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# Study of Cyclogenesis Parameters and Condition Leading to the Formation of Super Cyclonic Storm "Gonu"

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***Abstract:***
*Tropical cyclones are among the most destructive natural disasters of the world and about 7% of the global tropical cyclones form in the north Indian Ocean. The present study investigates cyclogenesis parameter and conditions leading to the formation of the super cyclonic storm Gonu, which was formed over the Arabian sea using Satellite, reanalysis dataset. Cyclogenesis parameters such as Sea Surface Temperature(SST), the mid -tropospheric relative humidity (MTRH), the vertical wind shear (VWS), and other satellite parameter such as Precipitable water and outgoing long wave radiation were examined to observe the condition leading to the formation of super-cyclonic storm Gonu. Using NCEP/NCAR reanalysis data,the Vertical wind shear is computed as the difference between 200hPa and 850hPa wind and Satellite microwave measurements show sea surface temperature (SST)increase in advance of significant cyclone intensification.*

***Keyword:*** *Tropical cyclones, cyclogenesis parameter, Sea Surface Temperature, the mid -tropospheric relative humidity (MTRH), Precipitable water (PW)*

## 1. Introduction

Tropical cyclones (TCs), also popularly known as hurricanes or typhoons, are among the most spectacular and deadly geophysical phenomena. It is an intense circular storm that originates over warm tropical oceans and is characterized by low atmospheric pressure, high winds and heavy rain. The winds associated with TCs usually exceed 120 km/hr and at times in extreme cases it exceeds 200 km/hr. Tropical cyclones are intense, rotating low pressure system, develop over the warm, tropical oceans, producing strong winds and heavy rainfall can lead to immense flooding. Most of the cyclones (87%) form between 20°N–20°S and two-third of TCs form in the Northern Hemisphere. In the tropical Indian Ocean, cyclones form over both the Arabian Sea and Bay of Bengal and there are marked seasonal variations in their places of origin, track and intensity. About 7% of the global TCs form in the north Indian Ocean. Of that, more number of cyclones forms in the Bay of Bengal (about three to four times higher) than in the Arabian Sea. In the north Indian Ocean, there are two important seasons for their formation, namely, Pre-monsoon (March-May) and Post monsoon (October-December). Highest frequency is seen during pre-southwest monsoon season (March–May), Southwest monsoon (June– August) and post-southwest monsoon (September–November) seasons. Roughly around 80 TCs develop globally each year. They generally develop over ocean water whose surface temperature exceeds 26°C, but they often move out of these regions into higher latitudes. TCs form in a region where the absolute vorticity of the airflow has a nonzero value. Henderson-Sellers et al. (1998), while discussing all the aspects of TCs, stated that the favorable conditions for the genesis of a cyclone are (i) large values of low level relative vorticity (ii) Coriolis parameter (at least a few degrees poleward of equator) (iii) weak vertical shear of horizontal winds (iv) high SST > 26°C and deep thermocline (v) conditional instability through a deep atmospheric layer and (v) large values of relative humidity in the lower and middle troposphere. It is not clearly known which one of the above parameters is playing a dominant role over Bay of Bengal and Arabian Sea.In the case of tropical Indian ocean (Rao, 1987; Gopalakrishna et.al.,1993; Murty,1983; Murty et.al.,1996; Seetaramayya et.al.,2001; Chinthalu et al.2001) reported cooling of the sea surface temperature (SST) due to the passage of cyclone in the Bay of Bengal and Arabian sea.November and May months account for the maximum number of severe cyclones over the north Indian Ocean. Thus the coastal regions of Bangladesh, India and Myanmar have indeed become more prone to the incidence of severe cyclones during November and May. A few cyclones form in transitional monsoon months June and September also. On an average about 5–6 TCs (maximum sustained wind of 34 knots or more) form in the Bay of Bengal and the Arabian Sea every year, of which 2–3 reach severe stage (maximum sustained wind of 48 knots or more). TCs with hurricane intensity in the Arabian Sea are rare phenomenon and that are generally formed over warm water during June through September. The present study uses a suite of satellite, re-analyses and other in-situ measurements from different sources.

