Tropical Cyclone Heat Potential (TCHP) from the NCMRWF NEMO based global ocean analysis and forecast system

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ABSTRACT. In this study, the Nucleus European Modelling of Ocean (NEMO) based global ocean analysis and forecast system configured at National Centre for Medium Range Weather Forecasting (NCMRWF) is used to compute the real-time TCHP monitoring capability on daily basis. It is produced in real time using the global ocean forecast system up to 10 days using the ocean only model and up to 15 days using the coupled atmosphere-ocean model for the real-time TCHP monitoring capability on daily basis. It is produced in real time using the global ocean forecast system up to 10 days using the ocean only model and up to 15 days using the coupled atmosphere-ocean model for the upper ocean and also for research purpose mainly for Tropical Cyclone (TC) study. Four pre-monsoon TCs with category above cyclonic storms in which two from Arabian Sea and two from Bay of Bengal are also examined. The Sea Surface Temperature drop is much more over the regions where the surface wind stress anomaly is strong. In both regions, various small scale warm and cold eddies are observed during TCs. TCHP anomaly is positive/negative over the region where Sea Surface Height (SSH) anomaly is positive/negative. From TCHP, it is manifest that the magnitude of TCHP anomaly is higher in BoB than AS region during TCs.

Key words – NEMO, ODA, TCHP, AS, BoB.

1. Introduction

Tropical cyclones (TC) are characterized by the most potentially destructive extreme events associated with a low pressure centre and strong wind. They affect the coastal population as well as marine community with dangerous effects of strong wind, heavy rain and storm surge. As we know that the Sea Surface Temperature (SST) plays crucial role in the genesis of TC. Various studies show that the threshold value for the genesis of tropical cyclonesis more than 26 °C SST (Palmen 1956; Gray 1968; and Wendland 1977). Further, it controls the primary energy supply for TC through the upward latent heat fluxes. However, the intensification of TC is a very complex process which involves a combination of different favorable atmospheric conditions such as the boundary layers, barotropic instability, wind shear, convection, Rossby wave, upper ocean circulation and air-sea interaction. Emanuel (2003) described the dynamics, thermodynamics and air-sea interaction of tropical cyclone after the reviewing the structure, behavior, and climatology of various cyclonic storms.

The track and intensity prediction of tropical cyclones is vital for evacuation of densely populated coastal areas. Recently, Mohapatra and Sharma (2019) described the climatological characteristics (spatial and temporal distribution and intensity) of TC, damage
potential, modeling and prediction, Prediction skills, information dissemination mechanisms, and socio-economic impacts. However, the dynamical and statistical models are basically used with fixed SST as boundary/predictor for the prediction of track and intensity of tropical cyclones. Rai et al. (2018) used the regional model to examine the role of varying resolution of the sea surface temperature (SST) on the prediction of tropical cyclone (up to 72 hr lead time) and shows that the SST changes the size, intensity and track of tropical cyclone. They also show that the high resolution SST provides as useful input parameter for the regional model to improve the track and intensity of tropical cyclone. Dube et al. (2020) used the two different version of ensemble prediction system with an additional perturbation of SST, deep soil temperature and soil moisture content and shows that the high resolution ensemble prediction system improves the tropical cyclone forecast in terms of strike probability, mean tracks and position errors, Reliability Diagram, and Relative Operating Characteristic. However, Ali et al. (2013) used the satellite derived SST and tropical cyclone intensity (CI) to examine the relationship in the tropical Indian Ocean and shows that more than 50% of cyclones have no
significant correlation between SST and CI. They further shows that the SST leading the CI by maximum three days.

Upper Ocean plays a key role in the intensification of TC. Further, the various researchers show the intensification of TCs while passing through the deep upper ocean mixed layer [Shay et al., 2008; Ali et al., 2007; Lin et al., 2009; Goni et al., 2009]. Further, Sharma and Ali (2014) examined the thermal structure of the upper ocean during various TC phases such as pressure drop, track change, intensity and storm surge height and shows that the upper ocean is more critical and sensitive predictor for TC as compare to SST. In this study, we used the global ocean analysis and forecast system to compute the upper ocean heat content up to 26° isotherm depth called Tropical Cyclone Heat Potential (TCHP) during the TC. This TCHP data is also produced in real time using the global ocean forecast system up to 10 days. Momin et al. (2014) used the two different horizontal resolution of NEMO forced by climatological boundary fluxes and showed that the high resolution model simulated the annual cycle of upper ocean very well. The NEMO based variational assimilation system called NEMOVar is a collaborative project with aims to develop and implement an advanced data assimilation techniques for multiscale applications. It is developed by number of partners such as Centre Européen de Recherche et Formation Avancée en Calcul Scientifique (CERFACS), European Centre for Medium-range Weather Forecast (ECMWF), Institut National de Recherche en Informatique et Automatique (INRIA), and Met Office. NEMOVar system was first implanted by ECMWF for non-operational and operational basis at ORCA025 configuration (Waters et al., 2014). Similar NEMOVar

