Abrupt Intensification and Dissipation of Tropical Cyclones in Indian Ocean: A Case Study of Tropical Cyclone Nilofar – 2014

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Abstract: This study aims to investigate the possible influence of different atmospheric forcing on intensification/dissipation of tropical cyclonic “Nilofar” in Arabian Sea appeared during the last week of October, 2014 which exhibited abrupt intensification and dissipation as well. The cyclone was monitored by the Tropical Cyclone Warning Center (TCWC) of Pakistan Meteorological Department and the Regional Specialized Meteorological Center (RSMC) of Indian Meteorological Department (IMD) continuously, issued warnings and advisories with the help of available synoptic observations, satellite data and numerical models. Almost all the essential ingredients for intensification and tracking of the cyclone were studied and monitored accurately. Although the track forecast of the cyclone remained up to mark; but great errors occurred in intensity forecast. The atmospheric vertical wind shear could not be studied accurately. The intensity of wind shear itself is dependent on both; the local and global atmospheric forcing and climate variables, reoccurring periodically, especially while occurring two or more at the same time. More studies are required for influence of these climate variables while co-occurring at the same time period. This study will help weather forecasters to pay special attention on variation of climate factors affecting the wind shear for proper forecasting of tropical cyclones in the Arabian Sea for the safety of coastal communities along the coast.

Keywords: Tropical cyclone, Nilofar, Climate variables, Co-occurring.

1. INTRODUCTION

It has been a history of abrupt formation, intensification and dissipation of tropical cyclones in the Indian Ocean. Although the old climatological records [1-2] reveals that over the past decades (1877-1989 and 1891-2003) the frequency of intense tropical cyclones in the North Indian Ocean has registered significantly increasing trends during pre monsoon and post monsoon season, the recent climate records (1990-2015) shows a decline in frequency of Severe Cyclonic Storms (SCS) and Very Severe Cyclonic Storms (VSCS) especially in the vicinity of Arabian Sea, the intensity (sustained wind speed more than 64 kts) has, however, significantly increased in Bay of Bengal and in Arabian Sea [3]. This increase in intensity is attributed to El-Nino/La-Nina [4-5] enhanced upward trends of black carbon and sulphate emissions [6] and vertical wind shear, which decreases considerably in June and September, in response to the doubled CO_2, in the North Indian Ocean [7].

Generally 5-6 cyclonic storms do form annually in North Indian Ocean (NIO) with the frequency of 2-3 of severe intense nature. Whereas, averagely one to two tropical cyclones form in the Arabian Sea each year and few of them are intense enough to be classified as very severe or super cyclonic storms because of a small area of the sea basin.

The tropical cyclone Nilofar, one of the most promptly intensified and dissipating cyclones in the vicinity of the Arabian Sea (about 1300 km south of Karachi) appeared during the last week of October 2014 as a low pressure area on 23rd October (0000Z), issued a tropical cyclone forming alert (TCFA) on 24th (2200Z), first warning on 25th (1200Z) and classified as named tropical Cyclone “NILOFAR” by Joint Typhoon Warning Centre (JTWC) on 26th October. The cyclone exhibited a significant pattern of instant escalation under a particular set of environmental conditions which made it Very Severe Cyclonic Storm (VSCS) on 28th and scattered within a little period of merely three days, and dissipated due to strong vertical wind shear (VWS) on 31st of October.

The Tropical Cyclone (TC) Nilofar being a well organized and intensified cyclone (Cat-4) in the Arabian Sea was reported to be dissipated due to the sudden encounter of upper air wind shear appeared in the way of this weather system. The vertical wind shear is vastly impacted by the local and planetary scale climate variables. Also, it is shown [8] that the well intensified and large tropical cyclones are less sensitive for wind shear as compared of those which are weak and small cyclones.

Although the formation, intensification of TC Nilofar appeared to be a normal seasonal phenomenon; but it exhibited a unique pattern of dissipation, and the strong

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vertical wind shear was reported to be the reason for its weakening, yet it is said that vertical wind shear itself is impacted by various climatic factors. We have tried to explore some climatic factors to know how the vertical wind shear impacts the intensification of the tropical cyclones in the vicinity of the Arabian Sea.

2. SIGNIFICANCE OF THE STUDY

It has been a long history of cyclone related destructions in marine countries all over the globe. Depending on different type of basin and bathymetry of the coasts, land falling and storm surges of cyclones results diverse degree of devastation along the global coasts. Two marine regions of the Indian Ocean, Bay of Bengal and the Arabian Sea, are intensively prone to tropical cyclones as compare to the other regions of the world's oceans. The highest number of life loss due to the cyclone disaster has been recorded in these regions. Past historical tropical cyclones like, Hooghly (1737), Coringa (1839), Great Backerganj Cyclone (1876), Great Bombay Cyclone (1882) have occurred in vicinity of Bay of Bengal and Arabian Sea, killing hundreds of thousand people and devastating properties with loss of billion dollars along coasts in neighboring countries. The Great Bhola Cyclone (1970) killed about 300,000-500,000 people in Bangladesh. The tropical cyclones during the near past like Cyclone 02B (1991) and Cyclone Nargis (2008) claimed about 135,000 and 138,366 human losses in Bangladesh and Myanmar.

Pakistan being a marine country is also prone to cyclone disaster; devastating coastal communities over the history. The cyclones (Past, Unnamed) approached/passed the Pakistan coasts historically includes, 1948 (04-09 June), 1959 (01-03-July and July 09-18), 1961 (20-27 June and Sep 05-16), 1963 (08-13 June), 1985 (28 May-June 01) and recent named, 02A (1999 May16-20), 01A (2001 May 21-28), Yemyin (2007 June 21-26), Phet (2010 May31 and 26 June) and Nilofar (2014 Oct: 28-31).

