Anthropocene Cyclogenesis over Bay of Bengal, Prediction by SMOreg, and Odisha Coast Landfall

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Abstract

Background

Recurrent tropical cyclones of thermal origin in the Bay of Bengal have regular damage to the 480km Odisha coasts of the east coast of India. The causes are violent wind, torrential rain, and storm surge inundations. The high sea surface temperature (> 27^0C), relative humidity, wind shear, Coriolis force, preexisting disturbances, warm oceanic current, easterly trade wind, and upper air cyclonic circulation. Odisha receives a lion's share of the cyclogenesis of the Bay of Bengal and is shattering the coastal inhabitants and the ecosystem.

Methodology and Results:

The cyclone data of India Meteorological Department from 1891 to 2020, post-Holocene, pre-Anthropocene, and golden spike periods are analyzed statistically. The categorization, naming, cause of ample cyclogenesis in the Bay of Bengal particularly along Odisha coast are discussed in the present study. The geological stratification, meteorological players, and coastal features of Odisha coast are discussed. The trend in CD's, CS, and SCS has been studied and prediction of these storms that shall brew and grow over Bay of Bengal fabric from 1980 to 2021, (during the golden spike period of the Anthropocene period) by using Linear regression and SMOreg soft computing machine learning model has been forecasted.

Conclusions

The decrease in cyclogenesis frequency but increase in amplitude, intensity, and severity is the present trend along with a southerly shift of landfall along the east coast. The reason is that the southwest monsoon brings with it high wind shear, which hinders cyclone development, and variation in wind layer shear.

Introduction

The cyclonic disturbances in the Bay of Bengal (BoB) are formed either in situ or remnants of the cyclones propagated from the China Sea. The pre-monsoon and post-monsoon favors disturbance formation and the Bay of Bengal (BoB) fabric is the breeding ground for the cyclonic storms inclusive of the remnant disturbances of the South China Sea. The two jinxes of cyclogenesis of BoB are less during pre-monsoon (March, April, and May), while most during the post-monsoon (October, November, and December) and least during the active southwest monsoon period. The Inter-tropical Convergence Zone (ITCZ) which is the main player, is housed in the Southern Hemisphere during summer shifts from the southern boundary during the pre-monsoon period. From April to December, the cyclonic storms form in the close vicinity of the ITCZ or low-level conditional instability of the 2nd kind (CISK) in the atmosphere where cyclonic vorticity pre-exists Laing et al, 2010[1]. Tang et al., 2020)[2].

The Coriolis force and trade wind promote to augments the air circulation in the southern boundary from West to East in the BoB. Simultaneously the northern margin of the ITCZ helps the air rotation to move reversely from East to West. The cross travel of winds forms low-pressure areas (LPA) in peninsular India, help to move along a trough line through the Indian landmass and move towards the disturbance in BOB.

The 2.172 mn km²area of BoB (0.6% of the total oceanic area) is tentatively divided meteorologically into 7 compartments without specific boundaries. Beyond monsoon season depressions and remnant storms of the South China Sea, most of the BoB disturbances were observed to be conceived in the southern part of BoB. The analysis of data from 1996 to 2020 reveals that a major share of the cyclogenesis starts either from the East Coast (EC) or from West Coast (WC) Bay (Fig-1) Mishra et al., 2014[3], Sahoo et al., 2021[4].

The Classification and naming:

The records of cyclones from IMD ledgers are available from 1891 onwards whereas records are sporadic and unreliable as they are from history, literature, and state sources. Systematically the tropical cyclones were classified into five categories during the 20th century as cat-1, cat- 2, … cat- 5 with a wind speed of >252kmph or above based on intensity and the wind force. However the tropical cyclones were classified as cyclonic storm (CS), severe cyclonic storm (SCS), and very severe cyclonic storm (VSCS) till 31st Oct. 1999 based upon 3mnt average wind speed, change in pressure in the eye, the wave amplitude, damages caused, *etc.* in India. The super cyclone (SC) was added when the Cat-5 cyclone crossed Paradip Odisha on 31st Oct 1999. Later after the cyclone Phailin on 12th Oct 2013, a new category has been added as an extreme severe cyclonic storm (ESCS) Mishra S. P. et al, (2019)[5]. The wind criterion is considered for classification bay disturbances in the Bay of Bengal (Table 1):

Table 1: The classification of tropical cyclones in the Indian Ocean based on wind velocity, a pressure difference of the eye, and the physical damages

Category	Life span	(Change pressure)	Wind speed	Beafa-urt's scale	Along off shore (allowed)	Wave height	Sea status
Disturbances	*days*	ΔhPa in mb	Kmph	Number	Activities	in m.	
Low-pressure area /Well marked (LP/WLP)	–	<4.0	<31	1-6	all	0-3	calm-rough
Depression (D)	02	4-6	31-49	5-6	all	2.5-4.0	Mod-Rough
Deep depression (DD)	03	7-10	50-61	07	alerted	4-6	Very Rough
Cyclonic Storm (CS)	3.5	11-15	62-88	08	No fishing	6 - 9	High
Severe Cyclonic Storm (SCS)	4	16-20	89-117	09-12	Suspension fishing, and all coastal activities	>14m	Very High
Very Severe CS (VSCS)	5	21-66	118-165	10		>14m	Phenomenal
Extreme Severe CS (ESCS)	5	67-79	167 - 221	12-14		>14m	
Super Cyclone (SuC)	5.75	>80	>222	>14		>14	

Note: Mean wind speed over 3 minutes and speed of CD's in kmph (sustained), ΔhPa =atmospheric pressure in S.I. unit as hecta-Pascal (hPa), (Source: IMD report; SOP< Cyclone warning India: http://rsmc newdelhi.imd.gov.in/uploads/report/61/61_245057), Kumar et al, 2016[6].

Review Of Literature

Odisha coast receives the largest numbers of cyclones (holds 6th rank in the globe) with the utmost risk of encounter to storm impacts, surges, winds, and inundation (Sahoo et al., 2018[7], Barik S. 2019[8]). The anomalies in SST (sea surface temperature), PIOD or NOID (+ve and -ve Indian Ocean Dipole), ENSO (El Niño-Southern Oscillation), and Madden Julian Oscillations (MJO) plays a pivotal role in shaping the tropical and subtropical climate (Roxy et al., 2019[9], Mishra S. P., 2019[5], Singh et al 2021[10], Pilai et al 2021[11]). Reliable track and time forecast is indispensable in predicting the cyclonic storms of higher-order as surged devastation is faced during landfall particularly (ESCS) since last 30years 1990 to 2020 (Mohapatra et al., 2013[12], Singh et al, 2021[10]),

The air-sea coupling during the cyclogenesis period is reducing the TCs number and intensity in NIO as threshold surface temperatures have surged and TC-induced cooling has gone down (Lengaigne et al., 2018[13], Neetu et al., 2019[14]). The warm pool at an altitude of 200millibar is attributed as one of the causes

for developments of cyclonic disturbances prior to their formation over BoB and generally before 3-4 days earlier, Mowla, 1967[15]. Depending upon the ocean the cyclones have different names in different states such as Typhoons - China Sea, Tropical Cyclones- Indian Ocean, Hurricanes-Caribbean Sea, Tornadoes-USA, Wily Willies- Northern Australia, Baguio- Philippines, and Taifu in Japan, Anwar, S., 2020[16]. Intensified post-monsoon super cyclones were reported during 1831 and 1885 and similar type on 31st Oct 1999 land falling at Paradip with unique characteristics of fast intensification, reasonably small eye radius, wind speed > 270kmph, huge surge >6m and consistent long life after slamming, Kalsi et al., 2006[17].

