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Variability of scatterometer based surface vorticity over Arabian Sea and its use in monsoon onset forecasting

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सार – इस शोध पत्र में दक्षिणी अरब सागर और उत्तरी हिन्द महासागर के निकटवर्ती क्षेत्रों में सतही पवनों और भ्रमिलता वाले क्षेत्रों में परिवर्तनों की जाँच करने के लिए अध्ययन से प्राप्त हुए परिणामों को प्रस्तुत किया गया है। इस उद्देश्य के लिए हाल ही के 10 वर्षों (2000–2009) के क्वीकस्केट दैनिक ग्रीडयुक्त आँकड़ों का उपयोग किया गया है। इनसे प्राप्त हुए परिणामों से केरल में मानसून प्रारम्भ होने से लगभग 4–7 दिन पूर्व दक्षिणी अरब सागर में सतही पवन गति और भ्रमिलता की बढ़ी हुई प्रवृति का पता चला है। इस प्रकार दक्षिणी अरब सागर पवन गति और भ्रमिलता की बढ़ोतरी से केरल में मानसून के आरम्भ को एक अच्छे पूर्वसूचक का आभास देती है। 15 मई से 15 जून के दौरान दक्षिणी अरब सागर और उत्तरी हिन्द महासागर के निकटवर्ती क्षेत्रों में समुद्री उपग्रह – 2 स्केट्रोमीटर सतही पवन और भ्रमिलता के क्षेत्रों का निरंतर मॉनीटरन करने पर मध्य अवधि मान से केरल में मानसून के आरम्भ होने का पूर्वानुमान लगाने के संकेत मिल सकेंगे।

ABSTRACT. This paper presents the results of the study undertaken to investigate the changes in the surface wind and vorticity fields over south Arabian Sea and adjoining north Indian Ocean and their association with monsoon onset over Kerala. For this purpose QuikSCAT daily gridded data of recent 10 years (2000-2009) have been utilized. The results show that there is a rising trend in the surface wind speed and vorticity over south Arabian Sea about 4-7 days before the monsoon onset over Kerala. Thus, the rising trends in the surface wind speed and vorticity over south Arabian Sea seem to be a good precursor of monsoon onset over Kerala. Continuous monitoring of Oceansat-2 scatterometer surface wind and vorticity fields over south Arabian Sea and adjoining north Indian Ocean during 15th May to 15th June could provide predictive indications of monsoon onset over Kerala on medium range scale.

Key words – QuikSCAT, Oceansat-2, Vorticity anomaly, Monsoon onset, Precursor, Outgoing long wave Radiation (OLR), Medium range.

1. Introduction

The onset of Indian summer monsoon over Kerala is one of the most important weather events in the Indian subcontinent. The onset of Indian summer monsoon represents significant changes in the large scale atmospheric and oceanic circulation in the Indo-Pacific region. At the surface, monsoon onset is recognized as a rapid substantial and sustained increase in rainfall. The first rains of monsoon occur over Burma and Thailand in mid-May and subsequently extend to the northwest. The monsoon sets over Kerala around 1 June with a standard deviation of about 8 days (Pai and Nair, 2009). In association with the monsoon onset, heavy rains occur over south peninsula after the cross-equatorial low-level jet is established across the Somali coast. This phenomenon is usually accompanied by the formation of a mid-troposphere shear zone across the Bay of Bengal to the south-east Arabian Sea in which a cyclonic vortex may be embedded. The northward progression of the monsoon is the manifestation of a large scale transition of a deep convection from the equatorial to continental regions (Rao 1976; Sikka and Gadgil 1980; Webster *et al.* 1998). By middle of July, monsoon covers the whole country.

Large scale changes occur in the circulation features in association with the onset phase of Indian monsoon (Ananthakrishnan *et al.* 1983; Pearce and Mohanty 1984; Ananthakrishnan and Soman 1988; Soman and Kumar 1993; Joseph *et al.*, 1994 & 2006). At the time of monsoon onset, there is a band of deep convection (low OLR) in the east-west direction passing through southern tip of India, a maximum cloud zone as identified by Sikka and Gadgil (1980).

While there exists no precise definition of monsoon onset, at the surface the transition is recognized as a rapid, substantial, and sustained increase in rainfall over a broad scale. Typically, rainfall amounts increase from below 5 mm per day prior to the onset to over 15 mm per day for several days following the onset (Anathakrishnan and Soman, 1988, Soman and Kumar, 1993). The evolution of the monsoon onset can also unfold in a variety of ways like strenghenining of lower level westerly winds, increase of surface vorticity and cooling of sea water over the Arabian sea and adjoining north Indian Ocean, with abrupt, gradual, or multiple transitions occurring in various years that together encompass different timings and spatial patterns (Flatau *et al*., 2001).

The main objective of the present study is to examine the variability in the surface wind and vorticity fields over the Arabian Sea and adjoining north Indian Ocean during transition phase of monsoon onset.

The India Meteorological Department (IMD) has determined the date of operational monsoon onset over Kerala (MOK) every year, for many decades. On an operational mode, the date of MOK is based on the synoptic conditions as given by Forecasting Manual Unit (FMU) Report No. IV–18.2 by Ananthakrishnan *et al.* (1968). The declaration of the date of MOK is primarily based on rainfall (Ananthakrishnan *et al.*, 1967). This criteria states that after 10 May, if any five stations out of the following seven stations, *viz*., Colombo, Minicoy, Thiruvananthapuram, Alapuzha, Kochi, Kozhikode, and Mangalore receive rainfall of 1 mm in 24 h for two consecutive days, the MOK may be announced on the second day. Accompanying such rainfall, the lower tropospheric westerly wind over Kerala is strong and deep and the relative humidity of the air is high from the surface to at least 500 hPa (Rao 1976). IMD has been taking these factors into consideration to determine the onset date.

Joseph *et al.* (2006) proposed a 3-tier strategy to determine the MOK objectively based on OLR and wind data in addition to rainfall realized around Kerala. In 2006, India Meteorological Department adopted new criteria for declaring MOK operationally. The criteria uses the information on rainfall and large scale circulation patterns as in Joseph *et al.* (2006) as follows:

(*i*) If after 10 May, 60% of the available 14 stations enlisted, *viz*., Minicoy, Amini, Thiruvananthapuram, Punalur, Kollam, Allapuzha, Kottayam, Kochin, Trissur, Kozhikode, Talassery, Cannur, Kasargode and Mangalore report rainfall of 2.5 mm or more for two consecutive days, the MOK may be declared on the second day, provided the following criteria are also satisfied in concurrence.

(*ii*) Depth of westerlies should be maintained up to 600 hPa, in the box equator to latitude 10° N and longitude 55° - 80° E. The zonal wind speed over the area bounded by latitude 5° - 10° N, longitude 70° - 80° E should be of the order of 15-20 knots at 925 hPa. The source of data can be RSMC New Delhi wind analysis/Satellite derived winds.

(*iii*) INSAT derived OLR value should be below 200 Wm^{-2} in the box confined by latitude 5° - 10° N and longitude 70° - 75° E.

