A STUDY ON TROPICAL CYCLONES OF THE ARABIAN SEA IN JUNE 2007 AND THEIR CONNECTION WITH SEA SURFACE TEMPERATURE

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Abstract:

The purpose of this study was to analyze the sea surface temperature of Arabian Sea and its correlation with the intensification of tropical cyclones. Advanced Very High Resolution Radiometer (AVHRR) satellite driven SST dataset of 0.25 degree horizontal resolution is used in this study. Forecast fields of a high-resolution regional model (HRM) have also been incorporated. An attempt was also made to analyze the possibility of predicting the SST for the month of June taking into account its teleconnection with El Nino Southern Oscillation (ENSO) index into account. The results showed that the average SST of Arabian Sea for the month of June during the period 1985-2007 is increased slightly while that of the Bay of Bengal is showing opposite trend. The SO index for the month of February does show a good correlation with SST of June but the correlation is not highly encouraging to be used as a prediction tool.

Keywords: *Tropical Cyclone, Sea Surface Temperature, AVHRR, Arabian Sea, ENSO, Linear Regression*

Introduction:

Asian monsoon is characterized by a seasonal reversal of lower tropospheric winds and a distinct seasonality of precipitation. During the summer season of northern hemisphere, winds flow from the Southern Hemisphere, accumulating moisture and depositing enormous amounts of precipitation over the south Asian continent. In the winter, dry winds blow from the cold land areas of Asia southwest toward the warm southern ocean [Webster P.J., 1987].

The periods of pre-monsoon and post-monsoon are significant in a way that the changing wind pattern gives birth to cyclonic circulation over the Arabian Sea and Bay of Bengal.

About 80 tropical storms (tropical cyclones with wind speeds greater than or equal to

17 ms–1) form in the world's waters every year [McBride, 1995]. Of these, about 6.5% form in the North Indian Ocean (Bay of Bengal and Arabian Sea) [Neumann, 1993].

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Though historically many tropical cyclones have been observed during pre-monsoon period but the June 2007 got attention because of two tropical cyclones in Arabian Sea. First of these cyclones was the Tropical Cyclone (02A) Gonu which lasted from 1st June to 7th June 2007. Tropical Cyclone Gonu was of category 5 with maximum wind speed of 260 kmh-1 having central pressure of 920 hPa [Joint Typhoon Warning Center]. The second cyclonic activity observed in June was of tropical cyclone 03B which lasted from 21st June 2007 to 26th June 2007. The maximum wind speed was recorded to be 95 kmh-1 with central pressure about 990 hPa [Joint Typhoon Warning Centre]. Both tropical cyclones inflicted heavy damage to life, infrastructure and property to settled areas in India, Pakistan and Oman [BBC].

The formation of two tropical cyclones in Arabian Sea within a month is alarming. As no severe cyclonic storms were reported in the Arabian Sea during the period 1970 to 1999. [Tropical Cyclone Advisory Rsmc 4th June, 2007, **Indian** Meteorological Department]. The current study was conducted to analyse the inter relationship of sea surface temperature of Arabian Sea and Bay of Bengal and to find its correlation with the tropical cyclones.

Intensive research has concluded that tropical cyclones depend on the ocean for their sustainability and intensification. Air-sea interaction, which is an important factor in cyclone formation and development, helps in interchanging the latent and sensible heat fluxes. Various studies have shown strong dependence of tropical cyclone intensity and sea surface temperature as warmer and deeper ocean mixed layers are very important for the development and intensification of tropical cyclones [Simon et. al., 1980].

But the dependence of tropical cyclone formation is not totally upon sea surface temperature as [Ramage C. S., 1972] observed that some tropical cyclones are not affected by the SST, as many other factors can influence the formation, movement and intensification of tropical cyclones.

Data Sets Used:

From the meteorological point of view the in situ observations of Arabian Sea SST is very important but unfortunately it is scarce. For a good dataset a large number of buoys and ships are required to collect the observations but a few are available there. Due to this problem, satellite driven SSTs are the only choice with all their limitations, however, it is available continuously and with almost no gap.