The deadliest cyclone that shattered Andhra coast were the cyclones in the year 1946, 1977, and 2014, the Tamil Nadu in the year1979, the West Bengal in 1993, the Odisha in 1971, 1989, 1999, 2013, and 2019 (Foni), Mishra et al., 2020[18], Pal, et al 2020[19]. About 30% of The BoB storms that landfall Myanmar coast can be segregated as 30% during May, 19% during April, 18% during Nov & Dec months, and the rest during monsoon seasons. (UN-Habitat, Myanmar-2015[20]). The Odisha coast geomorphology comprises deltas, sandy, stony (south) and muddy (North) beaches, spits, barrier islands, tidal flats, sand dunes, beach ridges, lagoons, swamps with mangroves, mangrove associates are responsible for worst hit by cyclones approaching from SSW through SE direction. (Shaji et al, 2014[21], Barik et al., 2019[8], Kankara et al, 2019[22]).

Applications of different soft computing models are exercised by different researchers to forecast the frequency and intensity, track of cyclones by the ANN (artificial neural network) over conventional linear or multiple regression methods (Baik et. al., 1998[23]; Ramírez et al., 2006[24], Chakrabarty et al., 2015[25], Choudhury et al 2015[26], Akbarinasab et al., 2019[27], Rüttgers et al., 2019[28], Benifa et al., 2021[29]). Researches on the cyclogenesis by utilizing computational models have been tried for predicting CD's and CS's over the Indian Ocean (Dvorak, 1975[30]; Roy B. et al., 2007[31], Nath et al., 2015[32]. Karthik et al., 2020[33], Mishra & Ojha 2020[34]).

Objective:

The objective of the concurrent study is to point out the causes of slamming a major share of the BoB storms along the 480km long Odisha coast. The trend of cyclogenesis in the Bay of Bengal during post-Holocene (1891-1949), pre-Anthropocene (1950 – 1980), and the present golden spike period of Anthropocene (1980 – May 2021) that demarcate the geological factors, human-induced carbon footprint, and climate-induced players which changed the SST, carbon sequestration and cyclogenesis. A prediction has been done for the period 2021-2030 using suitable machine learning models.

Methodology

The present scope of the study is to collect the cyclonic disturbances in the Bay of Bengal basin which is one of the vibrant gulfs of the North Indian Ocean (NIO). Its present geographical poisoning, vibrant physiography and stratigraphy is engulfing a lion's share of the cyclonic disturbances formed in the NIO. The classification, naming, and the players in the process have been reported. The cyclogenesis in the Bay of

Bengal, their formation processes, intensification, movement, land slamming, and their concurrent management policies are the focusing point of the research.

The soft computing study uses cyclogenesis data of 40 years starting from 1981 to 2020 based on Indian Meteorological Department publications and Wiki data. Three time-dependent observations such as CD, CS, and SCS are considered for prediction. The machine learning approach that is widely used for classification and prediction is preferred over traditional ARIMA (Auto-Regressive Integrated Moving Average). The present study makes use of WEKA, a popular software tool for the application of machine learning algorithms. The tool enables the creation of lag variables and converts the time series forecasting problem into a supervised machine learning problem. It also provides configuration options for the number of time units to forecast.

Data consideration:

The data reporting and hazard risk recording of cyclonic storms were started in 1891 through India Meteorological Department (IMD) established in India in 1875. The subcontinent has experienced 1597 cyclonic disturbances (CDs), out of which 670, and 321 numbers of CD's have developed slammed the EC, and WC of India. The lion's shares of 100 CS's (19.12%) out of a total of 523 cyclonic storms have intensified from CD's and have made their landfall along the Odisha coast till May 2021 inclusive the VSCS "YAAS" (Mishra and Ojha 2021[34]).

Past History:

As per record, the devastating intensified storm that slammed Odisha coast were 1737 (Oct), 1831 (Oct), 1864 (Oct), 1885 (22nd Sept), 1942, 1967, 1971, 1977, 1999 (Super Cyclone), 2013 (Phailin), 2014 (Hudhud), 2018 (Titli), Fani (3rd May 2019), and YAAS (26th May 2021) Sarkhel et al., 2019[35]. The cyclones are formed in-situ or remnants of typhoons of the South China Sea moved to BoB. They intensify and move towards the East coast of India. Many cyclones formed in May at times take a curvature heading towards Myanmar coast, the least formed June-Sept storms landfall across the north coast(Kolkata and Ongle). The Oct. to Dec. storms are devastating and cross all along the east coast of India and rarely move towards Bangladesh and Myanmar coast, **Fig 2 (a).**

Past statistics:

The cyclones (BoB+ AS + in-land) have been considered for the periods 1891 -1949 (post-Industrial revolution and post-Holocene epoch), 1950 -1979 (global atomic activities, i.e. pre-Anthropocene period), and 1980-2020, (Golden spike period of Anthropocene when the rate of demographic growth exceeded the rate of food production in India).

The analysis of data reveals that the number of CDs and TCs formed during the post-Holocene, Pre Anthropocene, and golden spike period of Anthropocene shows changes (**Fig 3, Table 2).**

Table 2: The number of CD's, CS's and SCS's that landfall the different coasts of India

Year	Cyclonic disturbances (CDs)				Cyclonic storms				Severe Cyclonic storms			
	BoB	AS	In-land	Total	BoB	AS	In-land	Total	BoB	AS	In-land	Total
1891-1949 (NO)	630	74	67	771	285	53	9	347	94	29	3	126
1891-1949 (%)	81.7	9.60	8.7	100.0	82.1	15.3	2.6	100	74.6	23.0	2 4	100
1950-1979 (No)	329	72	37	438	126	34	4	164	75	21	1	97
1950-1979(%)	75.1	16.4	8.5	100	76.8	20.7	2.5	100	77.3	21.7	1.0	100
1980-2020 (No)	261	89	38	388	111	47	1	159	67	31	0	98
1980-2020(%)	67.3	22.9	9.8	100	69.8	29.6	0.6	100	68.4	31.6	0.0	100
Acronyms: No: Number; BoB: Bay of Bengal; AS: Arabian Sea												

The % of CD's (D + DD's) formed for the three consecutive periods were 81.7%, 75.1%, and 67.3% during the period 1891-1949, 1950-1979 and 1980 - 2020 respectively (**Fig 3 (a), (b) and (c)).**

Those CD's were intensified to CS's and above during the same periods were also increasing gradually to 82.1%, 76.8% and 69.8% **(Fig 4 (a), (b) and (c)).**

But it is found that the growth from numbers of CS to higher-order storm categories like SCS, VSCS, ESCS, and SuC have shown a decreasing trend i.e. 74.6%, 77.3%, and 68.4% respectively, but with higher intensified CS's during the same periods. Among all the cyclonic formulations, 29% of the total disturbances have affected the Odisha coast. The vulnerability of the Odisha Coast Zone is relatively high in comparison to other adjacent states like West Bengal (14%), Andhra Pradesh (13%), and Tamil Nadu (7%) (IMD Report).