It is proposed to utilize the results of present study to examine the transitions during monsoon onset from Oceansat-2 scatterometer wind data. Oceansat-2 is an Indian satellite designed to provide service continuity for operational users. The main objectives of Oceansat-2 are to study surface winds and ocean surface strata, observation of chlorophyll concentrations, monitoring of phytoplankton blooms, study of atmospheric aerosols and suspended sediments in the water. Oceansat-2 has three payloads including a scanning scatterometer (SCAT). SCAT is an active microwave device designed and developed at ISRO/SAC, Ahmedabad. It will be used to determine ocean surface level wind vectors through estimation of radar backscatter. The scatterometer system has a 1 m parabolic dish antenna and a dual feed assembly to generate two pencil beams and is scanned at a rate of 20.5 rpm to cover the entire swath. The inner beam makes an incidence angle of 48.90° and the outer beam makes an incidence angle of 57.60° on the ground. It covers a continuous swath of 1400 km for inner beam and 1840 km for outer beam respectively. The results of present study will be tested during future monsoon onsets utilizing Oceansat-2 scatterometer data. As a preparatory to Oceansat-2 data utilization, the present study uses QuikSCAT scatterometer data for predicting the onset of monsoon.

2. QuickSCAT data

The daily QuikSCAT satellite data has been obtained from the website ftp://ftp.ifremer.fr/ifremer/ cersat/ products/gridded/mwf-quikscat/data/ from Jul 1999 to Nov 2009. The sea surface winds scatterometer on the QuikSCAT satellite is microwave radar launched and operated by U. S. National Aeronautics and Space Administration (NASA). Since July 1999, the QuikSCAT satellite scatterometer has provided spatially extensive measurements of near-surface wind speeds and directions over the world's ocean. With 1800 km swath, QuikSCAT samples more than 90% of global ocean every 24 hours. We use the wind speed and direction and zonal and meridional components at a given location obtained from the radar backscatter measurements of sea surface roughness at 25 km resolution and multiple azimuth looks.

Monsoon onset dates over Kerala have been taken from India Meteorological Department (IMD) quarterly journal MAUSAM from 2000 to 2009.

Year	*Month*	*Day*
2000	June	1
2001	May	23
2002	May	29
2003	June	8
2004	May	18
2005	June	5
2006	May	26
2007	May	28
2008	May	31
2009	May	23

3. Study areas and methodology

The Surface Vorticity (SV) and Surface Wind Speed (SWS) have been computed over each 50 × 50 km grid in the following boxes in the period ±7 days from the monsoon onset over Kerala during 2007-2009.

Box-1, : 70-75° E, 5- 10° N

Box-2 : 50-55° E, 0- 5° N

and Box-3 : 50-55° E, 5° S-0

The SV was calculated using all available QuikSCAT satellite data from May and June from 2000 to 2009 (*i.e.*, the rain-flagged data were not removed). The inclusion of rain-flagged data likely modifies the SV calculations; however, the noise induced by including these data is very small compared to the signal. The SV at one point ($\zeta_{i,j}$) can be calculated according to the equation

$$\zeta_{i,j} = \left(\frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}\right)_{i,j} = \frac{1}{2d}\left(v_{i+1,j} - v_{i-1,j} - u_{i,j+1} + u_{i,j-1}\right)$$

where i and j are QuikSCAT measurement at grid points along the west-east and south-north directions,

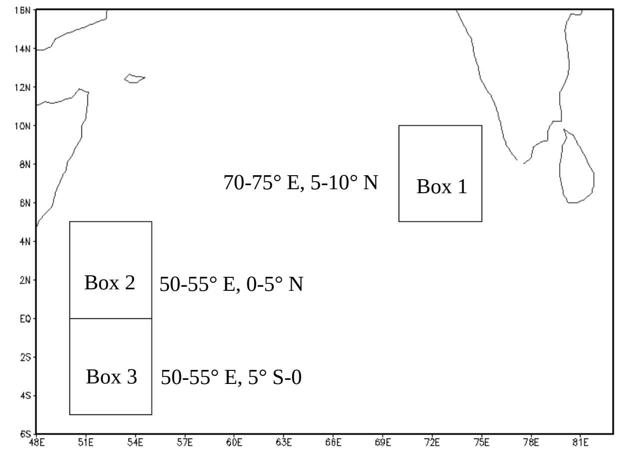

Fig. 1. Study regions; box-1, box-2 and box-3

zonal component u and meridional component v are two components of sea-surface winds along the west-east and south-north directions and d is the spatial distance between two adjacent QuikSCAT measurement points.

4. Results and discussion

Fig. 1 depicts the study regions over SE Arabian Sea and adjoining equatorial Indian Ocean. The daily variation of Surface Vorticity (SV), 7 days before and 7 days after the monsoon onset over Kerala during 2001-2003 and 2007-2009 has been presented in Figs. 2(a&b). During 2001-2003 high positive surface vorticity appeared in Box 1 about a week before the monsoon onset [Fig. 2(a)]. In 2007 the high SV was observed 4 days before the monsoon onset in Box 1. However, a steep rise in the SV was observed 6 days before the onset which reached its maximum value of $9 \times 10^{-5}s^{-1}$ on the onset day and steep fall thereafter. In 2008 also the observed SV was very high (about $6 \times 10^{-5}s^{-1}$) 4 days before the onset. A steep rise in the SV was observed 6 days before, however it reached its maximum value $9 \times 10^{-5}s^{-1}$ one day after the monsoon onset and fell steeply thereafter. During 2009 rising trend in the SV was observed 5 days before and continued one day after the onset and steep fall was observed afterwards. Thus, the surface vorticity increases in Box 1 before the monsoon onset over Kerala significantly. However, the lead time varies from year to year.

From Fig. 2(b) (Box-2) a steep rise in the SV was observed in 2007 two days before, peaked one day before and fell thereafter, but in case of 2009 monsoon onset the rising trend in the SV was observed 7 days before the monsoon onset, which reached its maximum value of 8×10^{-5} s^{-1} one day before onset. On the other hand during

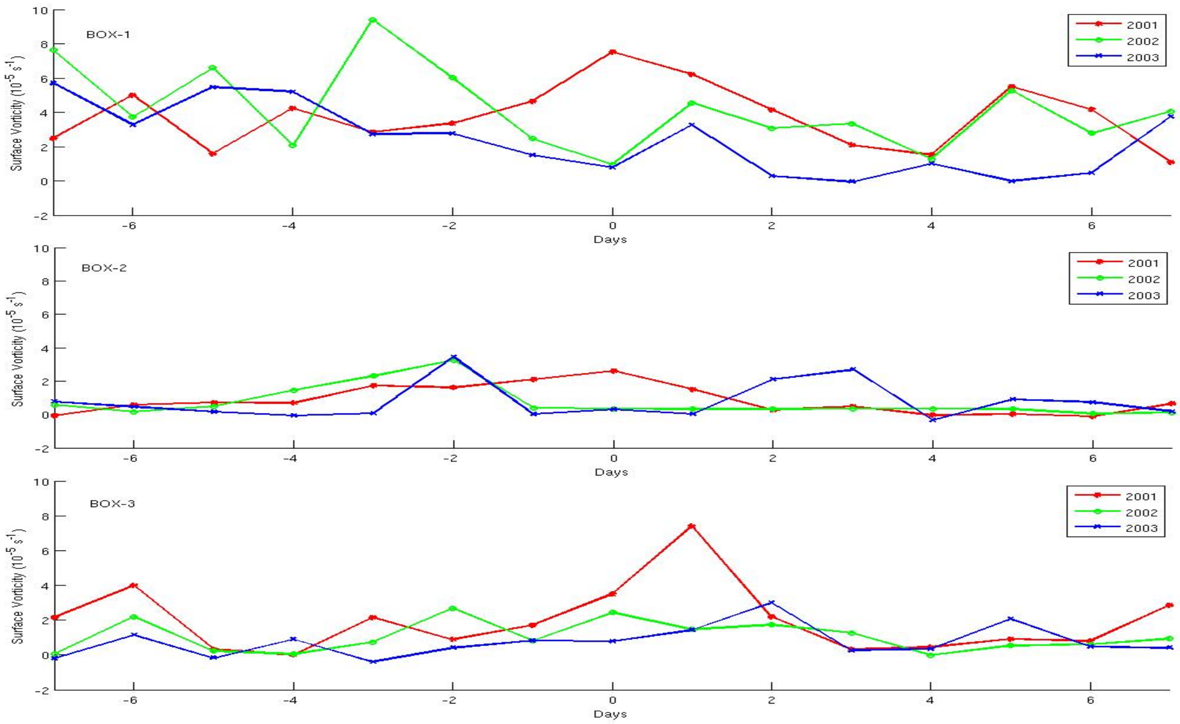

Fig. 2(a). Variation of surface vorticity (s^{-1}) 7 days before and after commencement of monsoon onset during 2001-2003

