



ISSN: 2319-5967

ISO 9001:2008 Certified

International Journal of Engineering Science and Innovative Technology (IJESIT)

Volume 4, Issue 2, March 2015

OSCAT Wind Stress and Wind Stress Curl during the Bay of Bengal Tropical Cyclone ‘Mahasen’

S. K. Sasamal, Sourabh Bansal, K.H.Rao, C.B.S.Dutt, and V. K. Dadhwal

National Remote Sensing Centre, Hyderabad. India

Abstract: The OSCAT wind stress and wind stress curl fields are analysed in the Bay of Bengal during a low pressure event developed in May 2013. The system has initiated as early as May 09, 2013 in the south of Andaman and progressed towards north and turned westward in the northern Bay. The wind stress (WS) during the event has reached to an extent of 0.4 N/m^2 . The spatial distribution of WS along the route of cyclone has shown three intensives areas around the center of the low pressure event. While, the WS curl (WSC) has varied over $-2 \times 10^{-6} \text{ N/m}^3$ in the coastal water Orissa to $2 \times 10^{-6} \text{ N/m}^3$ off the coast of Bangladesh, which has remained positive in the area of cyclonic activity. The impact of wind has reflected in the ocean surface which was evident from the observations of drifting buoys of the area. Temperature and salinity profiles of the in the area have indicated intensive mixing to deeper waters, which has remained in the south than those of the north in the cyclone affected area. The WS and WSC results along with field observations during the event are analyzed to explain the response of the surface waters of the ocean in the Bay of Bengal.

Index Terms— Tropical cyclone, SARAL AltiKa, Sea Surface Height Anomaly, Significant Wave Height, Surface Wind Speed.

I. INTRODUCTION

Tropical cyclones are one of those disasters that need near real time wind observations in high temporal and spatial resolution. The conventional modes of gathering wind data have proved cost intensive and difficult. Since the event arises and attains its intensity at the sea, the observations made at the sea are of significance to those who tracks the event. At the sea, collecting data of the ocean and atmosphere has remained a difficult task. The meteorological equipments at sea are sparsely distributed and restricted mostly to shipping lanes. Alternatively, the model wind estimations are yet to satisfy users in the field due to uncertainty in its accuracy and ability to predict. Hence, scatterometers are designed to provide high resolution wind vector at regular intervals around the globe. A good number of scatterometers are in space platforms like, SeaSat-A, ERS-1/2, NSCAT, Sea winds on Quick scat and ADEOS-2, ASCAT, HY-2 and EUMETSAT's METOP-A and METOP-B along with the Oceansat-2. This carry a rotating pencil beam scatterometer (henceforth termed OSCAT) to provide the ocean surface wind. This helps to monitor cyclones and predict their path at the sea. Besides, the scatterometer data are also used in the study of gas exchange, energy fluxes, mass, momentum and heat transfer across air-sea interface. The OSCAT winds help to study ocean circulation and sea ice formation. The present study explains their utility in the study of a low pressure system, a tropical cyclone developed in the Bay of Bengal in May 2013 as the ‘Mahasen’. In the process, the Ocean Surface Wind, the Wind Stress (henceforth WS) and the Wind Stress Curl (henceforth referred as WSC) fields from the OSCAT wind data generated at National Remote Sensing Centre (NRSC), Hyderabad are used. Earlier, similar studies are made using the WS and WSC to study ocean circulation, heat and mass exchange processes at the sea [1]-[4]. The WS and WSC products from QuickSCAT have also been analyzed to document their variability in the ocean response studies to the cyclones like, Nargis and Laila in the Bay of Bengal [5]. Using satellite data, the response of cyclone in the stratosphere and mesosphere gravity waves have also been reported using Visible/Infrared imager/Radiometer (VIIR) of Suomi NPP satellite [6]. However, the present work explores the scope of the OSCAT WS and WSC in the study of tropical cyclone ‘Mahasen’.

II. DATA AND METHODS

Indian Space Research Organization (ISRO) has launched OSCAT, the Oceansat-2 Scatterometer along with the Ocean Colour Monitor (OCM) and the ROSA (Radio Occultation for Sounding the Atmosphere) to study ocean and atmospheric processes around the globe on 29 September 2009. The satellite covers entire globe to provide the

sea surface wind products in 50 km and 25 km resolutions daily. The wind products are disseminated through the NRSC (National Remote Sensing Centre) and the SAC (Space Application Centre) web sites. Even the high resolution wind products of 12.5 Km spatial resolution are also provided from the NOAA (National Oceanic and Atmospheric Administration) and the Royal Netherlands Meteorological Institute (KNMI) web sites. At the NRSC, the OSCAT winds are used in the studies of monsoon, tropical cyclone formation, and ocean surface productivity. Recently, the OSCAT WS and WSC products are also provided from NRSC web sites. This gives an opportunity to study the ocean and atmosphere dynamics and helps to run atmospheric models to forecast weather systems. In this study, the OSCAT WS and WSC of the Bay of Bengal during May 2013 are used to study the tropical cyclone Mahasen. Suraiya (2013) has reported on the landfall along the coast of Bangladesh around Borguna and Patuakhali at 08.31 BDT (*i.e.* Bangladesh Time) [7]. The T 2.5/T3.0 cyclone picked up winds of 80 Km/hr and above along the coast with waves of 6 to 7 ft high has been observed by drifting buoys in the Bay of Bengal along the track of cyclone (Figure 1).

