STORM IMPACT ON SOUTH ODISHA COAST, INDIA

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ABSTRACT

Cyclonic storms from Bay of Bengal (BoB) are the usual phenomenon in East Coast of India. Storms hitting Odisha coast are part of storms originated in Bay of Bengal (BoB). Few of these storms hit the South Odisha coast between Gopalpur (Gpl) and Puri. Major storms crossed the Puri- Gopalpur coast in 20th century had devastated large areas of South Odisha. The last very severe cyclonic storm (VSCS) named PHAILIN, crossed Gopalpur coast on 12th October 2013 causing catastrophe after 14 years. The recent VSCS (HUDHUD) though crossed north Andhra coast but influenced severely the south Odisha coast on 12th October 2014. The adoptive measures taken by the administrative departments for both the meteorological events have reduced the number of mortalities and the trauma in the affected area. However, the devastation caused to the nature and its ecosystem is alarming. This paper presents a detailed study on the formation of disturbances in BoB, tracking, classification, and naming procedure. The violent storm PHAILIN has been compared with other prototype storms land falling in the same area and of almost equal intensity.

Key words: PHAILIN, HUDHUD, VSCS, Odisha Coast, Chilika Lagoon.

I INTRODUCTION

Odisha is a state situated in East Coast of India. South Odisha coast is of length 145 km covers Puri, Khordha and Ganjam districts and is densely populated. The state suffers from extreme weather like storms, droughts and floods. 7.4 million People are affected annually out of which 40.5% due to floods and 18% due to cyclone. It is reported that about 50000 mortalities have occurred due to natural disasters in Odisha within a span of 38 years from 1970 to 2007.

Cyclones of Bay of Bengal (BoB) are the regular natural phenomenon that devastates the east coast of Odisha. The state receives 44% of the total BoB disturbances following the West Bengal 24.5%. It has been predicted that there is a decreased trend in frequency and monsoon rainfall along the coastal districts of Odisha [1]. Few studies are reported about this trend in disturbances crossing south Odisha coast. Almost 67% of disturbances formed in BoB, moves northerly or north easterly cross East coast of India during monsoon period. However, balance 33% disturbances either dissipates within the BoB or taking a parabolic path, cross Myanmar coast.

South Odisha coast has not encountered any landfall of storms since last 15th Oct 1999. After 14 years, a severe cyclonic storm conceived in the South West (SW) Bay, in the West coasts of Thailand during 3rd Oct0ber 2013. The disturbance started moving in a WNW direction at a very slow speed of 15-20 km/h towards East Central Bay of

Bengal **Fig 1.** The storm intensified to a cyclonic storm by 9th October 2013. The Sea Surface temperature (SST) during inception was 28-29 ^{0} C with a very low wind velocity. The low wind shear was conducive for gaining turbulence and convection to the storm. The cyclonic storm focused the entire globe for its probable intensities, wind speed, landfall and impacts. The storm was named PHAILIN (Storm 2B) and can be compared with the Super-cyclone of Odisha 29th Oct 1999 and that of Katarina 29th Aug 2005 of USA.

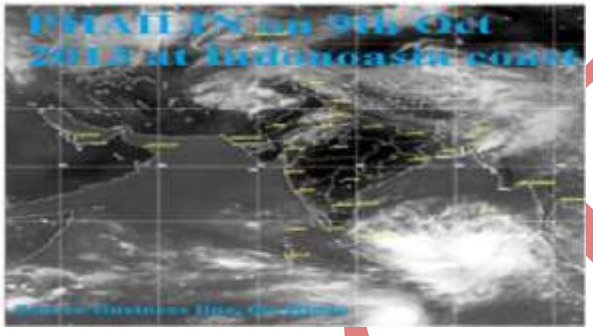


Fig 1: Phalin converted to CS on 09.10.2013

II PREVIOUS STUDIES

Tropical storms of BoB are associated with monsoon movement along the path of the trough line. 7% of global tropical storms occur in North Indian Ocean. The frequency of these disturbances is more in Bay of Bengal in east coast than Arabian Sea in the West Coast of India. History reveals 1840 cyclone through Chilika Lake and the catastrophic severe cyclonic storms of 1848, 1882 left its footprints over the then Puri and Ganjam districts of Odisha [2].

Analyzing RADAR and Radiosondes data of Calcutta and Visakhapatnam, it was predicted high humidity prevails over Orissa coast in the lower and middle troposphere with lapse rate nearly saturated adiabatic [3]. They also reported that disturbances of BoB are originated under vigorous active monsoon condition. They develop low pressure area and cause pressure of any inversion. It was also reported that cyclonic disturbances during active monsoon period (Jul & Aug) and their land falling along North Odisha coast was higher than the south Odisha coast. [2] From analysis of the IMD cyclonic storm from 1974 -1999, the decreasing trend in storm frequencies hitting East coast of India was reported [4].

It was also reported that out of 43 storms generated in the BoB during post monsoon period, 28 numbers weakened and dissipated in the BoB itself. Further, there exist an abnormality between 850hPa and 200hPa in the vertical shear zone with a change from positive to huge negative in the upper air cyclic circulation [5]. The causes of monsoon depression in BoB was attributed to very high sea surface temperature (SST) (>29 ^{0} C) and monsoon trough dips into the North BoB indicating low altitude cyclonic vortices with a high humidity content [7]. West ward propagation of disturbances or in-situ depletion of pressure intensities is the cause for the intensification of the depression to cyclonic storm. Taking statistical data of cyclonic disturbances, it is reported the frequency of land falling storm is

declining with change in monsoon pattern on vetting IMD data from 1891 to 2001 [1].SST is one of the prime causes of creation of disturbances in the ocean [10]. The genesis of cyclonic disturbances in BoB and its correlation with SST in different zones of Bay of Bengal was studied and reported that majority of storms occur with SST 27 ^{0} C to 30 ^{0} C. But there is no established fact of a relation between the storm and the wind speed [6]. Relation between the thermal budget and dynamical characteristics of monsoon storms considering MONEX Data [8 &9] is yet to be established.