Formation of cyclones in BoB:

The tropical cyclonic storm form in stages Stage I comprises of complex mesoscale vortex formation with a horizontal extension of 100 -200km and stage II is an intensification of the stage I vortex and decrease of central pressure and surge in spiral wind evolvement till cyclogenesis occur. The TC's in BoB form when sea surface temperature is high (>26.5^{0}C), the warm water column of 50m depth (the energy source), and highly moist air rise above the ocean surface common during moths April to Dec). Rising up moist particles starts cooling and forms droplets with a dust particle as the nucleus. Condensation the droplets release heat to the atmosphere. Release and transfer of latent heat to penetrate the surrounding warm moist airs create more wind and the system grows.

The intensification of an oceanic disturbance and formation of its eye can be correlated with during formation of clouds over the sea a column of LPA (Low-pressure area) is established and create a column between the cylindrical clouds mass due to the tangential forces acting called the eye of the intensified cyclone. The continuous supply of moisture from the surroundings makes the system dynamic and makes it capable of transgression. On landfall, the moisture supply is hindered and the cyclones divulge and dissipate. The eye of an intensified storm has a diameter ranging from 30 -60 km with almost calm wind, visible blue sky, least precipitation, and fair weather with 0-2^0 C warmer than the surficial temperature (Gray 1975[36], Roy et al., 2012[37], Pal et al., 2020[19], Anwar et al., 2020[16],Wahiduzzaman, et al., 2021[38]).

The vertical section of an intensified cyclone extends vertically up to 12km or more where from 0-3km the movement of the cyclone occurs, 3-7km represents the body of the vorticity zone and the outflow occur beyond 7km up to 12km or more, https://www.pmfias.com/tropical-cyclones-favorable-conditions-tropical-cyclone-formation/ . A well-developed cyclonic storm should have noticeable structural elements like boundary layer, central eye and its wall, cirrus cloud shield (CDO: Cloud dense overcast), rain bands, and upper tropospheric outflow. Failure to penetrate the cloud column with sufficient wind and moisture, the cyclone shall not grow and tend to decay and die Bandyopadhyay, et al, 2020[39].

Other propelling factors are IOD, ENSO, ITCZ positioning, upper-tropospheric westerly trough, are important as they could force huge volumes of wind shear (vertical) over CD's which may inhibit strengthening

Propelling of circulations in BoB:

After formation; the cyclone, the track may be conventional or nonconventional and at times also undergo dissipation and decay. Conventionally, the concurrent wind force propels the system to travel with sufficient vorticity forced by the Coriolis force (anti-clockwise in BoB), the centripetal force action of the earth's rotation, and the gravitational forces, (Roy et al., 2012[37]). The conjoint factors are low altitude positive vorticity, low shear force in layers of vertical wind shell, SST (> 26.5° Celsius), surged convective uncertainty, high RH in the low and mid-troposphere (Mohapatra et al 2015[40], IMD report 2015[41]). The genesis moves forward continuously in W to NW quadrant and never takes a reverse course towards the equator. Occasionally systems remain geostatic and accumulate more energy for changing direction or recurve in the BoB. Dominantly, the systems collapse or recurvate during pre-monsoon in the Bay of Bengal, http://www.rsmcnewdelhi.imd.gov.in/images/pdf/faq.pdf. The conventional projectile of propagation in NW-ly of the cyclones is generally followed in BoB (NIO). The factors for the unconventional track are the steering Jet current, preexistence of the previous cyclone, deep unstable RH, ITCZ poisoning, high SST within the zone of confluence, strong vertical wind shear in the region, and β – effect Mohanty U C 1994[42], Mohapatra et al., 2012[43], Paliwal et al., 2014[44], https://www.indiannavy.nic.in/ifc-ior/Cyclone_Study.

Fewer cyclones during SW monsoon:

The Bay of Bengal has become a warm pull having SST up to 30-32^0 C (Thresh hold 26.5^{0}C for cyclogenesis) due to global warming, tectonic/volcanic activities, and Terrestrial/Oceanic Carbon Sequestration. The vast expanse, escalated temperature, RH, huge vertical wind shear make the SE and SW

bay region vulnerable for cyclogenesis in BoB. The pre and post-monsoon days are conducive for the formation of disturbances and intensification due to easterly jet stream and positioning around the ITCZ (Fig 6), ENSO, and MJO activities.

The probable potential zone of cyclone genesis is North BoB during SW- monsoon. During SW-monsoon days, a monsoon trough is developed from NW India to the cyclonic disturbances in the bay till intensification to depression stage only. Such Oceanic disturbances have a short stay within the Bay. They dissipate without further intensification and cross the Odisha or WB coast and decays with a spell of heavy rain. This surged wind shear impedes the growth of cyclonic disturbances to cyclonic storms T**able 3.**

Table 3: The trend in the formation of CS's in BoB during monsoon seasons during post-Holocene, Pre Anthropocene, and present golden spike period.

Year	JUNE		July		August		September	
	No	% of total CS	No	% of total CS	No	% of total CS	No	% of total CS
1891 - 1949	30	27.03%	36	32.43%	22	19.82%	23	20.72%
1950 - 1979	6	20.69%	5	17.24%	5	17.24%	13	44.83%
1980-2020	2	20%	2	20%	1	10%	5	50%

On analysis it is inferred that the trend in formation CS's of higher frequencies observed higher during the post-Holocene period, July has the highest in number which has drastically reduced during the pre-Anthropocene period and only two during present golden spike period. Month-wise concern reveals September month is conducive for monsoon cyclones in the Bay of Bengal.

Prediction by soft computing:

A large series of data from 1891 to date is available. But data of the golden spike period (1980- 2020) has preferred to be used as there is an abrupt change in cyclogenesis after the golden spike period of the Anthropocene epoch. The conducive parameters for cyclogenesis that has changed thermal status over the Bay of Bengal by the active Barren Island volcanic activity, Sunda Island geographical turmoil, global warming, and carbon sequestration after 1980 onwards.

