Application of Scatterometer Observations Derived Surface Relative Vorticity in Detection of Tropical Cyclogenesis Over Bay of Bengal

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Abstract: ***The advent of satellite scatterometer technique for derivation of surface wind field helped meteorological community to gather widespread surface observational data over a broad oceanic area. Utility of surface relative vorticity derived from Quickscat satellite scatterometer data has been explored and an objective technique described in this study found to be an effective tool in identifying and monitoring genesis of tropical cyclone over Bay of Bengal. Higher values of maximum average surface relative vorticity over 220km x220km area with increase in order of $5x10^{-5}$ s^{-1} during 48 to 72 hrs prior to cyclone development are favourable for cyclogenesis over Bay of Bengal.***

Keywords: Scatterometer, Vorticity, Cyclogensis, Autocorrelation.

1. Introduction

Progress in understanding atmospheric system often comes about as a result of new instruments for making meteorological observations. Scatterometer onboard QuikSCAT satellite launched in 1999 is such an instrument for derivation of surface wind field and helped Meteorological community to gather widespread surface observational data over a broad oceanic area. Tropical cyclones (TCs) originated over oceanic area are most important destructive natural weather phenomena causing loss of human life and huge ecological and economical damages. Socio- economic impacts of TCs are considerable (Obsai et al; 1997). The coastal areas of India, Bangladesh and Myanmar suffer enormous loss of life and property due to cyclones over Bay of Bengal (BOB). On average annually 3-4 TCs are observed over BOB of which 1 or 2 becomes in very severe stage (Maximum sustained wind 64 knots or more). In the past, detection of the early stages of TCs formation was very difficult through surface observations due to paucity of meteorological data over oceanic areas.

Generally two cyclone seasons viz., pre-monsoon (particularly May) and post monsoon (particularly in October and November) are observed in the north Indian Ocean (NIO); sometimes a few cyclones also form in transition monsoon months of June and September. Severe cyclones can form during May but post monsoon cyclones are severest due to which this season is known as storm season in south Asia (Singh et al 2001).

TCs cannot be generated spontaneously. For development of TC, initially it is required to form a weakly organized system with sizeable spin and low level inflow. According to Gray (1968) distribution of genesis may be related to many environmental factors and one such important factor is large value of low level relative vorticity. A fundamental issue with TC genesis (TCG) involves the formation of the surface vortex prior to the onset of the Wind Induced Surface Heat Exchange (WISHE) intensification mechanism of Rotunno and Emanuel (1987). The generation of surface vorticity and its interaction within regions of deep cumulonimbus convection has been hypothesized in numerical (Hendricks et al. 2004; Montgomery et al. 2006) and observational (Reasor et al. 2005) studies to lead to the establishment of the initial surface vortex.

The main objective of present study is to investigate the potential of QuikSCAT data in monitoring TCs genesis and to develop an objective technique that will detect the early stages of TCG in the Bay of Bengal using this data.

2. Data and Methodology

The scatterometer derived 1˚x1˚ gridded surface vorticity data calibrated to a height of 10 meter that is used in this study is the research quality data set produced by Florida State University's Center for Ocean-Atmospheric Prediction Studies (COAPS). (http://coaps.fsu.edu/scatterometry/). The technique used to make the gridded wind data field from scatterometer observations is based on the method of Pegion et al (2000). The data ranges from July, 1999 to October 2008 have been used in this study. The grid points' area between equator to 22˚N latitude and 80˚E longitude to 100˚E longitude covering area of Bay of Bengal adjoining North Indian Ocean has been considered in this study. The tropical cyclone activity and its track record over Bay of Bengal for the period of 1999 to 2008 have been obtained from cyclone best track archives data of India Meteorological Department.