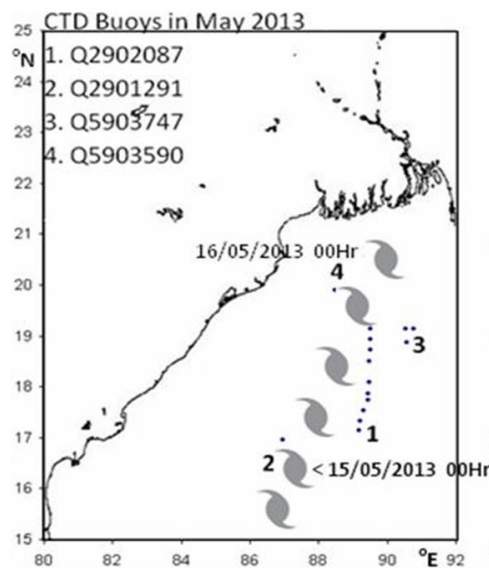


Fig 1. A segment of cyclone shows track of Mahasen with four drifting buoys of the northern Bay of Bengal.

The cyclone wind and derived WS and WSC products of the OSCAT are studied with reference to the impact of cyclone in the northwestern Bay of Bengal. The OSCAT is a conically scanning pencil beam scatterometer in Ku band (13.515 GHz) and rotate at 20 rpm. The sensor scans the ground with two spot beams of size 25 Km x 55 Km in two center propagating circular orbits along the path. The outer orbit scans in VV polarization with radius 918 Km and incident angle 49.33° , while the inner beam circles in radius of 700 Km with an incident angle of 42.66° . This makes a swath of 1800 km and covers the global ocean by 90 percent in a day. The OSCAT wind is estimated using σ_0 values in vertical and horizontal polarizations. The backscattered signal of microwave radar is known as the Bragg scattering. This is related to wave spectrums which resonate with the wavelength of emitted pulse. The small scale waves governed by surface tension at the air-sea interface with a wavelength less than 1.72 cm is considered as the major contributor in the assessment of wind speed and direction. The small waves often termed as ripples are aligned perpendicular to local wind. This is related to wind power. This helps to derive wind fields from scatterometer data. In practice, radar backscatter is linked with vector wind field through empirically developed geophysical model function. While the backscatter intensity is related to the wind speed, the multi-view multi-polarization of radar backscatter data helps to resolve direction of wind along with its intensity. The concept of resolving ambiguity in wind direction has improved from dual mode acquisition of backscatter in the Seasat SASS (Seasat Satellite A Scatterometer) to ERS AMI (Advanced Microwave Instrument) collecting data on same area from three different directions. This has been done through a rotating antenna with SeaWinds on QuickSCAT and ADEOS-II launched by NASA in 1999 and Japan in 2002. The OSCAT adopted a similar principle to launch Ku band conical scanning microwave sensor with a rotating antenna to provide high resolution ocean surface wind vector.



ISSN: 2319-5967

ISO 9001:2008 Certified

International Journal of Engineering Science and Innovative Technology (IJESIT)

Volume 4, Issue 2, March 2015

The OSCAT products are released at the SAC and the NRSC as level 2B organized in HDF5 format for the data received in individual swaths. The level 3 data on surface winds are provided as the girded maps [8]-[10]. The wind vectors are estimated as 50 x50 Km cells for 1800 Km swath. They are available in 34 nodes, while the map data are available in half degree grids. The data processing at the KNMI and the NASA has brought out wind products in higher resolution of 12.5 km. However, the present study has used the NRSC OSCAT products to estimate WS and WSC. Since the most of computational environment uses WS, the horizontal forcing component on the sea surface to represent vertical transfer of horizontal momentum, the WS parameter is estimated as,

$$\zeta = \rho_a C_D U_{10}^2 \dots\dots\dots(1)$$

where, ρ_a the density of air is considered as 1.3kg/m³, U_{10} , the wind speed at 10 meters, and C_D , the drag coefficient. Being a function of surface wind speed, the drag coefficients of Large and Pond (1981) are used in the present analysis. They are in four categories of wind speed as follows,

- a) for wind speed ≤ 1 m/s where, $C_D = 0.00218$;
- b) for wind between 1m/s and 3 m/s where, $C_D = (0.62 + 1.56/\text{Wind Speed}) \times 0.001$;(2)
- c) for wind between 3 m/s and 10 m/s where, $C_D = 0.00114$;
- d) for wind more than 10 m/s where, $C_D = (0.49 + 0.65 * \text{Wind Speed}) \times 0.001$.

This algorithms are used extensively in the ocean and atmospheric studies and upwelling along the coast of the United States [11]-[13]. The algorithm adopts a simple method of bulk formula to calculate the drag coefficient. This depends only on the wind velocity which provides a critical link between wind and WS estimation. While Hellerman and Rosenstein in 1983 introduced next level of complexity in the estimation of drag coefficient introducing air-sea temperature difference along with wind velocity. Jin *et al.*, (1999) have used air-sea exchange formulation of the Geophysical Fluid Dynamics laboratory Models [14]. The next level of development has been carried out using TOGA Coare algorithm which accommodates humidity, atmospheric pressure, short and long wave radiation fluxes, and height of atmospheric boundary layer along with wind velocity and air-water temperature difference [15]-[16]. The method adopts an iterative estimation of stability function using similarity theory. In this work, the first approach is used as developed by Large and Pond (1981) due to its simplicity. This has less dependency on other associated ocean and atmospheric parameters.

For the WSC estimation, the zonal and meridional components of WS and their difference between north-south and east-west direction are estimated. This represents the rotational field of wind that transfers momentum vertically across the air-sea interface. The differences in the change of meridional component of WS variation in east-west direction to those of the change in zonal component in the direction of north-south are used in the estimation of the WSC, which is formulated as;

$$WSC(\tau) = \partial \tau^y / \partial x - \partial \tau^x / \partial y, \dots\dots\dots(3)$$

where, τ^x and τ^y are the components of the wind stress vector τ . The positive WSC leads to divergence in the Ekman layer with upward pumping of subsurface cool nutrient rich water. This leads to reduction in sea surface temperature, surface mixed layer depth and enhancement in primary productivity. While the negative WSC lead to warming of the surface layer and deepening of surface mixed layer. This has been examined with thermal profiles of drifting buoys observed around the area. Figure-2 shows the WS and WSC distribution in the Bay of Bengal on 14 May 2013. The WS has shown a triple intensity points around the center of the event, while the WSC has shown positive field in the center and negative observations on the either side.