The westerly movement of the BoB disturbances was due to negative stream function tendency to the west of a depression [11]. Increased aerosols due to over exploitation of burning fossil fuels have weakened the tropical meridional overturning circulation and are the cause for the decreased disturbance activities in the BoB [12]. On study of the cause of cyclone it reveals that the slower a cyclone propagate, there is more accumulation of energy. The disturbances progress is slower and transforms to a higher stage of cyclonic system. The eye shown in Fig 2 is formed in a CS is the circular wall cloud within which pressure drop (up to a difference of pressure of 90 Hecto pascal (hPa) occur with a clear sky and light wind speed up to 10 to 15 knots and the eye extending from 20-40km depending upon intensity of the storm**.** As the storm touches land the wind direction become 180 deg. Out of phase. Always a cyclonic storm behaves like a heat engine [19].

27 out of 36 catastrophic global tropical cyclones of past in Indian Ocean are formed in BoB. Study of genisis and propagation of such storms univocal. Present study is entrusted with knowledge of the cyclone track, history of cyclones striking South Odisha coast from Gopalpur to Puri. It is extended to understand the configuration and the structural processes of storms over Bay of Bengal. The seasonal variability of cyclonic storms along the study area has been studied in general. Also attempt has been made to confer the impact and adaptability of cyclonic storm PHAILIN land falling Gopalpur coast on 12th Oct 2013.

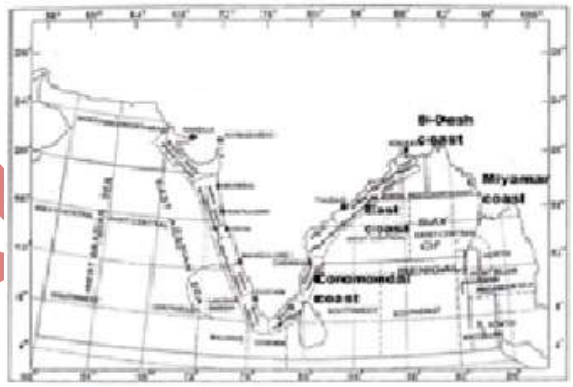


Fig 2: Zoning of Bay of Bengal and Indian coast

III DATA AND METHODOLOGY

The data utilized for the study are both primary and secondary. Secondary data consists of formation of different cyclones, period, impacts and tracking of different cyclonic storms of Bay of Bengal for two centuries. The

information is collected from different institutions like print media, electronic media, local field visits. Data processing is done by adopting appropriate statistical method. The maps and their study have been prepared taking help of meteorological personnel. Microsoft Excel, and various cartographic techniques used for better representation of the collected data. Satellite imagery studies have been conducted to trace the track and land fall. Local administration has been interacted for the casualties /trauma caused by the storms. Observations were taken at Puri beach. Field visits to the lagoon and tidal inlets were made. The visit and collection of field data of the river system connected with the lake is considered as primary data.

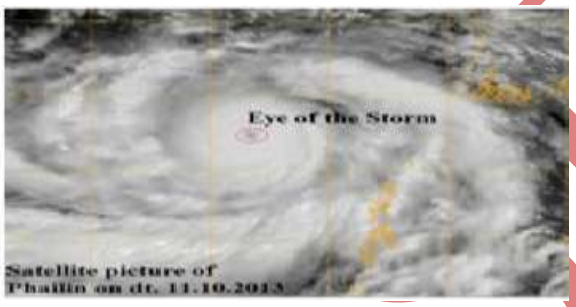


Fig 3: The Eye Phailin on 11.10.13

IV FORMATION OF CYCLONES

The vast area of sea from east coast of India to Thailand and equator to coastal areas of Bangladesh is about 4.4 million sq km approximately. No cyclones develop in equatorial region between 5N to 5S latitude as the coriolis force and wind speed is insignificant (Doldrums area). The sun earth geometry from September onwards causes a thermal lag in the equatorial region of Indian Ocean. The enormous latent heat stored (lasting for about 45 days) between the thermo-cline and the sea surface (about 100 to 200m depth) make conducive environment in North Bay for formation of disturbances [19]. There exist vortices, source and sink above and below 700 hpa level of the troposphere between 11^0 to 13^0N Latitude. After genesis, the disturbances propagate in a southerly direction due to Coriolis force during post monsoon period [8].

The SST pattern is influenced by Equatorial Trade Wind, El Niño, La Niña and ENSO also leave foot prints on the oceanic disturbances and monsoon rainfall trend in Bay and Indian peninsula [18]. In South Indian Ocean of Northern hemisphere, the cyclonic circulation is anti-clock wise. High temperature rise in SST results in declining the atmospheric pressure. The alteration in thermal profile and change in vortices form a low pressure area helps to intensify a disturbance further to cyclone. The rate of progress of this circulation decides the intensification of the disturbances. There is depletion in frequency of cyclonic disturbances on BoB during 20^{th} century but there is considerable increase in SST and surface air temperature (SAT). Similarly, it is debated about mid troposphere humidity. Anomaly in pressure in the vertical shear zone, increase in aerosol shall prompt for increase in intensity and abnormality in the formation of cyclonic storms in Bay of Bengal in near future.

