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Fani, an Outlier among Pre-monsoon Intra-Seasonal Cyclones over Bay of Bengal

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ABSTRACT: Bay of Bengal is prone to maximum rate of cyclogenesis of cyclonic disturbances and intensified cyclonic storms. The cyclones in the Bay of Bengal basin are most devastating, causing a large number of fatalities and huge infrastructural and pecuniary losses. The Coastline of Odisha had witnessed major land falls of cyclonic storms in comparison to other coastal states in east coast of Indian peninsula. Pre-monsoon cyclonic storms are rare compared to post monsoon in strength and frequency. The extreme severe cyclonic storm "Fani" has ransacked the Odisha coast causing 43 fatalities from 159 blocks in 14 districts, and huge pecuniary losses amounting to 2417.6 billion INR in spite of war footing precautionary measures. In this paper, the tracks of various intensified pre-monsoon and post-monsoon storms and their impacts are studied. The climatological impact of various dominating systems in Indian Ocean like El-Nino, La-Nina, El Niño-Southern Oscillation, Madden–Julian Oscillation, Indian Ocean Dipole, Boreal Summer Intra-seasonal oscillation are also considered. It is found that the tropical cyclonic storm Fani was distinct amongst the other pre-monsoon cyclones ever recorded in Bay of Bengal (during period 1891 to 2019). The socio economic impact of Fani has taught that instead of conventional approach of relief, rehabilitation and reconstruction (3R), combating storms needs to be added with adequate planning, disaster management, prevention and preparedness.

Keywords: Anthropocene, Bay of Bengal, Cyclonic Storm, East Coast, ENSO, Fani, NIO, Pre-monsoon Cyclones.

I. INTRODUCTION

Temperature and wind anomalies in ocean fabric or inland are called Cyclonic Disturbances (CDs) and their occurrences in the North Indian Ocean (NIO) are regular. NIO has two large Bays, the largest is the Bay of Bengal basin (BoB basin) and the other is the Arabian Sea (AS). The BoB basin brew about 75% of CDs of the NIO, Both the bays brew CDs almost every year and cause widespread damage to its coastal ecosystem either through strong gusty winds (cyclone) or floods due to heavy rainfall in the hinterland. These natural disasters cause heavy loss of lives, trauma, immense impairment to property and infrastructures during landfall. The west coast of BoB basin and east coast of India has four major coastal states i.e. West Bengal (WB, 157.5km), Odisha (476.4km), Andhra Pradesh (AP, 973.7km) and Tamil Nadu (TN & Puducherry, 906.9 km and 30.6 km) along East Coast (EC) of India. Odisha coast is 17% of coastal length of EC, but slammed by ≈44% of tropical cyclones (TCs) of BoB and the worst affected. About 75% cyclonic storms (CS) formed in the North Indian Ocean (NIO) enter BOB and ≈23% to Arabian Sea (AS) and rest dissipate within the sea (1891-2019). The frequency of disturbances in the BOB is more intense than the AS, because of the dry air blowing from the desert of the Middle East, disapprove culminating wind shear to form cyclogenesis. Mohapatra *et al.*, (2013) has reported that the major drivers are stratification, temperature (threshold ≥28ºC), intra seasonal timing, and vertical shear steer CD's in BoB preemptive and forceful in Bay of Bengal basin [1]. India received 317 severe cyclonic storms (SCS) and 73% (230) of it were spawned in the BOB (updated from 1891 to 2019 IMD record) [1]. Tyagi *et al.*, (2009) has reported that the TC's in BoB during pre-monsoon transition period (PMT) in the months March, April and May (MAM) are irregular but slamming east coast (EC) affecting millions of coastal population annually but along Odisha coast is rare (data 1891-2005). The PMT TC's in 21st century has anomalies of slamming at higher frequencies with short span of rainfall (For 2-3 days only) over EC of India particularly over Odisha coast on 3rd May 2019 (Fig. 1) [2].

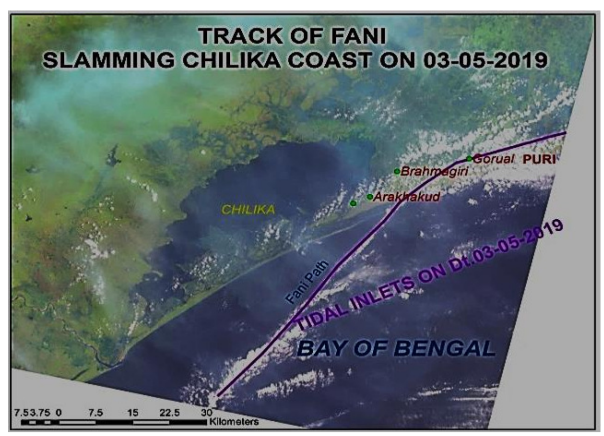

Fig. 1. GIS Fani image, after slam, Chilika Coast, Odisha.

The BOB, a sub-basin of north Indian ocean extends from ~ 5° to ~ 22° N Lat. and ~ 80° to ~ 90° E. Long.. The basin (~2173000 km^2) is enclosed within Thailand, Myanmar, Bangladesh, India and Sri Lanka including underwater 85°E ridges and partially exposed 90°E ridge. Cyclogenesis occur in the BOB mainly from April to November along with the south west (SW) monsoon activities in BoB. Cyclone activities are prominent in the PMT period and then from October to December during post monsoon.

A. Cyclonic storm in BoB

The cyclonic disturbances in Bay of Bengal (BoB) are compartmentalized to 8 categories depending upon wind speed (3mnt average) and fall in central eye pressure. The vulnerable cyclonic storms above 61 kmph and pressure fall in the eye the storm >10mb, wave height within sea from 6 to 9m is considered as cyclonic storm (CS). The CD's and above are categorized in to 5 classes as given in Table 1.

Table 1: The different categories of Cyclonic disturbances classified by India Meteorological Department [22].

Category	Wind speed 3 minutes Av		Pressure Change	Wave Height	Beaufort
	Knots	Km/hr	milli bar (mb)	meter	scale
LPA/WML	<17	<31	<4	<1.5	0-4
Dep. (D)	17-27	31-49	04 to 06	0-3	05 to 06
Deep Dep. (DD)	28-33	50-62	06 to 10	<6	7
Cyclonic Storm (CS)	34 - 47	63- 88	10 to 15	<9	9 to 11
Severe CS (SCS)	48 -71	89 - 118	15 to 20	9 to 14	11 to 12
Very SCS (VSCS)	64 - 90	119 -167	20 to 66	>14	> 11
Extreme SCS (ESCS)	91 - 119	168-221	67 to 79	>14	12 +
Super Cyclone (SuCS)	>120	>222	> 80	> 14	13 +

LPA: Low Pressure Area; WML: Well Marked Low; D: Depression ; DD: Deep Depression; CS: Cyclonic Storm; SCS: Severe Cyclonic Storm; VSCS; Very Severe Cyclonic Storm, ESCS : Extreme Severe Cyclonic Storm and SuCS: Super Cyclonic Storm.