Tropical cyclogenesis is a continuous process that may span several days, rather than a sudden event. The incipient of tropical cyclone acquires a low-level circulation and associated organised convection over an area and the two (together with the surface heat fluxes) begin to cooperate to amplify the system further. In view of this, a new data matrix of vorticity averaged over 2°x 2° data set (220kmx220km area) has been prepared for the area bounded by 5˚N to 22˚N latitude and 80˚E longitude to 100˚E longitude from the original 1°x 1° data set by incremental process as mentioned below.

Suppose A=[a_{ij}] be the matrix of original 1°x 1° data set and B=[b_{ij}] be the new data matrix. Then b_{ij}= (Σ a_{lk})/9 where l=i-1 to i+1 and k=j-1to j+1.

Primary cyclone season over north Indian Ocean is post monsoon months (October, November and December) in south Asia (Singh et al 2001). In this aspect a Time series of daily maximum values of average surface vorticity (ASV), (2°x 2° data, based upon new data matrix) over Bay of Bengal for the available data period 1999 to 2008 has been constructed and comparison study has been done for such vorticity values between occurrence and non occurrence cases of cyclonic activity over Bay Bengal. Autocorrelation function (Box and Jenkins 1976) of different lag has been applied to the above time series. Daily maximum ASV in association with first day of cyclone as dependent variable(Y) and previous consecutive mostly correlated lag days as dependent variables has been taken to construct a prediction equation using the multiple regression method. Threshold of predicted value and threshold for anomaly of predicted value from value of days just before of correlated lag days has been determined by iteration process for identifying tropical cyclogensis signature over Bay Bengal. The categorical score considered in this study is the probability of detection (POD), which evaluates the effectiveness of detection techniques. It is defined as

$$POD=H/(H+M)$$

where H is the number of hits and M is the number of misses.

3. Result and Discussions

Post Monsoon Season (October, November and December Months) is the peak period of occurrence of severe cyclonic storms over Bay of Bengal and Indian Ocean area. 17 TCs observed during the period of 1999 to 2008 have been considered in this study considering availability of scatterometer data in association with the occurrence period of the cyclones. The best tracks of these cyclones are presented in Fig.1. It is observed that lifecycle of most of cyclones covers area oriented from southeast Bay to southwest or west-central Bay and some of them moved northwards towards Bangladesh Coast across Central Bay and most of TCs were observed during month of October and November. Average vorticity pattern during October and November months are depicted in Fig.2 which reveals distribution of positive vorticity covers almost same area as followed by cyclone lifecycles or tracks. Though cyclone activity days is very less as compared total period, the much higher values of surface relative vorticity associated with cyclone activity contributed for higher positive vorticity over tropical cyclones tracks and genesis area. Time series of daily maximum ASV of 920 days of 10 years period (1999 to 2008) of post monsoon season has been depicted in Fig.3. Almost all the peak values of Daily maximum ASV as seen in the Time series graph are attributed with the occurrence of cyclonic storm activity over Bay of Bengal. Also the average value of Daily maximum ASV during post monsoon period based on the 10 years data is 3.1x 10^{-5} s^{-1} with standard deviation 2.6x 10^{-5} s^{-1} which may be due to fact that very high values of positive vorticity observed during persistent of cyclonic storm or low pressure system over the region. Autocorrelation function with Lag 15 is depicted in Fig.4. It is observed that there are significant coefficient correlation (CC) values upto Lag3 and the CC values are 0.69, 0.42 and 0.24 respectively for Lag1, Lag2 and Lag3. Daily maximum ASV in association with first day of cyclone as dependent variable(Y) and previous consecutive three days (termed as $D1_{Obs}$, $D2_{Obs}$ and $D3_{Obs}$) as three dependent variables has been taken to construct a prediction equation using the multiple regression method. The following prediction equation has been obtained.