## 2. Data and Methodology

### *2.1. NCEP-NCAR Re-analysis Data & Tropical Rainfall Measuring Mission/Microwave Imager (TMI)*
The NCEP/NCAR reanalysis system uses a state of the art analysis/forecast system to perform data assimilation using past data from 1948 to the present (Kalney et al. 1996). Data which is used for the study is the NCEP-NCAR (National Centre for Environmental prediction-National centre for Atmospheric Research), with 2.5ºX2.5º spatial and daily temporal resolution. The NCEP-NCAR reanalysis data used in this study consist of daily field of various variable such as zonal (u-component of wind)wind at 200hpa,850hpa,meridional wind(v-wind) at 200hpa(upper troposphere),850hpa(lower troposphere ), Precipitable water, Relative humidity at 500hpa for the study period (2th June-2007 to7$^{th}$ June-2007.The Sea Surface Temperature (SST) used in this study is taken from the TRMM Microwave Imager (TMI) on board Tropical Rainfall Measuring Mission (TRMM) satellite. TMI data are available since 1998 on a 0.25° X 0.25° spatial and daily temporal resolution (Wentz et al. 2000).

### *2.2. IMD Data Set form Cyclone Tracks.*
The source of data of tropical cyclone frequency in the north Indian Ocean for the period 1951–2009 is from India Meteorological Department(www.imd.gov.in). The cyclone track data in Arabian Sea during 2007 is from UNISYS (http://weather.unisys.com/hurricane).

## 3. Methodology

### *3.1. Computation of Vertical Wind Shear*
The parameter vertical wind shear is calculated as the difference in zonal component of the wind between the pressure levels 850 hpa (lower troposphere) and 200 hpa (upper troposphere).

$$VWS = U850 – U200 \ ms\text{-}1 \qquad \text{eqn(1)}$$

## 4. Result and Discussion
"Gonu" cyclone is the strongest cyclone on record developed in the Arabian Sea. It developed in the eastern Arabian Sea on June 1$^{st}$ 2007, and with favorable upper level meteorological environment and warm sea surface temperatures, it rapidly intensified and attained peak wind speeds of 240km/h on June 3$^{rd}$. It started weakening after encountering dry air and cooler waters and on June 6, it made landfall on the eastern tip of Oman. Finally it turned northward into Gulf of Oman and dissipated on June 7 after making landfall in southern Iran.An organized tropical disturbance was located about 645 km south of Mumbai, India, with cyclonic convection, and a well-defined mid-level circulation. A favorable upper level environment allowed convection to improve, and by late on June 1, the system developed into the extent that India Meteorological Department (IMD) classified it as a depression. Convection continued to organize and early on June 2$^{nd}$, the Joint Typhoon Warning Center (JTWC) classified it Tropical Cyclone 02A about 685 km southwest of Mumbai.

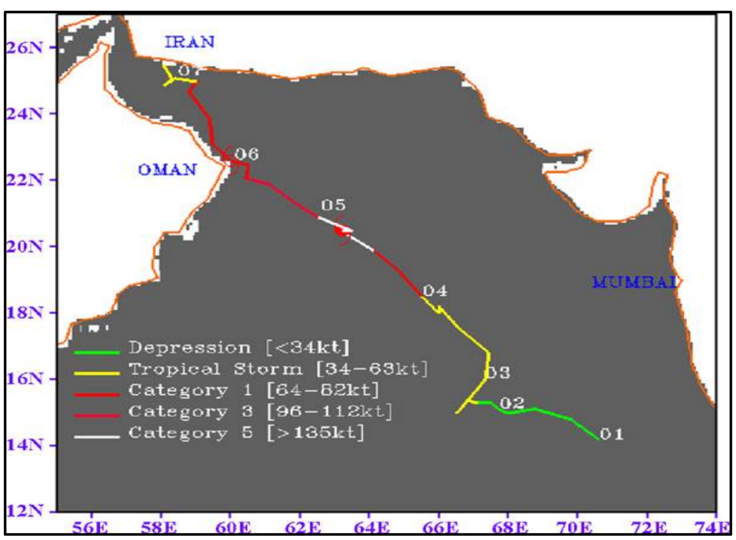



*Figure 1(a). The cyclone track of Gonu*

In the present study, variability of various cyclogenesis parameters and other air-sea interaction processes during the passage of cyclone Gonu is studied in detail. Figure 1(a) shows the track of the convective system formed over Arabian Sea from 1$^{st}$ to 7$^{th}$ June 2007..