II. REVIEW OF LITERATURE

Dvorak (1975) was the first to classify tropical cyclones (TCs) based on satellite imageries and interpretation of satellite data [3]. The vortices formed in BoB are on cyclonic move WNW ward depending upon the β- effect of the globe (spatial changes of the Coriolis parameter) [4, 5]. The distribution of the tropical cyclones in BoB for the period 1981-2010 indicated that major TCs, originate in the grid 10°–20°N Lat. and 80°–90°E Long. and move west ward [6]. Mohapatra *et al.,* (2013) had tested the track and landfall forecast errors of diverse CSs in BoB that is in conformity with global trend [1]. The rate of growth from CD over BoB is ≈35% of NIO are CS formations, from CDs to CS grow onlyby @ ≈16%, CS to SCS and above develop @ ≈7%. The WG -1 IPCC AR-5 2013 predicted that fewer TC's will generate due to warm climate in tropical oceans but a major number shall intensify to cause catastrophe. Sahoo and Bhaskaran (2015, 2018, 2019) mentioned that the semi enclosure funnel shape of BoB draws the storms and have five times more number of CDs in BoB than AS [7-9]. Hermes *et al*., (2019) have reported that Bay of Bengal (BoB) coasts slam the devastator cyclones of tropics (TCs) during pre and post summer south west (SW) monsoon [10]. Fosu & Wang; Li *et al*., observed that pre-monsoon BoB TC's are influenced by the onset of SW monsoon or under the sway of the Madden Julian Oscillation (MJO), or both, 500- 850-hPa and upper air temperatures or vortices anomalies [11, 12]. Orographic Vortices dissimilarities in peninsular India is structured by Vortex Froud Number (F_v) = V_{max} /NH, where V_{max} = Tangent Velocity of vortex wind (maximum), N= Stratification of atmosphere (Brunt-V¨ais¨al¨a atmospheric frequency of atmosphere). When $F_v > 1$, the orographic barrier is overtopped and $F_v < 1$, the orographic barrier is blocked for few days indicating formation of Low pressure area, clouds and continuous heavy rainfall [13]. The vorticity budget, the moisture budget, GPP (Genesis Potential Parameter) and instability in UA temperature at 500 to 850 hPa and temperature anomaly in SST are the causes for pre-monsoon cyclones in BoB. Neetu *et al*., reported that the influence of trade winds vs. sea surface temperature (SST) interactions over BoB plays vital role in cyclogenesis of CS for intense TCs [14, 15].

III. HISTORY OF PRE-MONSOON CSS IN BOB

The BoB cyclonic storms during PMT period originate within South West Bay and proceed E-ly, ENE-ly or NE-ly but normally tilted enroute and have a trend of landfalls along coasts of WB, BD or Myanmar [16]. But the CS Fani originated near eastern Equatorial Indian Ocean (EIO) and connecting south west (SW) BoB, developed to an extreme severe cyclonic storm (ESCS) and slammed south Odisha coast on 3rd April 2019. The cyclone caused vast devastation in Odisha, WB, BD resulting 89 deaths and financial loss of 2417.6 billion INR (final loss statistics yet to be assessed). The historic intensified CS during PMT, hitting Odisha coast was rarely reported. So it is sensed crucial to study the cyclogenesis of the unique unexpected PMT TC of BOB in North Indian Ocean (NIO) with special reference to ESCS, Fani as one of the tropical cyclone cells from Societal aspect, The storm traveled for 2545.2 km parallel to coast affecting 2417.6 billion INR for Odisha, for which recovery needs 29.32 Billion INR (Under Centre and in alliance with the World Bank (WB), Asian Development Bank (ADB), the United Nations (UN) as per Fani: damage, Loss and Needs Assessment (DLNA) report).

The recorded pre-monsoon TCS over BOB TCs and landfall EC of India 1891-2019 are given in Table 3. The major CDs in MAM months slammed EC of India documented from 1891 to 2019 reveals that out of fourteen, only six of them struck Odisha coast, four along AP coast and two along TN and one over WB coast Fig. 2 (a) (b), (c) and Table 2 and 3.

Table 2: Pre-monsoon cyclones hitting Odisha coast before 1891 (from literature).

S. No.	Name of Cyclone	Date	Death	Surge/wind/ rain/flooding	Details	Source
1.	>SCS (GTCCA)	18th Apr.,1700	NA	>118kmph	Andhra Pradesh, Many ships washed away and one ship driven onshore	Alam & Dominey-Howes (2015) [18]
2.	>SCS (GTCCA)	20th May 1787	20000	>118kmph	Landfall Coringa, Coastal Flooding, India	Alam & Dominey-Howes (2015) [18]
3.	>SCS (GTCCA)	11th May,1811	NA	>118kmph, 1.83m,	TN, India,6.43km inland storm surge	Alam & Dominey-Howes (2015) [18]
4.	>CS (GTCCA)	8th May, 1820	NA	62–117kmph,	Land fall, Nellore , Heavy inundation	Alam & Dominey-Howes (2015) [18]
5.	>SCS (BLS)	27Th May 1823	NA	High surge (10km inland, wind & rain	Flooded 10km inland, >118 km/h, shipsa village washed	Chittibabu *et al.*, (2004) [17]
6.	>CS,	May,1833	NA	Hefty rain, 62–117kmph,flood	Balasore dist. affected	Alam & Dominey-Howes (2015) [18]
7.	SCS	May,1834	NA	Strong wind	No flooding	Alam & Dominey-Howes (2015) [18]
8.	>CS	27th Apr-1st May, 1840	NA	62–117kmph Slam med south Puri	Puri, Cuttack, & BLS Districts flooding	Chittibabu *et al.*, (2004) [17]
9.	CS	May, 1841	NA	62–117kmph,	Slammed Chennei coast	Alam & Dominey-Howes (2015) [18]
10.	CS	2ndMay,1843	NA	62–117kmph,	Hit Ongole, flooding up to Garden house, MDS	Alam & Dominey-Howes (2015) [18]
11.	>CS	Apr.,1850	NA	Bet. False Pt. & Digha	surge at the mouth of Subarnarekha River.	Chittibabu *et al.*, (2004) [17]
12.	>CS	28th May, 1887	776 deaths	0.61m surge over high tide	Slam False Pt. , Coastal Flood upto 3.25 km	Chittibabu *et al.*, (2004) [17]

Fig. 2 (a): Pre-monsoon CS tracks in BoB (2000-2019) Source IMD modified.

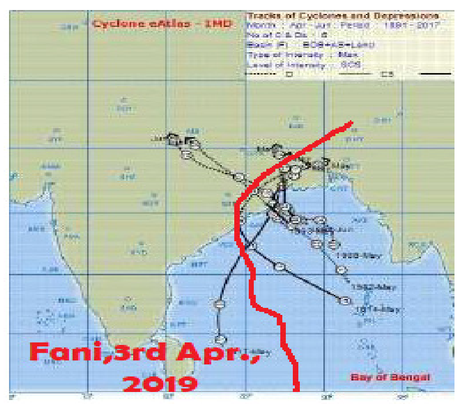

Fig. 2 (b): The pre-monsoon CS tracks land falling Odisha coast, Source IMD (revised).