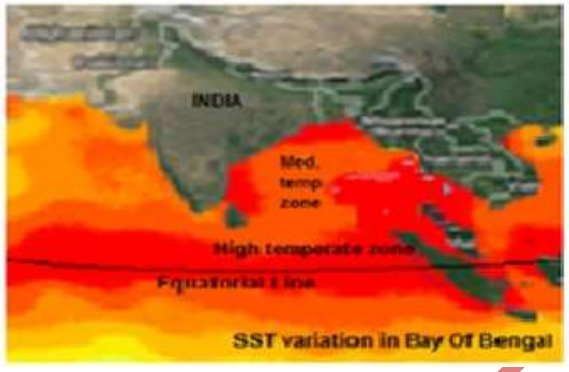


Fig 4: Trend in temperature variation in Bay of Bengal and coastal India

4.1 Stages of Cyclone

Generally tropical cyclones have four stages genisis (formation) stage, deepening (intensification) stage, Mature (occluded) and decay (Shearing) stage. Different countries classification, naming and stages of cyclones are different. To avoid those anomalies, the various stages of cyclone as per Beaufort wind force scale and India Meteorological Department convention [15]. **(Table I)**

4.2 Naming a cyclone

According to 27th session, 2000 on tropical cyclones held at Muscat, Sultanate of Oman, the members of WMO and Economic and Social Commission for Asia unanimously agreed upon naming each storm in the Bay of Bengal and the Arabian Sea from Sept-2004. Once the wind speed exceeds 62 km/h or more (the lower limit of cyclone) the disturbance is named from the approved panel of names prepared by WMO and decided by Regional Specialized Meteorological Centre (RSMC) New Delhi both for cyclonic storms in Bay of Bengal and Arabian Sea. The names are being given without repetition but chronologically as per the approved list. PHAILIN, the Tropical cyclone 02B,which remained active from 9th to 12th Oct 2012 in the Central Bay of Bengal with sustained winds of 100 knots gusting to 125 knots was named by IMD. The RSMC list of names of tropical cyclones in North Indian Ocean is given in table II (source IMD).

V GENERAL TREND IN MOVEMENT OF CYCLONES

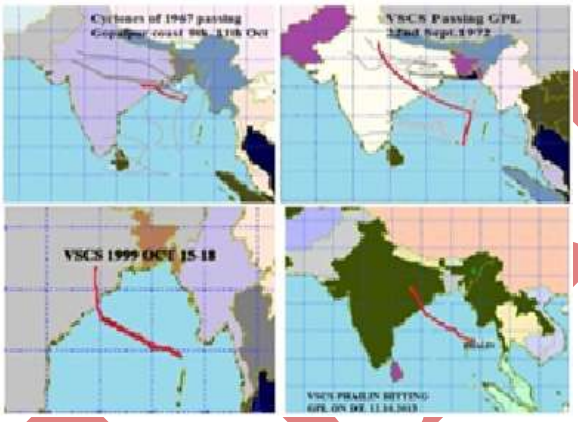
During JFM months, there is less chance of formation of cyclonic storms in BoB and a chance of hitting Puri- Gpl coast is least. They originate between 5^0 N to 8^0 N (South Bay of Bengal) and move westerly and hit between the east coast of Ceylon and south Tamilnadu coast. During the months of April the storms form between 8^0 N to 15^0 N and nearly at 85 ^{0}E move initially in a NNE-ly direction. But those forms in May as in the month of April, generally move in a N-ly direction, later take a NE-ly parabolic curvature and cross Arakan Coast of (Myanmar), Bangladesh or North East coast of India [13]. In the months of JJA months (SWM period), BoB storms changes its place of

origin to east or west central Bay between 16^0 N to 21^0 N and 90^0E - 92^0 E. Most of these storms move NW or Westerly direction and weaken after land falling. But disturbances formed during August take northerly parabolic curvatures. In the month of September, these disturbances start from 15 ^{0} N - 20 ^{0} N and 85^0 E - 90^0 E moves in a WNW direction and finally reach land after taking a North-Easterly move.

But during Oct-Nov months, most of the storms created between 8^0 N to 14^0 N. They initially move a long distance in NW-direction and finally take a NE turn and hit land between Andhra and Bangladesh coast. The frequency of Bay of Bengal storms during these months are the highest. But storms striking Coromondal Coast, move through the land, emerge in the Arabian Sea and re-intensify. Further the intra-seasonal oscillation activity in Indian land mass and adjoining Bay of Bengal is more during dry years than active periods which may have influence on tropical cyclones [17].

5.1 Cyclones of south Orissa

Cyclonic storms (except Depression and Deep Depression) that have land fall between Gopalpur and Puri coast has been collected from 1840 to 2013 and analyzed in table III**.** The cyclones hitting South Odisha coast in different months given in Fig 6.



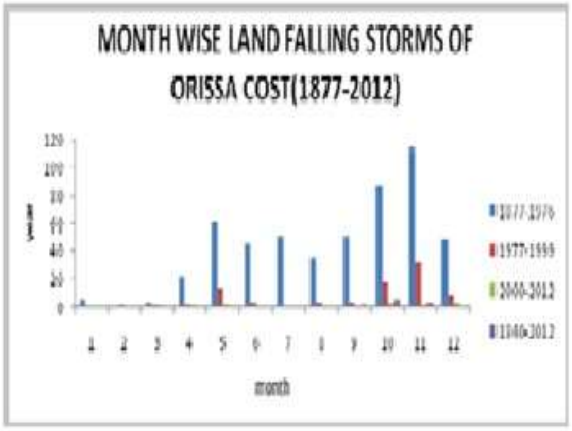


Fig 5: Comparison of tracks of cyclonic storms slam S78outh Orissa coast (1967, 1972, 1999 & 2013)

Fig 6: Frequency of cyclonic storm crossing Puri Gopalpur coast 1877-2013

To track the cyclone and study various parameters related to the cyclone, three very severe cyclonic storms (VSCS), one on 5th to 10th Nov 1995, 2nd on 15th to 18th Oct 1999 and the third PHAILIN from 9th - 12th Oct 2013 have been considered in table IV. These storms having land fall in the same area are compared. Data related to four past disturbances 1967, 1968, 1972, 1999 of BoB land falling near Gopalpur of Odisha coast have been collected from UNISYS weather data (Fig 5).

The disturbance Phailin as a Low Pressure started over Tenasserim coast south Indian ocean on 6th October 2013. It propagated to north Andaman Sea as a well marked low pressure area on 7th October. Then it was developed to a

depression on 8th Oct. (Lat. 12.00N and Long. 96.00E. On 9th it converted to Deep depression moving WNW, further intensified into cyclonic storm (CS) then to a VSCS on 10th Oct. IMD reported the VSCS rossed Gopalpur coast on 12th Oct at 10.30 PM with windspeed 215kmph wind speed when the central pressure was 940hPa (ΔP= 66 hPa).[20]

It is evident that the fierce Cyclone PHAILIN (Category-5) was a Super cyclone rather than a very severe cyclonic storm. To establish the fact a comparison has been made from the data received from the UNSYS system of Gopalpur and IMD data Puri which is 100km NE of Gopalpur. The data taken are hourly wind speed/direction, corresponding rainfall along with the difference of pressure in hPa from 12th Oct to 13th October 2013 (Table V).