Two popular machine learning algorithms, Linear Regression (LR) and Sequential Minimal Optimization Regression (SMOreg), are selected as candidates for the problem at hand. SMOreg is based on support vector machine and supports both linear and nonlinear regression models.

Both the regression algorithms are set to their default configurations in the tool environment. Linear Regression uses Ridge regression to avoid over-fitting and SMOreg uses Normalized Poly Kernel as a nonlinear kernel function. The performances of both the algorithms are evaluated using the holdout method taking 70% as the training data and 30% as the test data. The RMSE (Root Mean Squared Error) is taken as an evaluation parameter to assess the accuracy of prediction. The RMSE values of both the algorithms for 10 steps ahead (2020-2030) are observed on training and test data. On average, SMOreg generates slightly

less error than that Linear Regression (Table-4). Hence, SMOreg is selected for forecasting cyclogenesis in the present study.

Table-4: RMSE of Algorithms

Algorithm	Train	Test
LR	1.88048	2.74179
SMOreg	1.78064	2.56852

Results

The machine learning method, SMOreg has been used for forecasting of TC such as number of CD, number of CS, and number of SCS and above that shall occur in the coming decade 2021 to 2030 over BoB fabric. The forecast results are shown in Table-5 and Fig. 5 at a 95% confidence level.

Table-5 Forecast using SMOreg

Year	CD	CS	SCS
2021	5	1	1
2022	4	2	1
2023	5	2	2
2024	7	1	1
2025	6	2	1
2026	6	2	1
2027	6	1	0
2028	5	2	1
2029	4	1	0
2030	5	1	1

Odisha cyclones:

Odisha is very highly prone to tropical cyclones, and about 100 out of a total of 523 numbers formed in the Bay of Bengal from 1891 to May 2021. The numbers of *pre and post-monsoon* cyclones and above formed in BoB and landfall Odisha coast during 1970- May 2021 were 21 and 28 numbers respectively which is highest among all adjoining states along the east coast of India (Sahoo et al, 2018[45]). The Coastal districts like Balasore, Bhadrak, Kendrapara, Jagatsinghpur, are categorized as P-1 vulnerability and the districts Ganjam, Khordha and Puri are highly prone (P-2) categories as per IMD. Depressions and DDs formed during the monsoon period are more between WB, and Odisha coast. The IMD recorded district-wise probable

maximum storm surge (PMSS), and probable maximum precipitation (PMP) averaged of cyclones and severe cyclones that have slammed Odisha coast till 2020 are in Table 6.

Table 6: The statistics of the cyclonic storms and severe cyclonic storms with surge and rainfall averaged that landfall different districts of Odisha (Source IMD data 1891 to 2021))

District	CS by May 2021	SCS by May 2021	Average wind speed	Storm surge (PMSS)	Average r/f (PMP)	Physiographic coastal stratigraphy
Unit	Number	Number	Kmph	meter	cm	Characteristics
Ganjam	11	5	100	4	48	Straight
Puri	6	1	140	4	60	Convex coast
Khordha	4	0	100	4	52	West coast Chilika
Jagatsinghpur	17	4	140	6.5	60	Bulged coast
Kendrapara	17	6	65	8.5	60	Concave, plunged
Bhadrak	17	4	140	9.5	60	Concave, plunged
Balasore	28	5	75	11	60	Bulged coast

The north Odisha coast is vulnerable to CS, and SCS so also has high PMSS (Storm surge) values and PMP (Rainfall) Values. It is due to the coastal irregularities along the coastline. It is also observed that the number of cyclones land slamming the northern coasts of Odisha during the late 20th century has been decreased but that of the south Odisha coast have increased in the 21st century.

Why Odisha Coast is prone to invite Cyclones of BoB

1. **Stratigraphy:** The positioning of the Bay of Bengal and nonappearance of any landform of a vast tectonic region of maritime Southeast Asia except Andaman and Nicobar Islands, India within East Malaysia, Brunei, Indonesia, the Philippines, Singapore) and Odisha + AP coastline of India. The only barriers are fully submerged 85^0 and partly submerged 90^{0}C ridge. The northern coast has a shallow bottom and meso tidal areas are adding to coastal floods of low-lying coastal Odisha.
2. **Shape Factor:** Triangular funnel shape of the BoB accelerates storm surges especially during full or no-moon days (added with daily diurnal tides) during the pre-monsoon period when the estuaries are depleted. The high population density residing at low contour areas, flat slopped, river systems, large water bodies like lagoons (Chilika) and anastomosed drainages (Bhitarkanika) add to the vulnerability of cyclones in agricultural history.
3. **Meteorological factors:** The emergent cyclones formed and intensified from low-pressure areas to the specified tropical storm. They move towards the coast propelled by the adjacent pressure, sea surface temperature (SST), Tropospheric relative vorticity, inverse tropospheric vertical wind shear, monsoon

trough and Coriolis force. The disturbances over BoB oceanic fabric form grow and propagate under favourable conditions, to the ultimate destination of slamming landmass which is either the Odisha or the AP coast (Akter et al., 2017[46]).

4. **Temperature anomaly:** The most crucial factor is sea surface water temperature. Tropical cyclone requires warm temperature around 27°C to form in BoB and such suitable temperature is common. The Arabian Sea has a lower temperature due to the vast expanse, due to incursion of dry air of the Arabian Peninsula (desert), and critical wind shear during monsoon.
5. **Salinity strength**: BoB is less saline than the Arabian Sea as huge flow from inland rivers debouches the bay. The rate of evaporation is high from fresh water in contrast to saline water. Atmospheric (UACYCIR) instability (divergence), mid tropospheric high RH (Relative humidity), preexisting oceanic disturbances, and warm moist air become promising for cyclone genesis (Gray, 1975[36]).
6. **Retreating ITCZ:** the geographical setting of Odisha favours a suitable path for the retreating SW monsoon and on setting NE monsoon during October. The returning path covers Eastern Bihar, South of West Bengal, total coastal Odisha and northern coasts of AP. The time when the SST is warm (>26.5^{0}C), BoB experiences formation of most of the CD's and above in BoB favoured by the westerly wind direction from pre to post monsoon period. But during months of Jan and February the ITCZ shifts near the equator of the Southern Hemisphere.
7. **Flat terrain**: The land slamming of cyclones is opposed by high altitude mountains of EGB and WGB hills range. Does not allow storms to landfall along coast lines of TN, Kerala and Karnataka. The Mahanadi and the Godavari delta are wide, and flat, with flat deltaic terrain and welcome the BoB cyclonic storms for landfall.
8. **Oceanic Chemistry:** Warmer and sweeter (as more fresh water flowing to the BoB) contributing to higher amount of vapor formation which is conducive for cyclone formation. Global warming and tectonic and volcanic activities have made BoB a warm pool, low depth has increased carbon sequestration of the Bay.
9. **Remnant cyclones:** During NE monsoon days (Nov & Dec) the CS are frequently the remnants of the typhoons received from China Sea or from Malay Peninsula. They enter the BoB from back of A & N islands of India, and further intensify in strength due to favourable warm temperatures of sea and travel towards landmass. Those cyclones rarely landfall Odisha coast.
10. **Irregularities along coast:** The 480.4km long Odisha coast reported by Ramesh R. in 2012[52] has been updated by Kankara[22] as 549.5km during 2018. Continuous erosion and deposition has created more irregularities along the coast line and continuous loss of mangroves and mangrove associates and increase in numbers of ports harbors and Jetties is also inviting more numbers of BoB storms to slam Odisha coast.