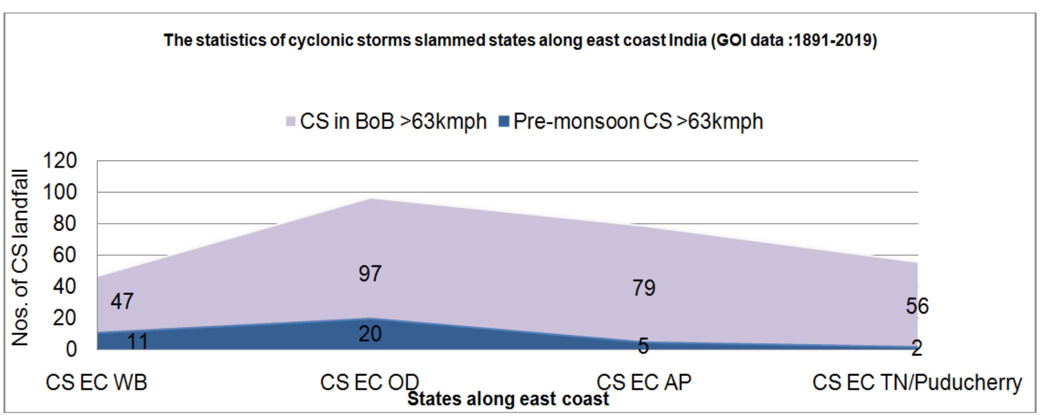

Fig. 2 (c) The numbers of cyclonic storms total and pre-monsoon days slam east coast of India: Data: GOI.

Table 3: The recorded pre-monsoon TCS over BOB TCs and landfall EC of India 1891-2019.

S. No.	Type of Cyclone	Growth period	Death	Surge/wind/rain/flooding	Information
1.	SCS	May 23rd –26th ,1893	N.A. (Odisha)	Heavy rain in BLS ,PRI, TC,	5K houses damaged.
2.	SCS	May 28th, 1904	N.A.	95Km/h	NA
3.	SCS	May 13-17,1910	N.A. (Odisha)	95Km/h, XX rain/ flooding	Crossed the coast near GPL.
4.	>CS	17th May, 1914,	NA(Odisha)	62–117kmph,	Slammed near Gopalpur.
5.	>CS	23rd May, 1943	NA(Chennai)	62–117kmph (TN)	Crossed 96Km south MDS
6.	CS-1976	Apr 29-2nd May	(Andhra Pr.)	95kmph (AP)	Between Nellore & Kavali
7.	SCS -1979	05 - 13 May 1979	700 lives, 30000cattles	Slam. Ongole (Bapatla) (AP)& TN	High floods. ≈ 748,000 homes lost: Rs 242 crore,
8.	SCS	30th May 1982	140 deaths	106kmph, (PDP)	500K homes affected
9.	SCS, -1989	23rd –27th May, 1989(Odisha)	24 lives, 1625 cattle killed ,	139 km/h,3 to 6 m surges	40 km NE of BLS, affected 3.7 million, Houses damaged – 92,000, crops damaged.
10.	SuCS West Godavari	04th - 09th May 1990	967dead (AP)	235kmph (T 6.5)	Crossed AP Coast about 40 Km S-W of MPT, Krishna mouth sternly affected
11.	CS BOB 01,JTWC	Mar 27-30, 2000	Dissipated later grew	85 kmph & Pre: 998 hPa, (TN)	Hit between Chennai and Pondicherry on April 1
12.	SCS: Aila (JTWC:02B)	May 26-27, 2009 hit Sagar Island	339 lives, 51 Lakh affected	110 kmph, 968 hPa & 6.m surge (WB)	$295.6 million (2009 USD), India (149lives), BD (190lives), Sundarban Area
13.	SCS(Laila), BOB-1	17th -21st May 2010	65 deaths (AP)	100km/h, 986 hPa	Krishna, Prakasam,and Guntur districts AP, $117.49 million (2010 USD)
14.	ESCS, FANI	26Apr -04 May,2019	96lives (unsettled),	Gusting 205 Km/h, 937 hPa (Odisha)	hit North Chilika, upset the coast districts India, Int BD.
NA: Not available, BoB: Bay of Bengal, ESCS: Extreme Cyclonic storm, BD: Bangladesh, BLS: Balesore, SCS:Severe cyclonic storms, PDP: Paradip, MPT: Machhalipatnam					

Source: https://en.wikipedia.org/wiki/, Chittibabu *et al.*, (2004) [17], Mishra *et al.*, (2019) [19], Alam & Dominey-Howes (2015) [18]

A. Landfall statistics of EC India

Normally the pre-monsoon CDs in BOB initially move NW-ly, gradually curve en route and slam the coasts of WB, BD, or Myanmar and occasionally few of them hit below 24º Lat ordinarily WB, Odisha and north AP coast. The Slamming of major CDs in BOB during monsoon months is along Kolkata to VSK coast. The landfall of post monsoon CDs generally occur all along the EC of India. The SuCS (WS>220Km/hr) and land fall along EC of India from 1965 to 2019 are in the pre-monsoon months of Apr (1No,1991), May (2No., 1990, 2019), monsoon months (1No, 2007) and Post monsoon months i.e. Oct (1No., 1999) and November (2nos, 1977 & 1988). Likewise the SCS in BoB slamming EC of India during pre-monsoon months between 1965 to 2019 are in April (2 nos,1966 &1977), May (7nos,1976, 1979, 1982, 1989, 2009, 2010, 2017) The coastwise landfall of CS in MAM months are in Table 4.

The state of Odisha had experienced 20 pre-monsoon TCs during1891-2019 out of which six times in the month of May in past (1893, 1910, 1914, 1982, 1989, and 2019). The list of cyclones affecting different states are WB (69), Odisha (101), AP (88) and TN (59) between 1891 -2019 IMD data updated, which has made Odisha as the nation's capital of disaster, (https://ncrmp.gov.in/cyclones-their-impact-in-india/). Odisha coast had multiple land fall in a year and the statistics of the TC's slamming Odisha coast from 1891-2019 is in Table 4. The coastal districts that received land fall of TCs of BOB of Odisha between1891 to 2019 were Balasore (32), Jagatsinghpur & Kendrapada (32), Puri (20) and Ganjam (17) between 1891 and 2002. The north AP coasts have higher statistics of landfall of TC's but they cause catastrophe in coastal Odisha like Hudhud in 2014 and Titil in 2018 Table 5.

Table 4: The state wise numbers of Trop. Cyclones land falling EC India studied by different researchers.

Name of state	Nos TCs	Nos(CDs)	The Nos TCs	Pre-monsoon	Mar-Oct	Nos of TCs	TCs (pre-monsoon)
Source	Sikka-2006	IMD	Mishra. A.2014	Sahoo B P et al 2015		Present study (Updated GOI data)	
Period(Year)	1981 -96	1891-2010	1891-2013	1970-2012	1970-2012	1891-2019	1970-2019
WB	05	152	69	9	29	47	11
Odisha	04	456	104	19	46	97	20
AP	08	133	83	5	36	79	5
TamilNadu	05	138	62	1	30	56	2
EC Ind (total)	22	879	302	34	141	279	38

Sources: http://www.rmcchennaieatlas.tn.nic.in; Mishra (2014 updated) [21]; http://www.cwcvsk.gov.in/; Sikka (2006) [20] ; Sahoo & Bhaskaran (2015) [7]; Mishra *et al.*, (2019) [19].

Table 5: Number of multiple TCs that slam Odisha coast during March to Dec year 1891-2019.