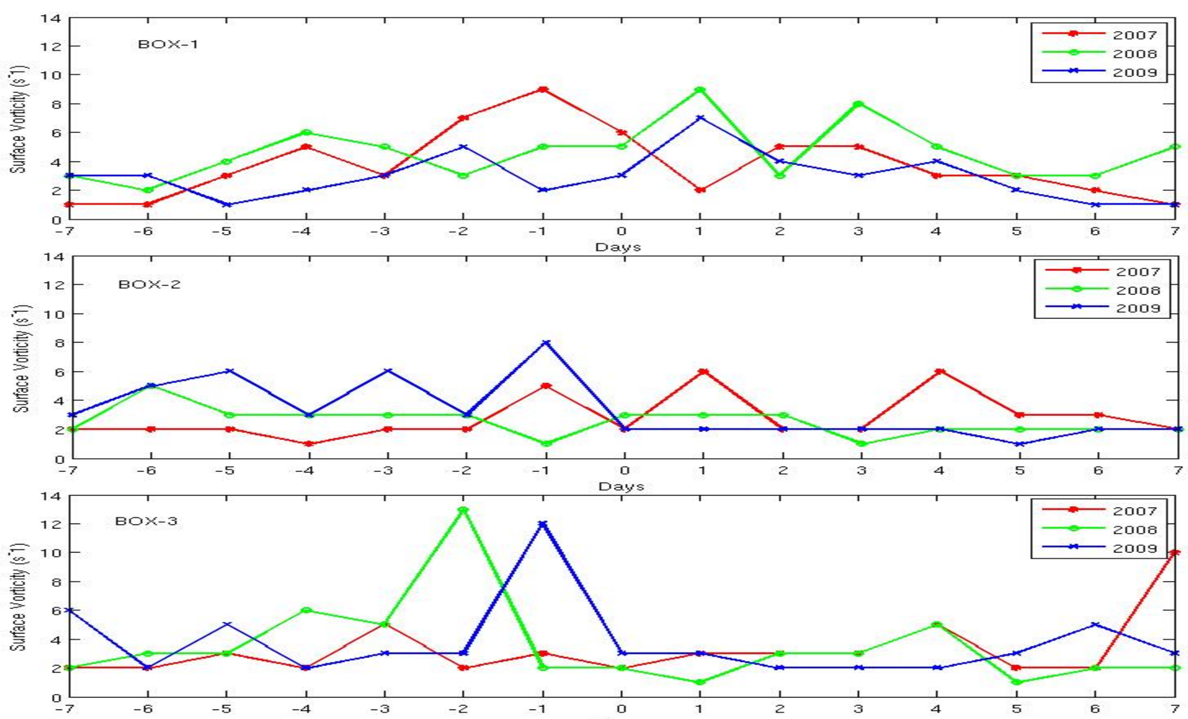

Fig. 2(b). Variation of surface vorticity (s^{-1}) 7 days before and after commencement of monsoon onset during 2007-2009

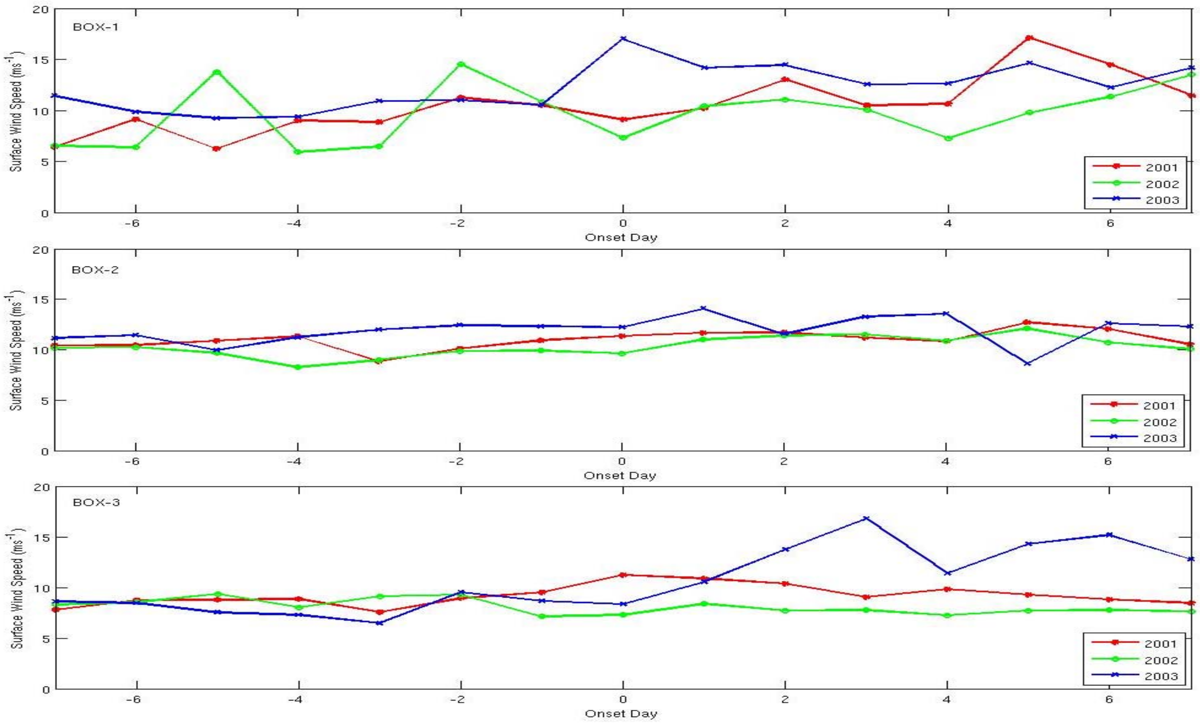

Fig. 3(a). Variation of surface wind speed (m/s) 7 days before and 7 day after the monsoon onset during 2001-2003