$$Y= 5.0+0.71x\ D1_{Obs} +1.31x\ D2_{Obs} - 1.78x0.D3_{Obs}$$

Then anomaly values of Y (Say Y_{anom}) from preceding fourth day values i.,e (Y- $D4_{Obs}$) has been examined. It has been found that the higher values of Y and Y_{anom} are associated with the cyclogensis days. Investigation through iteration process reveals that the value of Y greater than 6.7x10^{-5} s^{-1} and Y_{anom} greater than 4.5x10^{-5} s^{-1} is associated with probability of detection (POD) value as 0.76 for detection of Cyclogensis over Bay of Bengal. It is attributed with the fact that higher values of surface relative vorticity with significantly rise for 2 to 3 days is favourable for tropical cyclone development. Thus Daily maximum ASV derived from scatterometer data can be used as an important prediction parameter for identification of cyclogenesis over Bay of Bengal.

4. Conclusion

Surface vorticity at 10 meter height over ocean surface obtained from scatterometer observations derived wind field can be used as an important predictor of TCG over Bay of Bengal. The vorticity-based detection technique described herein is an effective tool in identifying and monitoring tropical cyclogenesis and its development over Bay of Bengal. Higher values of maximum average surface relative vorticity over 220km x220km area with increase in order of 5x10^{-5} s^{-1} during 48 to 72 hrs prior to cyclone development are favourable for cyclogenesis over Bay of Bengal.

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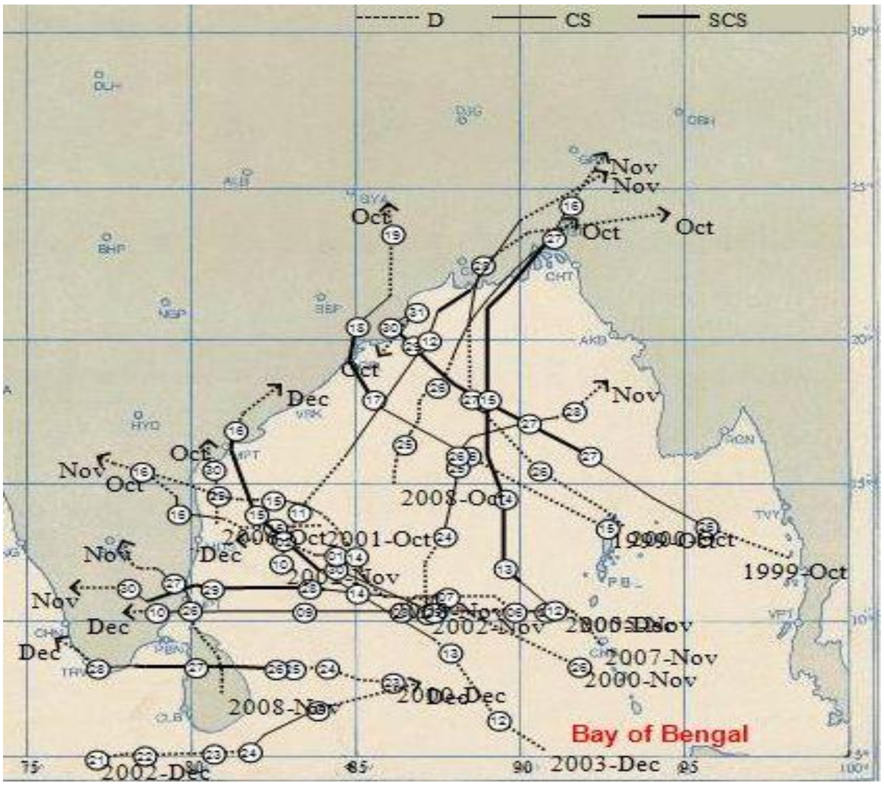

Figure 1: Tracks of 17 Tropical cyclones observed during the period of 1999 to 2008over Bay Bengal