### *4.1. Variabilities in Cyclogenesis Parameters Associated With Cyclone Passage*
In this section, various met-ocean parameters are examined in order to assess the variabilities associated with the cyclone passage.

4.1.1. Sea Surface Temperature (SST)

Ocean surface temperatures greater than 26.5°C (80F) through a depth of at least 50 meters are generally favorable for the formation of tropical cyclones. Anomalously high SST can cause more heat and moisture flux from the ocean to the atmosphere. This condition favors further development of the TC. Rapid deepening of the mixed layer is more likely once the SST is higher than 28.5°C. TCs feed on heat released when moist air rises, resulting in condensation of water vapor thus giving rise to warm core. A cyclone gets dissipated and loses its tropical characteristics (thunderstorms at the center and warm core) and becomes a remnant low pressure when it moves over waters with a temperature well below 26.5°C. Also, dissipation can also occurs if there is drop of more than 5°C in SST which is primarily a result of mixed layer deepening and surface heat losses. In the present study, the daily TMI SST data from 02-07 June 2007 has been examined to assess the impact of the cyclone on SST field, since the oceanic response to cyclones is very important for the formation and maintenance of the system. Fig 3.2 represents composite spatial distribution of SST before, during and after the cyclone transit. SST was more than 30.2°C before the cyclone formation ie. during 2nd and 3rd June 2007, over the Central and Eastern Arabian sea as shown in the fig3.2(a).A maximum SST of 31.0°C was observed near genesis area (67.0°E,15.0°N).

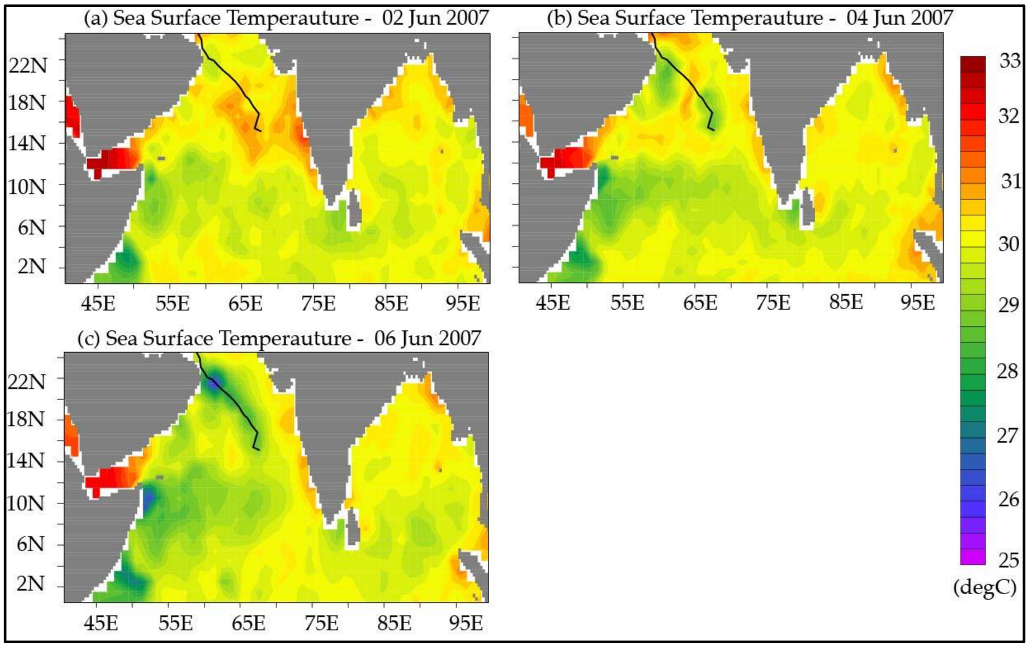
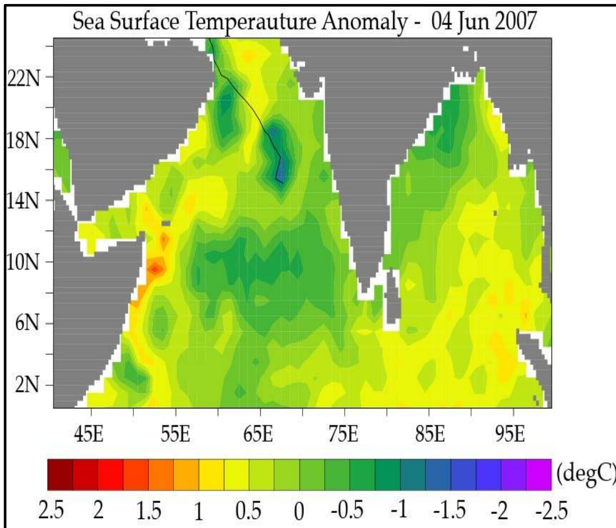