Fig 7: Tracks & area of influence of Phalin, 2013

VI IMPACTS

"It is forecast to slam an area populated with "4.5 million People, our thoughts go out to all those living in the cyclone's path," Jim Yong Kim, the president world bank said about the storm PHAILIN at the close of the annual World Bank-International Monetary Fund annual meeting. The full credit of 4% death toll due to a prototype cyclone of Storm 05B hit Paradip on 29th Oct of 1999 is awarded to local government of Odisha. 21 deaths reported during activity of the storm PHAILIN. Only those people died who could not move to a safer place. Cyclone Phailin hit 12 districts, 89 Tahsils and 14,514 villages of Odisha, said the Indian Army overseeing and rescue operation on Sunday. (India Today 26th Oct 2013) World Bank thanked the local government of Odisha for taking appropriate steps by evacuating 450000 people in Odisha to safer places during cyclone only. As per the report of local Revenue Minister 361000 people evacuated in a single day on 12th October only from 10 districts, highest of 120000 from Ganjam district followed by Puri, 80000 people. For this herculean task the state machineries were in top gear from 9th of October after receiving the warning from India Meteorological Department. Government of Odisha through its disaster management wing has been prepared to combat such a natural calamity from 2000.

The cyclone was accompanied by a devastating flood due to the deep depression rain in the eastern peninsular India. As per the report of Government of Odisha, the severe cyclonic storm and the accompanying flood ransacked 17 districts comprising 151 blocks, 18117 villages, 43 urban local bodies (ULB) with a population of 12.4 million of

the state. Human casualties due to cyclone were 21 and flood mortalities were 17 only. 22 blocks, 2812 villages, 18 urban local bodies are severely affected in Ganjam district and 11 blocks, 230 villages and 4 ULB'S of Puri district respectively are severely affected as per Local government report. The minimum deaths that occurred were 10 in Ganjam and 3 in Puri district. In total 4400 animals both large and small and 171 thousand numbers avifauna lost their life. (Report GOO 17th Oct). Beyond loss of lives, the ensuing storm is not less than that of 1999, 05B Super cyclone damages. 668 thousand Ha of crop area affected both due to cyclone and following flood in this present storm.

Similarly it is observed if there is no storm in BoB, there is a tendency of closure of mouth in the Chilika lagoon due to long shore drift.

Two major land marks of the present cyclone were sand casting and high long shore drift. There was 3.5 to 4.0 m of storm surge at the barrier spit of Chilika Lake. The outcrop of the VSCS is the partial closure of the tidal inlet of the artificial dredged old mouth near village Sipakuda. There was no overtopping along barrier spit though a large amount of water entered the Lagoon inundating the suburb low lying areas. The mouth was silted up and dragged about one km, partially closing the Sipakuda tidal inlet. Similarly the effect of the cyclone was severely felt at the Puri coast with sand casting of about 20cm to 50cm at a distance up to 500m near the shore with a storm surge of 3.0 to 3.5 m [Fig 9(C)]. Government officials reported the VSCS PHAILIN weakened before land falling hence the devastation was less.

6.1 Impact of storm 05B of 1999 and Phailin 2013

The comparison between the impact of the disasters caused by the two cyclones of 1999 and 2013 is shown in table VI. On comparison of two prototype storms that of 1999 and 2013, it is observed that the mortality rate has reduced drastically from 183 to 10 in Ganjam district only [16].

VII DISCUSSION

In general cyclones can neither be created nor be prevented from land falling except ameliorating its vulnerability by taking preventive measures.

About track: Mostly cyclonic storms in Bay of Bengal are originated during monsoon period in the east or west central Bay of Bengal during SW monsoon and move in a NW or westerly direction. During post monsoon period they are created in South or SE zone of Bay of Bengal near to equator move either in NW-ly initially and finally take a NE turn and hit East coast. But those cyclones which landfalls in between Puri and Gopalpur coast are generally originated in the eastern part of the Central Bay and move in a NW direction. Fig 7 shows the track of storm PHAILIN.

About frequency: Odisha coast is hinterland for cyclonic disturbances. From 1901 to 2013 the numbers of disturbances hitting East Coast of India are 682. Out of which 47.95% has struck Odisha coast. But the number of such disturbances land fall Puri-Gopalpur coast is 24 i.e.5.13%. The maximum number of cyclone land falling hit

Odisha coast during October and November as per 1877 to 2013 data. Very severe cyclonic storms with severe damages were observed in the years 1909, 1910, 1912, 1914, 1967, 1968, 1971, 1972, 1989, 1995, 1999 and 2013.

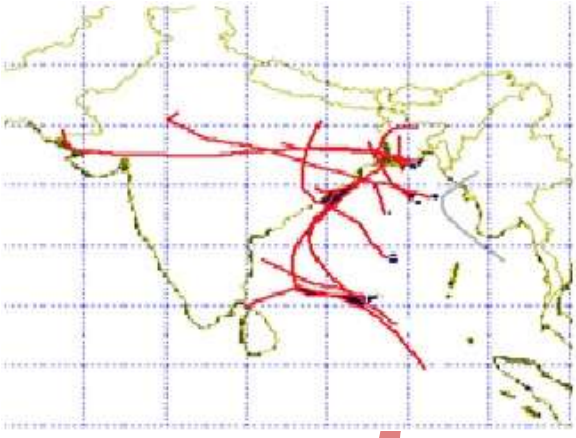


Fig 8: Storm tracks of maximum storms passing south Orissa coast 1968.