Sea surface temperature was analyzed by using AVHRR satellite data provided by NOAA [Richard W., et. al., 2007]. The dataset has grid resolution of 0.25 degrees horizontal mesh size and has time span from 1985 to 2007. The El Nino Southern Oscillation (ENSO) index was also used to find correlation between SST and SO indices and to find whether the SO index is helpful in predicting the SST of June in Arabian Sea.

Methods of Analysis:

The numerical simulation was carried by the High-resolution Regional Model (HRM) of Deutscher Wetterdienst (DWD). The HRM uses Arakawa C-grid second order centered

differencing and split semi-implicit time stepping. It has hybrid vertical coordinate, 20 to 40 layers and mesh sizes between 0.25° and 0.05°

HRM is being used as an operational forecast model in Pakistan Meteorological Department. The GrADS (Grid Analysis and Display System) was used to visualize the model (HRM) output and data sets of SST. Initially daily data of sea surface temperature was obtained from NOAA AVHRR satellite driven SST. The period used for the study is from 1985 to 2007 and month of June was analyzed specifically. The area averaged values of SST for Arabian Sea and Bay of Bengal were calculated using GrADS. The area selected for the Arabian Sea study has dimensions 9°N to 27°N and 60°E to 75°E and for the Bay of Bengal it extends from 9°N to 27°N and 80°E to 100°E. The High-resolution regional model (HRM) with horizontal grid resolution of 22 km simulated the salient features by using initial and boundary conditions of GME (Global Model Europe) of DWD. Linear regression technique and scatter plot analysis were employed to construct the time series trend and the correlation of the SST of Arabian Sea with the southern oscillation index (SOI)..

Results and Discussion:

The sea surface temperature of Arabian Sea during the period of tropical cyclones was observed to be mostly higher than 26°C. According to [Lars R. Schade, 1999] intensity of tropical cyclone is highly sensitive to sea surface temperature as it sets the stage of tropical cyclone and to the reduction of SST under the eye of tropical cyclone. [Lars R. Schade, 1999] Also found that tropical cyclone intensity is much related to SST under the eye of tropical cyclone than the ambient SST. For the tropical cyclones Gonu and 03B, the SST was analyzed during the life time of both cyclones.

Tropical Cyclone (02A) Gonu:

The tropical cyclone 02A (Gonu) has been declared as the strongest historical cyclone (super cyclone) in Arabian Sea [Joint Typhoon Warning Center]. The Gonu originated from a tropical disturbance developed about 645 km south of Mumbai, India on 31st May, 2007. By 1st June 2007, after getting energy from favourable conditions of SST and convection it intensified into a strong cyclone with wind speed reaching upto 260 kmh^{-1} and gusts of about 315 kmh^{-1}. [Joint Typhoon Warning Center]. The minimum sea level pressure as low as reached to 920 hPa at 4th June. [India Meteorological Department].

Fig 1 shows the SST on 1st June 2007, the area (covered by dotted rectangle) within 12°N to 21°N and 60°E to 72°E has SST on average above 30°C, which fetched the moisture to the cyclonic disturbance and resulted in its intensification. The tropical cyclone Gonu after moving from the origin fed by the latent heat released during the precipitation process over the sea. got more energy and developed to category 5 cyclone.

Fig 2 is shows the satellite image [courtesy EUMETSAT] of Gonu on 4th January, 2007 which is almost at the same place where the SST has been observed to be higher than 30°C. The observed track followed by the tropical cyclone Gonu during

its life span is presented in Fig 3. The elliptical portion is indicating the area where Gonu attained its maximum intensity. Rest of the beads in the chain reflects lower intensities at the earlier and later stages of its life cycle.