Figure-3 (a and b) shows the OSCAT WS and WSC from 10 to 15 May 2013 for the along track swath observation. The products are validated through the ocean surface wind observations, as the space based scatterometers provide wind through established the Geophysical Model Functions (GMF) based on the empirical relationships between surface roughness to frequency, polarisation, incident angle and viewing angle of the sensor. Since the ocean surface roughness is directly related to wind stress, the validation of scatterometer wind with the ocean surface wind holds good for the WS and WSC, as these products are the derivatives of the wind field. The details of their utilities can be explored elsewhere [17-18].

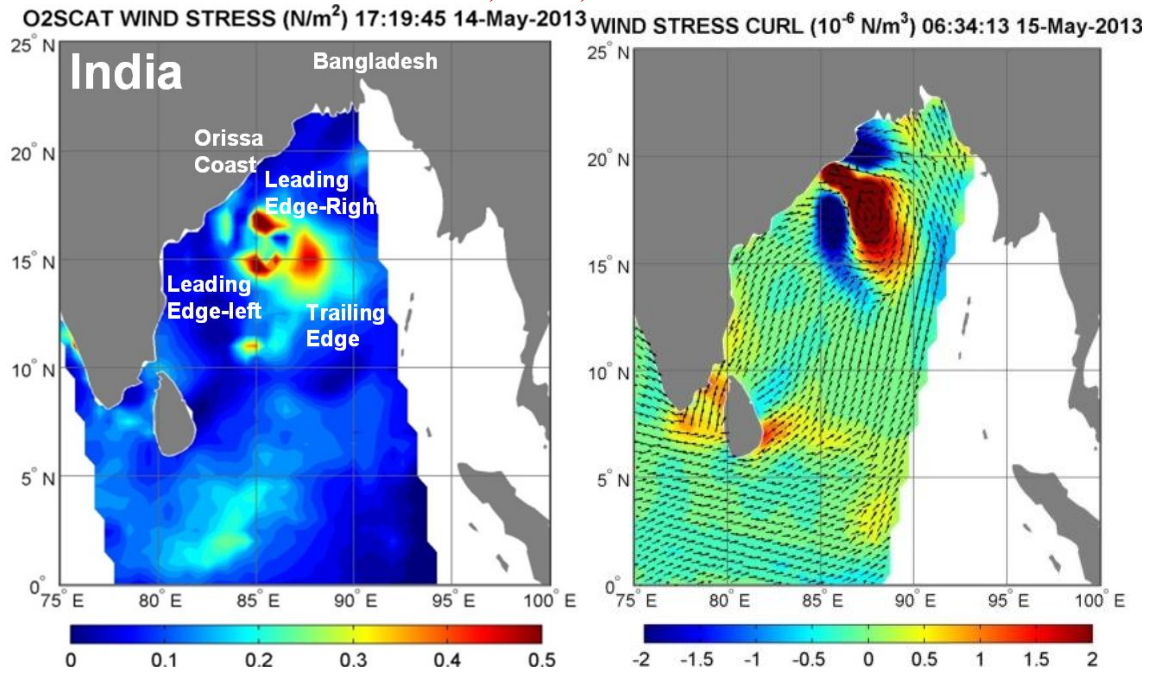


Fig 2. The OSCAT WS (N/m^2 ; on left) and WSC (N/m^3 ; on right) distribution pattern on 14 May 2013 in the Bay of Bengal

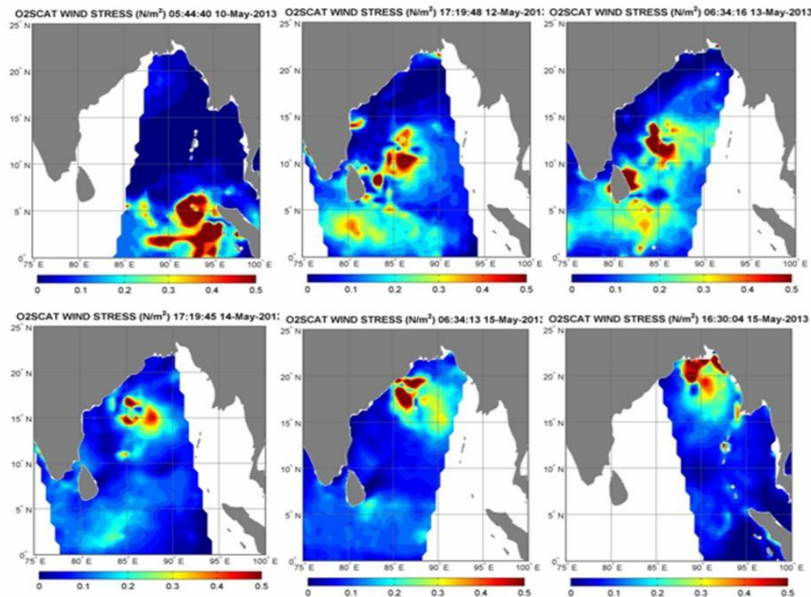


Fig 3a. The OSCAT WS (N/m^2) distribution in the Bay of Bengal is seen from 9 May 2013 to 16 May 2013.

The OSCAT wind data has been validated for 2012 RAMA buoy observations of the Indian Ocean region along with ECMWF and ASACT wind. Chakraborty and Raj Kumar (2013) have reported RMS error less than 2 m/s at 95% confidence level [19]. They have validated the OSCAT wind fields showing the estimations within the target of wind speed. Sivareddy *et al.*, (2013) has indicated a difference in the range of 2 m/s and direction within 20 degrees [20]. Indra Rani of ECMWF has also validated the OSCAT winds with model data along with the data from moored and drifting buoys of Indian Ocean [21]-[24]. Veroeff and Stoffelen (2012) and Prasant Kumar *et al.*, (2013) have also shown the results well with in the anticipated error level.

