson.1979
12	CS	13–17 May 1869	NA	Cape Negrais, Myanmar	crossed the Bengal coast	F. Henderson. 1979
13	CS-	26th May, 1887	0.61 m Surges,False PointJumbo	False Point to Sagar Island	776 drowned.Worst sea tragedy	Chhitebabu et al 2004[39]

https://en.wikipedia.org/wiki/List_of_BD_tropical_cyclones ,Chhitebabu et al 2004, Mishra S. P., 2016

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 aerosol 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 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 ofBOB 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[6].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

#	Name of Cyclone	Date	Death	surge/wind/rain	Details
1	SCS	May 23–26, 1893	NA	Heavy rain over BLS, PRI,CTC,	cyclones in May in the BOB in 25 years,5000 house damaged.
2	SCS, BD storms Barisal SCS	May 1898	Lost: 40000, 100,000 cattle	NA	Hatiya Island, Noakhali; storm wave sweptCollectorate records.
3	Noakhali CS	17-19 May1948	1200	NA	Between Chittagong, 20000 bovines lost&Noakhali; 20,000 cattle lost.
4	East & west Meghana estuary	16-19May, 1958	870 death 14,500 cattle	NA	Barisal (E), Noakhali; crop loss
5	SCS,Bagerhat&Khulna	5th - 9th May1961	11468(Cha Alexander)	2.44-3.05m, 161Kmph,	loss $11.9 bi., cattle: 25000, Rail track Noakhali – HNpur damaged
6	SCS Chittagang	28-29th, May, 1963	11,520 lives and 32,617 cattle lost	4.3-5.2m &max wind 203 km/h	Chittagong, Noakhali, Cox's Bazar, offshore&Sandwip islands,Kutubdia, Hatiya- Maheshkhali affected
7	VSCS Barisal CS 2B	11-12 May 1965	19279	3.7m,/ 162 km/hr	Barisal and Bakerganj most affected,Barisal alone 16,456 people killed.
8	SCS, Bhola	9-12th May, 1975	05 killed,	96.5 to 112.6Kmph	Affected Cox's Bazar and Khulna, fishermen missing
9	CS-1976	Apr 29-May 2,		95Kmph	Between Nellore and Kavali
10	CS Khulna	9-12 May1977	NA	112.63 km/h Chittagong	Affected Khulna, Noakhali, Patua- khali, Barisal, & offshore islands
11	SCS Ongle-Bapatla	05 - 13 May 1979	700 lives, 30000cattles	Fall bet. Ongole&Bapatla	Heavy floods. ≈ 748,000 houses, loss: Rs 242 crore South AP& TN