Soft computing predictions:

Machine learning techniques and various soft computing models are applied for short term and long-term forecast of TC's and predict intensity and change in intensity, wind field, path, track, storm surge, SST, air

moisture, air pressure rainfall, and impact of the cyclonic storms Kovordanyi et al., 2009[47]. Chen et al., 2020[48] presented in Table 7.

Table 7: The cyclogenesis prediction using soft computing methods by various workers

Method used	Area of study	Prediction for	Result	Reference
Multiple linear regr-ession (ANN,MLR)	Western north Pacific Ocean. 1997-2004	cyclone intensity prediction scheme (SCIPS)	Intensity rise, increase in lead hour (12to 120h)	Sharma et al., 2013
Neural network (NN model, MLR)	NIO (Post-moon- soon months)	Number of Seasonal TC's	Sept. favor the TC activity over AS	Nath et al., 2015[32]
K-Nearest Neighbor Tech (ML Tech.)	Thunderstorms	In storms and no storms	>82% compatible;	Chakrabarty et al., 2015[25]
SVM and neural network	BoB, AS	classification and prediction	Accuracy is better	Benifa et al., 2021[29]
Hybrid genetic algorithm XP boost	Bay of Bengal	Tropical cyclone categories	A better model to apply than others	Karthik et al., 2020[33]
Adaptive Neuro Fuzzy Inference System (ANFIS)]	Caspian Sea (Anzali)	Atoms. pressure & Wave Height	Fails during long lead time	Akbarinasab et al., 2019[27]
Generative adversar- yial network (GAN)	Typhoons Korea Peninsula	Typhoon track prediction	Averaged error of 95.6 km	Rüttgers et al., 2019[28]
neural net architect ture 1 (NNA 1, & 3()	BoB, & AS of the NIO	Track &Intensity prediction (TC's)	Least prediction error by NNA-1	Choudhury et al 2015[26]
Soft Comp. (ANFIS /SVM) technique, LSTM/CNN models	North Pacific Ocean	SST prediction	Increasing trend in SST. LSTM/CNN models better	Haghbin et al. 2021[50]
Regression (LR) & Sequential Minimal Optimization Regre-ssion (SMOreg),	Arabian Sea of NIO	Frequency of TC's	Increasing trend in TC's	Mishra & Ojha 2020[34]
LR or SMOreg	**Bay of Bengal**	TC's Frequency	**decreasing trend**	**Present study**

Discussion

Conducive physico-environmental factors liable for cyclogenesis may be tropo and strato-spherical dynamics or terrestrial/oceanic thermodynamics. During the post-monsoon period (Oct to Dec), the BoB is very much energized and active. The retreating of the Southwest monsoon and the onset of the Northeast monsoon is due to the shifting of ITCZ from North to south. The easterlies pick up moisture from BoB and strengthen to form most of the TC's over BoB, and the east coast from Tamil Nadu becomes prone to cyclones during Nov and Dec.

History reveals 26 deadly cyclones in BoB out of 36 most apocalyptic TC's, resulting in four TC's related demises out of five in the Deekhshit Globe 2021[51]. It is observed that the passive period for cyclones formation activities along the Odisha coast are delimited during the winter months (DJFM) and the active SW monsoon days (JAS). Major cyclonic disturbances that occur in the Bay of Bengal during active SW monsoon days are maximum intensify up to deep depression.

The geographical positioning and 480.4km long coastal Odisha (Ramesh et al., 2012[52]) (≈20% of total EC) is prone to BoB disturbances and receives ≈40% of cyclonic storms that hit the east coast of India. The Coastal landmass from Puri coast to Jagatsinghpur and from Bramhani estuary has been plunged into the Bay of Bengal and behaves as a part to it and welcomes major part of landfall. Two large wetland masses at the southern and the northern fringe (Bhitarkanika) and south (The Chilika lagoon) are the two extreme points where the bulging of the landmass starts.

All over the monsoon season, the CD's till forming as depressions, lie over a monsoon trough line (ITCZ), which extends from NW India to the northern fringe in the BoB. There is shift in positioning of the TEJ (Tropical Easterly Jet) (TEJ) along with shift in location of the ITCZ. Till the month September, the trough line and the TEJ firmly establishes its positioning along an east to west direction except a break in monsoon.

The CD's formed over north coastal area of BoB crosses Orissa or West Bengal coast within a day or two. These short-lived systems have landfall very quickly which is one among the reasons for their non-growth as a CS.

Cyclones brew in AS (Arabian Sea) and ordinarily move away from the west coast of India and travel towards coasts of Oman, Yemen or Somalia. This is due to strong winds from BoB and peninsular India pushing the cyclones/depressions further away. The numbers of brewing of cyclones in Arabian Sea is increasing both in frequency and intensity during last five years and there is shifting from Oman to Somalia coast.

Cyclone prevention and Mitigation:

The steps adopted to prevent the bio-system to ameliorate deaths; trauma and damage to the ecosystem are a hazard, and vulnerability analysis, awareness creation, early prediction, widespread warning, and prompt preparedness to meet exigencies like food, health, bovines, ecosystem, bio-system, and finally post-cyclone long term mitigation measures. The activities can be served by early warning through prediction, monitoring, setting institutes to educate the affected mass by generation, presentation & dissemination of warning, pre

cyclone preparedness state and central government through line departments, interaction by coordinating state/central disaster management organizations, post-cyclone disaster management.