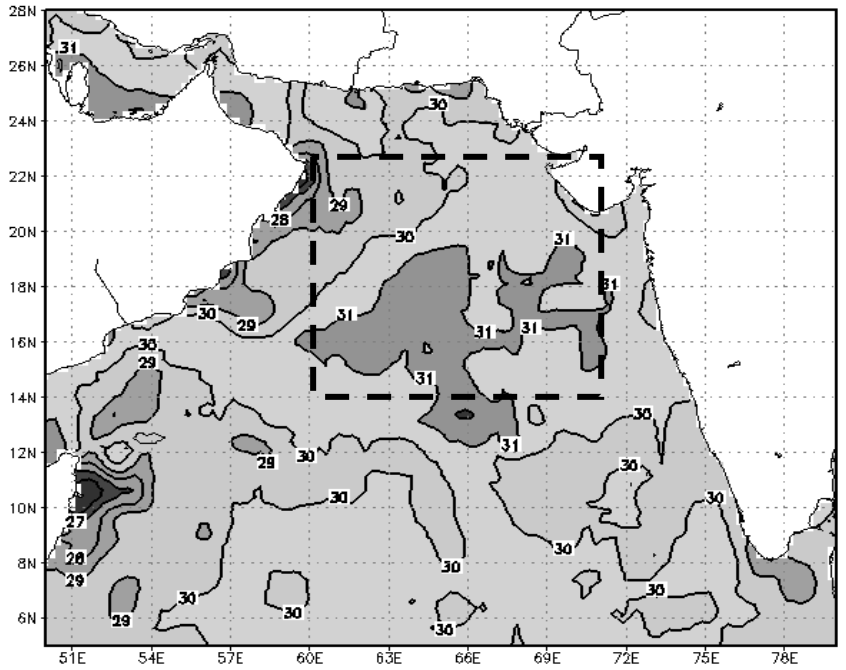

Figure (1): Sea surface temperature (°C) on 00UTC of 1st June 2007. Dotted rectangular box show the area of study in the Arabian Sea.

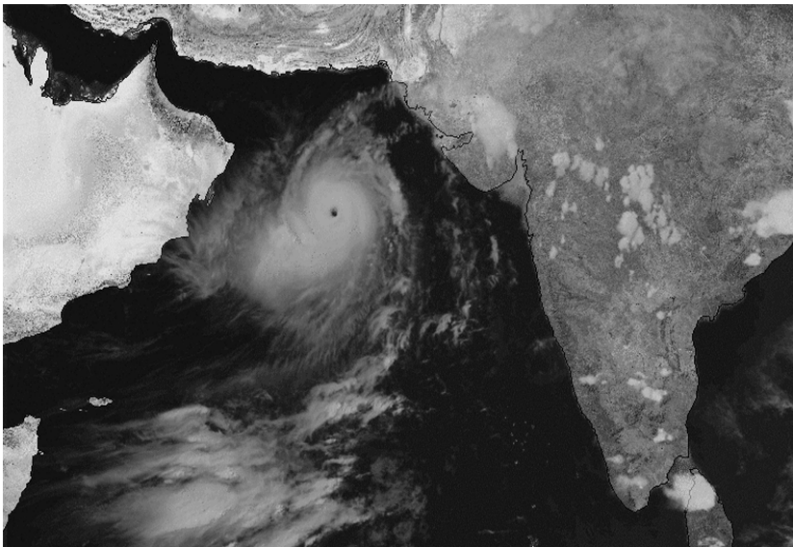

Figure (2): Satellite image (EUMETSAT) of Tropical Cyclone Gonu on 03UTC of 4th June 2007