S. No.	Nos of CS and >SCS hit Odisha coast/ year	Minimum CS(>34Kts)	Min one time SCS& above	Remarks/Source
1.	4 times TC, in a year	3 No. (1893)	1No(1893)	https://community.data.gov.in/year-wise-cyclones-34-knots-or-more-hit-to-odisha-east-coast-during-1891-to-2017/ One ESCS and one SuCs in the year (OND), Oct., 1999
2.	3 times TC, in a year	5 years (1892,1894,1900,1912,1943)	1time/yr(1892,1900,1912)	
3.	2 times TC, in a year (One SCS and Above , Other CS)	16 yrs (1891, 1909,1910, 1914, 1936 ,1944, 1968, 1971, 1972, 1973, 1979, 1982, 1984, 1985, 1989 & 2013	1891, 1909, 1910,1914, 1936, 1944, 1968,1971, 1972, 1973, 1979,1982, 1984, 1985, 1989 & 2013>SCS/year	
4.	1 times TC, in a year	98years	22years	
5.	Pre-mon TC (1970-2019)	20 Nos	1 Number	

B. Forecast Comparison with Fani

Initially the CS, Fani was predicted to landfall TN coast but latter to different places along AP coast and finally crossed north Chilika coast. The bending of the trajectory of the CS Fani westwards adjacent to TN coast may be due to the high pressure area developed over the Vidarva, MP and Gujarat towards end of April 2019. The CDs of the BoB usually instigate in northern fringe of SE or SW Bay above 8 to 10ºN, whereas Fani, formed in the vicinity to the Equator, around 2.7º N lat., below and close to the Sri Lankan landmass after 2005, Fig. 3 (a) & (b).

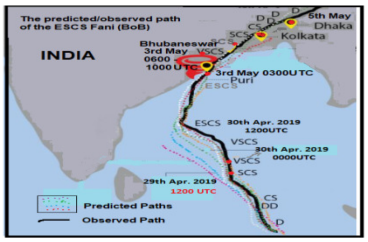

Fig. 3 (a) The predicted/ bserved track of Fani.

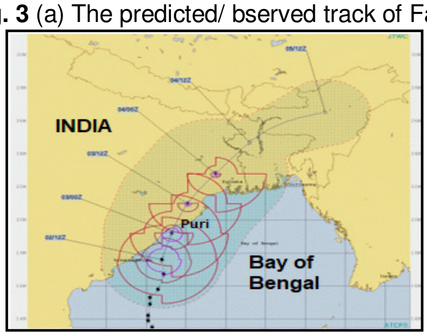

Fig. 3 (b) TC 01B (Fani) track of Joint Typhoon warning Center, 2nd May , 1500 UTC, WTIO-31, PGTW 021500 GMT.

The trajectory of the ESCS Fani was close to the coast line of southern India (in WC Bay) till it slammed south of Puri at 20ºN almost moving in a northerly direction.

IV. THE LIFE CYCLE OF ESCS FANI-2019

IMD and Ministry of Earth Sciences (MOES) jointly reported about favorable atmospheric conditions for formation of bay disturbance (LOPAR) covering south BOB and Indian Ocean near equator on 21st April 2019. They observed the LOPAR developed to a well-marked LOPAR on 25th Apr. 2019 and forecasted about its development as a VSCS. The disturbance concentrated into a depression on 26th instant and further intensified into a DD on 27th Apr. 2019.

Later at 1130IST (270600GMT), it intensified to a CS and titled as FANI when at EIO and adjoining SE BoB. The NIOT (National Institute of Ocean Technology), Chennai employed buoys in the BOB and the Arabian Sea to keep watch over the development of the LOPAR to depression, deep depression and finally the CS FANI, a Category 4 TC based on the Saffir-Simpson Hurricane Wind Scale. At CS stage FANI was an eye of 16 NM round, symmetrical eye surrounded by deep convection (JTWC). The ESCS over WC BoB traversed NNE-ly and slammed Odisha near north of Chilika coast with 3mnts averaged MSWS of 185 kmph gusting to 205 Km/h at around 0830Hrs IST on 03rd May, 2019. Latter weakened to a VSCS at 1130 hrs AM, 2019 and was near 20.2°N Lat and 85.9°E Long., near east of Bhubaneswar (Odisha) and ransacked the Puri to Cuttack and weakened further (Fig. 4). Details are in Table 6.

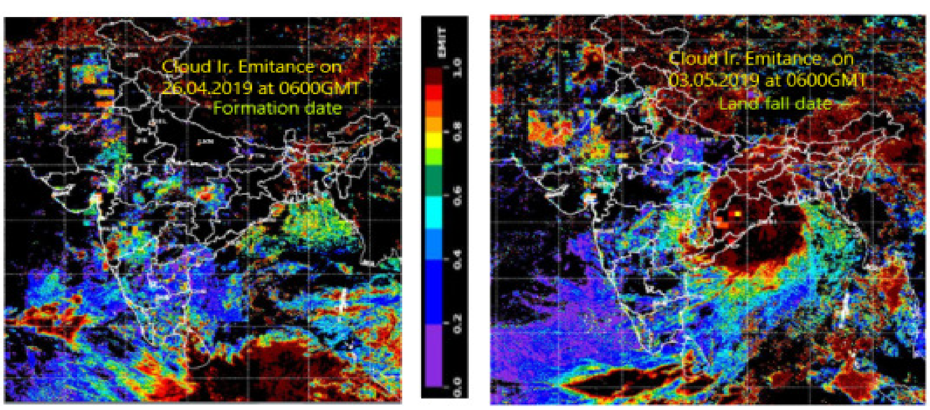

Fig. 4. 0600GMT: Cloud irradiation emitance on Formation date 26th Apr and on 3rd may 2019, (Slam date) (source: ISRO).

Table 6: The track /other factors of ESCS, Fani formed over BoB, 26th Apr-04th May 2019: IMD [22].

Date	UTC	Eye of the CD		SWS (3mnts)	Central Pressure	Pressure drop	Type of CS
		lat. ºN	long ºE	km/h	(hPa)	(hPa)	
26th Apr.2019	0300	2.7	89.7	46.3	998	04	Dep^{n}
27th Apr 2019	0000	4.5	88.8	55.6	997	05	Deep Depn
	0600	5.2	88.6	65	995	07	Cyclonic storm
28th Apr. 2019	0300	7.3	87.9	83	992	10	CS Sluggish
29th Apr. 2019	0300	8.7	86.9	83	992	10	CS Sluggish
	1200	10.1	86.7	102	986	16	SCS (grew fast)
30th Apr. 2019	0000	11.7	86.5	120	980	22	VSCS(grew fast)
	1200	13.3	84.7	167	962	40	ESCS(grew fast)
1st May 2019	0300	14.1	83.9	176	957	45	ESCS
2nd May 2019	0300	16.2	84.6	195	945	55	ESCS (fast move)
	1800	18.2	85.0	213	934	66	ESCS (fast move)
3rd May 2019	0230- 0400	19.6	85.7	213-185	950	50	ESCS (LANDFALL)
	0600	20.2	85.9	157	952	46	VSCS (Weakened)
	1500	21.5	86.7	111	980	18	SCS (Weakened)
4th Apr. 2019	0000	23.1	88.2	74	994	08	CS
	0300	23.6	88.8	56	996	06	DD
	0600	24.3	89.3	46	998	05	D
	1200	weakened to Well marked low over Assam					

A. Forecasts from Meteorological Dept.

Fani was associated with prevalence of Madden–Julian Oscillation (MJO) from west to east over BoB along with moderate El Nino, in the Equatorial Indian Ocean (EIO), (The Australian Bureau of Meteorology. Business line Agri-Business, Hindu 22nd April, 2019). The upper air was loaded with moisture, thunder clouds and rainfall. The Vidharva, MP and Rajasthan area in peninsular India was under prevalence of heat wave conditions. The weather tracker of the Climate Prediction Centre (CPC, USA) predicted about movement of the low clouds in troposphere moving east along the path of MJO wave inducing formation of CD. The prediction of the ESCS track had flummoxed the meteorologists as the path was initially deviated from the actual forecasted track. The OLR phase diagram, the anomalies and the MJO phase diagram was favorable for formation of CD in BoB is given Fig. 4.