The timely and accurate prediction of formation, intensification dissipation of cyclones, their land falling and storm surging is of vital importance for reduction of its impact on communities along the costs in marine countries in the vicinity of the Indian Ocean. Numeral studies have been made in order to establish an authentic relation with the geneses and tracking of tropical cyclones in the Arabian Sea with various atmospheric forcing and other climatic factors for accurate forecasting of land falling in the coasts of marine countries for the safety of property and lives of their coastal communities. An attempt has been made to study the impact of some climatic factors and atmospheric variables on geneses, intensification and dissipation of tropical cyclones particularly while occurring at the same time; in order to establish a sophisticated relation for better forecasting of intensification and dissipation of cyclones in the vicinity of Arabian Sea. The TC Nilofar was selected for this study as it was impacted by the vertical wind shear which was not considered to be emphasized up to the mark. This study will help Pakistan and neighboring marine countries in authentic prediction of tropical cyclones for safety of human lives and their properties along coasts.

3. LITERATURE REVIEW

3.1. Atmospheric Forcing Affecting Tropical Cyclones

3.1.1. Global and Periodical Atmospheric Conditions

The seasonal variations of tropical cyclone activity in North Indian Ocean greatly depend upon changes in one or more global atmospheric parameters/ atmospheric forcing like, El-Nino Southern Oscillation (ENSO), Madd0en Julian Oscillation (MJO), Indian Ocean Dipole (IOD) and Quasi Biennial Oscillation (QBO). Many studies have focused upon the variations in these values both before and during the tropical cyclone season. The inter annual variations in global atmospheric conditions widely affect the formation, intensification and dissipation of the tropical cyclones in different parts of the world's oceans. Some of the most influencing atmospheric forcing is discussed hereunder.

a. El Niño-Southern Oscillation (ENSO)

The ENSO is a major mode of natural climate variability. ENSO is generated by coupled ocean atmospheric dynamics in the tropical Pacific [9]. The impact of ENSO on tropical cyclones was first discussed by Gray [10] and recent 3 reviews of the relationship of ENSO and TCs are presented in [11] and [12]. Because of this strong influence and the predictability of ENSO, it is probably the largest single factor in seasonal TC forecasts.

b. Madden Julian Oscillation (MJO)

The MJO is the strongest mode of intra-seasonal variability in the tropics [13-15]. The MJO has a 30-90 day period and consists of large-scale coupled patterns of deep convection and atmospheric circulation, with coherent signals in many atmospheric variables. The MJO propagates eastward across the global tropics, with signatures in deep convection primarily in the Indian and western Pacific Oceans. The MJO is stronger in boreal winter than in boreal summer [16] and modulates the formation of tropical cyclones in several basins.

c. Indian Ocean Dipole (IOD)

The Indian Ocean Dipole (IOD) is the fluctuation of atmospheric pressure at two poles in (western and eastern) Indian Ocean. It is a coupled ocean and atmospheric phenomenon in the equatorial Indian Ocean that affects the climate of Australia and other countries that surround the Indian Ocean basin [17]. An index of temperature anomalies between western and eastern equatorial Indian Ocean is used to investigate the strength of IOD. The period when the SSTs are below normal in southeastern parts and above normal in western parts of the equatorial Indian Ocean is characterized as a positive IOD. And the period when the SSTs are above normal in southeastern parts and below normal in western parts of equatorial Indian is characterized as a negative IOD.

Tropical Cyclone activity in North Indian Ocean is notably influenced by the IOD mode. When the Indian Ocean is in a positive (negative) phase of the IOD, the North Indian Ocean (NIO) SST anomalies are warm in the west (east) and cold in the east (west), which can weaken (strengthen) convection over the Bay of Bengal and the eastern Arabian Sea, and cause anticyclonic (cyclonic) atmospheric circulation anomalies at low levels [18].

d. The Quasi-Biennial Oscillation (QBO)

The stratospheric quasi-biennial oscillation (QBO) is a quasi-periodic oscillation of the tropical winds in the stratosphere. The QBO dominates the inter-annual variability of the equatorial stratosphere, being manifested by alternating periods of easterly E and westerly W zonal winds that descend with time and then repeat with a very well-defined period whose mean is about 28 months. The QBO affects stratospheric dynamics globally and also has documented impacts on the troposphere [19] and the modulation of storm and depression tracks over North Indian Ocean in the equatorial stratosphere [20].

3.1.2. Local Atmospheric Conditions

The tropical cyclones do form under specific set of environmental conditions in the world's oceans. These conditions are considered to be pre-requisites for the formations and intensification of the tropical cyclones. Some of these are discussed here.

a. Sea Surface Temperature (SST)

The temperature of water surface is considered to be a primary condition for the formation of cyclones. The waters warm enough, not less than 26.5 °C, reaching in depth of sufficiently 50 meters for fueling the system requires for geneses a cyclone.

b. Lower Level Convergence (LLC)

The continuous inflow of the moist air at lower atmosphere acts as the fuel for intensification of a tropical storm. It is known to be an integrated part of the system for its sustenance.

c. Upper Level Divergence (ULD)

The outflow at upper atmosphere plays an important role in intensifying of a tropical cyclone.

d. Vorticity

System must develop at a distance of at least 500 km away from the equator for deflection of inflow of air in the system hence producing rotation. As the Coriolis force is negligible around the equatorial regions, the convergence and vorticity seldom occurs and discourages development and intensification of the cyclonic activity.

e. Vertical Wind Shear: (VWS)

The change in wind speed or direction with height is known as vertical wind shear. The wind shear of less than 10 ms-1 at mid-troposphere level is considered to be favorable for the system to sustain the mechanism throughout its development. A weak vertical wind shear allows storm clouds to rise vertically to high levels. Strong vertical wind shear disrupt the incipient tropical cyclone and can prevent genesis, or, if a tropical cyclone has already formed, large vertical shear can weaken or destroy the tropical cyclone by interfering with the organization of deep convection around the cyclone center [21].

f. Sea Level Pressure

Sea level pressure acts to directly impact the strength of the vertical wind shear. Gray [22] have suggested that abnormally low SLP indicates a pole ward shift and/or a strengthening of the Inter-tropical Convergence Zone (ITCZ). Both situations contribute to less subsidence and drying in the main development region through which easterly waves move. Knaff [23] indicates that low SLP is accompanied by a deeper moist boundary layer and a weakened trade wind inversion. Moreover, an enhanced ITCZ provides more large-scale, low level cyclonic vorticity to incipient tropical cyclones, thereby creating an environment that is more favorable for tropical cyclogenesis [24]. In contrast, above normal SLP tends to be associated with opposite conditions which are unfavorable for tropical cyclogenesis. Ray [25] has discussed the relationship between sea level pressure anomalies and Atlantic basin activity and analyzed Australian tropical cyclones and local pressure values.