12	SCS,Chittagang	24-25,May, 1985	11069lives,135033 bovines	3.0-4.6m,154 km/hr	Cox's Bazar, Noakhali and offshore islands affected
13	SCS, Balasore	May 23–27, 1989	24 lives, 1625 cattle killed	139 Km/h,3 to 6 m surges	40 km NE of Balasore.affected – 3.7 million,Houses damaged – 92,000, crops damaged.
14	SuCSMachhli-patnamW-est Godavari	04 - 09 May 1990	967deaths	235Kmph (T 6.5)	Crossed AP Coast about 40 Km S-W of Mach-patnamKrishna Estuary was severely affected
15	Cyclone Sandwip (Chittagong)	25-30 Apr, 1991(T 6.5)	138882people;cattle70000.	235 km/h, urge + tide= 6.1m	The loss of property was estimated at about Tk 60 bi., 139054 injured
16	SuCs (CS 02B), Timemaz.'Gorky'	24 .Apr- May 2nd, 1991(Cat -4 Cyclone,)	138,866 died & 139054 injured.	240Km/h (5m surge) 918)hPambar),	Fall Chitagong: offshore islands of Kutubdia and Sandwip, the lowlands Chittagong to Cox's Bazar.
17	CS BOB 01	May 30 – June 3, 1991	No fatalities	85 km/h, 990hPa	AS GorkyTrackfollowed BOB-01,1991, Relief affected
18	CS BOB 02	May 15-19, 1992	27lives, 19missing	65 km/h (T 6.0)	Rakhine State:433 homes destroyed and 24 boats sunk (Wiki -92)
19	Bangladesh VSCSESCS BOB 2	April 24 - May 2, 1994	285people	230Kmph (T 6.0)940 hPa	Damage $125 million (1994 USD), Areas affected BD, Myanmar
20	Bangla Desh(wiki) ESCS	May 14-20, 1997	1296 died,9663 inured	215 km/h (T 6.0)	Bangladesh, Myanmar and India affected, Landfall –hittagong(Wiki)
21	SCS BOB 1(01B)	May 13-17 1998	35died, 504 injured,	110Km/h,972hPa,surge1.8-3m	Land fall Chittagong. 4000 fisher man missed, 6,000 homes & dented 9945, Oil spill hazard Chittagong,
22	CS BOB 01,	March 27-30, 2000	No advisories	85 km/h / 998 hPa	landfall SE India, bet. Chennai and Pondicherry on April 1
23	VSCS, BOB 01 (01B), Srilanka	May 10 – 20, 2003	254 deaths	140 km/h	floods/landslide SW Sri Lanka,Loss 24750 homes fully/damaged 32426
24	VSCS,BOB 01	May 16 – 19, 2004	236 deaths	157 km/h	Damaged full Rakhine State Loss:$99.2 million USD
25	ESCS, Mala	April 25th-29th , 2006	37 lives	185 km/h ,954hPa	Landed Myanmar's RakhineState,left US$6.7 million
26	CS Akash, BOB 1B -2007	13th -15th May 2007	14 direct, 100missing	85.5Km/h,IMD,988 hPa, T 6.0	Crossed Chittagong coast, loss: $982 million (2007 USD), surge 3 m
27	ESCS, Nargis, Myanmar	May 2nd,2008	84500 lives	215Km/h (3.5 m),962 mbar	53,800 missing, Irrawaddy Delta, southern Yangon
28	CS, BOB Bijli,Trop. Cyclone1B	14-17 April 2009		75Kmph, 996mbar	landfall near Chittagong,BD but weakened to deep depression,
29	SCS:Aila (JTWC: 02B)	May 26-27, 2009	339 total lives	110 km/h, 968 hPa6.m surge	$295.6 million (2009 USD), Affected India, Bangladesh, Sundarban Area
30	SCS (Laila), BOB-1	17-21 May 2010	65people	100Km/h, 986 hPa	Coastal AP affected, Prakasam, Krishna and Guntur districts $117.49 million (2010 USD)
31	Viyar, BoB 01 JTWC(01B), Mahasen	10th to 17th May, 2013	107 total, 6 missing	85Kmph,$5.14million (2013 USD)	At least affected India Myanmar Bangladesh, Crossed BD Coast between Chittagong and Feni
32	CS, Roanu	17-22 May2016	227	85km/h,983 hPa	Crossed BD north of Chittagong
33	CS Marutha	April 15-17th 2017	4 killed in Ir-rawadydivn.	75Km/h and996 hPa	Generated south BOB and landfall near Sandoway in Myanmar
34	SCS Mora,BOB 02	28-31May 2017	31 dead: BD (9)+Myanmar(1) +IND(21)	110 km/h IMD) 978 hPa (mbar)	Moved NNE, Landfall Chittagong coast, loss USD 1.37 billion
35	ESCS, FANI	26Apr -04 May,2019	89 lives (unsettled),	Gusting 205 Km/h, 937 hPa	Crossed North Chilika, deva-stated the coast districts India, Int BD.

Source: https://en.wikipedia.org/wiki/ListofBangladeshtropicalcyclones,https://www.Downtoearth.org.in/news/historically-prone-to-cyclones-42421, https://en.wikipedia.org/ wiki/Cyclone Aila, Statistical Yearbook of Bangladesh (19th edition) 1999 and BD TCs by F. Henderson 1979.IMD reports and statistics from time to time. *Chitte Babu et al 2004[39]*, The above data tells that the numbers of pre-monsoon TCs during great acceleration period of Anthropocene epoch is high both in frequency and intensities.