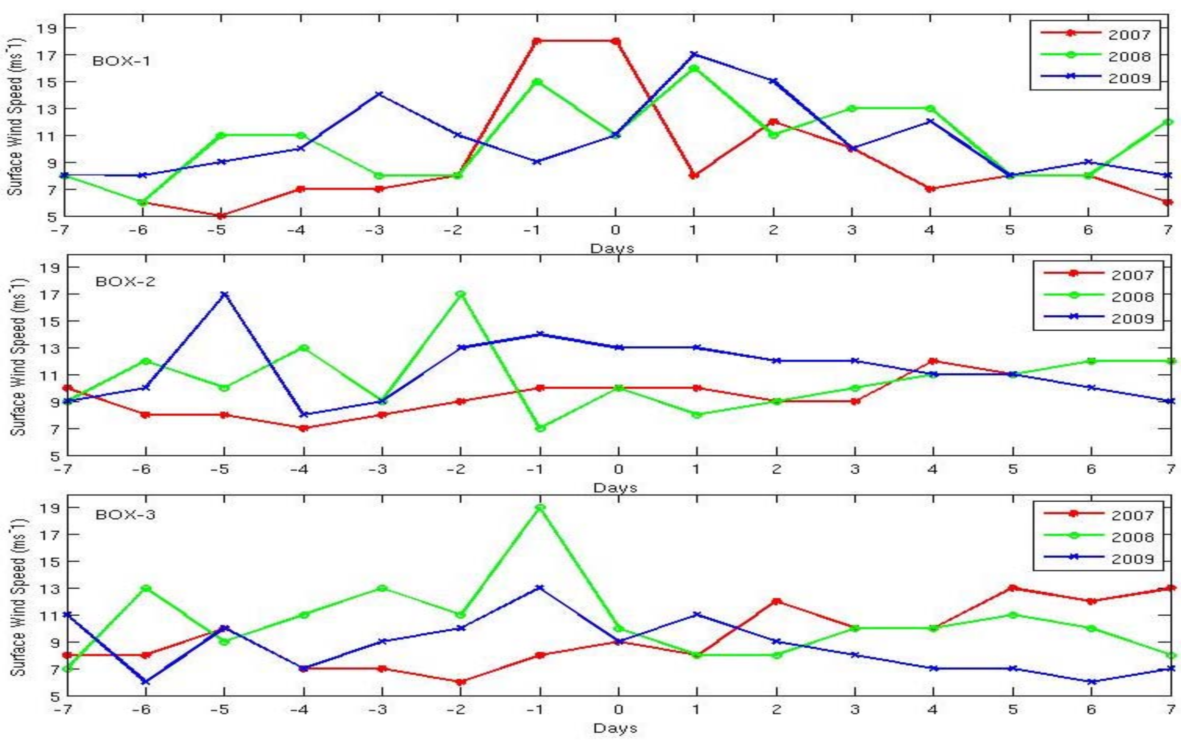

Fig. 3(b). Variation of surface wind speed (m/s) 7 days before and 7 day after the monsoon onset during 2007-2009

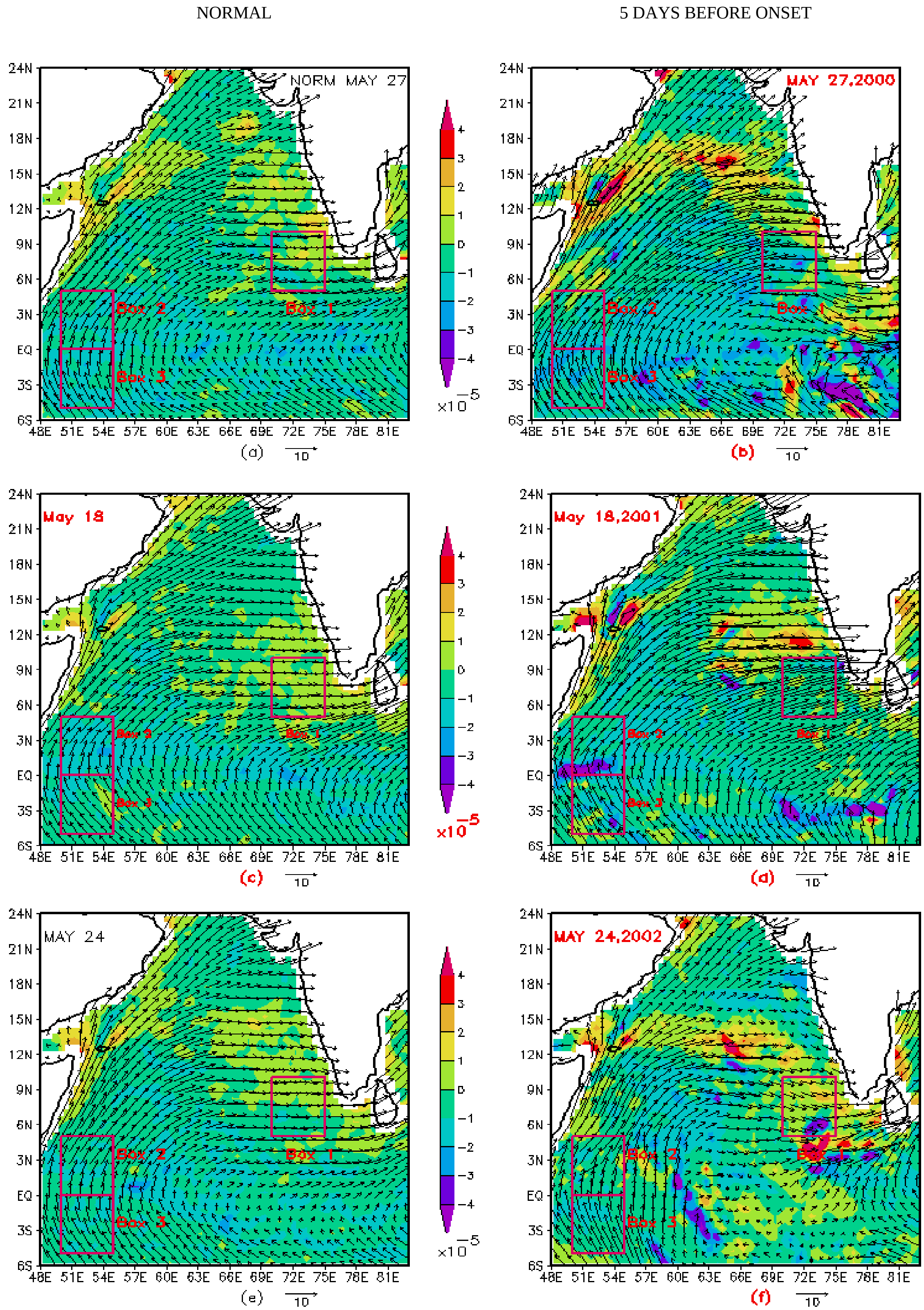

Fig. 4 (i) a-f. Comparison of normal surface vorticity and observed surface vorticity 5 days before onset during 2000-2002