4. RESULTS AND DISCUSSIONS

4.1. Cyclogenesis of Tropical Cyclone Nilofar

Formation of depressions in North Arabian Sea is infrequent during post monsoon season; but the instability still remains in order for depression or cyclone to form; particularly when sea surface temperatures and accumulated thermal energy are favorable. Under such set of atmospheric conditions a low pressure area was located by Regional Specialized Meteorological Center (RSMC)- India Meteorological Department (IMD) around Lat: 13.0° N-Long: 61.0° E on 25.10.2014 at 1200 Z with central pressure of 1004 hpa and wind speed 25 Kts (sustained, estimated) firstly named Tropical Cyclone (TC 04A) intensified further to Cyclonic Storm (CS) due to drop in pressure of 998 hpa and wind speed 35 kts on 26^{th} Oct: (0600Z) and moved the northward at Lat: 14.1 N-Long: 62.0 E.

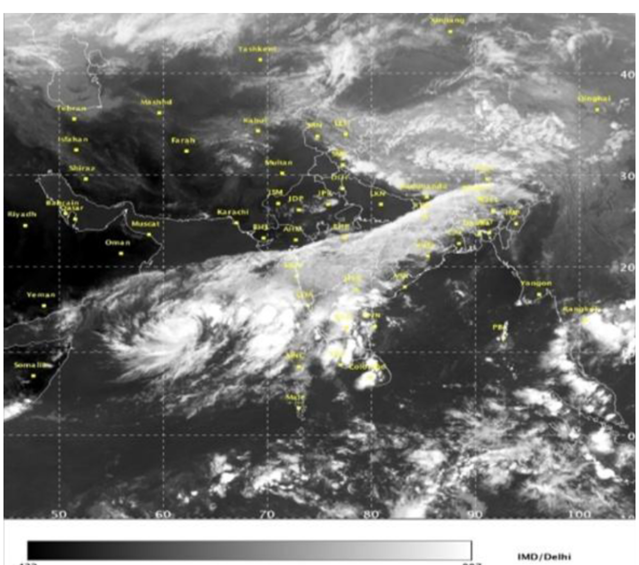


Figure 1: Satellite image INSET-3D IMG (IMD).

The satellite imagery shows its intensity of T-1.5 with intense embedded convective clouds shown in the S-west of the Central North Arabian sea (Figure **1**). The intensity of the system was reported T 2.5. The convection further increased from intense to very intense and cloud top temperatures reported to -92° C. The system further intensified and declared Severe Cyclonic Storm (SCS) on 26^{th} October of (2600 Z). The intensity of the system was recorded T-4.0 on 28^{th} October.

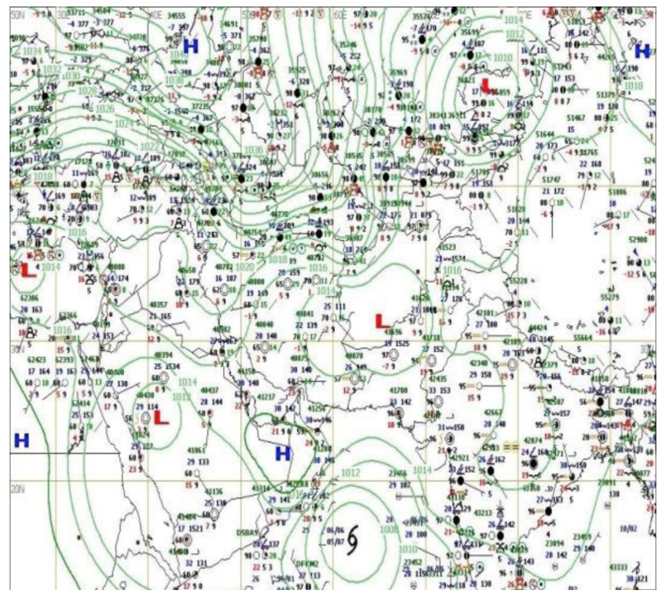


Figure 2: Nilofar located in surface charts (PMD).

System intensified further, but remained almost at same location with slight northward movement and named “NILOFAR” on 26^{th} of October. The Pakistan Meteorological Department located the cyclone in its daily surface charts on the same day. The thermal energy of 60-80 KJ/cm^2 favored the system to intensify further being moderate wind shear of 10-20 kts above the system and 25-30 kts in its northern region.

An upper atmospheric ridge (300 hpa) was located near $10\text{-}20^{\circ}$ N (Figure **3**) on 25^{th} October, 2014. The results were obtained by atmospheric data by NMCC-PMD using MessirVision.

A positive vorticity around the center of the cyclone of 100 - 200 $\times 10^{-5}$ m/s reported to be enhanced during last 6 hours. The positive convergence and divergence of the system initially was 10-20 $\times 10^{-5}$ m/s and 30-40$\times 10^{-5}$ m/s respectively on 26^{th} of October.