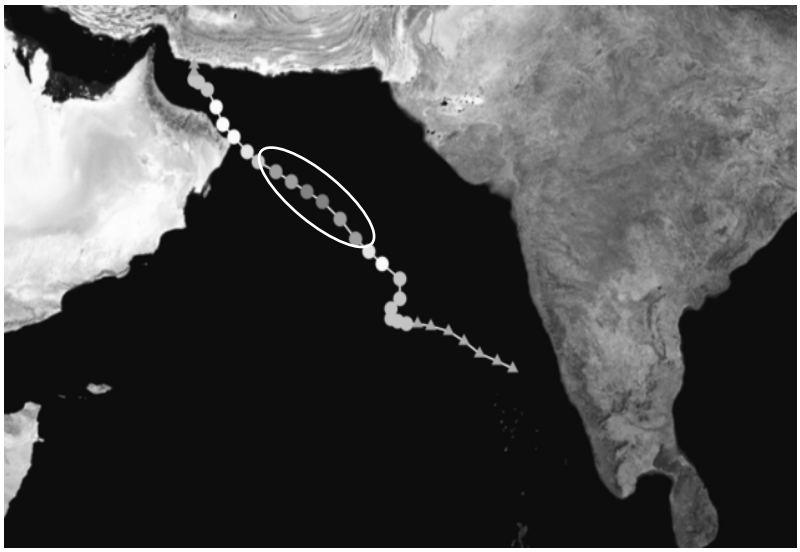

Figure (3): Satellite driven observed track of Tropical Cyclone Gonu.

Numerical Simulations:

Figs (4 & 5) are showing the forecast of High-resolution Regional Model (HRM) initialized from 00UTC of 3rd June, 2007.

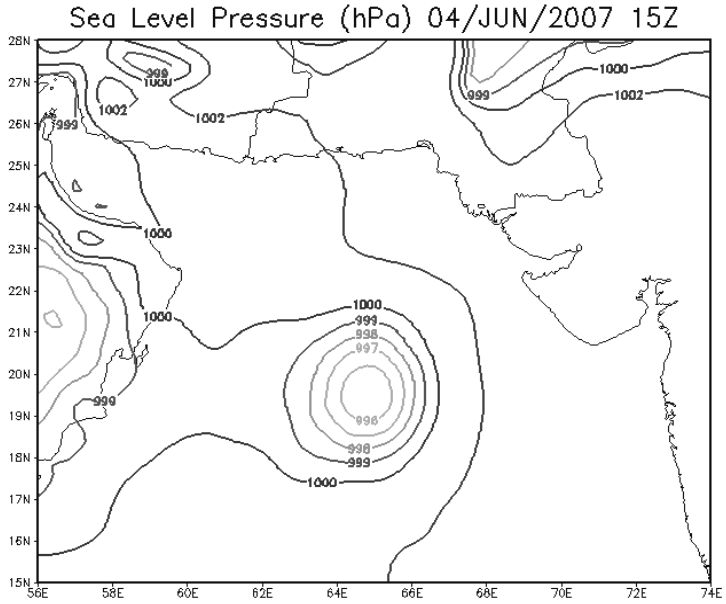

Figure (4): Forecast for Sea Level Pressure from HRM initialized from 00UTC of 3rd June, 2007.

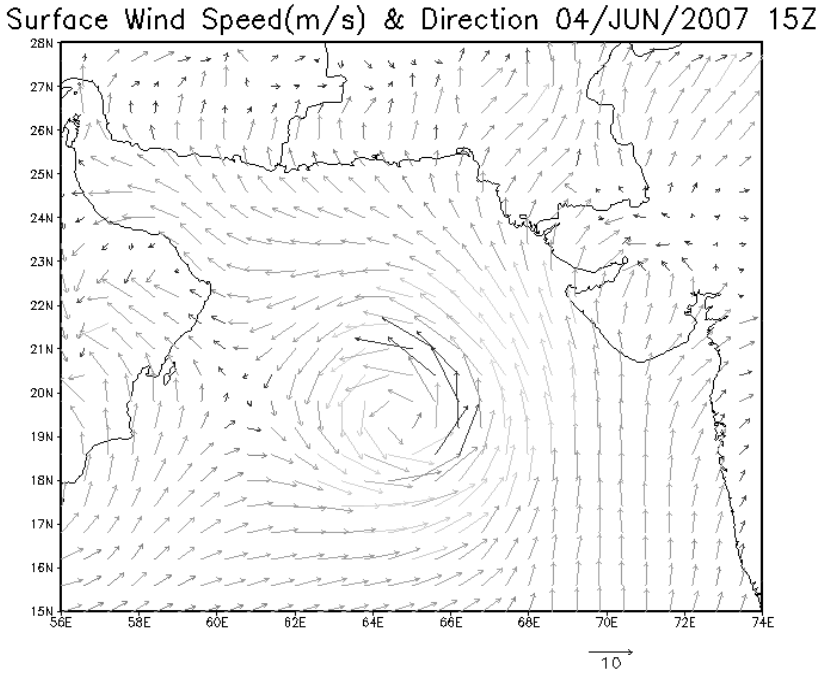

Figure (5): HRM forecast of wind speed and Direction initialized from 00UTC of 3rd June, 2007.