Temperature: The Western Indian Ocean (WIO) is usually cool, rest areas in IO is reaching SST> 28.0°C during summer. In 20th century, the WIO has heated up immensely and had reached almost isothermal potential to BOB that the warm pool was reduced the regional SST gradient. There was incessant rise of SST by 10C to 20C resulting from global warming (Fig 9c).

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 300C 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 (ΔP) 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 (ΔhPa) 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.

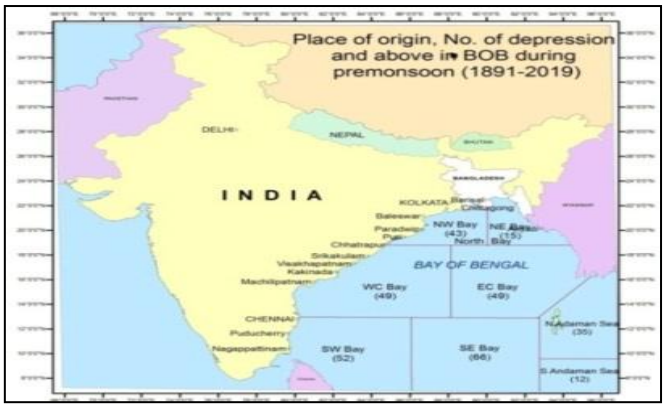

Fig. 3 (a) Freq./place of origin of cyclonic disturbances over the NIO during pre-monsoon season

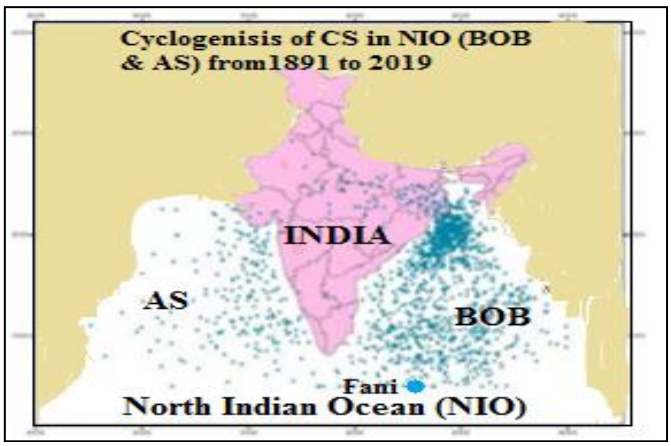

Fig 3(B): Annual formation in NIO (Data source: IMD, 1891 to 2017 updated) Nair et al., 2018 [33],

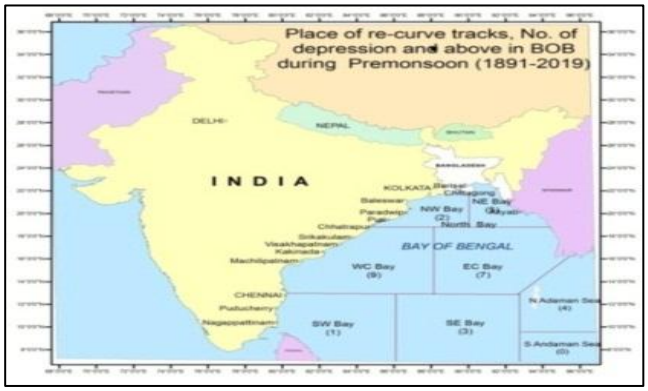

Fig 3(c) Frequency/Places where the cyclones curve over BOB (Source: IMD)

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.