5. MONITORING AND PREDICTION

The monitoring and forecast of TC Nilofar remained well organized by studying the related atmospheric conditions since inception of the system. A number of

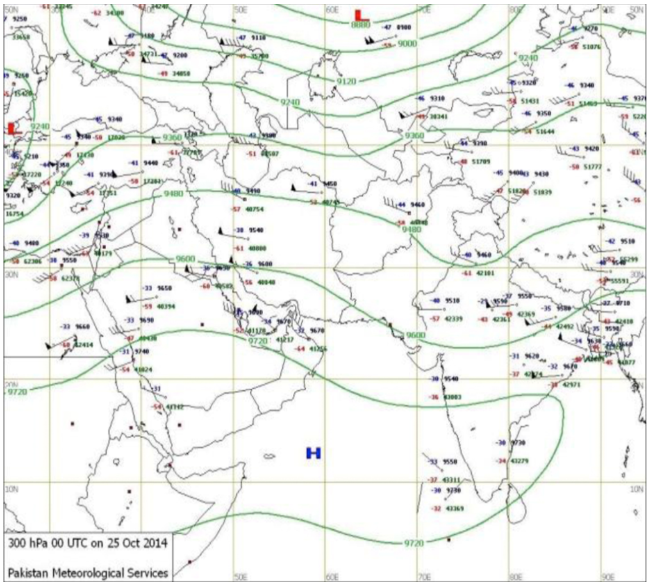
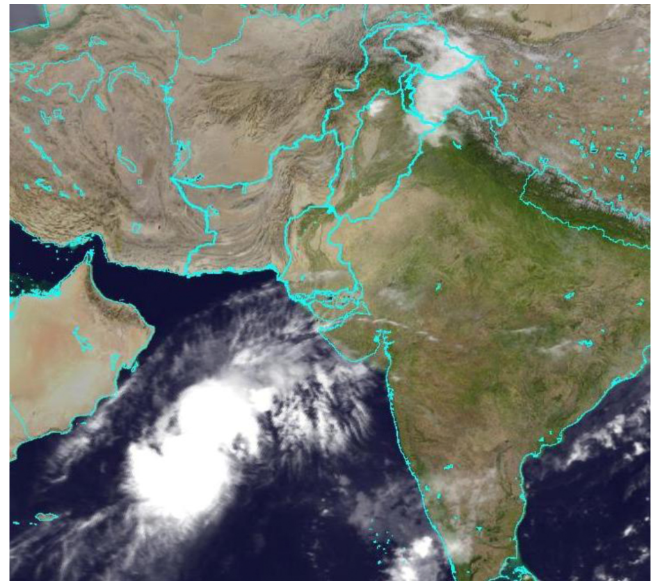


Figure 3: Upper atmospheric ridge at 300 hpa on 0000Z of 25th October, 2014 (Courtesy PMD).

alerts and warnings, consisting of maps depicting track and imageries, were issued by the Regional Specialized Meteorological Center (RSMC) of Indian Meteorological Department (IMD) and the Tropical Cyclone Warning Center (TCWC) of the Pakistan Meteorological Department (PMD) well in advance. IMD first reported a depression in SE-North Arabian Sea (Lat: 13.0° N-Long: 61.0° E) on 25.10.2014 at 1200Z and issued warning regarding the intensification of the system and predict for NW to NNWest ward movement during the next 2 days.

The PMD, as well, issued an alert regarding the formation and intensification of depression to deep depression and cyclonic activity in its first advisory issued on the same day, i.e., 26th October, (1700 PST) and indicated its movement towards the west-northwest and its tracking forecast Northeast wards during next days. The movement of the system was also forecasted by most of the models on 26th October 2014 initially north to northwestwards for the next couple of days and then to North-Northeast wards.

Due to its abrupt intensification and organized development the Nilofar was forecasted to be intensified more and upgraded to severe cyclonic storm by IMD during next 24 hours on 26 October 2014. The PMD subsequently issued weather advisory on the same day, i.e., 26'th October, regarding more intensification of the cyclone due to decreasing trend of vertical wind shear which predicted to be negative 10 to 20 knots.



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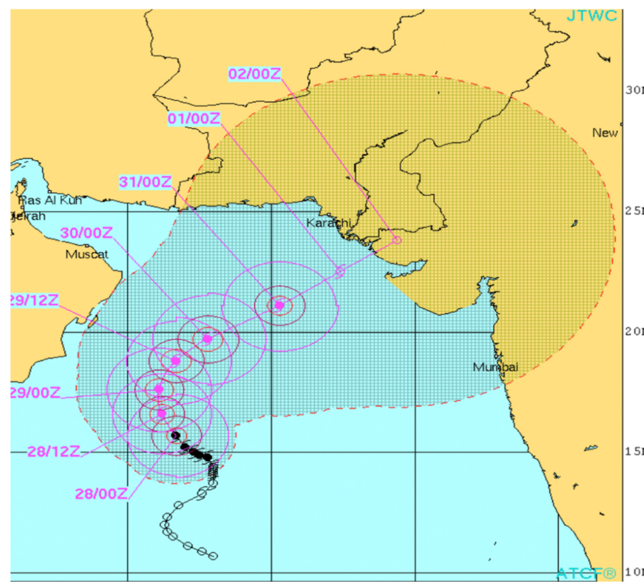

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Figure 4: (**a**): Satellite Image of 28th Oct 2014 at 0900 PST. (**b**): Predicted track (courtesy FY-2G & JTWC [28]).

On 27th October (0000Z), the various climate models forecasted the system to be more intensified to Very Severe Cyclonic Storm (VSCS) and track North-northwards during next 24 hours and northeastwards during the next 2 days. Most of the dynamical and statistical models were consistent on intensifying the system more and track north-northeast wards during next 24 and subsequent 48 hours. The system moved slightly northward and persists at 1,170 km south-southwest of Karachi and 850 km east of Oman and forecasted to track north-northeast wards and declared as Very Sever Cyclonic Storm (VSCS) on 28th October 2014 (Figure **4a**, **b**).