Fig 4 is showing the sea level pressure. The central pressure is less than about 996 hPa. Though the observed central pressure in case of Tropical Cyclone Gonu was 920 hPa. This problem may be due to the resolution factor of model. The fig 5 is showing the wind pattern (10m) exhibiting a strong cyclonic motion with wind speed of around 15ms-1.

Tropical Cyclone 03B:

Second significant event of June 2007 was the development of tropical cyclone 03B in the central north Arabian Sea. On 21st June 2007 the Joint Typhoon Warning Centre (JTWC) issued a tropical cyclone formation alert with wind speed of 55 kmh-1. From then onwards the system moved through northern Andhra Pradesh coast in the west-northwest direction [Indian Meteorological Department]. A strong monsoonal low-level flow contributed to increased cyclonic vorticity, along with low vertical wind shear and warm sea surface temperature. The system crossed the coast into the Arabian Sea on 24th June 2007. In the Arabian Sea, the wind shear and SST provided conducive conditions to gain strong vortex characteristics with strong convergence over the sea surface and divergence aloft. This warm-core vortex developed and gained strength of a tropical cyclone with winds gusting above 90 kmh-1.

From there on it moved northwest and reached within 95 km of Karachi. On 25th June 2007 the average wind speed measured to be 48 kmh-1 near the centre with surface pressure of 990 hPa. The system further intensified due to strong convection of moisture flux and abundant release of latent heat during the condensation and precipitation processes. The tropical cyclone made its landfall at about 03 UTC, June 26 along the Makran coast near Ormara and Pasni in southwest Pakistan.

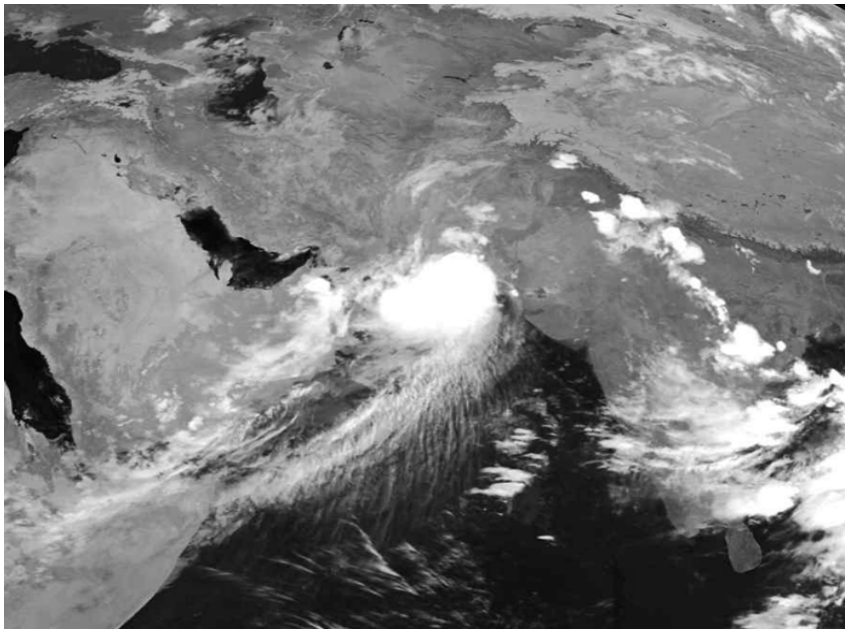

Figure (6): Satellite image (EUMETSAT) of Tropical Cyclone 03B on 25th June, 2007.

In Fig 6 the satellite image of Tropical Cyclone 03B on 25th June, 2007 is shown. By comparing the figs (6 & 7), one can see that the area close to the coast of Makran (enclosed by a rectangle) has SST greater than 30°C. This is almost the same case as observed in case of Tropical Cyclone Gonu already discussed..