(a) **Storm Surge:** The storm surge of 1.5m above height was expected in the coastal areas of Odisha to inundate the large low lying areas of Chilika Lagoon with creation of multiple tidal inlets. The concave and convex curvature of the coast line from Chilika coast to Balasore Coast, is conducive for high stellar tides, inundation of thickly populated coastal areas, cyclogenesis and falls in regular tracks of the TCs form in the BoB [23-26].

(b) **Geomorphological coastal changes:** There is always relation between opening of tidal inlets (TI's) in Chilika lagoon and cyclonic storms in BoB [27, 28]. Chilika lagoon was one of the most affected areas laid under the track of Fani. Two new tidal inlets (TI) were opened up in to the outer channel due to the Aeolian and upsurges developed during slamming of the ESCS. The increase in the TIs shall make the lagoon restricted and average salinity shall increase which shall affect its varying ecosystem in its various sectors. It was observed from satellite imageries (13th Feb. 2019) that there were two tidal inlets in the outer channel one near Arakhakuda and the 2nd was farther north. But as an impact of the ESCS Fani, there are four TI's opened up one left and the other right of the 2nd northern inlet (Fig. 5 (a) & (b) [28].

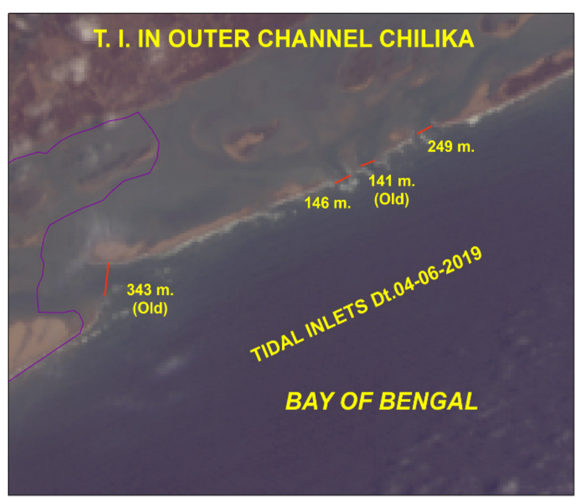

Fig. 5 (a) The 2 TI's in Chilika before the TC Fani (dt.4.2.2019) (b) The 4 TI's in the same outer channel on 4.6.2019.

(c) **Cyclogenesis of Fani:** The AIRS (Atmospheric Infrared Sounder or instrument) of NASA's Aqua satellite observed the cloud top temperatures by infrared light and reported about an intense thunder storms as cold as or colder than -5.30 C revolving with a large band towards east of the center on 30th April morning with clouded eye but curved bands of thunderstorms wrapping into the eye as initiative. ISRO'S MOSDAC has employed a Sun synchronous satellite named SARAL-Altika to study the Oceanic water level and the direction of current from 2013. The Sea surface patterns from the ISRO"S MOSDAC data exhibit different current patterns over Bay of Bengal pre and fag end of land fall of the storm hitting Odisha coast on 02.05.2019 in Fig. 6 (a) and (b).

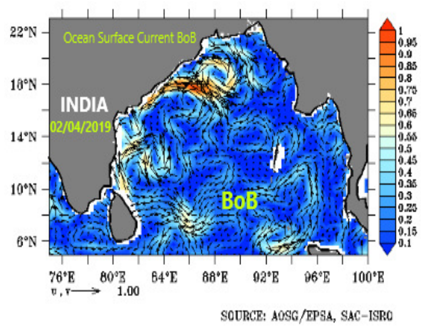

Fig. 6 (a): The ocean surface current on 02-04-2019.

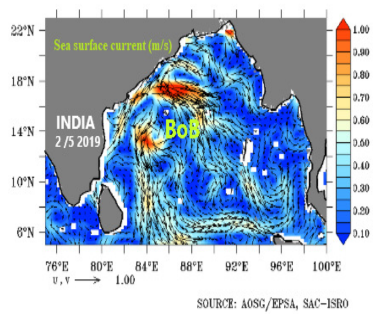

Fig. 6 (b) on 02.05.2019 (Before and after land fall Fani).

On the verge of land fall the ocean current has increased and the ocean current circulation is clearly marked whereas the ocean current pattern shows diverging throughout the Bay of Bengal.

B. Similar pre-monsoon CS's Tracks and FANI

Cyclones of MAM months in NIO/BoB are usually feebler than post monsoon months (O, N & D months). Only 36 instances of a "severe cyclonic storms" had formed in the BOB region in pre-monsoon since 1891 as per record of IMD. The only one among them was formed in 1956 that slammed east coast.

The rest 35 SCS's, swerved northeast to hit Bangladesh, Myanmar in the SE Asian region. The pre-monsoon cyclones Gorky (1991) and Roanu (2016) were parallel to ESCS Fani that devastated BD and Myanmar during landfall. The MAM month's climatological tracks of the TCs from 1891to 2019 are presented in Fig. 7. Major tracks exhibit NW-ly movement and passing TN coast whereas rest 50% moved NNE/NE-ly. Among the pre-monsoon CS systems, only three re-curved northeastwards, 2 dissipated over the sea and only 1 crossed West Bengal adjoining BD coast. The best track of Fani was unique moving part within BOB and rest a little away from the coast and curving NE-wards heading BD coast but having landfall at Puri.

Generally BOB disturbances originate in SE, East central or North Andaman Sea during months of May and move NW-ly. Generally CS of BoB extends rainfall for 3 to 4 days even more but the Fani has given rainfall for only 48 hours as if it was laden with energy but lack of moisture.

Thereafter the land fall generally occurs either along AP coast or taking a turn to hit Ganga-Brahmaputra delta. In pre-monsoon tropical storm cases they take parabolic turn to slam Myanmar coast. Fani was an exceptional case i.e. after formation it headed northerly direction with intermittent tilts Fig. 7 and Table 7.

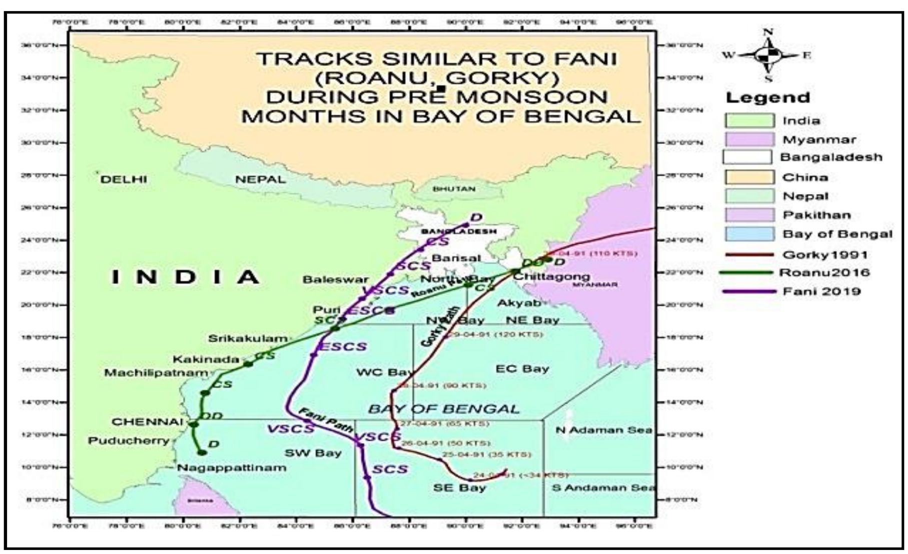

Fig. 7. Three parallel tracks of pre-monsoon CS in BOB.