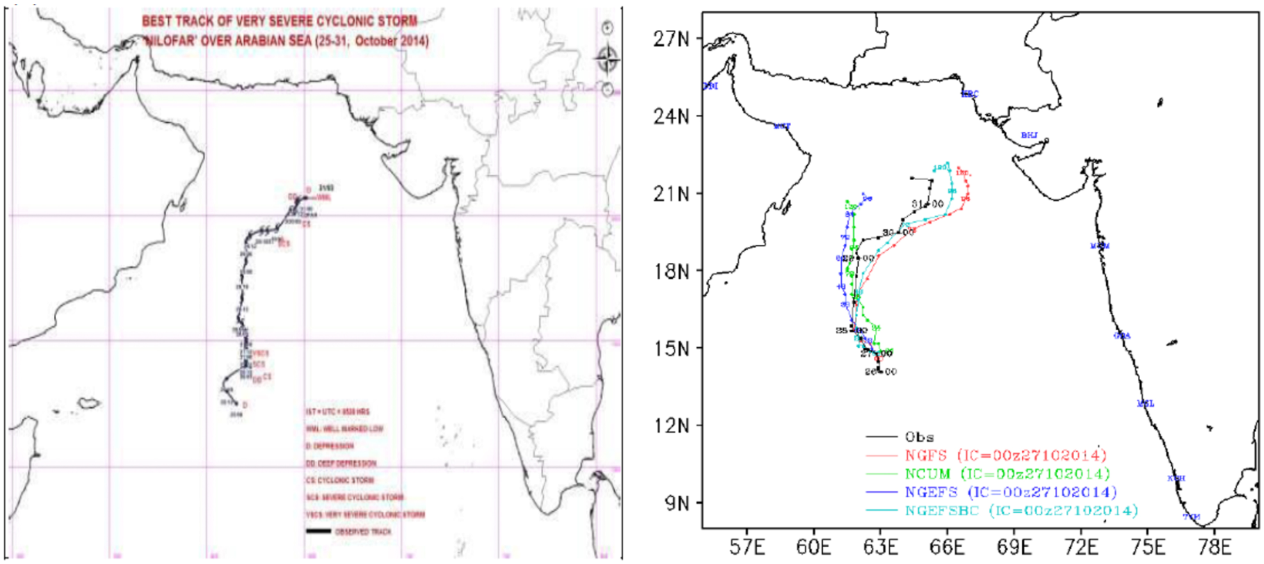
Table 1: Tracking Data of Tropical Cyclone Nilofar

NO.	DATE AND TIME	LAT	LON	WIND (Kt)	STATE
1	10/25/12Z	13.4	62.5	35	TR STORM
2	10/25/18Z	13.7	63	35	TR STORM
3	10/26/00Z	14.1	63	35	TR STORM
4	10/26/06Z	14.2	62.9	45	TR STORM
5	10/26/12Z	14.3	62.9	55	TR STORM
6	10/26/18Z	14.4	63	55	TR STORM
7	10/27/00Z	14.8	62.8	65	CYCLONE-1
8	10/27/06Z	15	62.4	70	CYCLONE-1
9	10/27/12Z	15	62.3	75	CYCLONE-1
10	10/27/18Z	15.4	62.1	90	CYCLONE-2
11	10/28/00Z	15.7	61.7	90	CYCLONE-2
12	10/28/06Z	15.9	61.7	90	CYCLONE-2
13	10/28/12Z	16.8	61.8	115	CYCLONE-4
14	10/28/18Z	17.8	61.9	115	CYCLONE-4
15	10/29/00Z	18.5	62	105	CYCLONE-3
16	10/29/06Z	18.7	61.9	100	CYCLONE-3
17	10/29/12Z	19.2	62.2	90	CYCLONE-2
18	10/29/18Z	19.1	63	65	CYCLONE-1
19	10/30/00Z	19.7	63.9	60	TR STORM
20	10/30/06Z	20	64	50	TR STORM
21	10/30/12Z	20.3	64.5	45	TR STORM
22	10/30/18Z	20.5	65	35	TR STORM

The cyclone persisted at almost same location with a little movement towards Pakistan (910 km SW) and Gujarat (900 km SW) coasts in morning of 29th October. Climate models forecasted a little decreasing in intensity of the system as a severe cyclonic storm to cyclonic storm and its movement towards North-northeast during next two days. Because of the movement tracks (Table **1**) and expected entrainment of cold, dry air from the coast and available enhanced vertical wind shear, the dynamical and statistical models, on 29th October, predicted the gradual weakening of the system and its movement towards the north and northeast along Pakistan's Sindh and India's Gujarat coasts during next two days. Consequently, the Tropical Cyclone Nilofar weakened from the very severe cyclonic storm (VSCS) to severe cyclonic storm (SCS). It moved north-northeast wards and located 770 km southwest from Karachi and 730 km southwest from Gujarat on 30th October, 2014 and dissipated due to increasing vertical wind shear and dry air offshore.

6. INTENSIFICATION AND MOVEMENT

Because of the prevailing favorable atmospheric conditions the tropical cyclone Nilofar exhibited a unique pattern of formation and Intensification. The local atmospheric conditions and the planetary scale forcing being very conducive the cyclogenesis took place in a quite normal way; as the surface skin temperature (SST) reported 28-30 ˚C, available moisture, a good inflow (Low level convergence), outflow (Upper level divergence) and decreasing vertical wind shear in the vicinity around the system favored the system to persist and intensify at the initial stage of its development. On the next day the sea surface temperature remained at same extent, but the estimated center pressure (ECP) dropped to 998 hpa; due to which the wind speed remained 35-45 kts. The satellite pictures show embedded clouds of intense and very intense convicted categorizing the system of T-3 intensity. The central pressure was recorded 994 hpa and sustained winds around the system were recorded 40-50 knots on 27th October. The wind shear reduced



a b

Figure 5: (**a**). Observed track of the 'NILOFAR' over Arabian Sea during 25-31 October, 2014 (JTWC). (**b**). Track forecasting by different models (Courtesy: RSMC-IMD report on TCNilofar).

to 5-10 knots increased lower level vorticity during last 24 hours ameliorated the system to be more intensified. The estimated central pressure on 28th October recorded 980 hpa and wind speed about 70 knots. The wind shear on the same day was about 10 knots, with increasing tendency. Because of no alteration in lower level convergence and upper level divergence, as well, the system remained almost persisting at the same location on 29th October. The satellite imagery depicted the intensity of the system as T 5.5 with very intense convection. The estimated pressure of 950 hpa at the center of the cyclone was recorded with wind speed about 100 knots gusting to 115 knots on the same day.