*Figure 2: TMI SST on (a ) 02-June 2007, (b) 04 June 2007 and (c) 06 June 2007, showing the changes in SST field associated with the passage of cyclone Gonu.*

Fig.2(a) shows that, before the cyclone passage, a cell of warm SST (above 31°C) could be seen at 15.1°N and 65.5°E, the genesis area of the cyclone. During the cyclone, a cell of low SST patch could be seen at 15.5°N and 67.5°E to the right of the cyclone track. This is in agreement with Sadhuram (2004), who states that the rightward decrease of SST should occur due to the transit of the cyclone. There are other studies that also suggest that SST usually decreases to the right of the cyclone track after the transit of the cyclone. As compared to the pre-storm SST fig2.(b), the strongest cooling in the SST is over ~2°C in the genesis area.Fig.2(c) shows the TMI SST data after the cyclone transit, ie 06-June 2007. A decrease in SST by 4°C occurs during this period, which shows a rapid cooling in the ocean-surface temperature. During and after Gonu, SST fell over the entire Arabian Sea, and there were two low-SST patches.

Figure 2.(d) shows the SST anomaly - SSTA (calculated relative to the 1999-2007 seasonal period) for 4th June 2007. The SSTA clearly shows that there developed a cold anomaly of more than 1.5°C because of the cyclone passage. This SST cooling could be primarily due to two reasons, first wind induced mixing and secondly, due to turbulent flux losses from the ocean. This prominent feature of cold SST patches at the trail of cyclonic storm is an example to cyclone forcing on the ocean. This negative feedback tends to decrease with the storm intensity. The temporal variability of SST at a location at which Gonu was designated a cyclonic storm (15N, 67E) is shown in figure 2.(e). Just prior to the formation of depression very high SST of around 30.45°C was observed at that location, which provided conducive oceanic environment for the cyclone intensification. Then temperature increases to 30.58°C. With the further intensification of the cyclone, rapid cooling of more than 1.2C is observed at the location within a span of three days



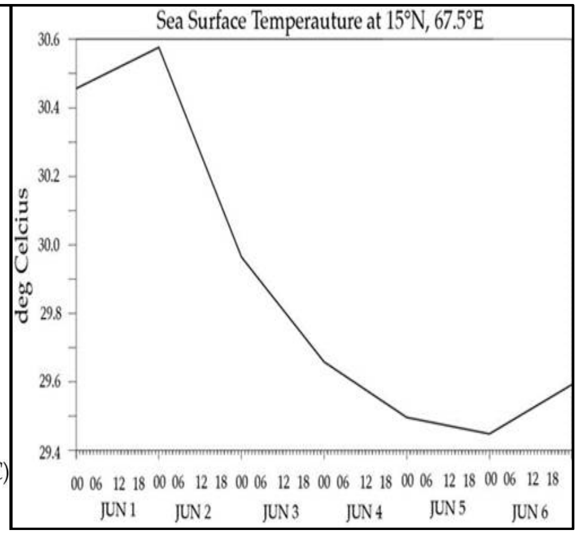




*Figure 2(d): TMI SST anomaly (SSTA) observed on 4th June 2007. SSTA is calculated relative to 10 year (1998-2007 seasonal period) Figure 2(e): Temporal variability of Sea Surface Temperature at 15N, 67.5E, the location at which Gonu was designated as a cyclonic storm*

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### *4.2. Mid Tropospheric Relative Humidity (MTRH)*

Relative Humidity is the amount of water vapor that exists in gaseous mixture of air. MTRH is the relative humdity at 500 hpa level in the atmosphere. Cyclones will weaken rapidly when they travel over locations where heat and/or moisture sources do not exist. Hence, high relative humidities in the lower (850 hPa) and middle troposphere (500hPa) are required for cyclone development. These high humidities reduce the amount of evaporation in clouds and maximize the latent heat released because there is deep cumulus convection and hence greater precipitation. No cyclogenesis can take place over regions where the seasonal 500-700 hPa humidity is less than 40%. Also, convection does not typically occur over regions where MTRH is less than 50-60%. Maps showing the spatial distribution of MTRH are shown in figure 3(a). It can be seen that a zone of high MTRH existed southwest of the cyclone genesis area. This triggered the cyclone to develop and intensify. In the following days (3rd, 4th and 5th June), the upper atmosphere in northern Arabian Sea becomes moister, with higher MTRH values, helping the cyclone to further intensify to a super cyclonic structure. When the cyclone approaches the Arabian landmass, MTRH values gradually decreases.