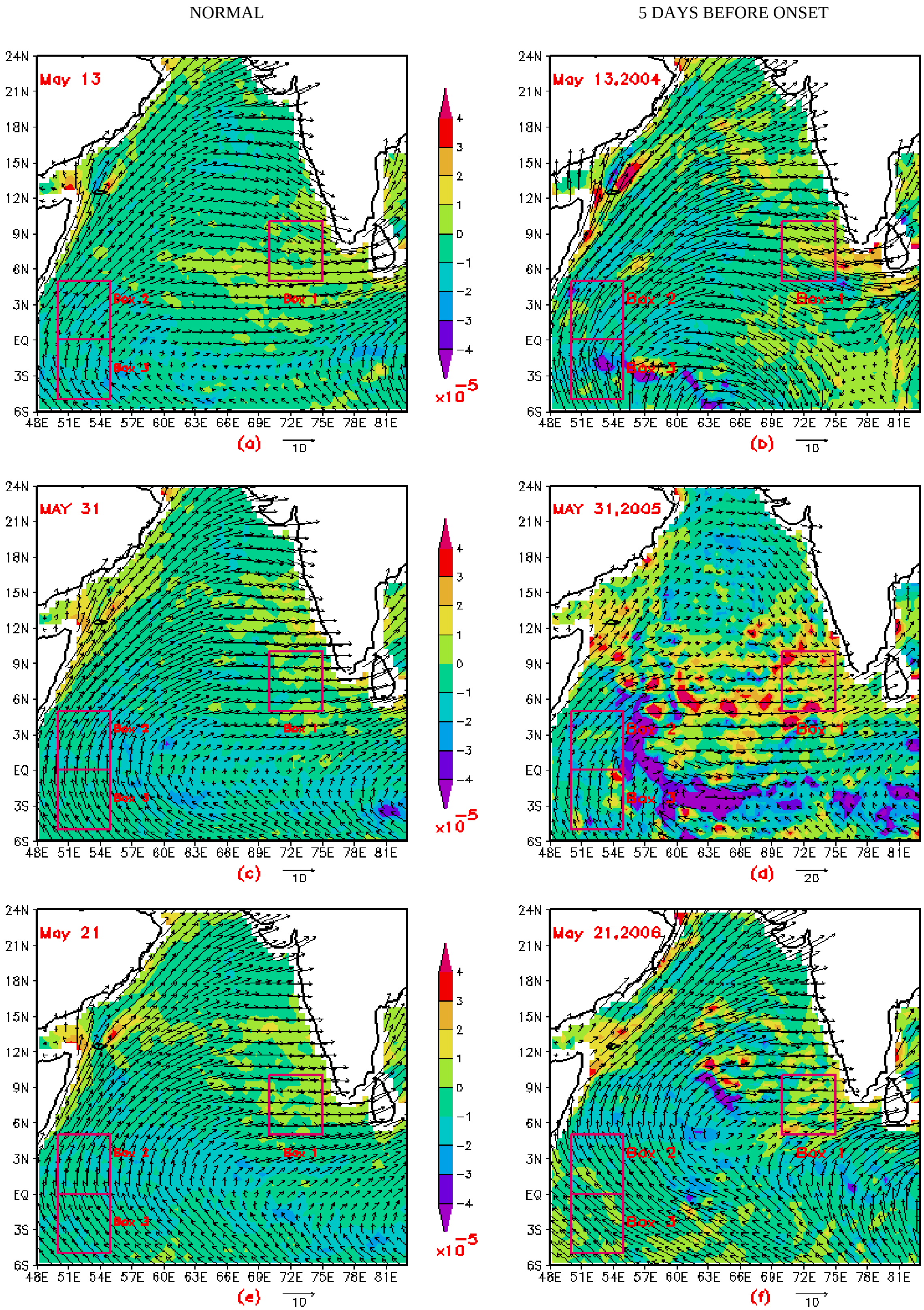

Fig. 4(ii) a-f. Comparison of normal surface vorticity and observed surface vorticity 5 days before onset during 2004-2006

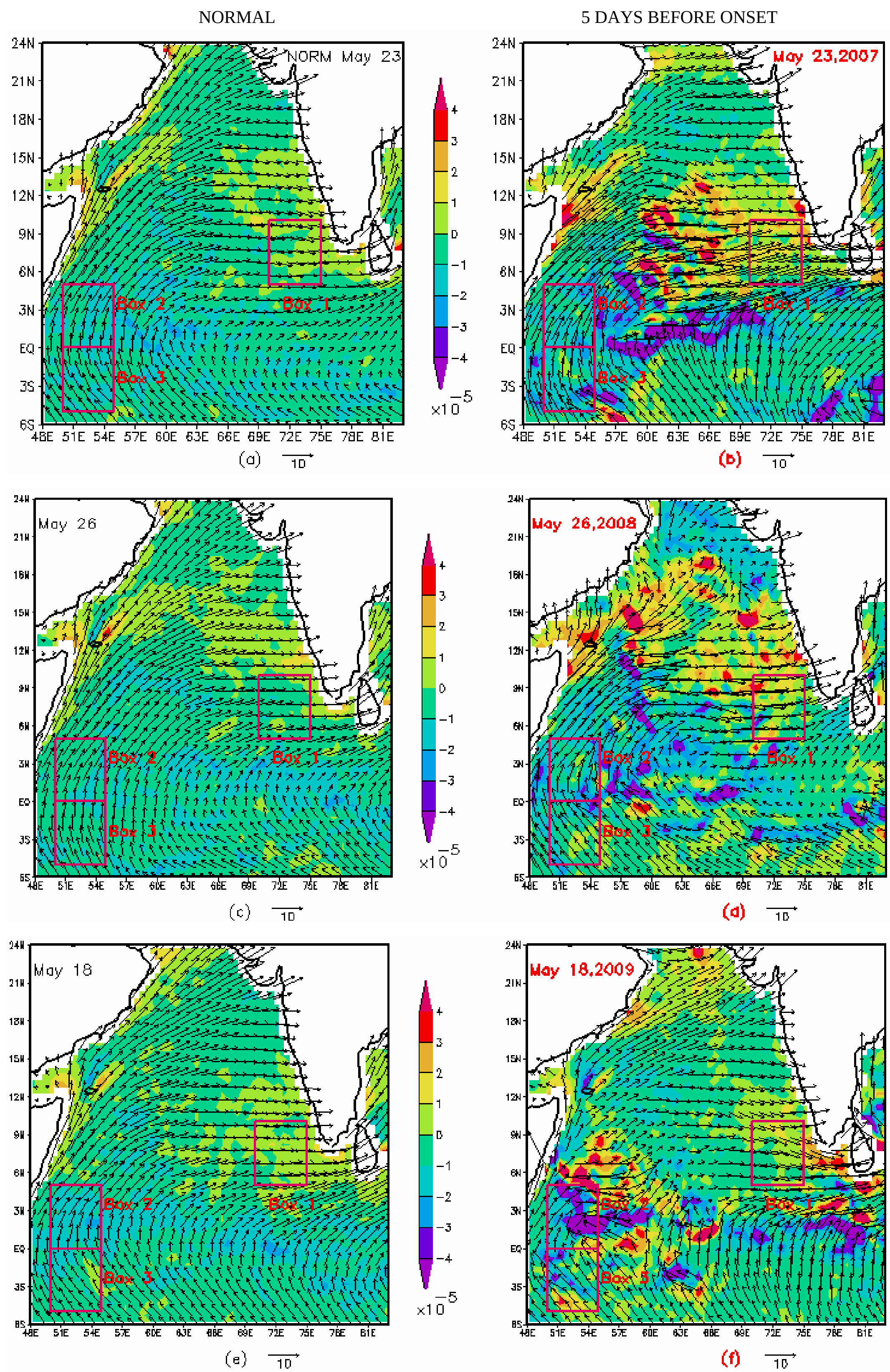

Fig. 4(iii) a-f. Comparison of normal surface vorticity and observed surface vorticity 5 days before onset during 2007-2009