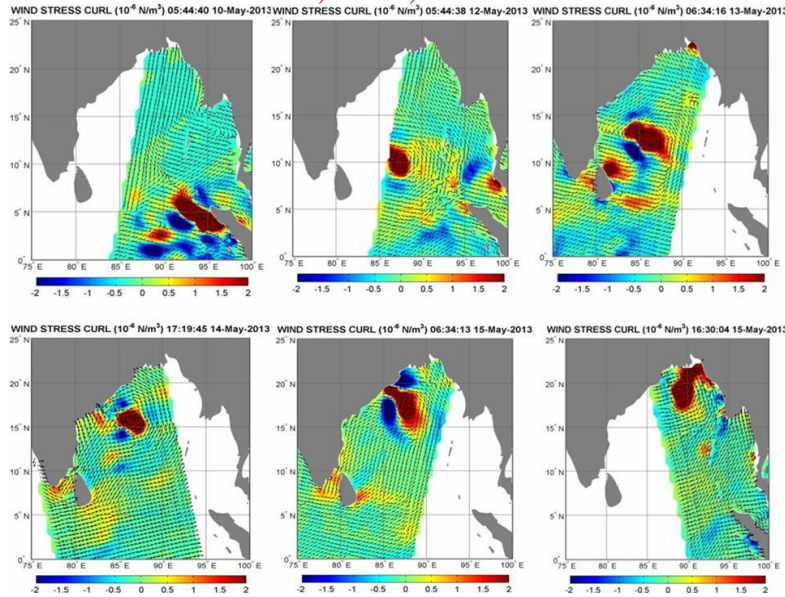


Fig 3b. The OSCAT WBC (N/m^3) distribution in the Bay of Bengal from 9 May 2013 to 16 May 2013.

Price (1981) has also indicated their suitability in their assimilation to the ocean and atmospheric dynamic models [26]. However, their utility to study high intensity wind field is limited. Behera *et al.* (1998) have studied the cyclone Phet winds [27]. The present work attempts to highlight utility of the OSCAT derived WS and WSC products in the event of cyclone Mahasen. As the wind data products are well validated, the derived products like the WS and WSC are expected to maintain a good quality. The WS products are available from ASCAT wind in quarter degree latitude and longitude grids for the period through the Asia-pacific Data Research Centre (APDRC) web site. They are examined to compare with those derived from the OSCAT, but failed to resolve features as seen in figures 2 and 3. The reason can be attributed to the resolution and timing of their coverage besides, processing schemes adopted. The OSCAT wind products are acquired through global coverage daily with the satellite passage of equator at noon time. While ASCAT equatorial time of ascending pass is at 21 Hours 30 minutes and repeat coverage of 5 days of near repeat period with swath of 550 Km which make a difference in daily product generation. The OSCAT winds in 1400 Km swath field with grid resolutions of 50 Km provides a better synoptic view. While, the ASCAT wind stress estimates has reached a maximum value of 0.9 Pa on 13 May 2013 for the cyclonic event. The OSCAT wind stress is around 0.5 N/m^2 (=Pa) for the high intensity area around the cyclonic event. There are no wind stress curl products at present to compare with those estimated from the OSCAT data. Thus their use in the analysis of the cyclonic event Mahasen provides a unique opportunity. However, their impact is studied with reference to associated observations made with the drifting buoys of the area. Two degree drop in temperature result 6 mb rise in pressure as observed from one of the drifting buoy observations in the northern Bay (Figure 4a). Further, the drifting buoy of the area has recorded observations related to change in temperature and salinity in the surface layers. The estimated density shows the modes of their mixing (figure 4b). The changes have observed from pre and post scenario with reference to the occasion of cyclone pass. This has shown the level of external forcing experienced over the area.

The drifting buoys in the area are identified as Q2902087, Q2901291, Q5903747 and Q5903590 in the northern Bay of Bengal during May 2013. They recorded temperature and salinity profiles with depth with their CTD are extracted for the duration of the cyclonic event. The data are organized to examine the impact of cyclone with reference to the profiles during the event and for those representing a week before and after the event.

The four buoys are identified to represent four quadrants around the passage of the cyclone. Most of the buoys has remained around their identified location except the one (Q2902087) in the south east region. This has moved northward over a distance of 200 to 250 Km in the north western part of the Bay of Bengal. The profile of first week

and last week of May has selected to represent pre and post cyclone scenario as, the event made landfall on 16 May 2013.

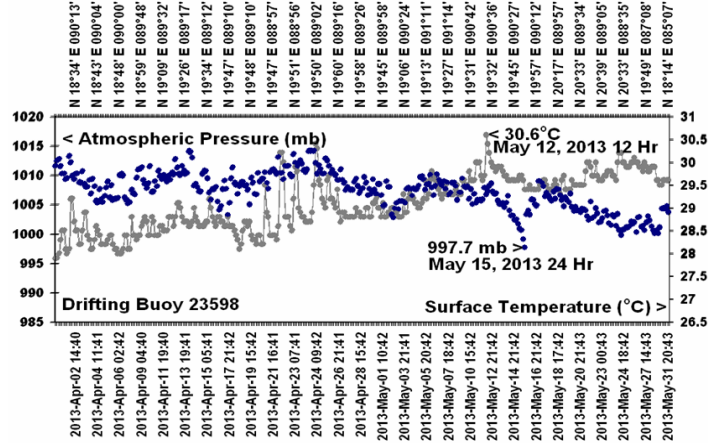


Fig 4a: Atmospheric pressure (mb) and Sea Surface Temperature (°C) recorded by the drifting buoy 23598 during April and May 2013 indicate their inverse relationship and response of cyclone ‘Mahasen’ in the Bay of Bengal.