| Date     | Category of cyclonic disturbance | Name of cyclone | Date     | Category of cyclonic disturbance |
|----------|----------------------------------|------------------|----------|----------------------------------|
| 16 May, 20 | CS                              | AMPHAN           | 22 May, 18 | CS                              |
| 17 May, 20 | SCS & VSCS                      |                  | 23 May, 18 | CS & SCS & VSCS                  |
| 18 May, 20 | ESCS & SuCS                     |                  | 24 May, 18 | VSCS                            |
| 19 May, 20 | ESCS                            |                  | 25 May, 18 | VSCS & ESCS                     |
| 20 May, 20 | VSCS & SCS                      |                  | 26 May, 18 | VSCS                            |
| 21 May, 20 | CS                              |                  |          |                                  |
| 27 Apr, 19 | CS                              | FANI             | 10 Jun, 19 | CS                              |
| 28 Apr, 19 | CS & SCS                        |                  | 11 Jun, 19 | CS & SCS & VSCS                  |
| 29 Apr, 19 | SCS                             |                  | 12 Jun, 19 | VSCS                            |
| 30 Apr, 19 | VSCS                            |                  | 13 Jun, 19 | VSCS                            |
| 01 May, 19 | VSCS & ESCS                     |                  | 14 Jun, 19 | VSCS                            |
| 02 May, 19 | ESCS                            |                  | 15 Jun, 19 | VSCS                            |
| 03 May, 19 | ESCS & VSCS & SCS               |                  | 16 Jun, 19 | VSCS & SCS & CS                  |

National Centre for Medium Range Weather Forecasting (NCMRWF) implemented the state-of-the-art modelling framework of Nucleus European Modelling of the Ocean (NEMO, Madec, 2008) for research activities, initialization of global coupled model and also for ocean state forecast. Momin et al. (2014) used the two different horizontal resolution of NEMO forced by climatological boundary fluxes and showed that the high resolution model simulated the annual cycle of upper ocean very well.
system at ORCA025 configuration is also implemented at National Centre for Medium Range Weather Forecasting (NCMWRWF) in collaboration with Met Office for producing real time ocean analysis (Momin et al., 2020a). This analysis is further used to initialize the ocean component of the coupled atmosphere-ocean model configured at NCMRWF with aims to predict the weather and climate at different time scales such as short, medium, extended and seasonal (Gupta et al., 2019a; 2019b). The global ocean analysis has ¼ degree resolution and 75 vertical levels starting from 0.5 m. Momin et al., (2020b) used NEMOVar to study impact of Altika derived sea level anomaly data and shows that the sea surface height is improved after assimilation of altimeter data.

3. Methodology

In this study, the NEMO based global daily ocean analysis from 2016-2020 are used to study the upper ocean parameters during passage of pre-monsoon TCs. Table 1 shows the list of cyclones with details of their name, date and category of TCs for Arabian Sea (AS) and Bay of Bengal (BoB) regions. Total four TCs (two in AS and two in BoB) with category above cyclonic storms are considered during the study periods. During the passage of TCs, the three important upper ocean parameters such as Sea Surface Temperature (SST), Sea Surface Height (SSH) and TCHP are studied in term of climatology, mean and its anomaly. Here, the global NEMO analysis of temperature and salinity is used to compute TCHP by adding heat content in a vertical column from sea surface to 26 °C isotherm depth. The Upper Ocean parameters are average over the TCs period defined in Table 1 while the climatology is computed for respected TCs month from 2016-2020. The surface wind stress used as air-sea momentum flux is defined as

\[ \tau = (\tau_x, \tau_y) = \rho_a C_d W(u, v) \]  

Where, \( \tau_x \) and \( \tau_y \) are east-west and north-south components of wind stress respectively. \( W(u, v) \) is magnitude of surface wind (at 10 m) with its east-west and north-south components \( (u, v) \) from NCMRWF Unified Model (NCUM). \( \rho_a \) is the density of surface air, \( C_d \) is the drag coefficient. Estimating the surface wind stress is most crucial especially during the tropical cyclone due to wind dependent drag coefficient. In this study, the wind stress is computed using the Coordinated Ocean Reference
Experiments (CORE) bulk formulae developed by Large and Yeager (2004). SSH is defined as the vertically integrated sea surface changes in the entire water column. It is related to the density variation through the changes in temperature and salinity. Further, it provides the information of subsurface ocean and air-sea interaction parameters such as thermocline depth and TCHP, and thus is another important for the coupled atmosphere ocean phenomena.