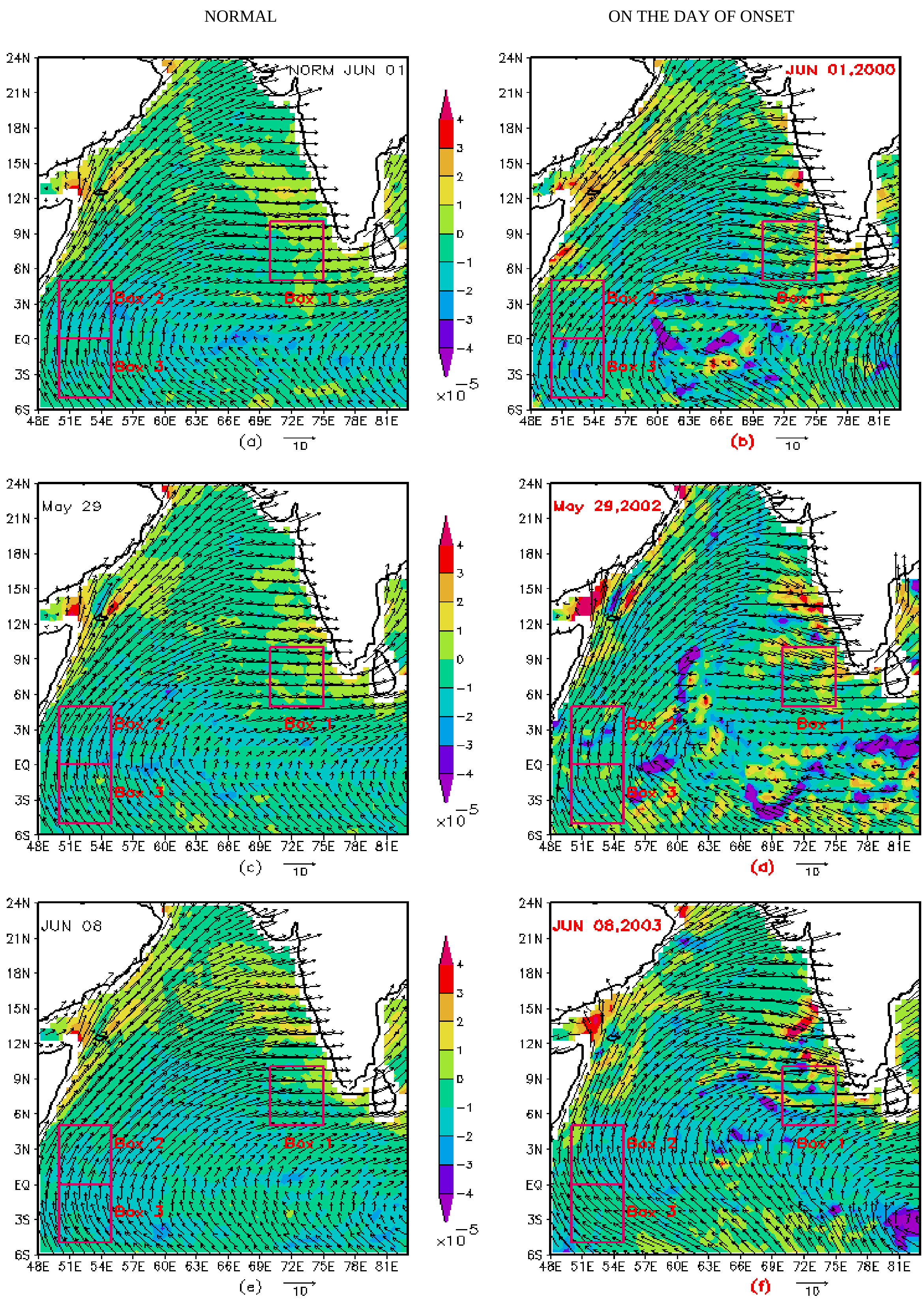

Fig. 5 (i) a-f. Comparison of normal surface vorticity and observed surface vorticity on onset day during 2000, 2002 and 2003

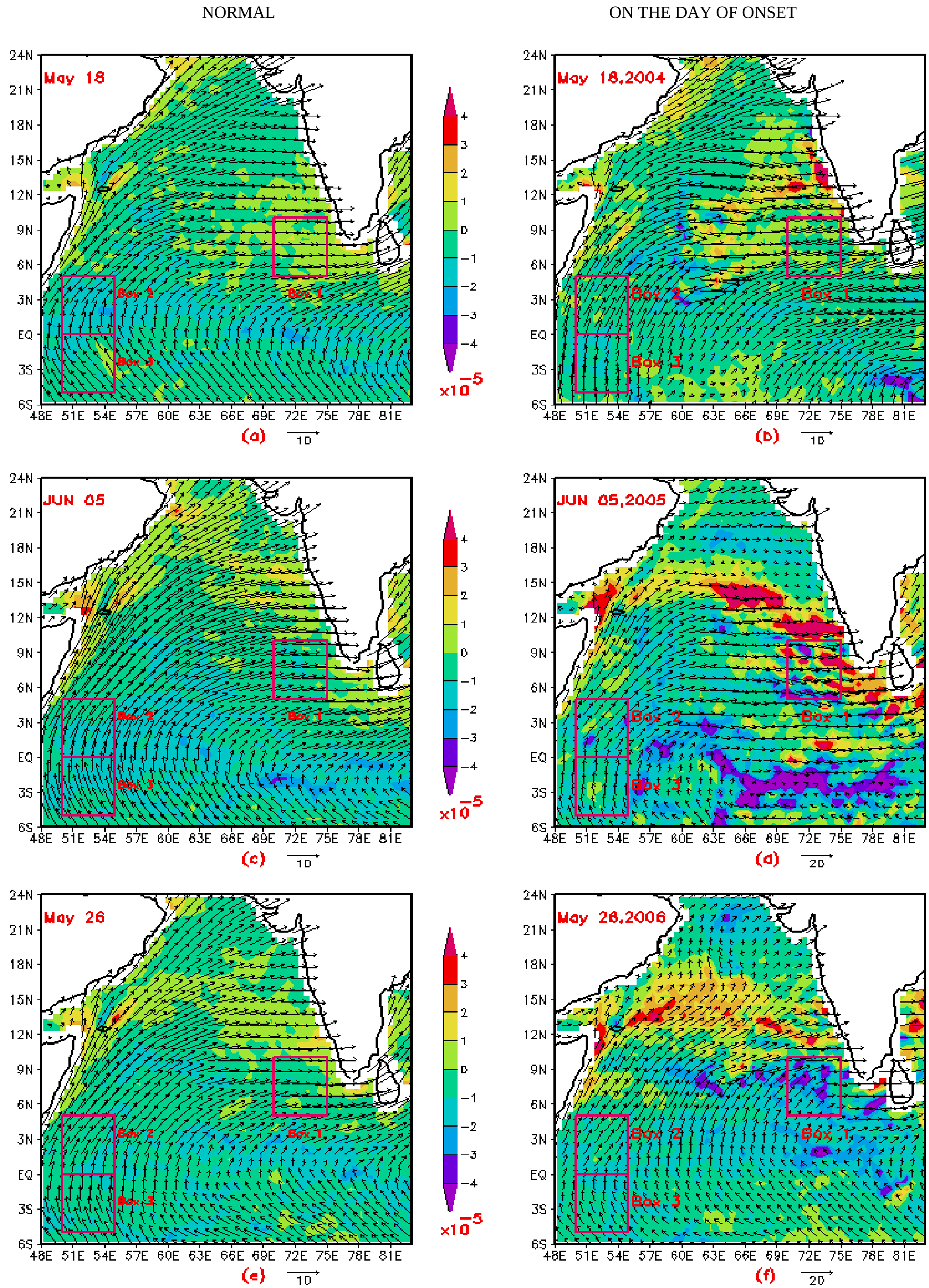

Fig. 5 (ii) a-f. Comparison of normal surface vorticity and observed surface vorticity on onset day during 2004-2006