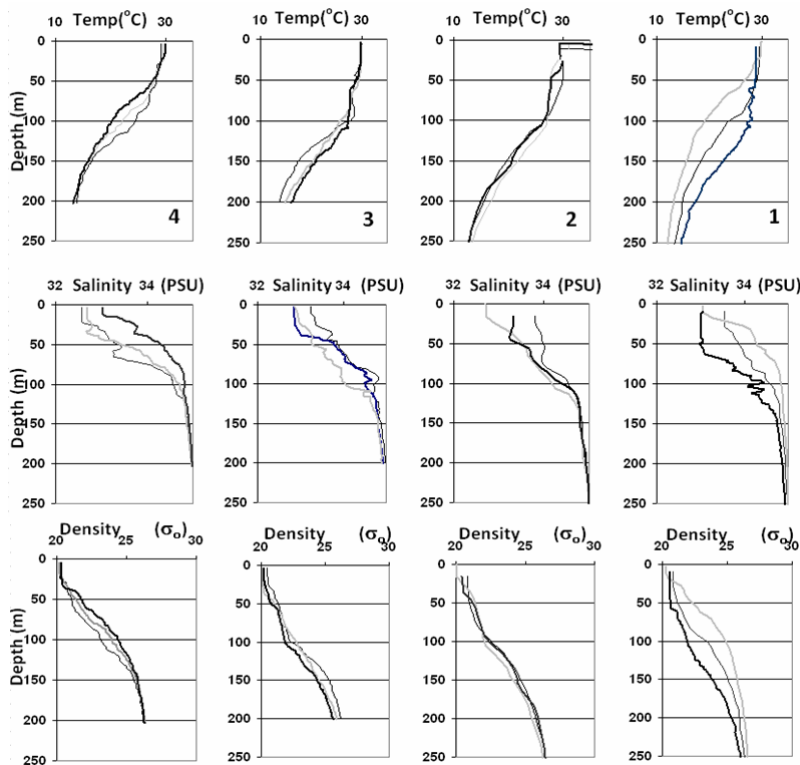


Fig 4b: TMI SST fields of the Bay of Bengal from 9 to 23 May 2013.

The Q5903590 CTD data buoy at location 4 (figure 4c) represented the north western Bay of Bengal indicating intense mixing in the surface layer. While the buoys Q2901291 and Q2902087 located to the south of cyclone track, and later has moved northward. The drifting buoy Q5903747 in deep waters remained to the east of the cyclone track. All these buoys are exposed to the strong cyclonic wind and hence, reflected their effect on the ocean surface. Thus, temperature and salinity profiles of the buoys are used in the study of the WS and the WSC products in the northern Bay of Bengal. Besides, the change in surface temperature can also be observed from microwave Sea Surface Temperature observations of the Bay of Bengal by Tropical Rainfall Monitoring Mission (TRMM)

data. The warm waters are observed in the central Bay at about 31°C and cold waters of about 29°C in the northern Bay and the south of Srilanka (Figure 4c).

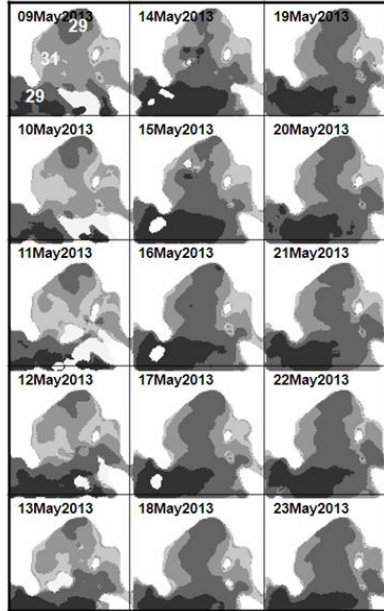


Fig 4c: Temperature and salinity profiles for four buoys as shown in the map of figure 1 for the day of 2, 17 and 31 of May 2013 (dark line represents the observation on the date of cyclone and other dotted and gray lines represent profiles of prior and post cyclone scenario).

IV. RESULTS AND DISCUSSION

The cyclone Mahasen has made the landfall on 16 May 2013 along the coast of Chittagong, Bangladesh. Even though observations have suggested a strong system since its initiation in the southern Bay in the early parts of May 2013, the cyclone ended up with low intensity phenomena on its landfall in the northern Bay. During its itinerary, the OSCAT WS and WSC products are examined for their spatial distribution of intensities in high spatial resolution to understand areas of wind convergence and divergence at the sea. Their impact on the ocean surface waters is evident from drifting buoys observations made in the area. The daily fields of WS and WSC are estimated from the OSCAT wind for the Indian region and regularly are provided through NRSC web site. The figures 2 and 3 show a gradual migration of high intensity wind field from south to northern part of the Bay. The strong winds in the south on 10 May 2013 have corresponded well with low pressure area off the west coast of Indonesia. Subsequently, this has shifted to 10°N, 87°E in the south central Bay on 12 May 2013. The low pressure has intensified further on 13 May 2013 and migrated further north to 15°N on 14 May 2013. On 15 May 2013, the event traced along the northeast coast of India in the early hours of 06:34 UTC, and later has shifted eastward to the coast of Bangladesh in late hours of 16:30 UTC. The event has made landfall around Chittagong, Bangladesh in the early hours of 16 May 2013. The event has covered an area of 1000 x 1000 sq Kms in the southeast part of the Bay of Bengal with WS of 0.4-0.5 N/m². This has resulted from disturbances of westerly wind in the eastern part of the equatorial Indian Ocean. These lead to develop atmospheric vortices of wind field which has migrated away from Inter-Tropical Convergence Zone. This is evident from high intensity WS of 0.4 to 0.5 N/m² as seen on 10 May 2013 and corresponded well with high intensity positive WSC of 2x10⁻⁶ N/m³ around 5°N, 95°E (figure 3). On 10 May 2013, the disturbance developed into a well defined system after moving in the northwest direction around 12°N and 88°E. The event has further strengthened with WS over 0.5 N/m² and WSC over 2x10⁻⁶ N/m³ on 13 May 2013. The system has moved in the northwest direction. On 14 May 2013, the WS field show three distinct areas of high intensity around a well defined low in the centre around 16°N, 87°E (Figure 2). The wind field with a positive WSC spread over an area with a diameter of about 200-300 km. The event has moved over the coastal waters of Orissa on 15 May 2013 showing intense WS fields on either side of the track with central high intensity of the WSC. On 16 May 2013, the system has shifted northeast and the cyclone crossed the coastline of Bangladesh at Chittagong in the noon hours. The WS has accumulated along the coast with positive WSC. This has led to relatively high intensity surge of water level on the western side of the cyclone landfall.