The sea surface temperature remained near 28° to 29° C around the system. The wind shear moderately increased by 10-15 knots on 29th October. On the next day the system abruptly weakened to T 3.5 as estimated central pressure increased to 987 hpa and wind speed reduced to 60 knots gusting to 70 knots. The system initially moved to northwestward and then true northward. It was located some 1250 km south of Pakistan coast, 880 km southeast of Oman and 1200 km southwest of Gujarat on 26th and 25th. Thereafter, it moved to north-northeast wards (Figure **5a**) A majority of models were consistent on track forecasting of TC-Nilofar. Different models run at the Indian National Center for Medium Range Weather Forecasting (NCMRWF) (Figure **5b**) predicted the north-north eastward movement of the system, which was in agreement with the actual track at a great extent. However, the error in intensity at the decay phase of the cyclone was also occurred, which needs to be addressed in future study.

Due to the increased wind shear and continued intrusion of cold and dry air of the coasts, the intensity of system drastically reduced on T scale at T 3.5 with cloud temperature -78° C, the system weakened during 30th and 31st October 2014. It persisted as the low pressure area in waters at southwest of Karachi and Gujarat on 1st of November, 2014.

7. WEATHER REALIZED

Although the system did not make a landfall, yet it gave widespread heavy and very heavy rainfall western Indian coasts, Goa, Konkan and Madhya Maharashtra during the intensification phase of the cyclone. No significant rain was reported at dissipating stage of the cyclone. Karachi and other coastal areas of Pakistan also experienced light to moderate rainfall during intensifying period of ropical Cyclone Nilofar [26] (IMD report on TC-Nilofar-2014).

8. EXPECTED STORM SURGE ASSOCIATED WITH TC-NILOFAR

Although the tropical cyclone Nilofar had not made a landfall and dissipated in waters near the Gujarat coast there was not any storm surge to be recorded, yet the Pakistan Meteorological Department (TCWC-Karachi) had calculated (not issued) the expected storm surge associated with the tropical cyclone

Nilofar, using model IIT-D (Indian Institute of Technology-Delhi). The expected storm surge was about 1.3 meters along the Gujarat coast (Figure **6**).

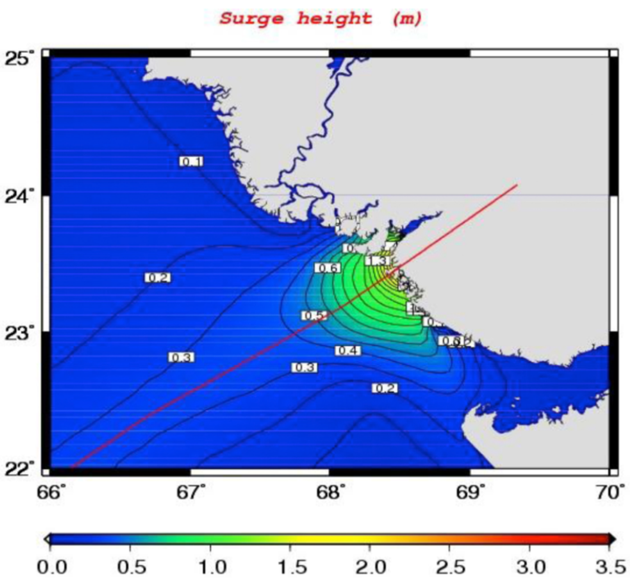


Figure 6: Simulated storm surge associated with TC-Nilofar (Using IIT-D in PMD).

However the maximum significant wave height of approximately 12.8 meters was calculated in the middle of the Arabian Sea (61.7 ˚ E-17.9 ˚ N) using Regional Tidal Hydrodynamic and Wave Model of Royal Haskonining DHV (RHDHV) [27] (Figure **7**).

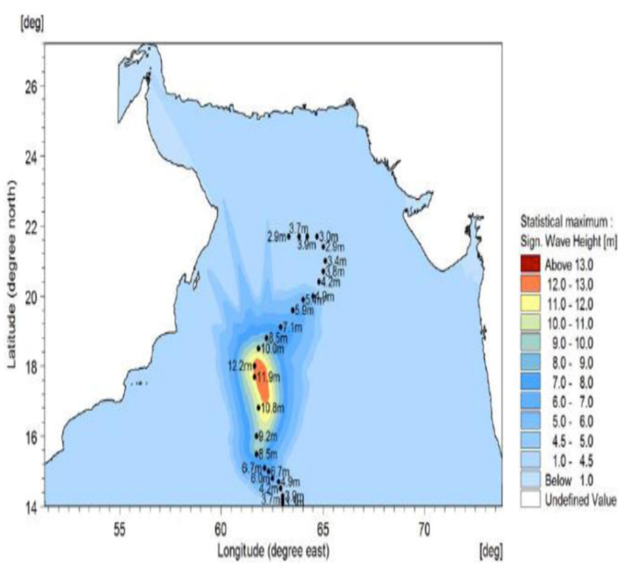


Figure 7: Significant wave height for TC-Nilofar (Using RHDHV) Courtesy: Sarker MA.

9. ATMOSPHERIC CONDITIONS

The local atmospheric conditions persisting in the vicinity of the Arabian Sea impacting the Tropical Cyclone Nilofar are discussed here under.