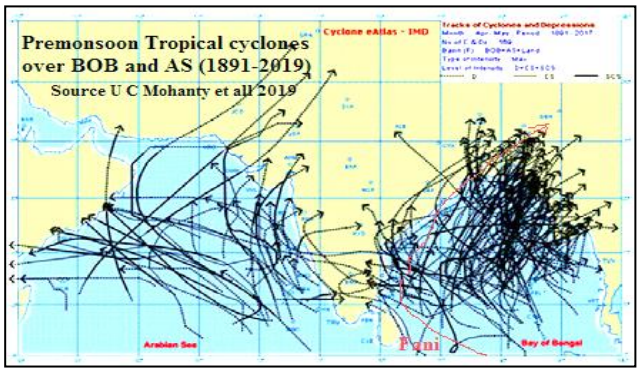

Fig 4 (a): All tracks of CDs during in BOB

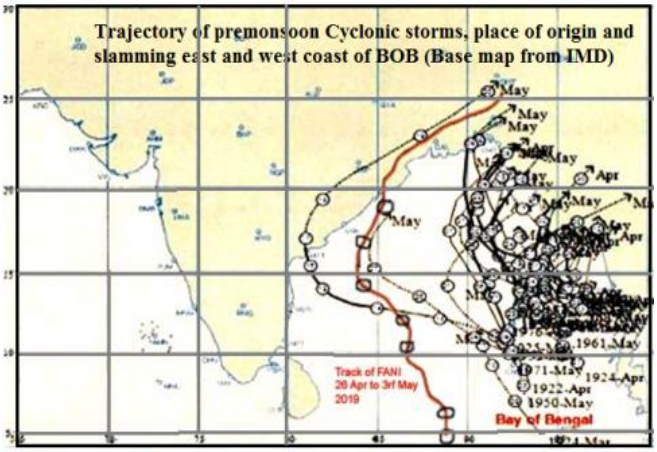

Fig 4(b) NE curvature. (Source: Mohanty U C et al ,2019 & IMD, e- Atlas,)

The Re-curvature:

Re-curvature to the NE or E or SW is common in the track of TCs in the BOB and AS basins during its active lifecycle. The frequency of re-curvature is higher towards the NE compared to SW or E Bay. Frequency of re-curvature is higher in AS cyclones moving north above a limit 15°N Lat. and slams Gujarat coast. But BOB storms during MAM can re-curve at any point mainly NW to NE enroute Fig 3(a), Fig 3(b), and fig 3(c).As per the study Mohapatra M. M. et al 2013[1], only 8 TCs (6 in BOB and 2 in AS) had changed their course en-route out of 33 TCs over NIO basins (2003-2011). Prevalence of mid-lat. trough in westerly's over mid-upper tropospheric level upon Indian landmass prevent the CS entering EC, India, which initiate condition for curving. Huge supply of moisture and thermal energy from the Indian main 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) thttp://www.Rsmcnew delhi.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, SLCD: Slow change in direction, SCD: Sudden change in direction and SMSCD: 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

Date/year	Type of BOB CS & above	Type of track	Landfall/weaken CS	Direction Of curvature	Place of form	Place of land fall/
Mar 27 –30,2000	CS	SM	Landfall	NNE	SE Bay	Chennai
May 10-19, 2003	VSCS	SCD	Land fall	NW–N –NE	SE Bay	West Myanmar
May 16-19, 2004	SCS	SCD	Land fall	NE track	EC Bay	Myanmar(Sittwe)
April 25-29, 2006	VSCS(Mala)	RM	Land fall	N –ly	SE Bay	Myanmar Rakhine
May 13-16, 2007	CS ((Akash)	RM	Land fall	N-ly	EC Bay	BD-Myanmar
Apr 27-3rd May 08	VSCS Nargis	SCD	Land fall	NE-ly	EC Bay	southern Myanmar
April 14-17, 2009	CS Bijli	RM	Land fall	WNW–NE-NW	WC-Bay	Chittagong, BD
May23–26 2009	SCS (Aila)	RM	Landfall	N-ly	EC Bay	SagarIslandWB
May 17-21 2010	SCS (Laila)	SM/SCS	Landfall	NW- NWN	SE Bay	Bapatla, AP Ind
May 10-17, 2013	Viyaru,Mahasen	SM/SLCD	Landfall	NW – NE ly	SE Bay	Chittagong, BD
May 17-22, 2016	CS, Roanu	SCD	Landfall	NE-ENE	SW Bay	BD,Chittagong,
April 15-17,2017	CS Marutha	RM	Landfall	NE	SW Bay	M yan mar coast
May 28-31 2017	SCS Mora,	SLCD	Landfall	E-NNE	SE Bay	BD,Chittagong
Apr 26th -3rd May 2019	ESCS, FANI	SM/SlCD	Landfall	NW-NNW-N-WNW-NNE	Near Equator	Puri, Odisha Ind.