ISSN: 2319-5967

ISO 9001:2008 Certified

International Journal of Engineering Science and Innovative Technology (IJESIT)

Volume 4, Issue 2, March 2015

The WSC fields show convergence and divergence of surface wind in the northern Bay. This indicates areas of upwelling and sinking along the coast. The positive WSC in the offshore waters has corresponded well with the central part of the cyclonic event. This has led to divergence in surface waters at the sea. Since the cyclone has developed as a low pressure event area along the coast of Indonesia on 10 May 2013, the WSC field in the Bay of Bengal are analysed from 12 to 16 May 2013 (figure 3). On 15 May 2013, the strong negative WSC fields around 20°N in the coastal waters have indicated a strong upwelling. On 16 May 2013, the cyclone has made the landfall indicating a moderate surge of the coastal waters. This has happened due to low tide condition prevailed in the area. The low tide has restricted surge induced inundation along the coast. The areas of surge in the coastal water are evident from the positive WSC on 15 May 2013 (figure 3). Similar observations have also been made by Maneesha *et al.*, (2012) with a previous cyclone, Nargis, that has passed through the Bay of Bengal in May 2008 [5]. The WSC has indicated upwelling leading to cooling of the surface temperature. Price (1981) has reported on deepening of mixed layer to the right of cyclone track [26]. The modeling work on wind forcing has shown asymmetry in flows around the center of the cyclone with high magnitude on its right [27]-[28]. This supports the present observation in the northern Bay developed under the influence of Mahasen.

The WSC has remained positive in the center of the event, which indicates dominance of variation in zonal components over the meridional components of the WS field. This has remained around $2 \times 10^{-6} \text{ N/m}^3$ in the central part of the event (Figures 3). This led to divergence of surface waters, while the negative values on either side led to convergence of surface waters. This is evident from upwelling of nutrient rich subsurface water that has attracted high primary productivity in due course of time. The negative fields lead to convergence of surface water which has raised the level of coastal water. This has matched well with those of storm surge levels along the northern coast of the Bay of Bengal as predicted by IMD. The WS fields are also used in the ocean circulation and gas exchange studies through air-sea interface. Even though the observations are difficult during the cyclonic events, they can be inferred from microwave temperature and ocean colour products of the satellites those passed over the area. The sensors attached with moored and drifting buoys in the area have recorded observations of temperature and salinity in the area of the event.

The impact is analyzed with reference to the hydrographic profiles of the drifting buoys those covered in the area under the cyclonic event. High temperature in surface layers are observed with the profiles collected prior to arrival of cyclone than those collected afterwards (figure 4a). There is a good relationship between atmospheric pressure and sea surface temperature. Temperature is reduced by vertical mixing induced by surface wind (figure 4b). This indicates heat transfer to deeper water. While salinity profiles of those regions have shown change in salinity to a depth around 60 to 70 meters below the surface. While the buoy on its south has exhibited temperature changes up to 100 m depth. The low salinity and high temperature waters are observed in the region. The buoy Q5903747 around 19°N (at location 3) has passed on the east side of the cyclone track. Their hydrographic profiles have shown high salinity at depths between 50 and 100 meters and low in the surface water. This indicates suppression of upwelling in the area. While, the buoy Q2902087 that moved northward from 17°N to 19°N (at location 1) has indicated intensive mixing from the surface extending to a depth of 100 m. The salinity profile has indicated reduction of its concentration up to 150 m. The profiles show post cyclone adjustment by increase in salinity. Thus, the impact of cyclone has been observed in the surface waters of the Bay of Bengal.

The impact has also been seen in the SST field of TMI data from 9 May to 23 May, 2013 (Figure 4c). The surface waters are warmed to an extent of 31°C in the central part of the bay, which has turned cold after the event. The surface water in the north has remained cold at about 29°C, while the area of their coverage has reduced gradually from 9 to 13 May, 2013. From 14 May 2013 onwards the central bay has cooled and got connected with the cold waters of the southern Bay of Bengal. The cyclonic wind has also induced cooling in the region due to enhanced evaporation and mixing of cool subsurface waters that has appeared due to upwelling in the region.

V. CONCLUSION

The WS and WSC products from the OSCAT data sets generated at NRSC have provided an opportunity to study the low pressure events like, the tropical cyclone Mahasen. The wind data products in high resolution could resolve features associated with the growth and decay of the cyclonic event developed in the Bay of Bengal. The analysis wind has indicated three distinct areas of high intensity wind around the centre of the cyclone. This is seen through out its life from its beginning at the coast of Indonesia to landfall along the coast Chittagong. There are two



ISSN: 2319-5967

ISO 9001:2008 Certified

International Journal of Engineering Science and Innovative Technology (IJESIT)

Volume 4, Issue 2, March 2015

intensive areas of wind fields on the leading edge, which has followed with a relatively less intensive field of trailing winds on its back of the track. A central low is seen in the fields of the WS and WSC products. Their impact is observed in hydrographic profiles of the drifting buoys indicating intensive mixing in the surface layer. On land fall of the cyclone, the rise in water level along the coast is also evident from the WS and WSC fields. Hence, the products of the OSCAT gave this opportunity to study their response and also expected to provide better insight with high resolution wind data expected in near future. This is expected to provide better understanding of the ocean atmosphere processes including the distribution of coastal productivity and sediment patterns in the area.