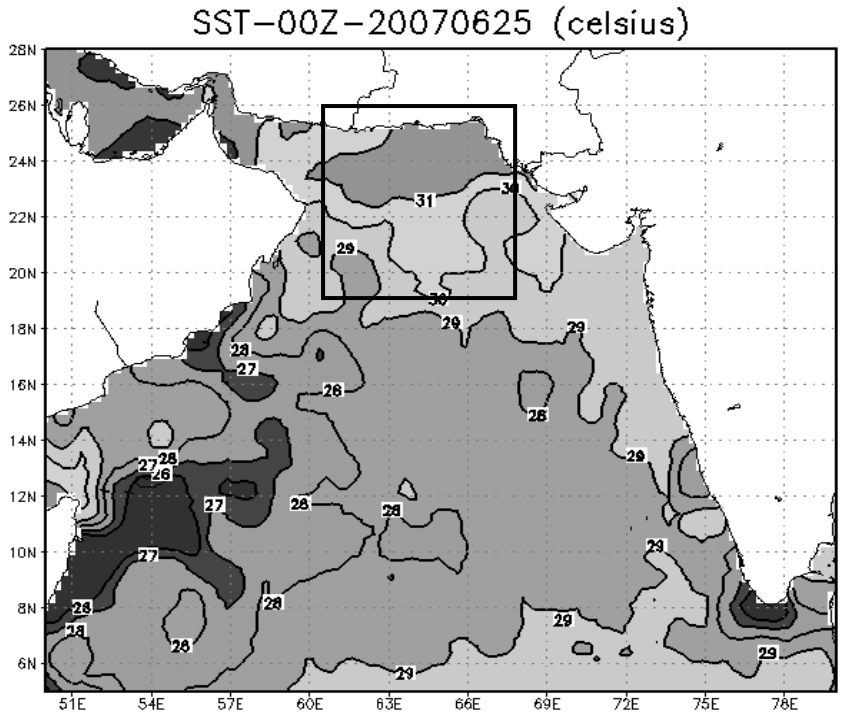

Figure (7): SST on 00 UTC of 25th June, 2007

Numerical Simulations of 03B:

Figs (8 & 9) are showing the forecast (00 UTC, 26 June, 2007) of HRM initialized from 23rd June, 2007. Sea level pressure (fig 8) pattern gave almost the exact location of central part of Tropical Cyclone 03B as was observed as shown in satellite image fig 6. Fig 9 shows the wind speed and direction.

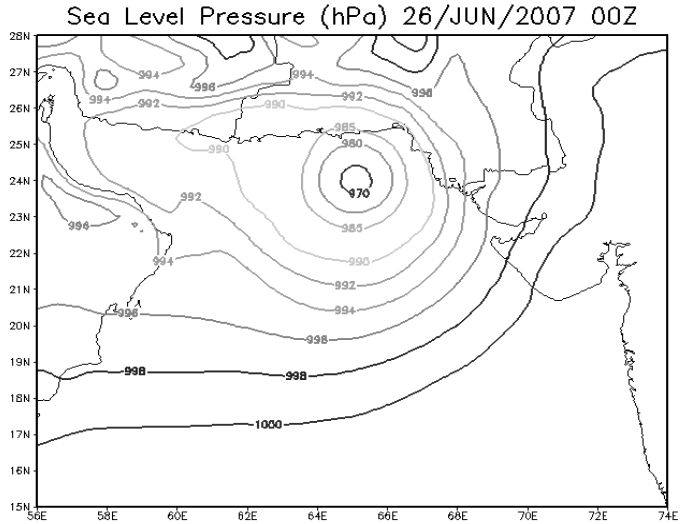

Figure (8): Forecasted of Sea Level Pressure with HRM initialized from 00UTC of 23rd June 2007.