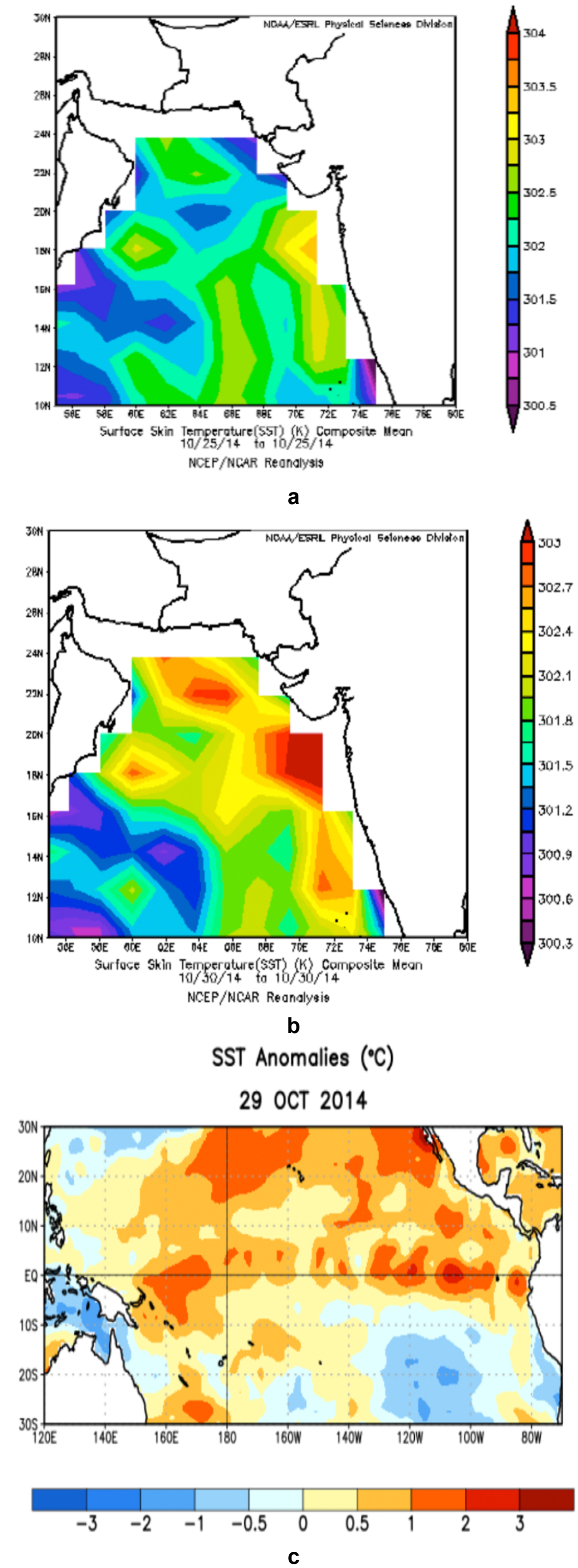
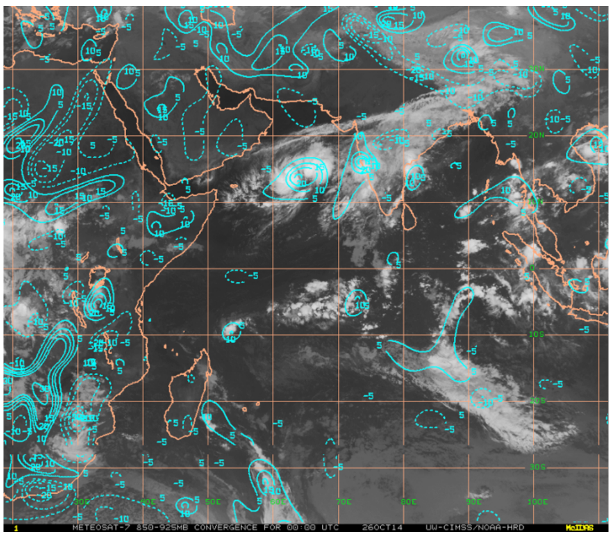


Figure 8: SST as on (**a**) 25th and (**b**) on 29th October 2014 (**c**) average sea surface temperature (SST) anomalies (°C) for the week centered on 29 October 2014. [NOAA/NCEP-CPC].

a) Sea Surface Temperature

Sea surface temperatures during the course of genesis, development and intensification of tropical cyclone Nilofar reported very conducive (28-30° C) at the time of its formation and development/ intensification i.e., from 25th-29th October 2014. (Figure **8a** and **8b**) depicts the increasing trend of sea surface temperature, which remained largely above 27 °C which encouraged the continuous development of Tropical Cyclone Nilofar.



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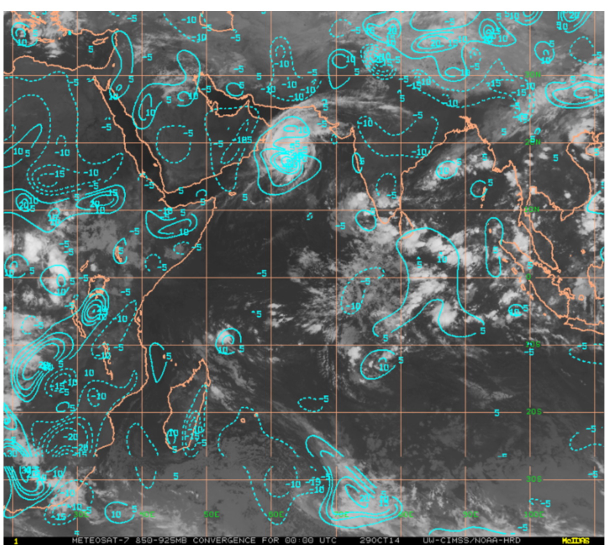

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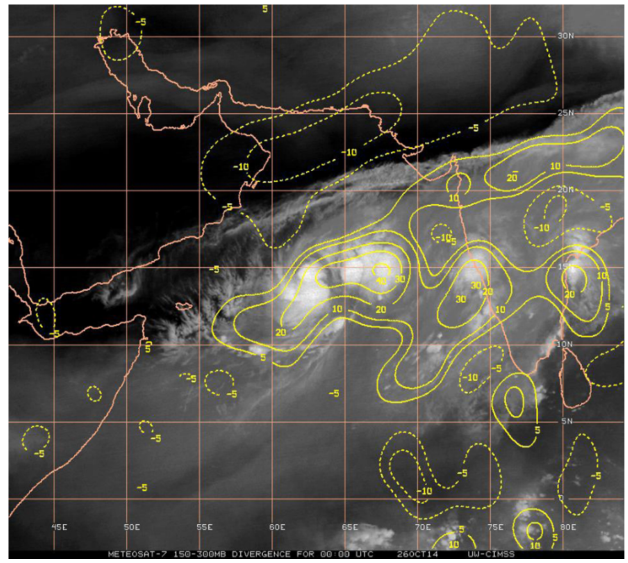
Figure 9: Low level convergence at 850-925 mb level on (**a**) 26th and (**b**) on 29th October, 2014 (Courtesy UW-CIMSS/NOAA HRD [29]).

b) Lower Level Convergence

The convergence of 15-20 m/s and 20-25 m/s at 850-925 mb level was recorded on 26th and 29th October, 2014 respectively (Figure **9a**, **b**).

c) Upper Level Divergence

The divergence aloft over TC Nilofar remained well organized throughout its life cycle (Figure **10a**, **b**). A divergence of 20-40 m/s was recorded on 26th October, 2014 and 40-50 m/s on 29th October, 2014.