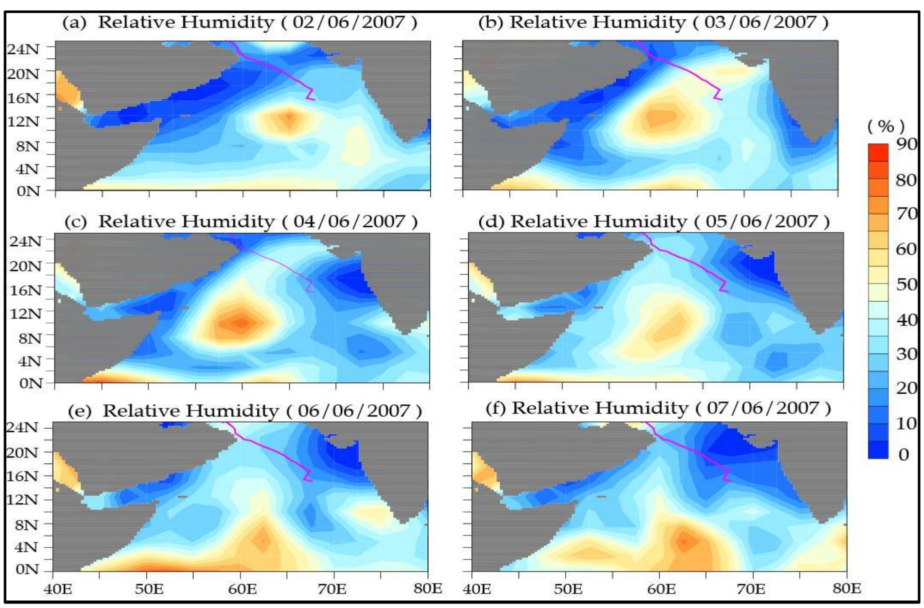


*Figure 3(a): Mid Tropospheric Relative Humidity (MTRH) observed during the cyclone Gonu's developmental phase.*

### *4.3. Precipitable Water (PW)*

Precipitable water (PW) is the amount of water in a column of atmosphere i.e. it is the depth achieved if all the water in that column were precipitated as rain. This is most deeply related to deep convection.

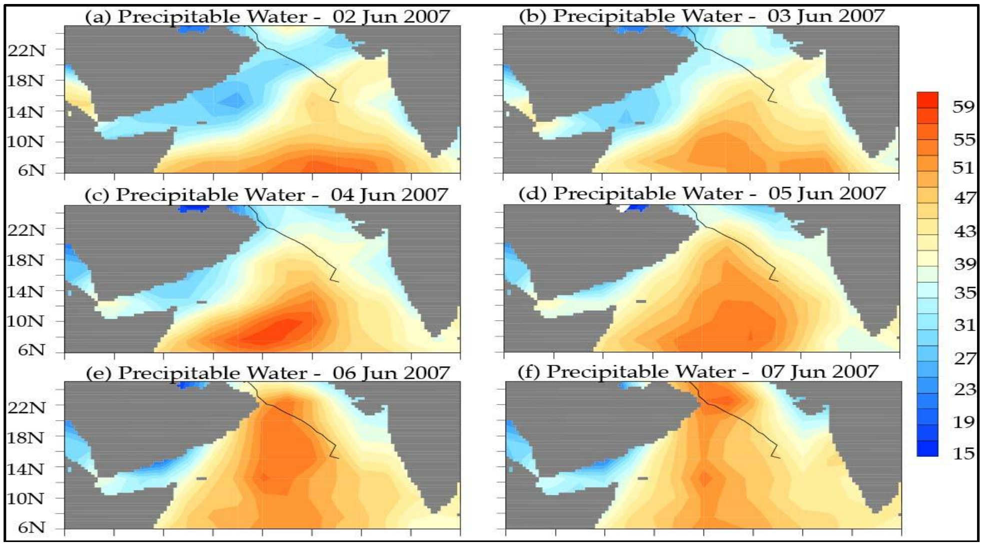


*Figure 4 (a): Precipitable water observed during cyclone Gonu's developmental phase.*