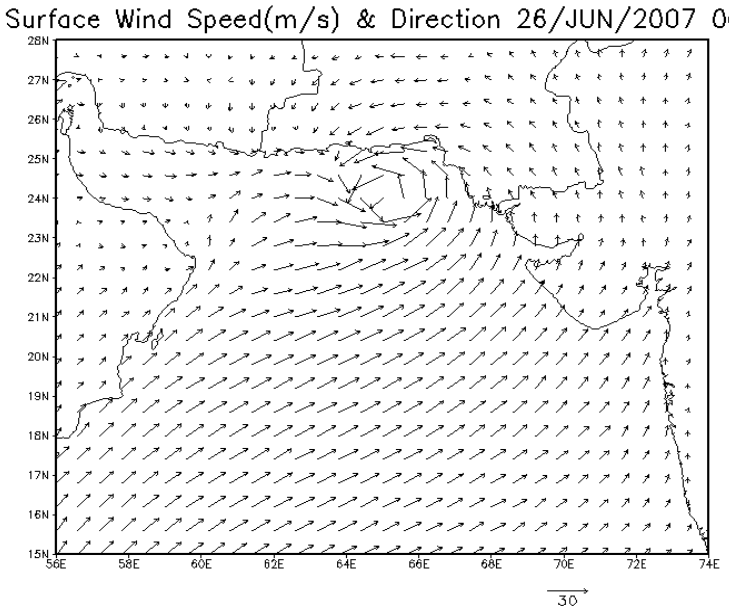

Figure (9): HRM forecast of wind speed and Direction initialized from 00UTC of 23rd June 2007.

The maximum wind speed forecasted for the 00UTC of 26th June, 2007 was about 30 ms-1. The forecasted sea level pressure (~970hPa) is lower than the JTWC observed values (~990hPa) central SLP of tropical cyclone.

Since historically, no severe cyclonic storm was reported in the Arabian Sea during the period 1970 to 1999 [Indian Meteorological Department], so to study this unusual change in behaviour of tropical cyclone in Arabian Sea, the sea surface temperature data for the month of June from 1985 to 2007 was analyzed. Though up to 2000, there is no significant change in the SST of the Arabian Sea but the period 2001 to 2007 shows considerable changes.

Sea Surface Temperature Analysis:

For the sea surface temperature analysis, AVHRR satellite data was used which is provided by NOAA. Area average value of SST was measured for month of June (1985 to 2007) and the area of Arabian Sea was selected with dimensions extending from 9°N to 27°N and 60°E to 75°E. For the Bay of Bengal, area was selected with dimensions 9°N to 27°N and 80°E to 97°E.

Scatter chart plotted (fig 10) for Arabian Sea area-averaged SST against that of Bay of Bengal does not show any prominent correlation as the R-square value is 0.1626.

So we can say that the SSTs of June for both Arabian Sea and Bay of Bengal do not affect each other much.

The time series of area-averaged SST of Arabian Sea and Bay of Bengal in fig 11 is showing the slight increase in the SST of Arabian Sea while the SST of Bay of Bengal has a slight decreasing trend. The slope obtained from linear regression gives the extent of the trend in both the cases which in both the cases are quite small, though positive and negative.

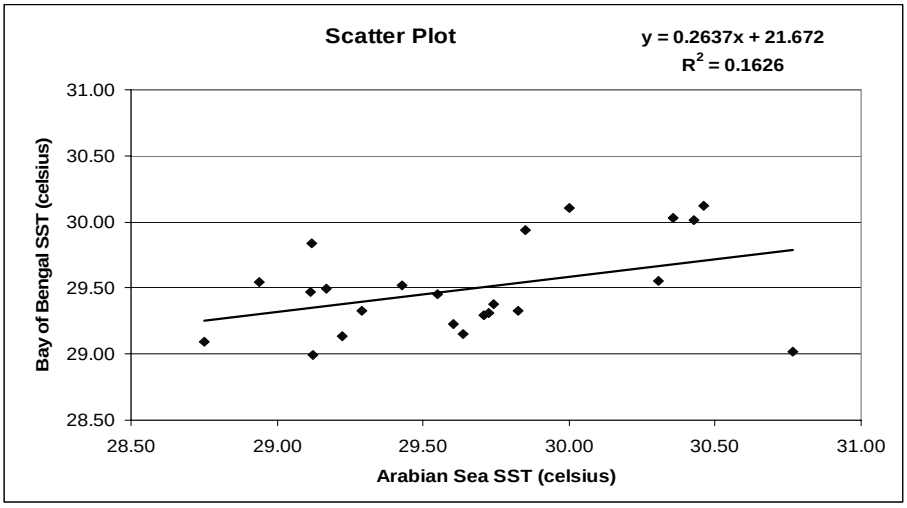

Figure (10): Scatter chart plotted for Area-averaged values of SST for Arabian Sea and Bay of Bengal.