Storm year 1968: The year 1968 (21st to 28th October and 10th to 13th November) is considered to be the most devastating year for the lagoon Chilika so also south Orissa coast. A number of storms either slam the coast or they have passed near the coast (Fig 8). This was resulted in silting up of few channels in the vicinity, the river Dahikhia, Sunamunhi and drainage channels like Chammu and Eknalia leading to Chilika. The sea and the lagoon geometry has altered by creating three new tidal inlets (Sanpatna, Kalabanta and saibahata) and resulted in changing the chemistry, ecology and morphology of the lagoon. From that period the health and ecosystem of the lagoon has been deteriorated.

The difference: At the time of slamming the coast near Gopalpur on 12th Oct, maximum sustained surface wind speed of the cyclone was about 115 knots (215 kmph) and estimated central pressure was 940 hPa with pressure drop of 66 hPa.(IMD) [20]. But the Joint Typhoon Warning Center (JTWC) has estimated the wind velocity as 140 knots (240 km/h) with gusting wind 170 knots (290 km/h), a category 5 tropical cyclone to PHAILIN. The controversy that the ensuing cyclone PHAILIN whether a VSCS or a Supper Cyclone is still under debate. Considering maximum wind speed criteria, PHAILIN may be categorized as a super Cyclone but the pressure drop criteria the storm find a place as VSCS type. The T-number attached to the storm was 6 by the India Meteorological Department and danger signal number 10 was hoisted at Puri and Gopalpur Port. The central pressure difference has identified as a VSCS. The storms,HUDHUD and Phailin are prototype, originated from identical area and moved almost in the parallel track but there is wide difference in intensity, wind speed,central pressure difference. There is wide difference in rainfall as an impact of the prototype storms.(Fig-9) and Table -5

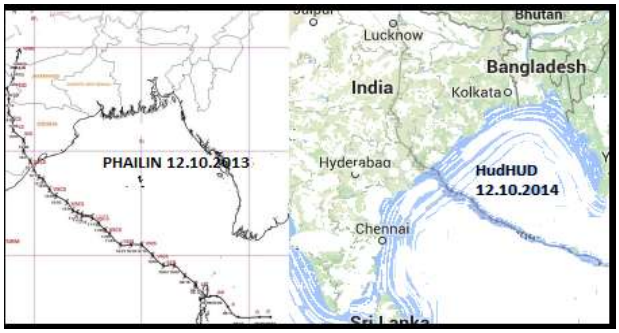


Fig 9: Track comparison between Phailin and Hudhud

Fig 10: LANDSAT Imagery closure mouth chilika South Orissa, Coast on 18-10.2013 (Images: USGS/NASA)

7.1Anthropogenic activities

Human interventions over the hydrologic system started from the second half of twentieth century. Before 1950, as a natural process the air and the surface of the Bay of Bengal and Arabian Sea was warmed up and loaded with moisture due to evaporation and evapo-transpiration. The warm upper air was propagating NE direction from high to low pressure region. This was causing the moist air to get cooled up at higher altitude causing precipitation over the land and sea. However, in the 2nd half of 19th century, due to anthropogenic activities and the increased GHG concentration in atmosphere, a protective layer of CFC gasses is created and triggering to reflect the moist air to the sea from land. This phenomenon is one of the main cause of decreased rainfall on the land mass and creation of less number of disturbances in the Bay. In case of PHAILIN, it is observed that such a super cyclone with wind speed of more than 240 km/h has given rainfall of 15cm only but a large amount of sand is blown to the coast.

Adaptation: Thousands of mortalities and morbidities have been saved due to proper tracking,

warning, maintaining intact telecommunication, sufficient evacuation from coastal areas and pre-operational rescue measures as disaster management. During the period of land falling, Vehicles toppled for hours; house hold materials flew like projectiles and caused turmoil disrupting communication. But the proper management and appropriate adaptability to combat the storm have saved many a lives. As aftermath of storm Phailin, a tidal inlet that was opened from the Chilika lagoon to Bay of Bengal near Sipakuda on Sept 2000 has been closed partly due to sand accretion and long shore drift (Fig 10).

Just after the swell in the adjacent Chiliika Lake, most of the fishes and shrimps moved away to Sea and the lake is today deficient of aqua fauna. The mangrove around and in the barrier spit has been ruined causing biodegradation and a heavy ecology loss. However the endangered species like Irrawadi dolphin, the guest winged birds have not fall short of their regular number. Though the mangroves along the shore have been shattered, the time shall heal the loss (Fig10)

VIII CONCLUSION

From the above discussions, it is imperative that the cyclonic storms in Bay of Bengal form throughout the year and movement are along the trough line. CS, SCS and VSCS that hit Puri-Gopalpur coast are periodical but there is no consistency in period of recurrence which even exceeds more than 10-20 years.

During pre monsoon more than half the disturbances converted to CS and balance weakens. Odisha coast receives less than 5% in Bay of Bengal during that period. Those storms formed during monsoon cross east coast of India more than 60%, where as North Odisha receive major percentage of it. The Post monsoon period (Oct-Nov months) south Odisha and North Andhra coast receives the major share of total more than 10% of storms heating East coast of India. But during winter south Odisha coast receives minimum number of cyclonic storms.

Regarding place of origin of cyclonic disturbances in Bay of Bengal, during winter (DJFM months) the small numbers of disturbances are formed east or South Andaman Sea propagate in a W or NW-ly direction. During (Apr-May) months, the frequency increases, the place of start is 10 ^{o}N to 15 ^{o}N near Andaman Islands and NW or N-ly direction. When monsoon is active (JJAS months) the storm activities are originated in East or west central Bay of Bengal and intensity of such storms are less. But the havoc causing cyclonic storms originate at S or SE Bay of Bengal, propagate a large distance and intensify even to super cyclones during the post monsoon months (Oct to Dec)

The cause of formation of BOB disturbances is mainly due to formation of vortices due to high sea surface temperature (SST) and low velocity propagation of storms. The formation of such storms is influenced by La Nino, La Nina and ENSO activities of Pacific Ocean.

Storms are major causes of opening and closing of tidal inlets in the barrier spits of Chilika lake and being triggered by eclipses. The cyclonic storms crossing between Puri and Gopalpur coast at times alter the dimension of the tidal channel; either closes or opens mouths from the lagoon to the Bay.