4. Upper ocean parameters during TCs

4.1. Sea surface temperature

For TCs, the primary heat source is the upward latent heat fluxes that are directly related to SST. Figs. 2(a-c) shows the climatology, mean and anomaly of SST during composite TCs in AS (upper panel) and BoB (lower panel) regions. The composite mean wind stress anomaly is also overlaid over the SST anomaly during TCs in the AS and BoB regions. The composite mean wind stress anomaly also indicates the cyclonic circulation in west central AS and near the Gujarat coast for AS regions, and in west central BoB region. The composite SST anomaly shows the SST drop (0.2-0.8 °C) during TCs. Further, this cyclone-induced SST drop directly related to a negative feedback of energy supply through negative total heat flux and, subsequently to limit the strength of a cyclone. Similarly, the drops in SST anomalies of more than 1 °C have been observed over the different oceanic regions such as Atlantic Ocean; Indian Ocean, and South China Sea at daily scale (Leipper 1972; Shay et al., 2008; Lin et al. 2003; Veeranjaneyulu Ch and A. A. Deo 2019). Further, the SST drops is much more over the regions where the surface wind stress anomaly is strong.

4.2. Sea surface height and tropical cyclone heat potential

Figs. 3(a-c) shows the climatology, mean SSH and its anomaly during composite TCs in AS (upper panel) and BoB (lower panel) regions. In both regions, various small scale warm and cold eddies are observed during TCs. Here warm and cold core eddy are associated with positive and negative SSH anomaly respectively. All TCs except Amphan TC passes through the negative SSH anomaly. The warm core eddy is also observed during the Amphan TC in BoB region. This may be one of reason for rapid intensification of Amphan TC. Shay et al., 2008 shows the sudden unexpected intensification of Hurricane
Figs. 4(a-c). Tropical Cyclone Heat Potential (KJ cm$^{-2}$) in AS (upper panel) and BoB (lower panel) during the TCs (a) Climatology (b) Observed and (c) Anomaly in AS and BoB regions.

Fig. 5. Scatter plot of SSH (m) vs TCHP (KJ cm$^{-2}$) during the FANI TC (27-3 May, 2019).

$y=0.002x+0.38$

Corr=0.75
Opal in the Gulf of Mexico after passing over a warm core eddy with drop of pressure from 965 to 916 hPa in 14-hour period. Further, an increase/decrease in SSH represents a corresponding increase/decrease of the warm water (or heat content) of the ocean. TCHP anomaly is positive/negative over the region where SSH anomaly is positive/negative [Fig. 4(c)]. From [Fig. 4(c)] it is manifest that the magnitude of TCHP anomaly is higher in BoB than AS region during TC. Further, the scatter plot of SSH and TCHP in BoB region (80-95° E; 4-20° N) during FANI cyclone (27-03 May 2019) clearly shows the strong relation with correlation of 0.75 (Fig. 5). There are more than 30,000 points collohsed SSH and TCHP points in this analysis. Ali et al., 2007 also described the close relationship between the TCs intensity with SSH anomaly in the BoB region.

5. Summary

In the present study, we used the Nucleus European Modelling of Ocean (NEMO) based global ocean analysis and forecast system to compute the Tropical Cyclone Heat Potential (TCHP) at daily time period. The TCHP data are produced in real time up to day 10 using ocean only model forecast and up to 15 days using the global coupled model forecast. This data will be useful for monitoring the global Upper Ocean as well as for research purpose especially during the Tropical Cyclones (TCs). We further analyzed the long term TCHP data (2016-2020) from NEMO analysis system during four TC cases with category above cyclonic storms. In four pre-monsoon TCs, out of which two from Arabian Sea (AS) and two from Bay of Bengal (BoB) are considered here. During the passage of TCs, the three important upper ocean parameters such as Sea Surface Temperature (SST), Sea Surface Height (SSH) and TCHP are studied in term of climatology, mean and its anomaly. The composite SST anomaly shows the SST drop (0.2-0.8°C) during TCs. This cyclone-induced SST drop directly related to a negative feedback of energy supply through negative total heat flux and, subsequently to limit the strength of a cyclone. In both AS and BoB regions, various small scale warm and cold eddies are observed during TCs. TCHP anomaly is positive/negative over the region where SSH anomaly is positive/negative. The magnitude of TCHP anomaly is higher in BoB than AS region during TC. Finally, NCMRWF is actively analyzing various oceanic parameters during TC operationally and for research purpose from ocean forecast system and coupled forecast system.

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