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. 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 astronomical tides significantly add to height of the surge if the cyclone is making landfall during high tide (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 2005had the tide + surge of 13m.East coast delta between150 N upto 250N is well stretched and shallow and wide 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:

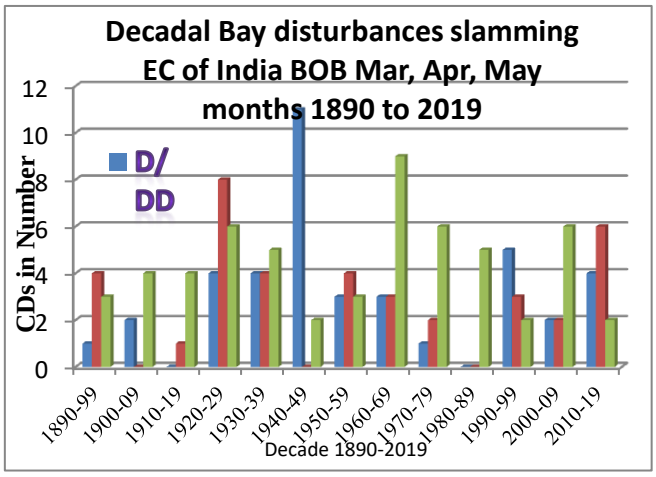

Fig 5; The decadal pre-monsoon bay disturbances over BOB slamming EC India (1891-2019)

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.

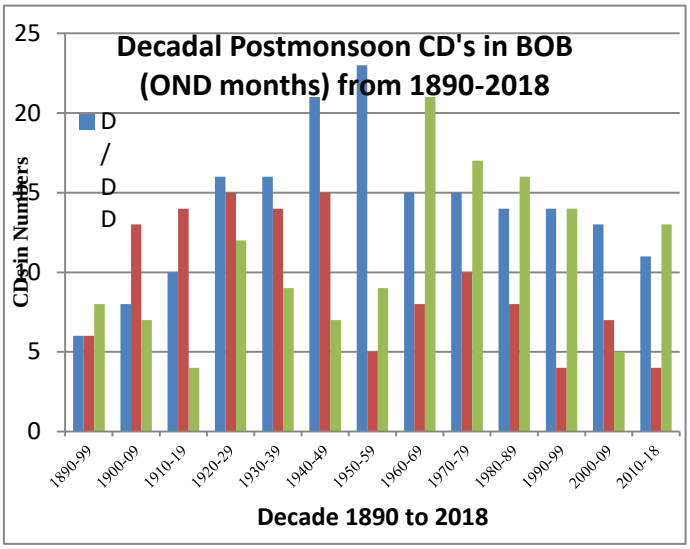

Fig 6; Decadal post-monsoon BOB disturbances in BOB slamming EC India (1891-2019)

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, Srilanka 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,

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.

El Nino's are of two types i.e. traditional El Nino and El Nino Modoki. El Nino is characterized by strong anomalous warming in the eastern equatorial Pacific along the coast of Ecuador and Peru, which inhibits warming by usual cold upwelling and depletion of nutrient rich deep ocean water. El Niño phenomenon occurred in the year 1982–83, 1997–98, 2002–03, 2004–05, 2006–07, 2009–10, 2014–16, and 2019 in recent past. The year 1997-1998 witnessed major ENSO activities there after the years from 2014 to 2016. Strong El Nino years, recorded erratic monsoon onset over Kerala (MOK), setting early or late.

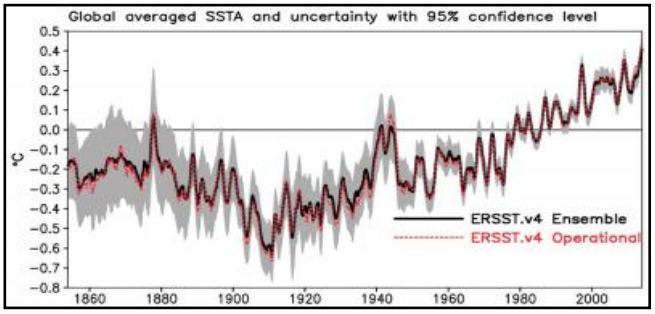

Fig 7: Reconstructed SST data NOAA (https://climatedataguide.ucar.edu/climate-data/sst-data-noaa-extended-reconstruction-ssts-version-4), Huang et al, 2017[46]