(a) October (b) November

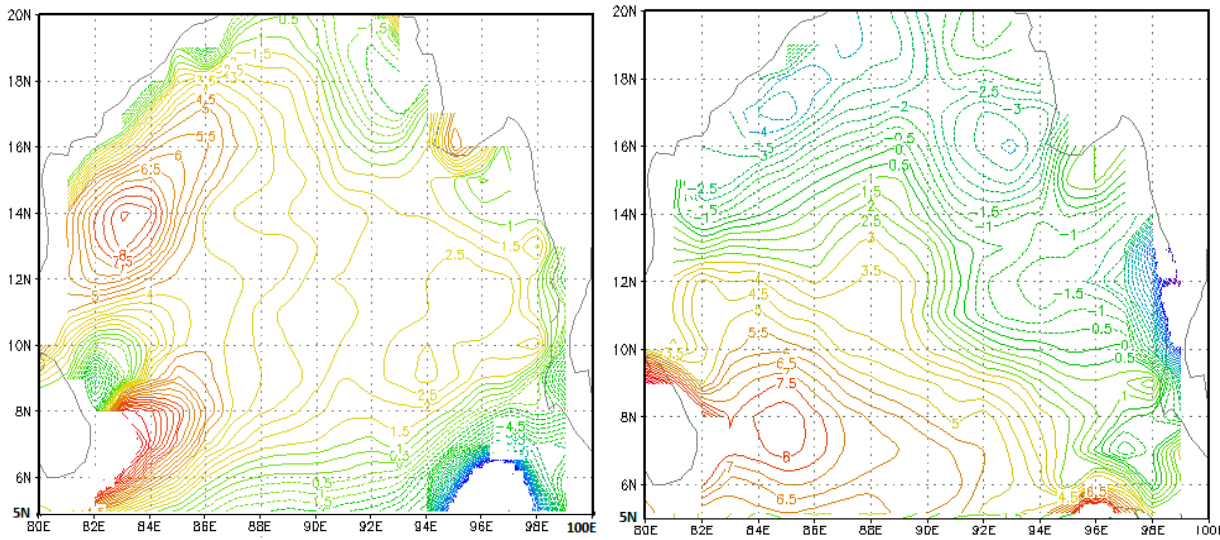

Figure 2: Mean surface relative vorticity(x 10^{-6} s^{-1}) pattern during (a) October and (b) November over Bay of Bengal.