According to NOAA the forward speed of tropical cyclones 0-5 deg N, 5-10 deg N, 10-15 deg N, 15-20 deg N and 20 to 25 deg N were 25.9Km/h, 22.0, 19.2, 17.4 and 17.5 Km/h respectively (https:// www.aoml.noaa.gov/hrd/ tcfaq/G16.html). But in case of Fani the forward speed of the ESCS was always within 11-18 Kmph which was very sluggish but towards the end it was increased to 24-25Km/h. So Fani could gather momentum, moisture and energy and was intensified during its sluggish period.

The PMT storms trajectories over BOB are generally smooth and normally take a kink at 10-15º Latitude. In case of ESCS, Fani, the initial course was veered and squirting by changing path intermittently on 28th, 29th April and on 1st May forced meteorologist to change their forecast.

The ESCS, Fani had travelled with a slow moving system from beginning but the progress became very fast during land fall. The ESCS was traversing under favorable weather conditions i.e. SST was in the range of 30°C to 32°C and low vertical wind shear.

MJO (Madden–Julian oscillation) was maintaining a long time and good amplitude. The tropospheric cloud pattern was favorable and sluggish movement of the ESCS Fani made it vicious to be apocalyptic to the environment and ecosystem (29th April, 2019 12:03 PM | Skymet Weather Fig. 8(a), (b) and (c).

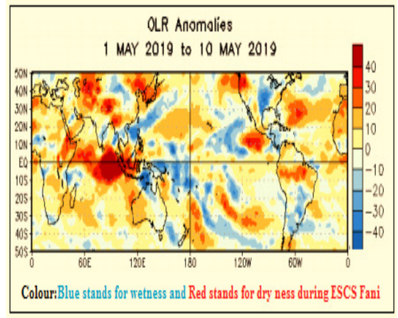

Fig. 8 (a) Outgoing longwave radiation (OLR) anomalies, 1st May to 10th May 2019.

Table 7: Difference in Physiognomies of Pre-monsoon similar Storms Gorky1991, ROANU 2016 and FANI 2019 over BOB all running parallel to East coast of India (IMD and Wiki reports).

S. No.	Physiognomies	SuCS BOB (TC 02B)1991(Gorky)	ROANU BOB 2016	FANI BOB 2019	Dissimilarity
1.	CD category	SuCS (T-5)	Cs	ESCS (T-5)	All dif. category.
2.	Span/place	Apr. 24- May 2nd, 1991, EIO& West Andaman Sea≈	17-22 May2016 SW BOB	25thAp -3rd May 2019, EIO adj SE Bay2.7^{0}N & 88.7^{0}E	1st two mid-May /Fani in late May
3.	Hrs of life depn-landfall	103hrs	126hrs	204hrs, Puri,	Average134 hours for VSCS/ESCS type
4.	Length of travel (Km)	≈ 2750Km	≈(2300Km)	≈(3030Km)very slow	Fani very slow than other two
5.	Place of Origin	SE BOB, near Andaman sea	SW BOB & adj. Sri Lanka	EIO & adj. SW Bay	Roanu near Srilanka coast,
6.	Lat& Long	10.0^0 E/ 91.35ºN	(11.0^0 E/91.0^0 N)	(2.7^0 E/ 89.7^{0}N)	Fani formed in unexpected place,
7.	LPA to depn	≈12hrs	03 UTC 14th May to 03 UTC 17th	Apr 25th at 00 UTC to 26th 03UTC	Fani intensified faster than Roanu
8.	Depn to CS	Depn ≈30hrs, DD -≈21hours 24th (IMD)	03 UTC17th to 00 UTC 19th (45hrs)	26th 03UTC 06UTC 27th (27hrs)	Fani intensified faster than Gorky &Roanu
9.	CS to SCS	≈54hrs 25th to 27th	Static as CS ≈42hrs hit BD coast	06UTC 27th to 09UTC 29th (54hrs)	Slowest growth is of Fani
10.	SCS TO VSCS	≈24hrs(27th to 28th)	Weaken inland BD as depression	09UTC 29th to 00 UTC30th(15hrs)	Fastest growth
11.	VSCS to ESCS	From 28th to 29thESCS & 29th to 30th as SuCS	Weakened	12UTC 30th to 03UTC 3rd (63hrs)	Slowest growth of Fani
12.	Start to slam Track: close to coast	Kept distance from coast	Close to coast all through	Initially at distance & then moved close to coast	Fani was less close to landmass
13.	IMD 3mnts av windspeed	235 km/h	84km/h	115Kts =m213Km/h	Fani has persisted this wind speed for 2hours
14.	Maxm Pres- sure drop	918 millibar, ΔhPa = 36mbar.	983millibar, ΔhPa = 45mbar.	932 millibar ΔhPa = 66mbar.	Pressure drop & wind speed Fani is ESCS
15.	External subsystem influenced	Large subtropical ridge over Thai land, turned N-ward	land interaction and large scale diurnal variation	Damage was more for effect of upper tropospheric westerly trough lying west of system.	Damage was more for effect of upper tropospheric westerly trough lying west of system.
16.	Close to EC coast	Never close to coast within the mid Bay	ESE,Chennai 50km on18th, 68 kmESE-MPT,19th,35km S of KPT ,40 km SE PDP & 70 km SSE Sag-Island on 21st	Last stretch when strengthened to ESCS was coase to coast	After fani dead fishes found floating in rivers and channels
17.	Special characteristics	Not calculated	Cross equator inflow warm & moist air sustained converging about the system	Velocity Flux, 203 kts, Added Cyclone energy 16.72 × 10^4 knots &PDI were, & 15.12 ×10^6kts	Long period av. (1990-2013) of 5.28 ×10^2 knots, 8.6 × 10^4 knots & and 2.8 ×10^6 kts respectively

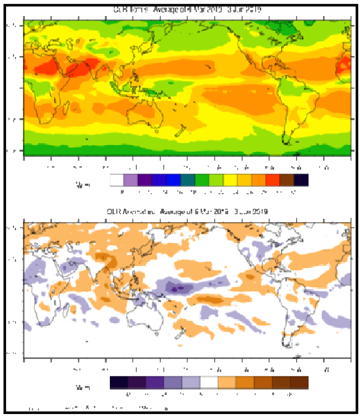

Fig. 8 (b) Global maps of OLR of same period.

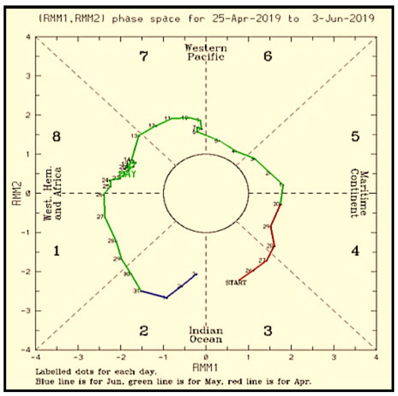

Fig. 8 (c) MJO Phase diagram (25^{th} Apr to 3^{rd} June, 2019), Source: http:// www.bom.gov.au/climate/mjo

C. Fani: the outlier to Odisha coast

Fani initialized near equatorial zone (near 2.7ºN and 88.7ºE) which was rarest point of formation (after 2005) and 2^{nd} of the type after 1891. The CS, Fani is the most intense pre-monsoon CS recorded after 31^{st} May-05^{th} June, 1982 crossing Paradip coast, Odisha during the month of May & April. Phailin was the another intense cyclone after SuCS-1999 crossed Odisha coast on 14^{th} Oct 2013 during 21^{st} century to cross near Chilika Coast. The life span of the CS from depression to land fall are generally 4days, whereas Fani, as the pre-monsoon CS was in sea for 134 hours (5 days & 14 hrs). The ESCS Fani had travelled the longest path (~ 3030KM) before slamming north Chilika coast, Odisha particularly in the month of April which is unique.