Results

Analysis of 130years tropical storm data that has generated by IMD till date reveals that:

i. Major cyclones formed during the month of May take a curvature ENE and slams the Myanmar coast, whereas during June-Sept they landfall along the northeast coast between Kolkata and Ongle (AP). The storms of post-monsoon hit anywhere along the west coast of India and devastating.
ii. Active monsoon cyclones have drastically decreased representing the impact of climate change and anthropogenic stresses.
iii. Three distinct partitions due to climate changes synchronous with Anthropocene, plate tectonics, geological, and global warming impact on cyclogenesis in BoB. The three periods under analysis are (a) ***Period I****: Post Holocene 1891-1949 (Industrial revolution period); (b)****Period II:*** *Pre-Anthropocene Period 1950-1979 (after atomic testing or explosion and pre-independent India) and (c)* ***Period III:*** *Golden spike period (1980- May 2021;)*
iv. *The trend of formation of % of BoB* ***CDs*** *were 75.1-81.7% prior to 1979 But have decreased to 67.3% during Period III whereas No of CS have reduced 76.8-82.1% to 69.8% and number of higher order storms (SCS, VSCS, ESCS and SuC) 74.6%,77.3% to 68.4% respectively in the three periods.*
v. *The prediction of CD's, CS's and higher order storms shows that their number shall be reduced with time from 2021-2030.*
vi. *The 480km of Odisha coast has become hot spot for slam of BoB storms in the last decade and also the place of landfall shifted from north to south gradually.*

Conclusion

The reason is that the southwest monsoon brings with it high wind shear, which hinders cyclone development, and variation in wind layer shear. After trying with LR and SMOrg model, the prediction by the later model seems to be better considering the strengths and limitations of both models. The features, like track, intensity, velocity, storm surge, life span, and rainfall, along the coastal areas are the forecasting factors that make the job of the meteorologist's challenging. The predictions under anthropogenic climate change and global warming need more expertise and scientific methods like averaging, statistical, numerical, hybrid modelling, and simulations correlating with past storms to forecast the upcoming features. Thus, it suggests further research studies.

Declarations

Ethics approval and consent to participate: The results/data/figures in this manuscript have not been published elsewhere, nor are they under consideration by another publisher. All authors of the manuscript have read and agreed to its content and are accountable for all aspects of the accuracy and integrity of the manuscript.

Consent for publication: Informed consent was obtained from all individual participants included in the study.

Availability of data and materials: Some or all data, models, or code that support the findings of this study are available from the corresponding author upon reasonable request.

Competing interests: Authors have declared that no competing interests exist. The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. No, I declare that the authors have no competing interests as defined by Springer, or other interests that might be perceived to influence the results and/or discussion reported in this paper.

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Figures

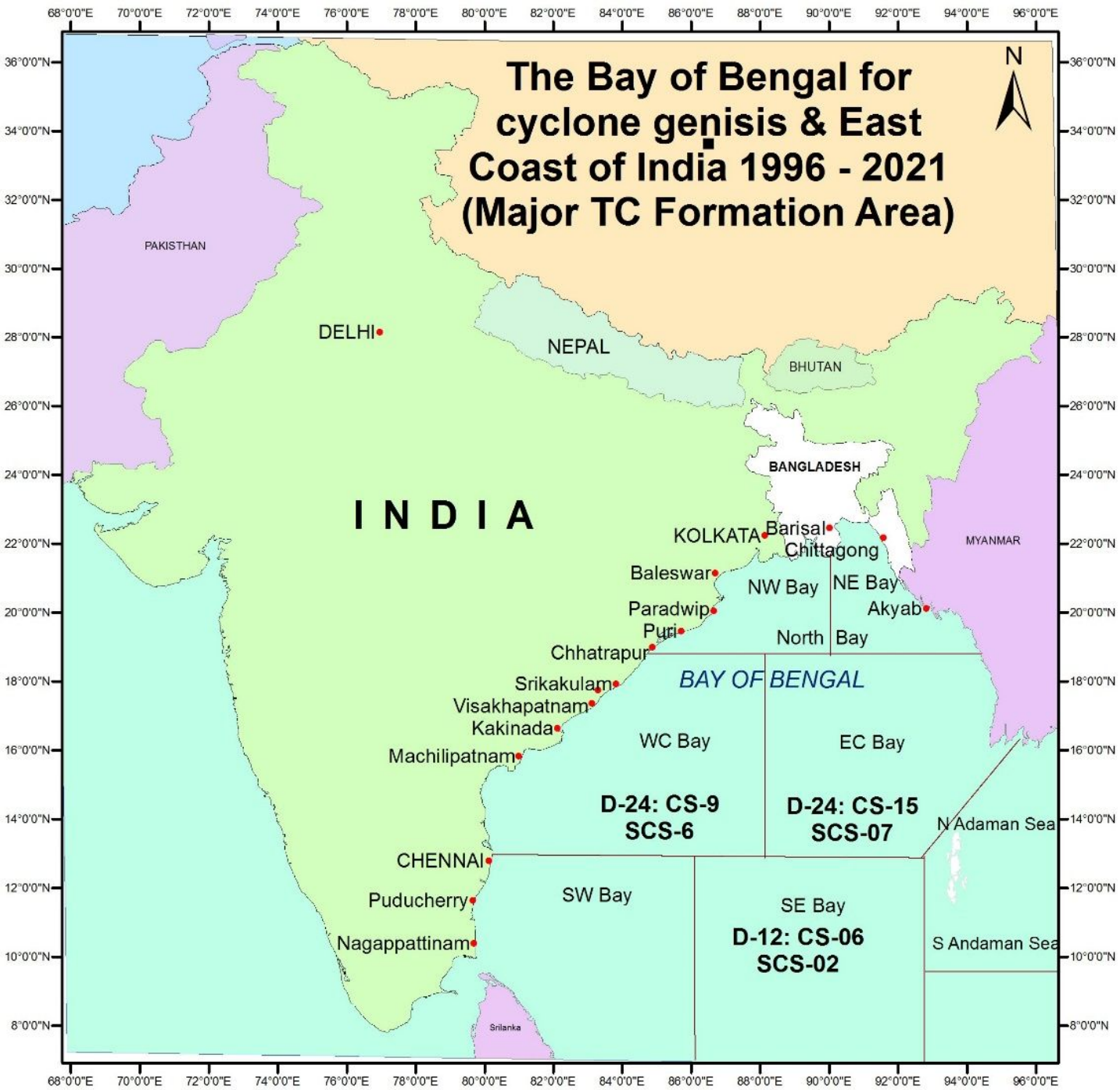

Figure 1

The incubation area of various disturbances of BoB in NIO (After 1996).