High levels of precipitable water are an indicator of cloud precipitation efficiency. An environment of high precipitable water levels implies more cumulus convection and greater vertical coupling of the troposphere because entrainment of moist air into up-draughts inhibits their growth less than entrainment of dry air. PW was around 20 % higher at the genesis region compared to other parts of the Arabian Sea. The intensification and northward movement of the cyclone is closely associated with an increase of PW along the cyclone path. Higher values of around 60mm are observed along off the Oman coast on 5$^{th}$ June.

### *4.4. Low Vertical Wind Shear (VWS)*

It is the difference between zonal wind fields at 200hPa (1.5km) and 850hPa (12 km). A wind shear of less than 10m/s (20 knots or 22 km/h) between the surface and the tropopause is required for cyclogenesis. The increase in the vertical wind shear on 6$^{th}$ June has been found to play a significant role in the loss of intensity of GONU.A low VWS value of >|10|m/s was observed in the cyclogenesis region before the formation of the cyclone. This low VWS values were maintained during the formative stages of the cyclone. During these periods (2$^{nd}$, 3$^{rd}$, and 4$^{th}$ June), the low VWS helps the updraft of moisture and hence enhanced convection. This in turn helps to trap the energy necessary for the cyclone formation and intensification. As time advances, the shear was seen to be increasing while the depression intensified in that region. VWS further increased when the system intensified into a cyclonic storm.

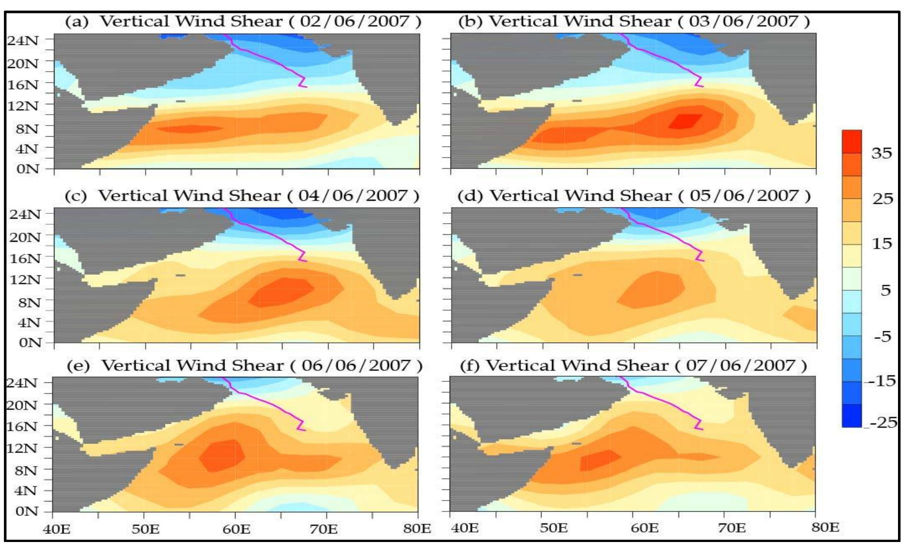


*Figure 5(a): Vertical Wind Shear (VWS) observed during the cyclone Gonu's developmental phase*

## 5. Conclusion

The present study investigates the condition leading to the formation of super cyclonic storm Gonu. Cyclogenisis parameters, such as the SST, MTRH, RV, and VWS were examined. Further more,the variability in different parameters from satellite data such as SST, PW, WS were also investigated from the pre-disturbance to the cyclonic stages. In this study, during the cyclone, cells of low SST could be seen at 15.5°N and 67.5°E to the right of the cyclone track by using SST from TRMM microwave Imager.The analysis from the TMI measurements shows, SST increase in advance of 2day before the significant cyclone intensification. Meteorological

Parameters such as PR associated with cyclone GONU (June 02-07,2007) are found strongly coupled and are associated with the intensity variation of cyclone along its track. In both the intensification and decaying stages of GONU, PR observed to be very high.

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