Contrasting other storms, its trajectory was zigzag till it intensified to ESCS. The course was clockwise NNW direction instead of anticlockwise turns (NNE direction) during pre-monsoon. The travel of the CS with rapid strengthening in BoB was erratic and became sluggish (14.7 km/h) for VSCS and towards the summit before land fall it was very fast (24Km/h) contradicting the track forecast of IMD. The maximum pressure drop and MSW at the eye it was about 934 hPa and 213Km/h in WC Bay which is rare in the month of May. Generally the CS in BoB weakens only after slamming the coast but Fani had started weakening after 6hours. Fani maintained its strength for about 6hours as VSCS after landfall and destroyed the capital city Bhubaneswar.

V. DISCUSSION

Mayotte islands, near Madagascar in Comoro archipelago, got a seismic hum (1800 earth quakes of magnitude 3-5) associated with continuous tremors from May 2018 (https://www.national geographic.com/ science/2019/05/strange-waves-rippled-around-earth-may-know-why). The low-frequency rumble ripple of seismic swarm was observed on the earth's crust for long distance. The series of underwater volcanic eruption in the east coast of Mozambique might have raised the SST of NIO and WIO associated with magma eruption under sea. The geothermal energy generated must have raised the SST nearby and transmitted favoring the PIOD with mild El Nino activity. That would have induced formation of the TC to develop to a huge energy source. This energy initiated cyclogenesis of IDAI hurricane, Kenneth in SIO and simultaneously Fani in North Indian Ocean which is unprecedented and at uncommon place of origin and made NIO as the cyclone year.

A. Impact of the ESCS Fani

Fani has devastated catastrophically at the places after land fall *i.e.* Puri, Cuttack, Khurdha, Jajpur, Mayurbhanj and Kendrapada districts of Odisha only, causing total 65 fatalities and the fiscal loss assessed was 2417 Billion INR. The ESCS has ransacked 159 blocks, 52 ULBs, 18168 villages and 16.53 million populations, 556761 houses damaged, and lost huge vegetation, electrical structures and summer standing crops ~18.8Mha in Odisha state. The Special Relief Commissioner, Odisha has reported that 556761 houses were damaged, 8778420 live stocks were dead and the poultry sector was seriously affected. The total death toll due to Fani was 89 out of which 65 in Odisha which further accounts 39 in Puri district only, followed by Khurdha (9), Cuttack (6), Jajpur (4), Mayurbhanj (4), Kendrapada (3). There were 160 people injured. Livestock casualties were over 34 lakhs and ≈16 million people were affected. The worst affected Puri district was reported to have 8944 houses completely collapsed and 248139 houses partially damaged and total collapse of communication and electricity as an outcrop of the cyclone.

BOB basin is funnel designed. The East Coast base line of India has seven major pockets, mostly the debouching zone of the major east flowing rivers. These zones are designated as the calamitous threat zone for slamming of BoB storms at these warps. The Tropical cyclonic storms cause the determined destruction when they landfall the north Andhra coast to BD coast based upon the power and direction of hit. The cloud states pretentious are Andhra Pradesh, Odisha, and West Bengal by Pre-Monsoon intra transitional storms. The losses become huge not like west coast as the terrain from 15-25km is low and flat (throughout Coromondal coast), high population density and architecturally unsafe dwellings. Unexpectedly after the SuCS 1999, the coastal tract from Srikakulam to Paradip has become more vulnerable to CS and about 20 tropical high intensity cyclones had struck both during pre/post monsoon. The pre-monsoon CD's follow the track of the Upper air cyclonic circulation from 850mbar to 200 mbar current of the wind and move North Westerly at the initial stage and afterwards in the deep sea arcs ENE-ly to ESE-ly influenced by the climatic anomalies.

Table 8: Review of two BoB ESCS, Phailin land falling south, and the Fani north of Chilika.

S.N.	Characteristics	Phailin	Fani	The comparison
1.	Life span over BoB (D to D)	8th to 12th Oct 2013 (108hrs) post monsoon	26th Apr to 3th May 2019 (204 hrs., Pre- monsoon	Fani: Longer stay in BoB for 51hrs. than Phailin
2.	Place of origin (eye lat.0 N/ long. 0 E	12.0/96.0 (North Andaman sea)	2.7/ 89.7 (WC Bay near equator, rare)	Phailin remnant CD of China Sea (S), Fani is in situ
3.	Growth time Depression(<49Km/h) Deep Dep^n <61Km/h) CS (<88Km/h) SCS (<118Km/h) VSCS (<167Km/h) ESCS (221Km/h)	21hrs 9hrs (slow) 21hrs (rapid) 3hrs (rapid) 9hrs 54hrs	21hrs 6hrs(rapid) 51hrs (slow) 9hrs (slow 9hrs 63hrs	The intensified ESCS Fani stayed long in CS, SCS and ESCS stage in BoB to gain more moisture, energy and became stronger to slam coast than Phailin
4.	Cause of intensification	i. UA level div. (200hPa) & Low level vorticity & conv. ii. SST : 28-29ºC, iv. Sea Th. energy 60-80 KJ/ cm2,v. MJO index: phase 6, amp.>1, eye pressure 940 hPa drop by 66 hPa, wind Speed 200-213 km/h gusting	i. Anti-CYCIR from mid-troposphere to the NE of the system ii. High Ocean heat content iii. Eye pres. 932 hPa, drop by 66hPa,wind speed 175-185km/h gusting 205 Km/h, warm Feb. El-Nino, worm pool in BoB.	Fani though the strongest cyclone crossing Odisha coast but in strength weaker than Phailin of 2013. Fani is the pre-monsoon strongest CS crossed Odisha coast in the satellite record. The MJO index laid over Phase 6 for Phailin but in case of Fani it was over phase 8
5.	Landfallt (lat. /Long.)	19.26°N / 84.82°E	19.75ºN/ 85.7ºE	Phailin (south), Fani (north) of Chilika lake
6.	Landfall surge above Astronomical tide)	2-2.5m above high tide	1-1.5m above high tide	Phailin caused more inundation
7.	Rainfall during slamming	Northern sector (Banki 38cm)	Northern sector (Berhampur 30cm)	Phailin affected more inland area
8.	Time, Track and Land fall prediction (IMD)	Nearly accurate	Lot of fluctuations initially	There were sluggish drive of the storm initially.
9.	Tilt and Kink	Initially west, then NW-ly and finally after slamming moved northerly	From clockwise NNW dir^n instead of anti-clockwise turns moving to NNE dirn.	Unique and unexpected frequent tilts in initial paths up to intensification upto SCS
10.	Damages caused	44 people dead, 22 blocks, damaged 256,633 homes &15million affected	64 people dead, 159 damaged 508467 homes & affected 16.53 million in Odisha only	The wind speed of Phailin is higher than Fani but the long stay as VSCS inland after landfall caused havoc in Puri & Khurdha

The tracks of all CS's are dissimilar and never alike. Cyclones are escorted by strong Aeolian forces, heavy precipitation and surges (extraordinary when high tides) instigating fatality, trauma, bionetwork, structures and possessions. The CS's fatalities estimated are about 76% in Asian subcontinent in the tropics of the globe. It is evaluated that about 9.15 lakh transience has been caused by meteorological disasters in Asian subcontinent and about 0.695 millions of deaths have occurred due to Tropical cyclones (The report--Atlas of Mortality and Economic Losses).