Adequate adaptive measures and precautionary actions can ameliorate the deadly un-eventualities of a storm. Exemplary case is the devastator storm, the Phailin in comparison to previous storms that passed South Odisha Coast. Adaptability lessons learned of combating severe cyclones from PHAILIN can be well implemented to other prototype cyclonic storms of the globe [14].

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REFERENCES

1. **Mohapatra M, Mohanty U. C. (2006):** “Hydrological aspect of cyclonic disturbances influencing Orissa” http://nidm.gov.in

2. **Chittibabu et al (2004):** " Mitigation of flooding and cyclone hazard in Orissa, India", Natural hazards vol. 31 pp 455-485
3. **Rao Y. P. et al (1970):** "Discussion of typical synoptic weather situation, South West Monsoon – active and week monsoon over Orissa" Forecasting manual part III India meteorological department FMU. Rep. No III-3.2.
4. **Alam M. M. et al (2003):** "Frequency of bay of Bengal cyclonic storms and depressions crossing coastal zones" International journal of climatology, Volume 23, pp- 1119 to 1125.
5. **Mandke S. K. et all (2003):** "A study on decreasing storm frequencies over bay of Bengal" Journal India geophysics Union, Vol - 7(2) pp- 53-58
6. **Saha D. R.,(1977):"**Some aspects of life history, structure and movement of monsoon depression" ,Pure and Applied Geophysics, Vol 115 p- 1501-1529
7. **Sikka DR. (1980): "**Some aspects of the largescale fluctuations of summer monsoon rainfall over India in relation to fluctuations in the planetary and regional scale circulation parameters". Proc. Indian Acad. Sci. Earth Planet. Sci. 89:179–95
8. **Rajamani et al (1989**): "Some dynamical characteristics and thermal structure of monsoon depression over the Bay of Bengal", Tellus 1989 Vol 41 A pp 255-269
9. **Saha, K., and Saha, S., 1988:** "Thermal budget of a monsoon depression in the Bay of Bengal during FGGE-MONEX 1971". Mon. Wea. Rev., 116, 242-254.
10. **Ramesh kumar M. R. et al (2010):** Impact of global warming on cyclonic storms over north Indian ocean" Indian Journal of Marine Sciences, Vol. 39(4) pp- 516-520
11. **Chen Tsing-Chang et al (2005):** "Westward propagation of Indian monsoon depression", Tellus (2005), Von. 57 A, PP – 758-769
12. **Bob Yirka (2011**):"Research model shows monsoon change in India may be result of manmade aerosols", phys.org.com
13. .**Muthuchami A**. et al (2007):"Probable storm motion in the bay of Bengal in April and May" Journal Indian Geophysics Union, Vol II, No -4, pp 209-215
14. **UNEP Global Enviornmental Alert service (2013):** "Cyclone Phailin in India : Easrly warning and timely actions saved lives", Thematic Focus, Enviornmental governance, disasters and conflict, www. Unep.org./geas . Com ,
15. **Siddiki, U.** R. et al (2012): "Cyclonic track analysis using GIS over Bay of Bengal" International Journal of Applied Sciences and Engineering research, Vol. 1 Issue -5 pp689-701
16. **Government of Odisha (2012): "** Ganjam District Disaster management Plan 2011 -2012**"** District Emergency Operation centre , Ganjam, Chhatrapur, Odisha
17. **Mishra V. et al (2012): "A** comparative study of the Indian Summer monsoon hydro-climate and its variation in three reanalysis." Clim Dyn, DOI 10.1007/s00382-012-1319-y, Published online: 8th march 2012, Springer.

18. **Krishnamurthy L. , Krishnamurthy V. (2013):** "Influence of PDO on South Asian summer monsoon and monsoon-ENSO relation" UCAR/NOAA Geophysical Fluid Dynamics Laboratory, Princeton University Forrestal Campus, 201 Forrestal Road, Princeton, NJ 08540-6649, E-mail: Lakshmi.Krishnamurthy@noaa.gov, COLA Technical Report 321,March 2013
19. **Ranganathan C.** (2012:" "Descriptive & illustrated meteorology and weather" Flat 201, Montana heritage estate, Dodabalpur Road, Banglore 560-564
20. **India Meteorological department,(2013):"** Very Severe Cyclonic Storm, PHAILIN over the Bay of Bengal (08-14 October 2013) : A Report **",** Cyclone Warning Division**,** India Meteorological Department, New Delhi ,October 2013

Table I: Classification of cyclonic storms as per World Meteorological Centre and India meteorological Department.

Sl	Type of disturbances	T-number	ΔhPa	Wind Δspeed (knot)	Wind speed km/h	Beau-fort Scale	Wind descriptive terms	Wave height (m)	Sea state	Sea descriptive term
1	Depression (D)	1-1.5	…….	<28	31	0-6	Calm-strong breeze	0-3	0-5	Calm-rough
2	Deep depression (D0. D)	2.0	4.5	28-33	51-61	7	Near gale	4.0	5-6	Rough –very rough
3	Cyclonic Storm (CS)	2.5-3.0	6.1-10	34-47	62-88	8-9	Gale-severe gale	5.5-7.0	6-7	Very rough-high
4	Severe Cyclonic Storm (SCS)	3.5	15	48-63	89-117	10-11	Storm-violent storm	9.0-11.5	8	High-very high
5	Very severe cyclo-nic storm (VSCS)	4.0-6.0	20.9-65.6	64-119	118-220	12	Hurricane	14+	9	phenomenal
6	Supper cyclone (SC)	6.5-8.0	>80	>120	≥221 km/h	12	Hurricane	14+	9	phenomenal

Table II: Names of different RSMC cyclones in Bay of Bengal and Arabian Sea (North Indian ocean)