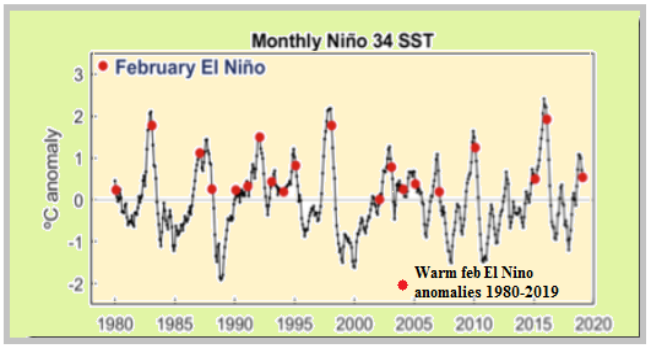

Fig 8: ENSO Time series depicting by monthly Niño 3.4 anomalies from 1980 to February 2019, https://wattsupwiththat.com/2019 /04/09/2019-enso-forecast

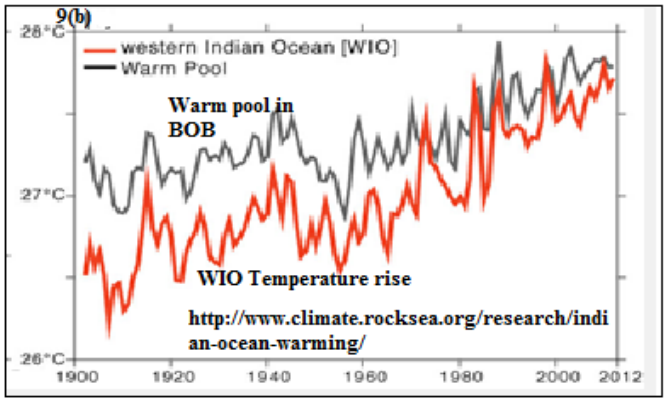

Fig 9: 20th century, WIO warming, reaching the SST of warm pool, BOB, weakening the SST gradient www.climate. Rocksea.org/research/indian-ocean-warming

The El Nino Modoki is a coupled ocean-atmosphere event in the tropical Pacific which is associated with strong anomalous warming in the central tropical Pacific and cooling in the eastern/ western tropical Pacific. El Niño Modoki (a Japanese word meaning a similar but different thing) event favors the initiation of CDs over NIO. The tropical cyclones originate over BOB are more during the

El-Nin˜o Modoki years compared to the only El-Nin˜o years Sumesh K. G., 2013[12].El Nino Modoki event years are identified as 1957–59, 1963–64, 1965–66, 1968–70, 1977–78, 1979–80, 1987/88, 1990/91, 1991/92, 1992/93, 1993/94, 1994/95, 2002/03, 2004/05, and 2009/10. Chunzai Wang et al 2013[47],2019[48].. Recent increase of formation unusual CDs over the NIO basins, can be explained by El Nino Modoki events i.e. due to warm moist conditions in the Central Pacific and dry cold in Eastern and Western pacific.

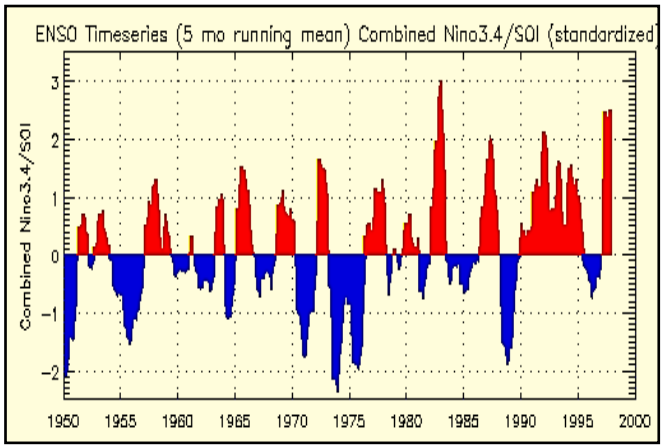

Fig10: ENSO:5-month running mean time series: https://www.esrl.noaa.gov/psd/people/cathy.smith/best/