The year, 2018 and 2019 were considered as the storm year (14 and 12 CDs) in NIO in the outset of 21st century as seven consecutive intensive CDs were formed in NIO (in BoB and AS basins). The pre-monsoon intra seasonal CDs above DD in the NIO were CS - Sagar (May 16th to 20th), ESCS Mekunu (May 21st to 27th) and the post monsoon intra seasonal storms were Luban in AS basin (Oct 6th to 15th). The rest 5 CD's above CS in BoB were Daye -CS (19th to 22nd, Sept, AP coast), VSCS -Titili (Oct 8th -12th , WS 150kmph, distraught North AP and South Odisha), SCS - Gaja (Nov 10th to 13th ,TN coast) and SCS Pethai (Dec 13th -18th , NE India) during 2018 causing death was 343 and with fiscal loss of $4.33 billion (WIKI). But year 2019 there were only two intensified CS in BoB the Fani as PMT storms and the VSCS Bulbul (6th to 11th Nov, WB coast) as a remnant of storm Matmo of South China Sea.

The strategies conducive for conception of CD's over NIO are ENSO, La Nina, The intra seasonal Oscillations like MJO (median Jullien Oscillations) and boreal summer intra-seasonal oscillation (BSISO), and IOD's mainly during pre-monsoon [29-31]. ISO plays pivotal role in pre-monsoon TCS initiation and growth in BOB and drag the system NW-ly. Kikuchi & Wang (2010) [32], reported that pre-monsoon TC cyclogenesis during year 2007 (one), 2008 (one) and 2009 (two) numbers of tropical CS brew in BOB as the GPI (Inter annual variation of the genesis potential index) was high.

Anthropocene signatures of TC's and climate change (CC) initiatives discussed in International Workshop on Tropical Cyclones-VI (IWTC-VI), Rogers *et al.*, (2018) and the conclusion were challenging. The recent increase in modernization has resulted as societal impact [33]. The pecuniary/ ecosystem damages from tropical cyclones are due to large population along coastal areas and the congregation of ecosystem hubs along coastal track like lagoons, bays and swamps in the EC India. The human effort to minimize CS severity by spraying Silver Iodide (AgI) or covering the potential zone by nano-particles found to be risky and polluting.

B. Policy implications

Cyclogenesis and Tracking of BoB cyclones (TCs) are complex over NIO. It is done by collection and processing of data taken from sea or land observations, radar observations and satellite images from Kalpana-1 (2002) and INSAT – 3A (2003) by Regional Specialized Meteorological Centre. From the data and post-season analysis of the CDs, model comparisons give the cyclogenesis and the best track data. It is found that IMD forecast of position, intensity, track has less error

39, 40 and 37 km in NIO, BoB and AS respectively [1]. The track of cyclones in India after landfall is generally done by using the CWC RADARs fixed at coasts of India and also the satellite imageries are analyzed which is difficult as the sky is cloudy during storms [1, 37].The Standard (Std) Operating Procedures (SOP) from MoUD, Govt. of India assigns effective disaster handling of UF in three phases as *pre-phase* (preparedness for disaster reduction and community capacity development), *in-phase* (early warning and communication, awareness generation, efficient response with planned evacuation and relief) and *post-phase* as restoration with re-habilitation.

C. Lessons Learnt

The implications taken during Fani were with prevention, mitigation, plan, train, early warning system improvisation, and preparedness before the cyclones Fani in *pre-phase*. The public awareness generation, mock drill, evacuation, forecasting, medical awareness were well generated as pre-cyclone activities. During the cyclone (*in-phase*) the emergency responses and action plans like repairing trauma, alerting people about current track, wind speed, storm surge and possible devastations were made by the NGO's and government organization line departments. After cyclone, (*post-phases*) the activities are under process of recovery and reconstruction to repair and renovations are in progress. The conventional approach in 20th century was relief-reconstructs and rehabilitate. Odisha had learnt lessons from the super cyclone -1999 where about 10000 people died. The approach to combat cyclone from relief- reconstruct- rehabilitate to *plan- prevent and prepare* in addition to conventional approach. The ESCS Phailin has taught us all the above. But towards mitigation, we cannot prevent the cyclones and even they become apocalyptic when develop to higher order. But present ESCS Fani has taught us prevention, mitigation and preparedness in addition to all disaster response.

VI. CONCLUSION

Tropical cyclones, oceanographic Aeolian forces, venue of origin, the track and the place of landfall have been changed dramatically from 1999 after the super cyclone at Paradip town, leading to snags for shaping exact track, trends of propagation and intensity of cyclogenesis though enormous development has been incorporated through models and GIS studies. The variability prediction of the systems of TCs over BOB is not yet established and are to be finalized whether exclusively natural, manmade or combined effect. MSL rise, global warming, PIOD, BSISO, CC change and abrupt SST anomalies are considered. But surprisingly the overall frequency of CDs in BoB has not changed significantly. But the intensified TCs hitting the EC has posed changes in their frequencies, track, place of landfall, impact, and intensities [34].

Fani, one of the strongest pre-monsoon tropical ESCS ever recorded in the BoB and the natural event was repeated after a gap of 43 years. The uniqueness of Fani as CS is due to place of formation, abnormal longevity in BoB, hitting in an unusual season and from unique direction. It was more devastating presumably energized by the underwater volcanic activity near Mozambique 4 to 5 months prior with increase in POID. Fani originated near the Equator and covered longer route, alternate sluggish and fast moving through an unusual trajectory to reach the landmass could be the factor for gaining strength. Since the inception, it was intensified rapidly to a CS further grown to ESCS stage as the CD was born with high energy inherited from the equatorial zone SST, the cause for cyclogenesis [35].

About 10 numbers of CS and above formed in BOB from 1893 to 1978 (87 years) during PMT period. Most of the Storms either crossed Myanmar coast or Bangladesh coast or passed between Ganga-Brahmaputra deltas. But The ESCS Fani acted as grim reminder that MAM storms can hit the Northern EC of India and can be apocalyptic.

From decadal storm statistics in NIO during 1891 to 2019 (Aug), 1891 to 1990, and 1990-2019 (Aug) reveals that the average CS frequencies was 61.15, 55.3 and 80.67 respectively [36]. The probable host of factors causing CS Fani may be volcanic eruptions within WIO, unusual rise in SST over the BoB, prevalence of ENSO activities, nuclear activities along coastal areas and excess fossil fuel consumption (huge aerosol particles generation). The charged active particles chemically react with solar emission and along with sun earth geometry triggers cyclogenesis in BOB.

Fani is one of the cataclysmic PMT ESCS over BoB hitting Odisha coast ever recorded which originated at 2-3ºN Lat. and slammed 20ºN after 10days as per the trajectory of storms. The distinctiveness of Fani amongst pre-monsoon TCs in BOB is due to its place of origin, timing, distance covered, sluggish movement, strength, intensity and unusual landfall. Other notable distinctiveness is its movement in a track under warm, weak El Nino and weak ENSO, PIOD and MJO favorable condition.

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