ACKNOWLEDGMENT

The work is a part of Oceansat-2 geophysical product development activity towards National Information System for Climate and Environment Studies (NICES) activity at NRSC, Hyderabad. The authors acknowledge Dr. V. K. Dadhwal, Director, and Dr. C.B.S. Dutt, NRSC for all his support and encouragement during this work.

REFERENCES

- [1] Pond, S. and Pickard, L., *Introductory Dynamical Oceanography*, (Great Britain: Pergamon Press), 1983, Pergamon Press, Great Britain.
- [2] Sverdrup, H. U., "Wind-Driven Currents in a Baroclinic Ocean; With Application to the Equatorial Currents of the Eastern Pacific," *Proceedings of the National Academy of Sciences*, 1947, **33**, pp.203-218.
- [3] Stommel, H., The westward intensification of wind-driven ocean currents. *Trans. Amer. Geophys. Union*, 1948, **99**, 202–206.
- [4] Smith, S. D., Wind stress and heat flux over the ocean in gale-force winds, *J. Phys. Oceanogr.*, 1980, **10**, 709-726.
- [5] Maneesha K., V.S.N. Murty, M. ravichandran, T.Lee, Weidong Yu, and M.J. McPhaden, Upper ocean variability in the Bay of Bengal during the tropical cyclones Nargis and Laila, *Prog. Oceanogr.* 2012, **106**, 49-61.
- [6] Yue, J., Miller, S.D., Hoffmann, L., Straka III, W.C., Stratospheric and mesospheric concentric gravity waves over tropical cyclone Mahasen: Joint AIRS and VIIRS satellite observations *J. Atmos. Sol. Terr. Phys.*, 2014, **119**; pp. 83-90.
- [7] Suraiya B., Alam, M. S., Ali, M.S., 2013, *Cyclone Monitoring towards Disaster Mangement of Bangladesh*, *Open Jour. Comp. Sci.*, 2013, **1** (2), pp.1-10.
- [8] Padia, K. (2010), *Oceansat-2 Scatterometer algorithms for sigma-0, processing and products format*, Version 1.1, April 2010.
- [9] SAC Report, *Oceansat-II scatterometer payload. Preliminary Design Review Document*, SAC/SCATT/PDR/01, 2005.
- [10] Large, W.G., and Pond, S., Open ocean momentum flux measurements in moderate to strong winds. *J. Phys. Oceanogr.*, 1981, **11**, 324-336.
- [11] Koracin, D., C. E. Dorman, and Dever, Coastal perturbations of marine layer winds, wind stress, and wind stress curl along California and Baja California in June 1999. *J. Phys. Ocean.*, 2004, **11**, 324-481.
- [12] Samelson, R. M., P. Barbour, J.Barth, S. Bielli, T. Boyd, D. Chelton, P. Kosro, M. Levine, E. Skillingstad., and J. Wilczak, 2002, Wind stress forcing of the Oregon coastal ocean during the 1999 upwelling season, 2002, *J. Geophysical Res.* 107, 2-8.
- [13] Dorman, C. E. Holt, T., Rogers, D.P., and Edwards, K.A., Large scale structure of the June-July 1996 marine boundary layer along California and Oregon. *Mon.Wea.Rev.*, 2000, **128**, 1632-1652.
- [14] Jin, X., X. Zhang, and T. Zhou, Fundamental framework and experiments of the third generation of IAP/LASG world ocean generation circulation model, *Adv. Atmos. Sci.*, 1999, **16**, 197-215.
- [15] Fairall, C.W., E.F. Bradley, D.P. Rogers, J.B., Edson, and G.S. Young, Bulk parameterization of air-sea fluxes for tropical Ocean Global Atmosphere Coupled Ocean-Atmospheric Response Experiment. *J. Geophys. Res.*, 1996, **101**, 3747-3764.
- [16] Chiranjivi Jayaram, Udaya Bhaskar T.V.S., Debadatta Swain, E. Pattabhi Rama Rao, Saurabh Bansal, A. Jeyaram and K. H. Rao, *Generation of OSCAT Winds Daily Composites NRSC–ECSA–OSG–June2013–TR–532*, 2013, pp.42.
- [17] Liu, W.T. and W.G. Large, Determination of surface stress by Seasat-SASS: A case study with JASIN data. *J. Phys. Oceanogr.*, 1981, **11**, pp.1603-1611.



ISSN: 2319-5967

ISO 9001:2008 Certified

International Journal of Engineering Science and Innovative Technology (IJESIT)