Another important fact that can be observed in the graph is the sharp increase in SST of Arabian Sea after 2000. Since 2000, the Arabian Sea is exhibiting almost sinusoidal behaviour with wavelength of about 2 years. It can further be noticed that during the strongest El-Nino year of the globe (1997-98), the SST of the Arabian Sea and the Bay of Bengal also touched the new high. Although El-Nino events are defined by relative thermal behaviour of Eastern equatorial Pacific Ocean but temperature over the Arabian Sea and the Bay of Bengal also followed the similar pattern during historic strongest events of 1982-83 and 1997-98. Further systematic research may provide some local indicator to predict El-Nino and La-Nina events.

These results also suggest the importance of prediction of SST of the Arabian Sea to explore dew dimensions of meteorological research. So an attempt was made to understand the interconnection of SST with the El Nino and Southern Oscillations (ENSO). The ENSO has significant influence on Asian monsoon on temporal and spatial scales. The occurrence of El Nino is generally associated with a weak monsoon in south Asian region, and La Nina is associated with a strong monsoon [Webster and Yang 1992].

The best correlation was found for ENSO index of February to the Arabian Sea SST of June which was 42%. But this correlation is not significant at any considerable level of confidence in the view of SST prediction. The R-square values for the months of April,

May and June are 0.33, 0.20 and 0.0001 respectively. So this analysis suggests that ENSO does not have any strong influence on SST of Arabian Sea for the month of June.

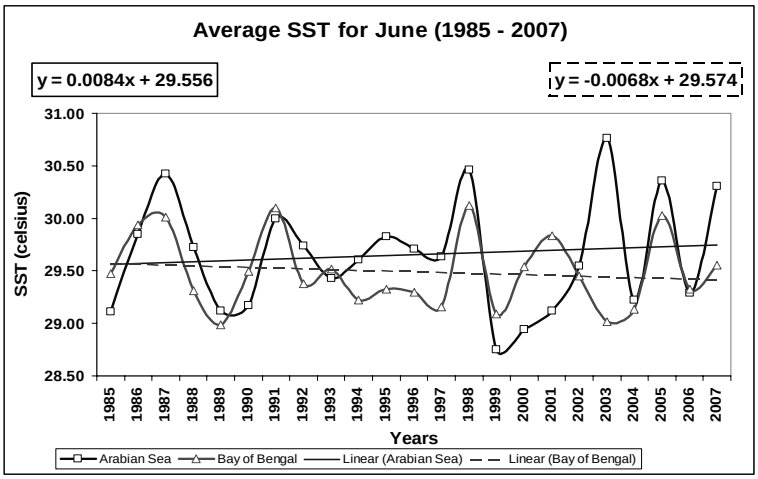

Figure (11): Graph showing time series (1985-2007) of Area-averaged SST of Arabian Sea and Bay of Bengal.

Conclusions:

The average SST of Arabian Sea in the month of June is showing slightly increasing trend for the period 1985 – 2007, while that of Bay of Bengal for the same period is showing negative trend. This may give rise to more frequent and intensive cyclonic storms in future in the Arabian Sea.

The SST analysis compared to the HRM forecast does show some agreement for SST and tropical cyclone intensity. The higher SST (greater than 30°C) values near the coast line of Karachi and Makran probably caused the system (Tropical Cyclone 03B) to intensify the system before its landfall and to move along the observed track. At the time of intensification of Gonu, SST was also greater than 30°C. Same factor was observed in case of Tropical cyclone Gonu from the forecast field of HRM.

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