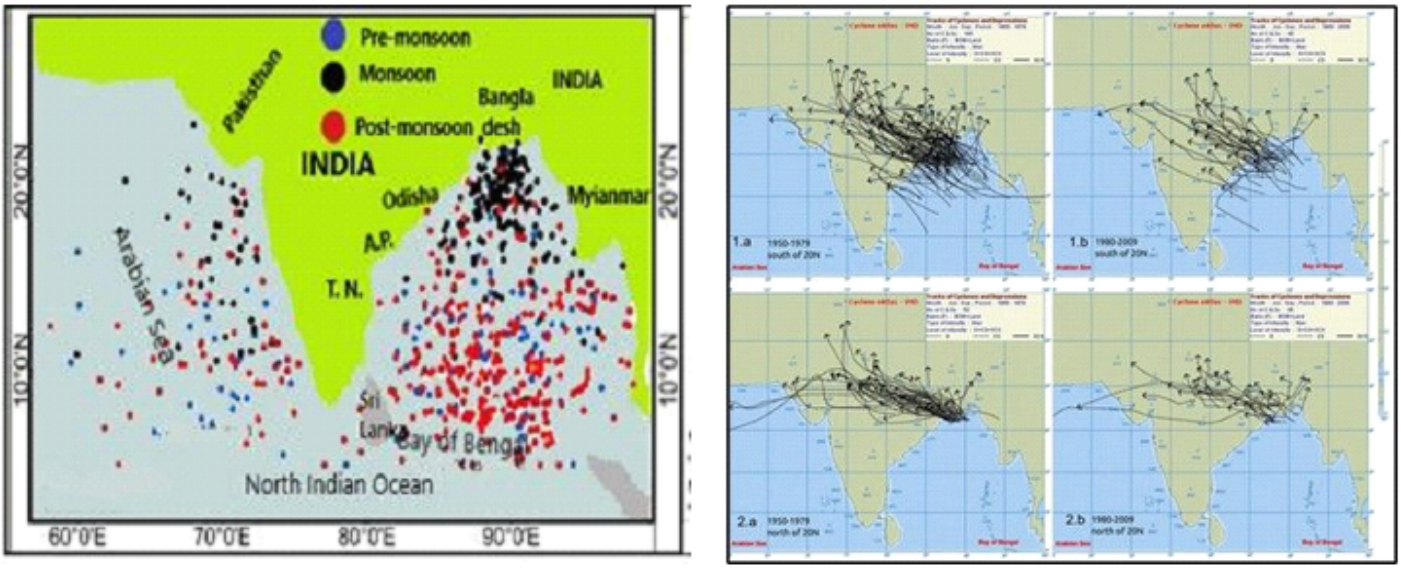

Figure 2

(a) : The cyclogenesis place during pre, active, & post-monsoon in NIO (Source : Pal et al 2020) Fig 2(b): the frequency of track of CS's in North West bay in monsoon days (E-Atlas, IMD)

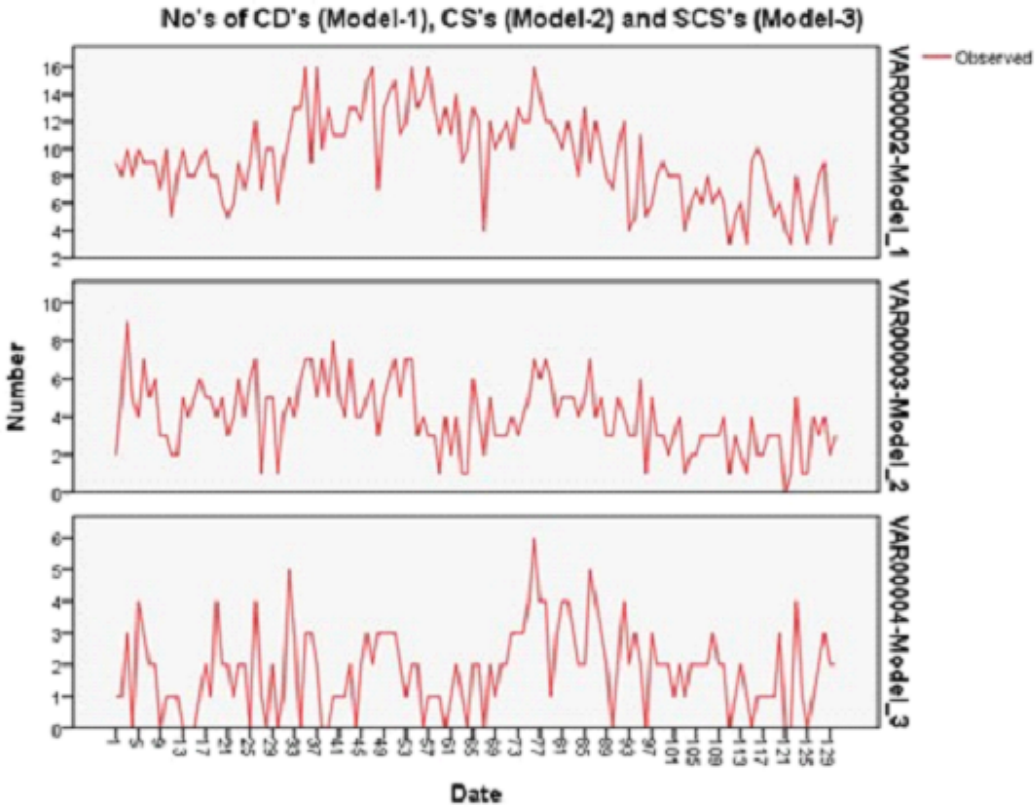

Figure 3

The No's of formation of CD's, CS's and SCS's in BoB (Source IMD)