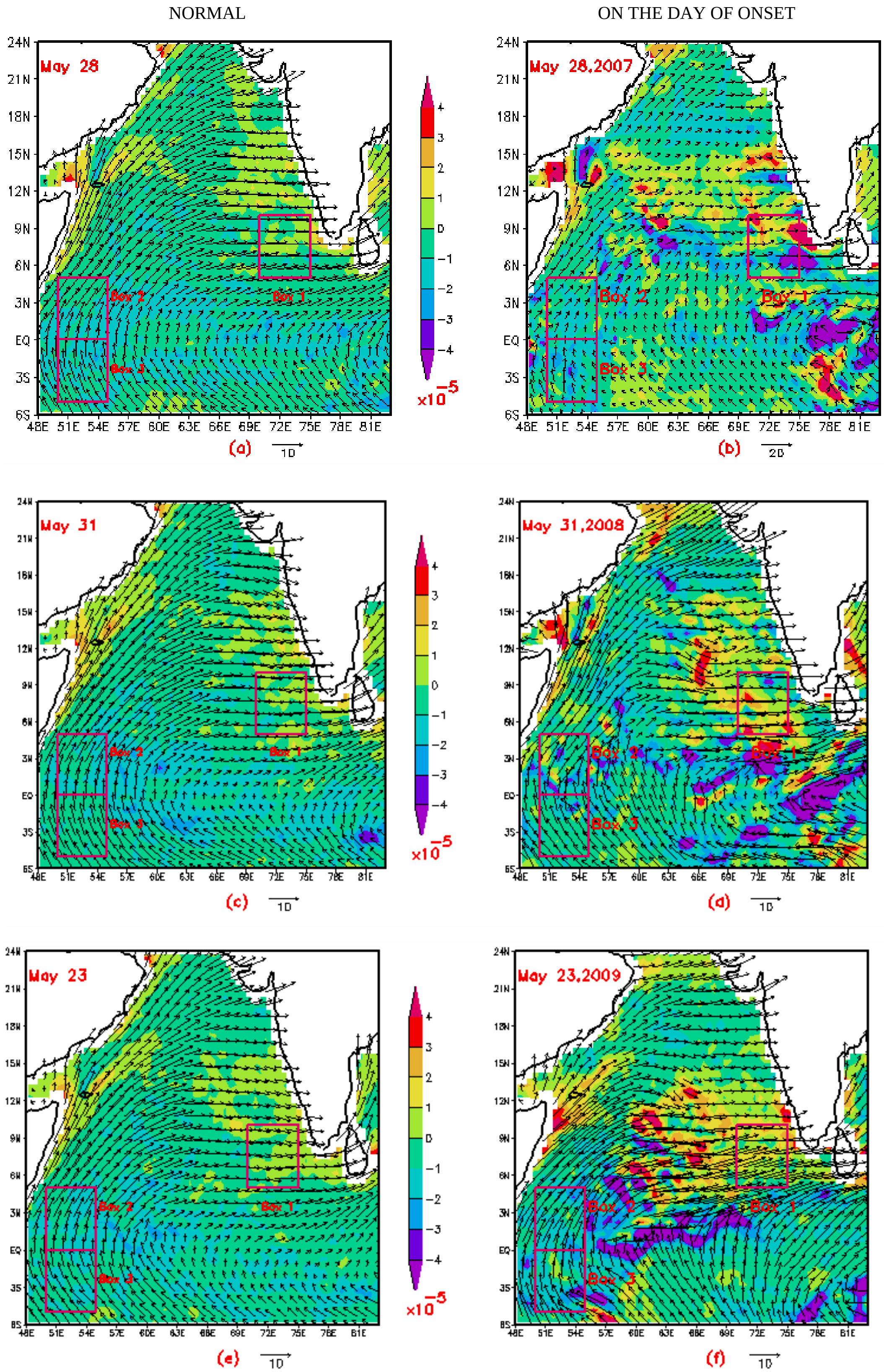

Fig. 5 (iii) a-f. Comparison of normal surface vorticity and observed surface vorticity on onset day during 2007-2009

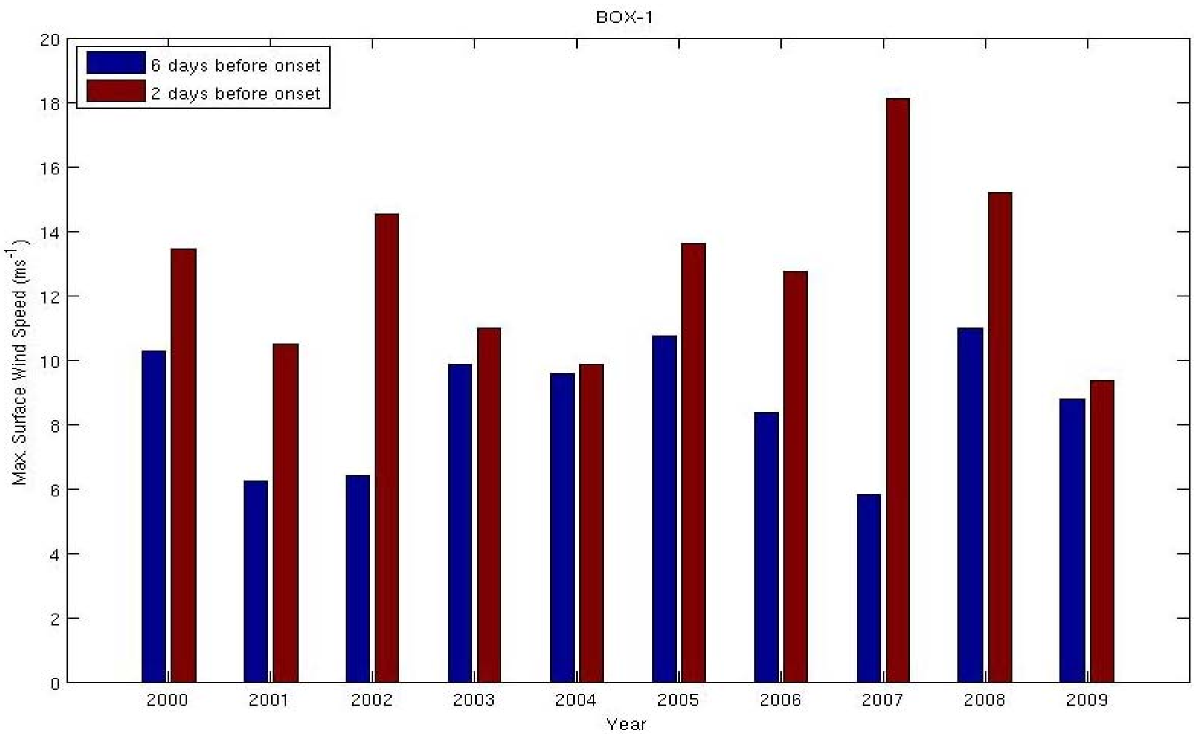

Fig. 6. Comparison of maximum surface wind speed observed 6 and 2 days before onset during 2000-2009

2008 the SV increased steeply 7 days before, which reached its maximum value 6 days before onset and remained constant for a few days and fell steeply thereafter.

During 2007 steep rise in the SV was observed in Box-3 (Fig. 2) five and three days before onset and steep fall in the SV was observed thereafter. In case of year 2008 the rising trend in the SV was observed 7 days before, which reached its maximum value of 13×10^{-5} s^{-1} two days before the onset. Steep rise in the SV was observed 5 days before and steep fall in the SV was observed 2 days before onset. However, some fluctuations were also observed after the peaking of SV. During 2009 high values of SV appeared 5days before onset. Rising trend in SV was observed 6 days before, which reached its maximum value of 12×10^{-5} s^{-1} one day before the monsoon onset and fell steeply thereafter.