The Fig-9 indicate the status of ENSO, El Niño in Februaries for 20years (Niño 3.4 > 0°C), based on the NOAA data (+0.5°C) for the period 1980-2019.Judith Curry and Jim Johnstone, CFAN's 2019. ENSO forecasted as there shall be fast cooling in the SE Pacific tropics than in the NE Pacific so that the pre- monsoon-2019 shall be heading to El Niño Modoki signature in 2019. Due to El Nino Modoki event strong divergence over the western Pacific and BOB had the Fani ESCS. El Niño Modoki events reorded during the years : 1914-15, 1923-24, 1940-41, 1941-42, 1963-64, 1968-69, 1977-78, 1979-80, 1987-88, 1990-91, 1991-92, 1992-93, 1993-94, 1994-95, 2002-03, 2004-05, 2009-10 and 2019(Weak), Ashok et al 2007[49], Weng et al 2013[50]http://www.jamstec. go.jp/ frsgc/research/d1/iod/Modoki home.html.en.based on the NOAA data La Nina:In 21st century the remarkable prolonged La Nina prevailed from 2000-2002, back to back, La Nina between 2007-10, strong La Nina from 2010-2012.In La Niña years, the trade winds blows very strong so that the central and eastern Pacific water become cold as happened in the year 1984, 1988-89 (strong La-Nina), 1996, 1998-2000, 2005-06, 2007-08, 2011-12, 2016-17 and 2019 which had favoured 1st recorded SuCS over NIO (SuCS, Paradeep 1998). The observed years with strong La Niña events were 1973–76, 1988–89,1998–2000, 2007-08, 2011–12 and 2017-18.https://www.cpc.ncep.noaa.gov/ products/precip/ CWlink /MJO/enso. shtml. Equatorial Indian Ocean Oscillation [EQUINOO]:TheIndian Ocean Dipole (IOD) (detectedin 1999) is a coupled ocean-atmosphere phenomenon where the SST difference between two poles,the West AS at Mozambique (WIO) and other at south of Indonesia EIOatalong lat. 10°N and 10°S. Equatorial Indian Ocean Oscillation [EQUINOO] is generated due to the swinging of warm water and atmospheric pressure between BOB and AS, found from IO dipole mode Index (DMI).

Fig 11: DMI time series from January 2015 to July 2019,: Source:http://www.bom.gov.au/climate/enso/indices.shtml?bookmark=iod

The PIOD is +ve IOD when, Indian Ocean winds blow from east to west (BOB to AS). It is developed along the equatorial area of NIO from April to May climaxing in October. During negative IOD (NIOD) it results vice versa. The +ve and -ve IOD index 2015-2019 according to Australian weather Dept is in Fig 11. As impact PIOD favour more cyclones in AS whereas NIOD favors more Cyclogenesis in BOB. IOD years are 1960 1961 1963 1964 1972 1974 1981 1982 1983 1989 1992 1994 1996 1997 1998 2006 2010 2012 2014 2015 2016, 2019 http://www.bom.gov. au/climate/iod

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 recurs 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 (<−0.3ONI), 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 Sunders 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:

High water surface area and raised SAT/SST are significant contributing factors for formation and growth of BOB disturbances which occur in summer season only. However fewer disturbances are formed during pre-monsoon as dry and hot air from west obstruct the rise of air and restrict creation of clouds. During the post monsoon period there is no such blocking restrictions and presence of increased water surface area due to rise of SAT/SST which is conducive for formation of very strong TCS (**Table-5**).