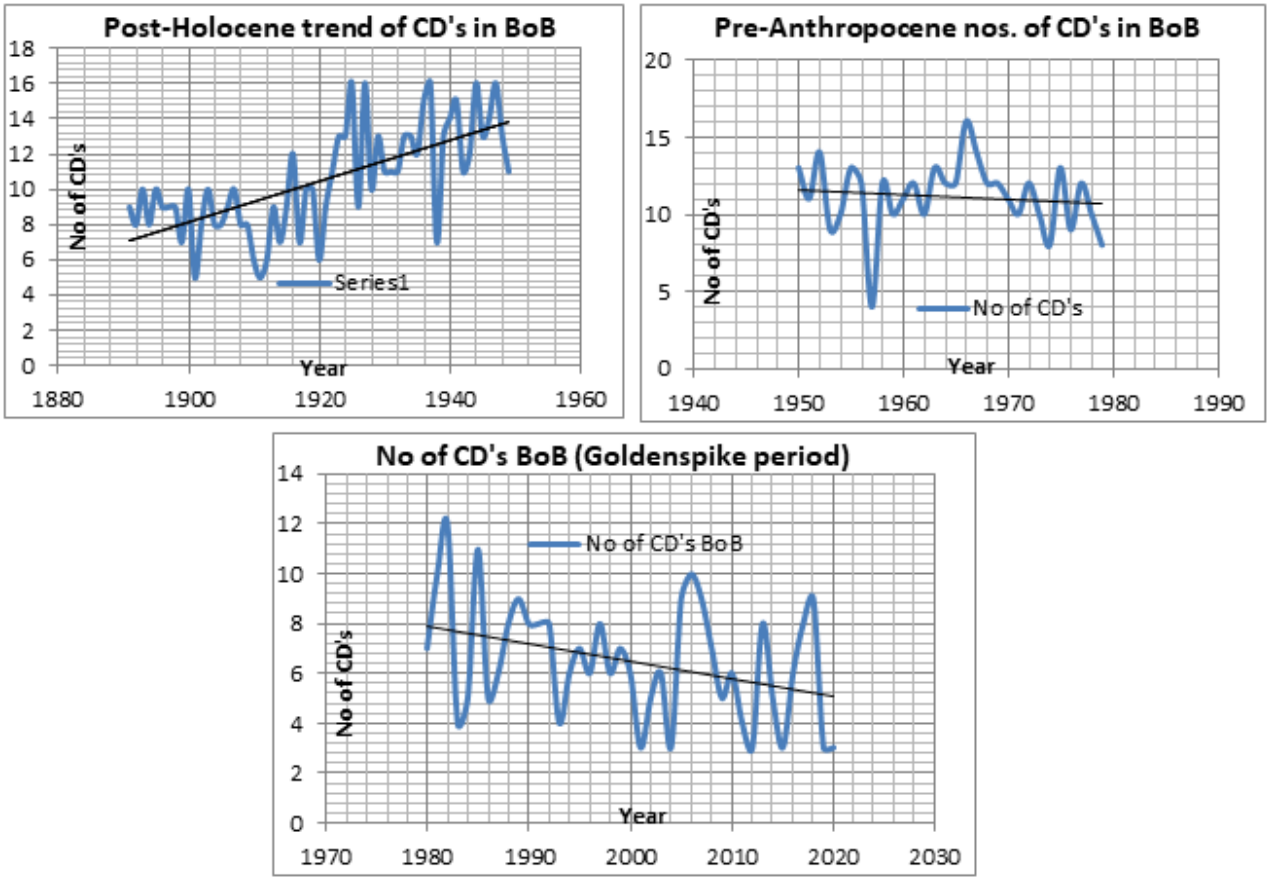

Figure 4

(a) & (b) : Number of CD's in BoB during post-Holocene and Pre-Anthropocene CD's in BoB (C): The annual trend of CD's in BoB (Golden spike period of Anthropocene Epoch

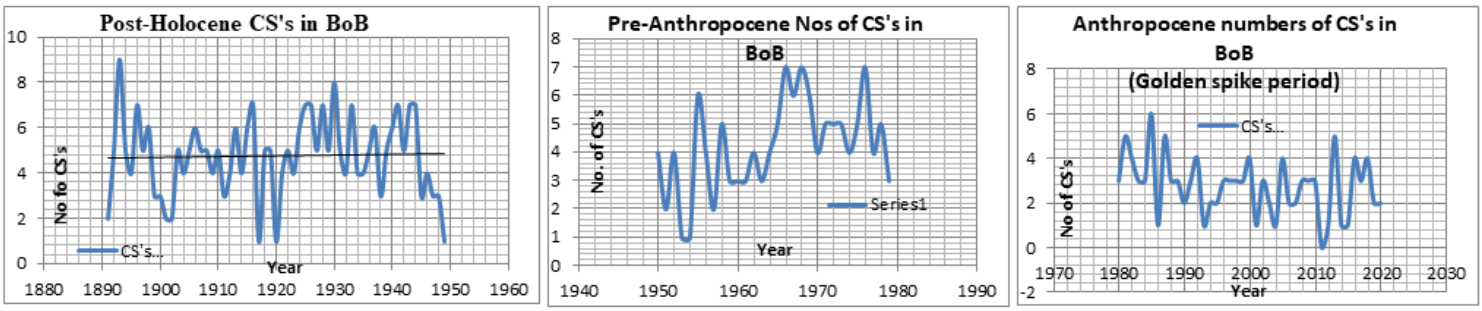

Figure 5

(a): Trend of post-Holocene CS's in Bay of Bengal (b): Pre-Anthropocene Epoch, and (c) Golden spike period trend of CS's in BoB.

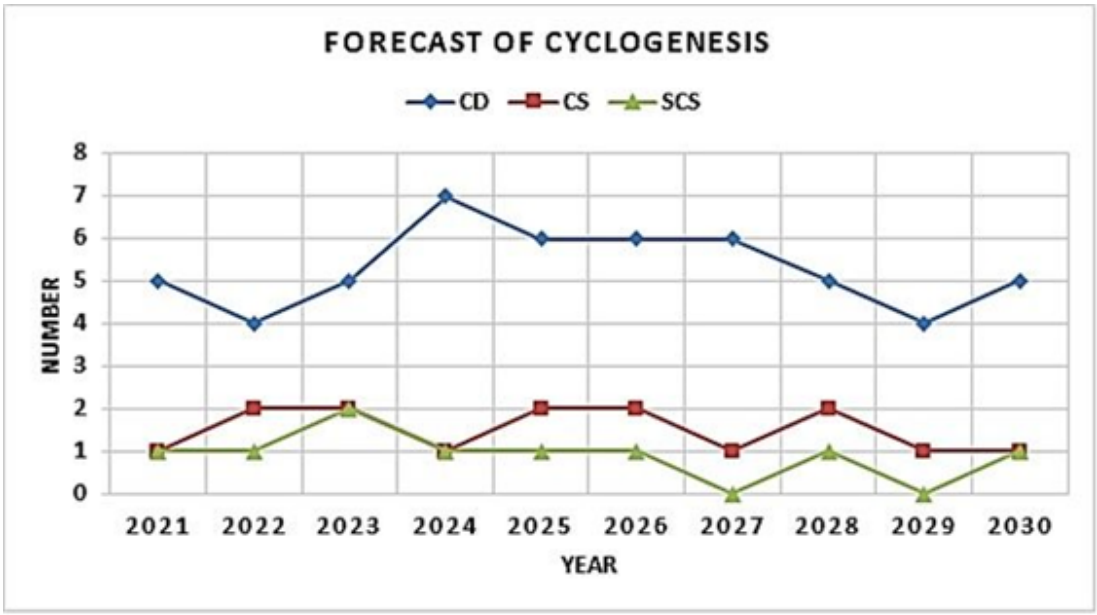

Figure 6

Cyclogenesis Forecast using SMOreg

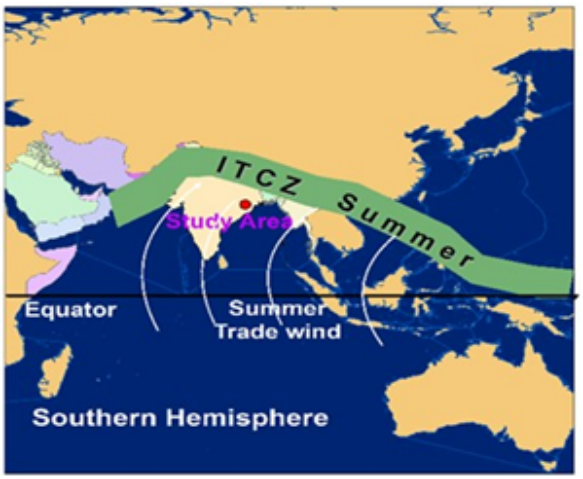

Figure 7

Positioning of ITCZ in Indian subcontinent during summer days (Source: modified: https://scied.ucar.edu/docs/why-monsoons-happen