The daily variation in the Surface Wind Speed (SWS) during 2001-2003 and 2007-2009 seven days before and seven days after the monsoon onset has been depicted in Figs. 3(a&b). In Box 1 rising trend in the SWS was observed about 4-6 days before onset. SWS generally increased to about 10 m/s about 4 days before and remained constant at the time of monsoon onset and steep fall thereafter was observed. The SWS reached about normal value within a week after the monsoon onset. In 2008, the SWS was observed 8 m/s a week before onset which peaked 5 days and 1 day before onset and reached its maximum value of 16 m/s one day after the onset. During 2009 rising trend in the SWS was observed 7 days before the onset. A steep rise in the SWS was observed 6 days before the onset which doubled within a week and steep fall in the SWS was observed one day after the monsoon onset.

In Box 2 also a steep rise in the SWS was observed 4 days before the onset which peaked (10 m/s) one day before the onset during 2007. The SWS remained constant (10 m/s) one day after the onset and steep rise in the SWS was observed 3 days after the onset which again peaked to 12 m/s 4 days after the onset. During 2008 the SWS started with 9 m/s 7 days before onset and steep rise in the SWS was observed 3 days before the onset which peaked 2 days before the onset and reached its maximum value of 17 m/s and steep fall in the SWS was noticed thereafter. During 2009 the SWS increased steeply 7 days before onset which reached its maximum value of 17 m/s 5 days before the onset and steep fall in the SWS was observed

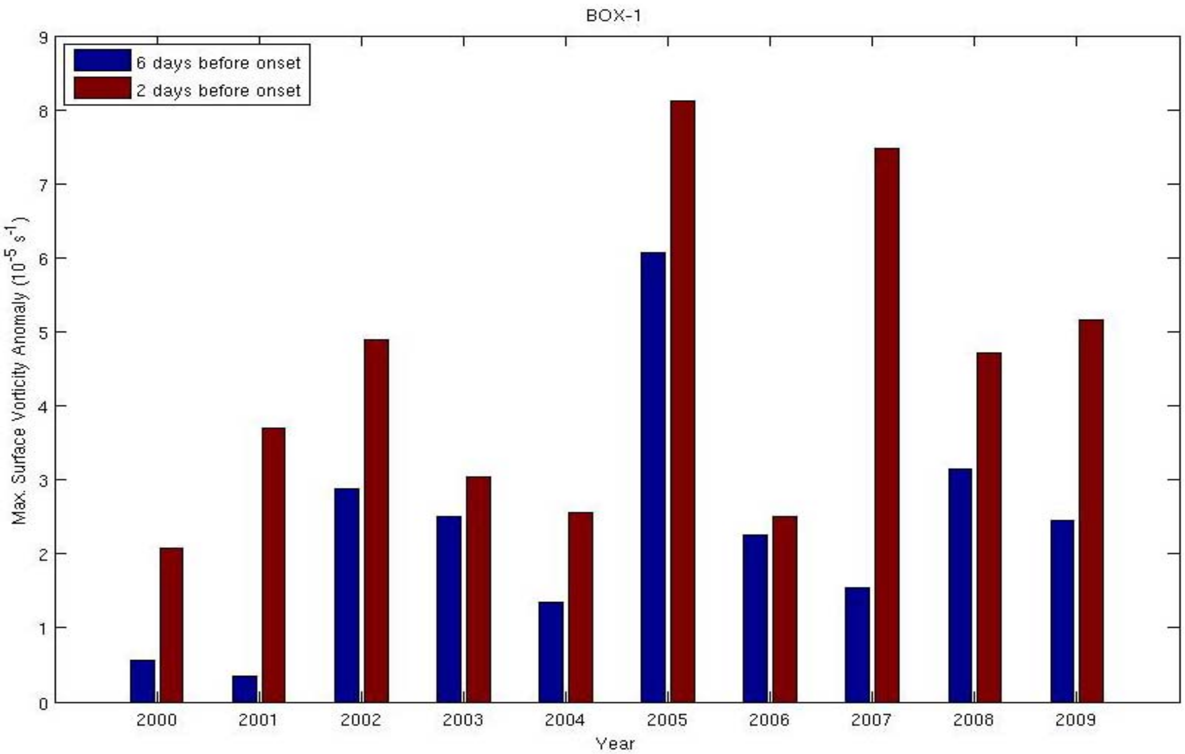

Fig. 7. Comparison of maximum surface vorticity anomaly observed 6 and 2 days before onset during 2000-2009

the next day. The SWS again increased steeply 4 days before the onset which doubled (14 m/s) within three days and decreasing trend in the SWS observed after the onset.

The comparisons of normal surface vorticity with onset day surface vorticity and the vorticity 5 days before onset have been depicted in Figs. 4(i-iii) and Figs. 5(i-iii). The normal SV has been computed from 2000 to 2009 gridded QuickSCAT average daily surface vorticity. Five days before the monsoon onset the SV over southeast Arabian Sea was 3-4 times of the normal SV and 2-3 times over Kerala coast and in Box 1 and Box 2 about 1.5 times of the SV during the period 2000-2009. It may be emphasized again that surface vorticity does increase at the time of monsoon onset but lead time varies from year to year. The rain flagged data has been removed from the QuikSCAT data considered here.

The normal SV and the onset day SV over Arabian Sea and adjoining north Indian Ocean have been depicted in Figs. 5(i-iii). In 2007, the SV was 4-5 times of the normal SV. In Box 1 it was about 4 times of the normal SV. In Box 2 it was about normal SV and Box 3 the SV was about twice of the normal SV on the onset. In 2008, the SV was 2-4 times of the normal SV off Kerala coast. In box 2 SV was about twice of the normal SV on the onset day and about normal SV in the Box 3. In 2009 the SV was about 3-4 times over south Arabian Sea and SWS was about 1.5 times off Kerala coast. The observed SV was about 1.5-2 times in Box 3.

The comparison of surface wind speed 6 days and 2 days before onset have been shown in Fig. 6. Maximum surface wind speed increased to 10-15 m/s over southeast Arabian Sea during the period from 6 to 2 days before onset.

The comparisons of the Surface Vorticity Anomaly (SVA) 6 and 2 days before the monsoon onset have been depicted in Fig. 7. During 2007 there was a huge difference in the SVA observed 6 and 2 days before the onset. The observed SVA was 1.6×10^{-5} s^{-1} and 7.6×10^{-5} s^{-1} in Box 1 six and two days before onset. In 2008 the SVA increased about 1.5 times 6 and 2 days before the monsoon onset. Similar trend in the SVA was observed during 2009 also. The observed SVA was 2.2×10^{-5} s^{-1} and 5.2×10^{-5} s^{-1} six and two days before the onset.

In all the 10 years considered in the present study the SVA increased steeply over southeast Arabian Sea during the period from 6 to 2 days before onset.

5. Conclusions

(*i*) The results of the study have shown that scatterometer based surface vorticity and wind could be good precursors for monsoon onset over Kerala. The rising trends in surface vorticity and wind over southeast Arabian Sea are evident about 4-7 days before the monsoon onset over Kerala.

(*ii*) Extended zone of positive surface vorticity appears over southeast Arabian Sea about 5 days before the monsoon onset over Kerala.

(*iii*) There is a steep increase of 3-4 times in the scatterometer based surface vorticity in some years between the period from 6-2 days before the monsoon onset over Kerala. However, in some years the increase is not so steep being only one-and-half times. This may be due to weak monsoon onset in these years.

(*iv*) The results could find applications in the utilization of Indian satellite Oceansat-2 scatterometer data in monsoon onset forecasting on medium range scale.

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