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

Year	D+ DD	≥C S	Tot al	Warm/Coldt rend(FMAM J)	El Nino Event	ONI MAM	ENSO events	IOD yrs&type/ MJO	CDs in BOB, Pre-monsoon
1990	17	7	24	Normal(Inc)	La Nada	0.3	Passive	Neutral	SuCS BOB 01 02B)
1991	13	7	20	Warm	St. Nino, Mod	0.5	Strong	Neutral	CS 01A ,CS BOB02
1992	24	11	35	Warm (de)	Lanada, Modoki	1.1	Strong	NIOD	CS BOB01
1993	9	6	15	Warm (Inc)	La Nada	0.7	Strong	Neutral.	No CDs
1994	10	9	19	Normal(Inc)	EL Nino, Mod	0.4	Moderate	PIOD	BOB1B(D),ESCSBOB2,
1995	14	8	22	Warm(dec)	La-Nina	0.1	Strong	Neutral	BOB 01, 02 & 03
1996	18	12	30	Cold(Inc)		-0.3	Passive	NIOD	DD BOB (01B)
1997	16	7	23	Warm(Inc)	V. st. El Nino	0.8	Very st.	PIOD	ESCS BOB 01 01B)
1998	23	15	38	Warm(dec)	St. La Nina	0.5	Strong	NIOD	SCS BOB 01 (01B)
1999	18	14	32	Cold(Inc)	St. La Nina	-1.0	Moderate	Neutral	CS, BOB 01 weak
2000	13	11	24	Cold(dec)	Weak LaNina	-0.8	Weak	Neutral	CS, BOB 01
2001	11	7	18	Cold(dec)	La Nada	-0.3	Passive	Neutral	No CDs
2002	14	5	19	Normal(Inc)	Modoki El Nino	0.2	Moderate	Act. MJO	No CDs
2003	12	7	19	Warm(dec)	La Nada	0.0	Passive	Neutral	DD, BOB 01, DD
2004	17	9	26	Warm(cons)	Modoki El Nino	0.2	Weak	Neutral	VSCS, BOB 01 B
2005	19	3	22	Warm(dec)	WeakLa Nina	0.4	Weak	Neutral	ESCS, BOB 1,
2006	18	7	25	Cold(de)	Weak El Nino	-0.3	Weak	PIOD	ESCS, Mala,
2007	19	11	30	Normal(de)	St. La Nina	-0.2	Strong	Neutral	BOB 01D,CS Akash
2008	17	7	24	Cold(In)	WeakLa Nina	-0.9	Weak	Neutral	ESCS, Myanmar
2009	14	5	19	Normal(In)	ModokiElNino	-0.2	Moderate	Neutral	CS Bijli, SCS Aila
2010	14	12	26	Warm(de)	St.LaNinaMod	0.4	Strong	St. NIOD	SCS Laila
2011	16	4	20	Cold (In)	Mod La Nina	-0.6	Moderate	Neutral	BOB 1 (D)
2012	10	2	12	Cold (In)	La Nada	-0.4	Passive	PIOD	No CDs
2013	16	13	29	Normal (de)	La Nada	-0.2	Passive	Neutral	CS Viyaru, BOB 2D
2014	13	9	22	Normal (In)	Weak El ino	0.1	Weak	NIOD	BOB 1(D), BOB 2D
2015	21	10	31	Warm(In)	V. st.ElNino, Modoki	0.8	Very St.	PIOD	No CDs Pre-monsoon
2016	15	6	21	Warm(de)	ModokiWeakLa Nina	1.0	Weak	NIOD	CS Roanu,
2017	16	6	22	Nor (In)	WeakLa Nina	0.3	Weak	Neutral	CS Maruth, SCS Mora
2018	23	16	39	Cold In)	WeakELNino	-0.4	Weak	PIOD	BOB 01 (DD)
2019	4	5	9	Warm Const	Weak El ino	0.8	Weak	progress	ESCS Fani
	148	83	231						

WE=Weak El Nino, ME=Moderate El Niño, SE=Strong El Niño, VSE=Very Strong El Nino (May 2019 ONI is 1.15)
WL=Weak La Nina, ML=Moderate La Niña, SL=Strong La Niña, ONI: Oceanic Nino Index
Av ONI -=0.8, 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), MAM: March April & May months , St. : Strong, Yr.: Year , In.: increasing, , de: decreasing , Con: constant,

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 cyclonic 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-Ninâ years. The frequencies of severe cyclonic storms are more during strong La-Nina years than La-Ninâ Modoki years. Over BOB, there is less numbers of CDs during La Nina Modoki years due to less low level convergence, than La-Niña 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 curvatures. 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 UACYCIR 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 Luban (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 (IWTC-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]) though 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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