Country/sl	**Bangladesh**	**India**	**Maldives**	**Myanmar**	**Oman**	**Pakisthan**	**Srilanka**	**Thailand**
Name (1-8)	Onil	Agni	Hibaru	Pyarr	Baaz	Fanoos	Mala	Mukda
9-15	Ogni	Akash	Gonu	Yemin	Sidr	Nargis	Rashmi	Khaimuk
16-22	Nisha	Bijli	Aila	Phyan	Ward	Laila	Bandu	Phet
23-29	Giri	Jal	Keila	Thane	Murjan	Nilam	Mahasen	Phailin
30-36	Helen	lehar	Madi	Nanauk	Hudhud	Nilofar	Priya	Komen
37-43	Chapala	Megh	Roanu	Kyant	Nada	Vardah	Asiri	Mora
44-50	Ockhi	Sagar	Mekunu	daye	Luban	Titli	Gigum	Phethai
51-57	Fani	Vāyu	Kikaa	Kyarr	Maha	Bulbul	Soba	Amphan

Table III : Bay of Bengal Cyclonic disturbances Severe Cyclonic storms (SCS) and Very severe cyclonic storms VSCS) and CS Super cyclonic storm crossing Gopalpur to Puri coast, Odisha.

Sl No	Year/ date	Type	Landfall	Surgeht. mtr	wind km /h	Damages caused	Reference
1	27Apr/1840	VSCS	Chilika	--	--	Most severe damage in Puri	Tripathi S 2011
2	1842	SCS	Puri	--	--	Flood in Puri and Khordha district	Chittebabu 2004 [2]
3	13Oct/1848	VSCS	Puri	--	--	Tower of Konark temple was damaged	Tripathi Sila 2011
4	6 sep/1882	VSCS	GPL	--	--	Heavy flood	Chittebabu 2004
5	19 Nov/1889	VSCS	GPL	6.1m	--	Rapid dissipation of severe storm	Chittebabu 2004
6	18/Jun1890	VSCS	Chilika	observed	--	Extensive damage by surge	Chittebabu 2004
7	1/July/1890	SCS	Puri	--	--	Less damage	Chittebabu 2004
8	Nov 1891	VSCS	Puri	--	--	Fleets damaged. 548 death	Tripathi S 2011
9	10/June1892	VSCS	Puri	--	---	Heavy rain/ extensive damge	Chittebabu 2004
10	7/Sept1892	VSCS	Puri	--	--	Heavy rain	Chittebabu 2004
11	21/Sept1893	VSCS	Puri	--	--	Heavy rain	Chittebau 2004
12	26/Oct 1909	SCS	GPL.	--	--	22 deaths/Severe damage	Pattanaik ,2011
13	13/May1910	SCS	GPL	--	--	Heavy rain	Chittebabu 2004
14	13/Nov1923	VSCS	GPL	--	--	20 deaths/ Highflood/ severe damage	Chittebabu 2004
15	19/Nov1924	SCS	GPL	--	--	Damage to crops and structures	Chittebabu 2004
16	4/Nov 1936	VSCS	Puri	--	137	Severe flood Puri dist.	Chittebabu 2004
17	10/ Oct. 1938	VSCS	Ganjam	-	170	Severe damage	Chittebabu 2004
18	16/Nov. 1942	VSCS	Ganjam	Super Cyclone	168	close to coast and weakened/ heavy loss	Chittebabu 2004
19	22Sep1943	SCS	Chilika	--	--	Less damage	Chittebabu 2004
20	22/July 1951	SCS	Puri	--	--	Heavy rain	Chittebabu 2004
21	19Aug1957	SCS	Chilika	--	--	Heavy rain	Chittebabu 2004
22	9-11th Oct. 1967	VSCS	Puri	5m/25 km u/s	157	1100 lives lost, 50,000 cattle perished	De U. S. 2005
23	10/Sept / 1968	SCS	Chilika	25km U/S	111	26.9 lakh ha affected Full solar eclipse	De U. S. 2005
24	26 Sept / 1968	SCS	Chilika	25km U/S	111	78 deaths,26.9 lakh ha Full solar eclipse High flood	De-05/Chhit ebabu -2004
25	29 Sept / 1968	SCS	Chilika	--	--	Heavy rain/flood	De/ 2005 /Chhi tebabu -2004
26	10 Nov / 1968	SCS	Chilika	5km U/S flooded,	--	78 deaths,26.9 lakh ha Full solar eclipse High flood, New mouths	De 2005/Ch hitebabu -2004
27	7/Sept	SCS	Gpl	-	185	90 deaths, Structures/crop damage	W. B.Report /03,

	1971					6240000 ha	Chhite babu/04
28	22 Sept 1972	VSCS	GPL	Surge 2.4m	136	130 death/Severe damage to property and crop	Imd.GOI, Khatua 2000
29	7/Aug 1981	SCS	Puri	-	83	15 deaths/High flood,	Chhitebabu - 2004
30	24 Sep 1981	SCS	Puri	-	102	Less damage in study area	Chhitebabu -04
31	20/Sept 1985	SCS	Puri	2.8m	-	Substantial damage	Chhitebabu - 2004
32	21/ Jul 89	SCS	GPL	2.0	102	Affected North Andhra coast	Chhitebabu -04
33	7th Nov 1995	VSCS	GPL	1.5m R.	111	96 deaths,.28 Mha crop damaged	Chhitebabu/04
34	15th Oct 1999	VSCS	GPL	2.0m Rushi R.	185	295 Deaths/ 331Th houses , crop affected 1.58M ha	Khatua 2000/ Chhitebabu/04
35	12th Oct 2013	VSCS flood Odisha	GPL	4.5m	240	21 deaths(CS), flood 17, 123.96 ha crop affected Died: Cattles 1487,small animals 2906, birds 170970 as on 17.10.2013	NDTV data

Table IV: Comparision of position and windspeed of storms slammed Puri-Gopalpur coast, 1995, 1999 and 2013