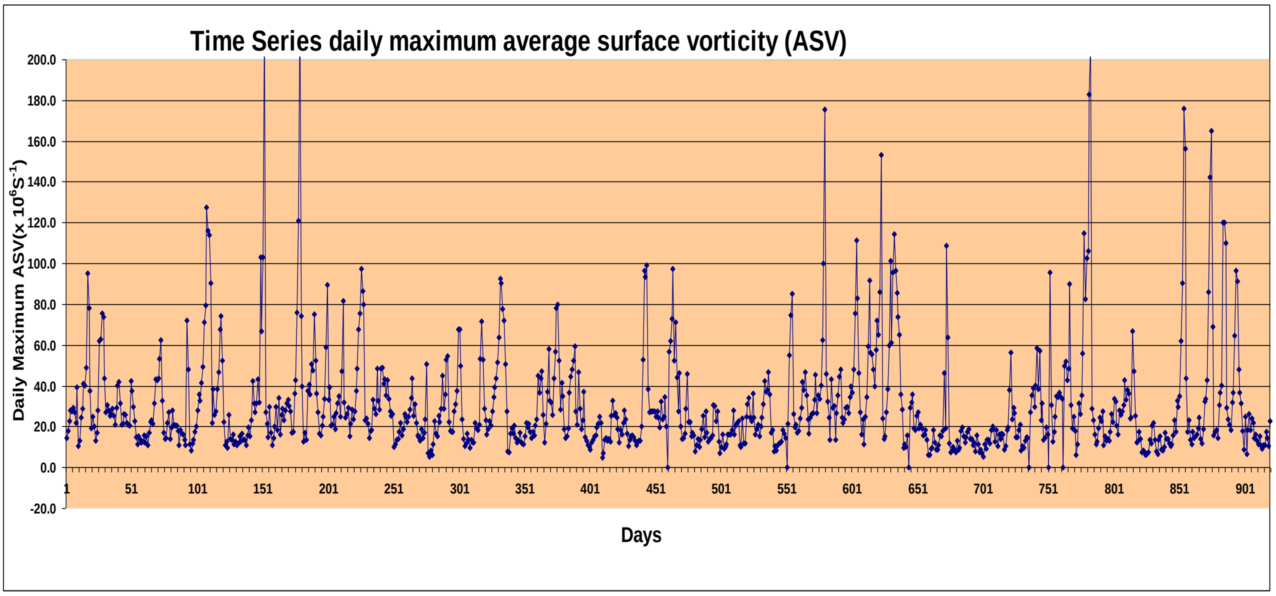

Figure 3: Time series of daily maximum ASV of 920 days of 10 years period (1999 to 2008) of post monsoon season

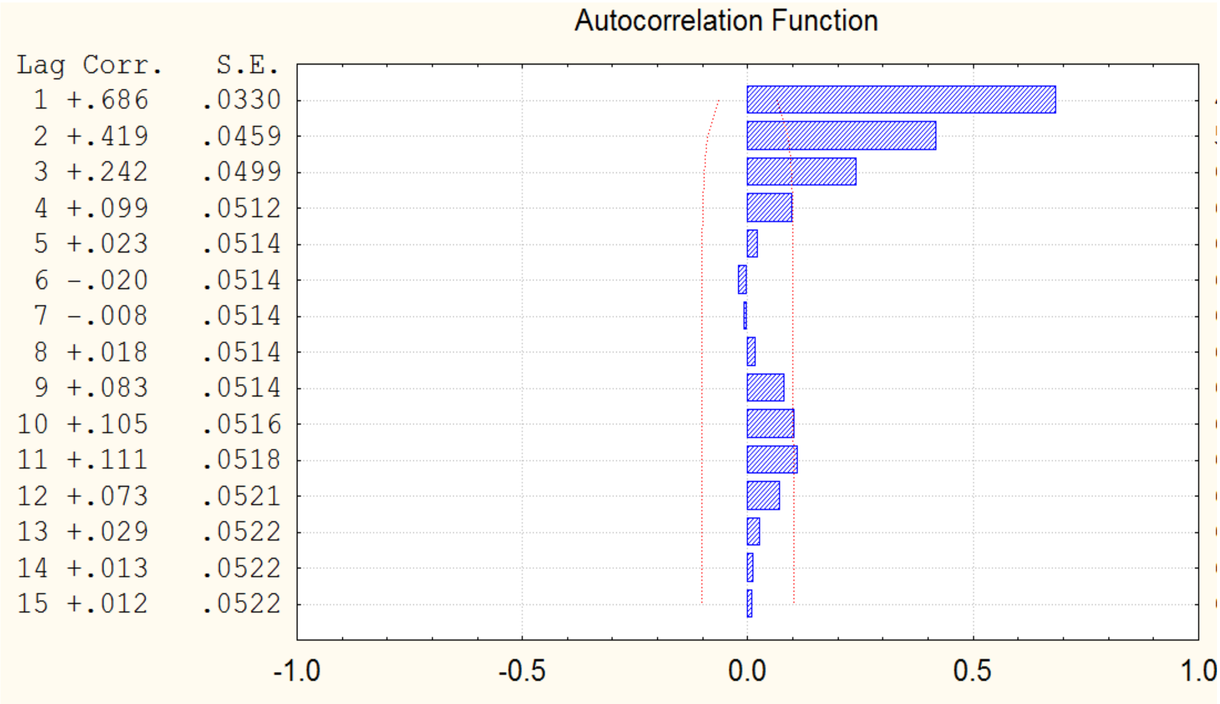

Figure 4: Autocorrelation functions (upto Lag 15) for the time series of Daily maximum average surface relative vorticity during post monsoon season