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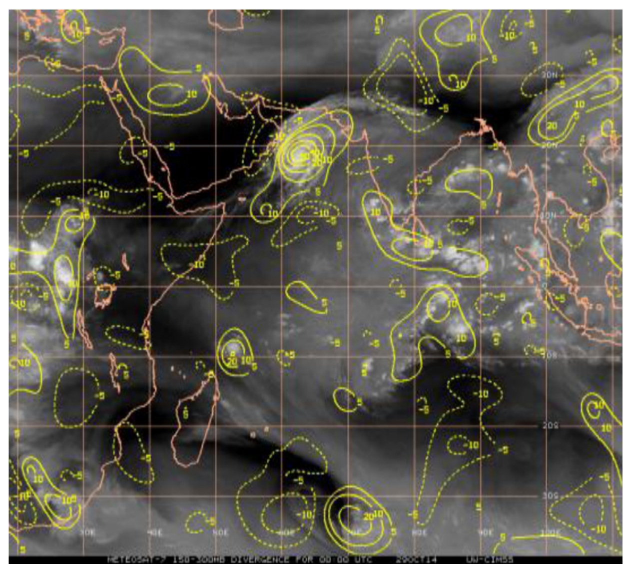

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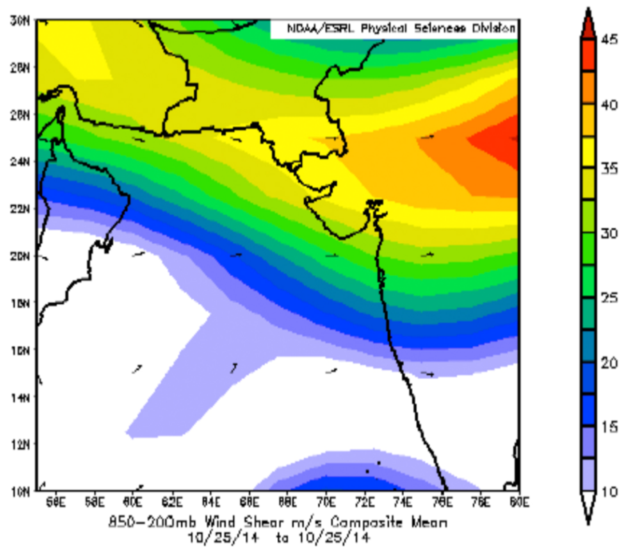
Figure 10: Upper level divergence at 150-300 mb level on (**a**) 26th and (**b**) on 29th October, 2014 (Courtesy UW-CIMSS/NOAA HRD).

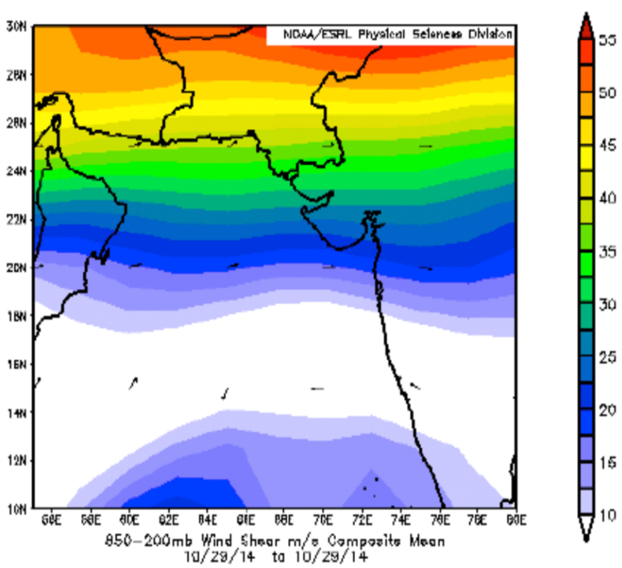
d) Vertical Wind Shear

The absence/weakening any of the above discussed meteorological parameters drastically defuse the strength of a tropical cyclone. The moderate to lower atmospheric wind shear ascertains the overall persistence and the existence of the tropical cyclones. The cyclone systems having lower vertical wind shear

(VWS), while moving to the coastal zones, results land falling besides facing drier and colder air of the coasts to their core region. The TC Nilofar, besides having intensified due to the essential ingredients, dissipated over the waters due to abruptly increased wind shear. The VWS reported at initial stages of its development was between 5 to15 m/s at 850-200 mb on 25th and it increased 20 to 30 m/s on 29th October, 2014 as it moved in eastward direction to the Gujarat coast (Figure **11a**, **b**).



a



b

Figure 11: VWS at 850-200 mb on (**a**) 25th and (**b**) on 29th October, 2014 (NOAA-ESRL/PSD).

10. CONCLUSION

Cyclone Nilofar exhibited a rapid intensification and dissipation as it intensified into Severe Cyclone Storm (SCS) to Very Severe Cyclone Storm (VSCS) within nine hours i.e. 26/2100 Z-27/0600 Z and dissipated after merely four days. It observed traditional tracking pattern in the North Arabian Sea, which was accurately predicted with the help of different models, but the intensity of the cyclone was over estimated for which the forecast regarding landfall and rainfall could not occur in that extent due to abrupt dissipation of the system. The atmospheric wind shear said to be the main cause of intensification and dissipation of a tropical cyclone, but the wind shear itself is dependent on both; the local and global atmospheric forcing persisting periodically, especially while occurring two or more at the same time.

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