VSCS 5th-10th Nov 1995 (UNISYS data)			VSCS 15th-18th Oct 1999 (UNISYS data)			VSCS 9th-12th Oct 2013 (UNISYS data)		
Date/time in IST	Lat 0N / Long 0E (Position)	Wind speed Km/h	Date/time in IST	Lat 0N/ Long 0E Position	Wind speed Km/h	Date/time in IST (Position)	Lat 0N / Long 0E (Position)	Wind speed Km/h
5th/1730	8.6/96.4	28 (D)	15th/ 0530	14.5/92.7	37 (D)	9th/0530	13.2/93.4	65(CS)
5th/2330	9.1/95.3	28(D)	15th /1130	15.2/91.4	46 (D)	9th/1130	13.4/92.8	74(CS)
6th/0530	9.6/94.3	37(D)	15th /1730	15.4/90.2	56 (DD)	9th/1730	13.7/96.2	74(CS)
6th/1130	9.9/93.6	37(D)	15th/2330	15.8/89.3	83 (CS)	6th/2330	14.1/91.6	93(SCS)
6th/1730		37(D)	16th/0530	16.2/88.3	83(CS)	10th/0530	14.4/91.3	102(SCS)
6th/2330	10.6/92.2	46(D)	16th/1130	16.6/87.4	103(SCS)	10th/1130	14.9/91.0	120(VSCS)
7th/0530	11.3/91.4	56(DD)	16th/ 1730	17.1/86.5	103(SCS)	10th/1730	15.4/90.3	185(VSCS)
7th/1130	12.0/90.4	65(CS)	16th/2330	17.5/85.8	148(SCS)	10th/2330	15.6/89.4	232(SC)
7th/1730	12.6/99.2	65(CS)	17th/0530	17.7/85.3	222(SC)	11th/0530	15.8/88.8	250(SC)
7th/2330	13.0/87.9	93(CS)	17th/1130	18.0/84.9	222(SC)	11th/1130	16.1/88.4	250(SC)
8th/0530	13.8/86.9	103(SCS)	17th/1730	18.5/84.7	222(SC)	11th/1730	16.7/87.7	259(SC)
8th/1130	14.7/86.0	103(SCS)	17th/2330	19.2/84.7	180(SCS)	11th/2330	16.987.1	259SC)
8th/1730	15.6/85.1	130(SCS)	18th/0530	20.1/84.6	167(SCS)	12th/0530	17.4/86.5	259(SC)
8th/2330	16.5/84.2	130(VSCS)	18th/1130	21.1/84.5	120(SCS)	12th/1130	18.0/85.8	241(SC)
9th/0530	17.6/83.5	130(VSCS)	18th/1730	84.7/22.4	75 (CS)	12th/1730	18.7/85.3	222(SC)

9th/1130	19.2/83.4	103(SCS)			12th/2330	19.6/84.9	185(VSCS)
9th/1730	21.3/83.4	75(CS)	One nautical mile=1.852 km		13th/0530	21.2/84.0	120(VSCS)
9th/2330	23.3/83.7	56((DD)			13th/1130	22.7/83.3	52 (DD)
10th/0530	24.7/84.8	46(D)					
10th/1130	25.4/85.9	46(D)					
10th/1730	26.0/86.8	28(D)					
10th/2330	26.5/87.6	28(D)					

Table V: The pressure difference, the wind speed and rainfall at Puri during PHAILIN trespassing

		PHAILIN						HUDHUD			
Date	Time in IST	Lat 0N	Long. 0E	Wind in KMPH	TYPE	Date	Time in IST	Lat 0N	Long. 0E	Wind in KMPH	TYPE
8.10.13	o530					8.10.14	o530	12.50	92.50	64.82	CS
	1130						1130	12.60	91.80	64.82	CS
	1730						1730	13.00	90.70	83.34	CS
	2330						2330	13.40	89.60	92.6	SCS
9.10.2013	o530	13.2	93.4	65	CS	9.10.2014	o530	13.60	89.20	101.86	SCS
	1130	13.4	92.8	74.08	CS		1130	13.70	88.70	111.12	SCS
	1730	13.7	92.2	74.08	CS		1730	14.00	88.20	111.12	SCS
	2330	14.1	91.6	92.6	SCS		2330	14.20	87.80	111.12	SCS
10.10.2013	o530	14.4	91.3	101.86	SCS	10.10.2014	o530	14.40	87.60	120.38	VSCS
	1130	14.9	91	120.38	VSCS		1130	14.80	87.10	120.38	VSCS
	1730	15.4	90.3	185.2	VSCS		1730	15.40	86.90	138.9	VSCS
	2330	15.6	89.4	231.5	SC		2330	15.90	86.50	157.42	VSCS
11.10.2013	o530	15.8	88.8	250.02	SC	11.10.2014	o530	16.00	85.80	157.42	VSCS
	1130	16.1	88.4	250.02	SC		1130	16.00	85.20	194.46	VSCS
	1730	16.7	87.7	259.28	SC		1730	16.30	84.80	203.72	VSCS
	2330	16.9	87.1	259.28	SC		2330	16.60	84.60	203.72	VSCS
12.10.2013	o530	17.4	86.5	259.28	SC	12.10.2014	o530	17.20	84.20	203.72	VSCS
	1130	18	85.8	240.76	SC		1130	17.50	83.50	212.98	VSCS
LANDFALL	1730	18.7	85.3	222.24	SC	LANDFALL	1730	18.00	82.90	194.46	VSCS
	2330	19.6	84.9	185.2	VSCS		2330				
13.10.2013	0530	21.2	84.0	120	(VSCS)	13.10.2014	0530				
	1130	22.7	83.3	52	(DD)		1130				

TableVI: Prototype Cyclones 05B 1999 and PHAILIN 2013, HUDHUD comparison for Ganjam district, Odisha

Item of impact of cyclone on Ganjam district Orissa	05B Cyclone 1999	PHAILIN 2013
Disaster parameters and sectors affected		
Maximum Wind speed	222km/h	259 km/h
Rainfall received	194.72 mm	150mm (aprox)
Population affected	31.40lakhs	15.02lakhs
No of Blocks affected	22 blocks	22 blocks
No of Gram Panchayats affected	444 GPs	475 GPs
No of villages affected	3162 villages	2812 villages
No of Urban Local bodies affected	18 ULBs	18 ULBs
Human casualty	183 deaths	10 deaths
Crop area affected in ha		216100 ha