Volume 4, Issue 2, March 2015

- [18] Portabella, M. and A.C.M. Stoffelen, On Scatterometer Ocean Stress, *J. Atm. Oceanic Technol.*, 2009, 26, 2, 368-382, doi:10.1175/2008JTECHO578.1.
- [19] Ralph F. Milliff, Jan Morzel, Dudley B. Chelton, and Michael H. Freilich, 2004: Wind Stress Curl and Wind Stress Divergence Biases from Rain Effects on QSCAT Surface Wind Retrievals. *J. Atmos. Oceanic Technol.*, 2004, **21**, pp.1216–1231.
- [20] Abhisek Chakraborty and Raj Kumar, Generation and validation of analyzed wind vectors over the global oceans, *Remote Sensing Letters*, 2013, 4:2, 114-122.
- [21] Indira Rani, S. and M. Das Gupta, Oceansat-2 and RAMA buoy winds: A comparison. *Journal of Earth System Sciences*, 2013, 122(6), 1571-1582.
- [22] Indira Rani, S., M. Das Gupta, Priti Sharma & V. S. Prasad , Atmosphere-Ocean, Intercomparison of Oceansat -2 and ASCAT Winds with In Situ Buoy Observations and Short -Term Numerical Forecasts, *Atmosphere-Ocean*, 2014, p101.
- [23] Sivareddy, S., M. Ravichandran, and M.S. Girishkumar, Evaluation of ASCAT-Based Daily Girded Winds In the tropical Indian Ocean, *American Meteorological Society*, 2013, pp.1371-1381.
- [24] Verhoef, A. and A. Stoffelen, 2012, OSCAT winds validation report, OSI SAF report, 2012, SAF/OSI/CDOP2/KNMI/TEC/RP/196.
- [25] Prashant Kumar, K.P. Harish Kumar, and P. K. Pal, Impact of Oceansat-2 scatterometer winds and TMI observations on Phet Cyclone simulation, *IEEE Transactions on Geoscience and remote Sensing*, 2013, 51, 6, 3774-3779.
- [26] Price, J.F., Upper Ocean response to a Hurricane, *J. Phys. Oceanogr.*, 1981, **11**, pp.153-175.
- [27] Behra, S.K., Deo, A.A., and Salvekar, P.S., Investigation to mixed layer response to Bay of Bengal cyclone using a simple ocean model. *Atmos. Phys.*, 1998, **65**, pp.77-91.
- [28] Hellerman, S. and M. Rosenstein (1983): Normal monthly wind stress over the World Ocean with error estimates. *J. Phys. Oceanogr.*, 13, 1093–1104.

AUTHOR BIOGRAPHY



S. K. Sasamal, Scientist 'SF', NRSC, Hyderabad is born on 10 May 1960 in state of Orissa, India, and graduated with Physics (Hons.) in 1980 completed M.Sc. (Oceanography) and M.Phil. in 1982 and 1984 respectively from Marine Science Department of Berhampur University, Orissa. Since 1986, worked in Central Salt and Marine Chemical Research Institute, Bhavnagar; National Institute of Oceanography, Goa; Indian Institute of Remote Sensing, Dehradun; and and at present in the National Remote Sensing Center, Hyderabad as scientist 'SF' with responsibilities to work on Ocean remote sensing activities of Indian Space Research Organization, India. He has worked on the operationalisation of the Potential Fishing Zone maps for coastal fisherman community and worked for satellite remote sensing solutions for the Port and Harbor activities at Calcutta and Mumbai, India. Recently he is working with Ocean circulation with SARAL AltiKa and Oceansat-2 Scatterometer wind to support National Information on Climate and Earth Science activities of NRSC. He is a Life member of Indian Meteorological Society, Hyderabad Chapter. He has 30 publications to his credit as peer reviewed manuscripts in national and international journals.



Saurabh Bansal, Scientist, NRSC is born on 20 May 1990 in Haryana, India has completed Central Board of Secondary Examination (CBSE) and under-graduation program in Physical Sciences and subsequently graduated from Indian Institute of Space Science and Technology (IIST) with major subjects in Astronomy & Astrophysics in 2012. Presently, he is working as a scientist in Ocean Sciences Group of Earth and Climatic Sciences Area (ECSA) at National Remote Sensing Centre (NRSC, Hyderabad) since September 2012. Having experience in handling scatterometer and Altimeter data products, he works towards the estimation of ocean surface currents. He is actively involved in National Information System for Climate and Environmental Studies (NICES) Products on ocean wind stress, wind stress curl, ocean mean temperature, Ekman currents and geostrophic currents. He has published two papers on the ocean surface winds from satellite data and five ISRO technical reports.



ISSN: 2319-5967

ISO 9001:2008 Certified

International Journal of Engineering Science and Innovative Technology (IJESIT)

Volume 4, Issue 2, March 2015



Dr CBS DUTT was born on 15th July 1955 and obtained his M.Sc in 1978 and PhD in 1982 and carried out phytochemical pigment characterization using UV/Visible spectrophotometric and various chromatographic methods. From 1978-1981, he has worked in an Industrial Maltichem research Centre (MRC) at Nandesari, Baroda Later from 1981-1984, he has served as an Assistant Professor (forestry & Ecology) at Indian Institute of Remote Sensing (IIRS) a unit of ISRO. Subsequently from 1985-till date he worked as member of NNRMS programs, Deputy Programme Director ISRO-GBP, lead a ISRO-ICARB-W BOB ocean cruise, Programme coordinator, Megha Tropiques, Project Director for Astro Biology Balloon experiment to study the Origin of Life.

Presently from 2010-onwards as Deputy Director (ECSA) at National Remote Sensing Center (NRSC) responsible for implementing organized Atmospheric and Ocean graphic research applications using satellite sensors. Dr Dutt is also Program Director for (NICES) for implementing National Information system for Climate and Environmental Studies. He is a life member of IMS, ISRS, NIE, IAASTA, and fellow of National Institute of Ecology (FNIE) and served as 2 times National Vice-President to NIE. Dr DUTT has published 92 publications to his credit and guided 4 doctoral students.



Dr V.K. Dadhwal is a distinguished Scientist and Director, National Remote Sensing Centre (NRSC), Indian Space Research Organization (ISRO), Hyderabad since May, 2011. His research interests are Crop modeling, Remote Sensing Applications in Agriculture, Terrestrial Carbon Cycle, Land Cover Land Use Change Modeling, and Land Surface Processes. He has received ISCA Young Scientist Award, 1987; INSA Young Scientist Medal, 1989; Indian National Remote Sensing Award, 1999; Hari Om Ashram Prerit Dr Vikram Sarabhai Award, 1999; ISRO-Astronautical Society of India Award 2005; ISRO Merit Award, 2006; and Corresponding Member, International Academy of Astronautics, 2010. He is a member of Journal of Indian Society of Remote Sensing, vice

president of Indian National Cartographic Association, and science panel member of Terrestrial Carbon Observation (TCO) of FAO, Rome. He has published about 140 peer reviewed journal papers.