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Diagnostic study of a recurving cyclone – 'MALA' over the Bay of Bengal

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सार – दक्षिण पूर्व बंगाल की खाड़ी के ऊपर एक अत्यंत भीषण चक्रवातीय तूफान 'माला' (25–29 अप्रैल 2006) बना। आंरभ में यह तंत्र उत्तरपश्चिम की तरफ आगे बढ़ा जबकि 25–26 अप्रैल 2006 के दौरान सघन होकर चक्रवातीय तूफान में बदल गया। इसके बाद यह तूफान प्रतिवक्र होकर उत्तर–उत्तर पूवी दिशा की ओर बढ़ा और 29 अप्रैल, 2006 को अत्यंत भीषण चक्रवातीय तूफान के रूप में इसने अराकन तट को पार किया। इससे इस क्षेत्र में जान व माल की क्षति हुई।

प्रतिवक्रता के बाद लगातार तीव्र होना इस तंत्र का विशिष्ट लक्षण रहा । इस शोध पत्र में इस तंत्र के तीव्र होने और आगे बढ़ने के साथ जुड़े विभिन्न नैदानिक लक्षणों का विश्लेषण और उनका विवेचन किया गया है। तंत्र की तीव्रता ओर उसके आगे बढ़ने का पूर्वानुमान करने के लिए विभिन्न गतिकीय और तापगतिकीय प्राचलों का पूर्वसूचकों के रूप में उपयोग किए जाने के बारे में इस अध्ययन द्वारा बताया गया है। दक्षिण भारतीय महासागर के ऊपर अत्यंत भीषण चक्रवातीय तूफान 'माला' के साथ भ्रमिल की परस्पर क्रिया का भी इसके विवेचन किया गया है।

ABSTRACT. A very severe cyclonic storm "Mala" (25-29 April 2006) developed over south east Bay of Bengal. Initially the system moved northwestwards while intensifying into the stage of cyclonic storm during 25-26th April 2006. It then recurved and moved in a north-northeasterly direction and crossed Arakan coast as a very severe cyclonic storm on 29th April, 2006 causing loss of life and property over the region.

The unique features associated with this system was the continuous intensification after the recurvature.Various diagnostic features associated with intensification and movement of this system have been analysed and discussed. The study highlights the use of different dynamic and thermodynamic parameters as precursors for prediction of intensity and movement of the system. It also discusses the interaction of very severe cyclonic storm Mala with a vortex over the south Indian Ocean.

Key words – Cyclone, Track, Intensity, Recurvature**.**

1. Introduction

Cyclonic storms are low pressure systems which are classified based on associated sustained maximum wind speed when they form and move over the ocean area. As per India Meteorological Department (IMD), a low pressure system is said to be a cyclonic storm if the wind speed is 34-47 knots, a severe cyclonic storm if the wind speed is 48-63 knots , a very severe cyclonic storm , if the wind speed is 64-119 knots and a super cyclonic storm , if the wind speed is 120 knots or more. Based on the above classification , a very severe cyclonic storm " Mala" over the Bay of Bengal crossed Myanmar coast on 29th April causing loss of human lives and properties of coastal Myanmar.

The severe cyclonic storms over the Bay of Bengal show bimodal behaviour in their frequency of occurence with primary maximum occuring in the month of November and a secondary maximum in May (IMD, 1979, 1996). Twenty one cyclonic storms developed over the Bay of Bengal during the month of April out of which 7 intensifed into the severe cyclonic storm stage during the period of 1891-2006. The frequency of very severe cyclonic storms crossing Myanmar coast in the month of April is very rare. Most of these storms formed in southeast and adjoining central Bay of Bengal and move initially towards northwesterly/northerly directions and then recurve towards the northeast striking Myanmar / Bangladesh coast. The systems which crossed 85° E while moving westwards/northwestwards have generally crossed

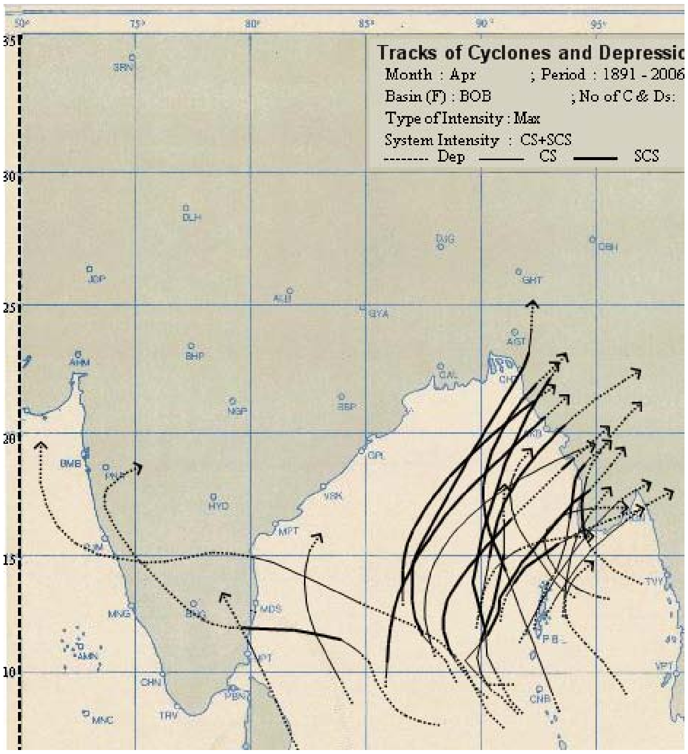


Fig. 1. Track of the storms over the Bay of Bengal in the month of April during the period of 1891-2006

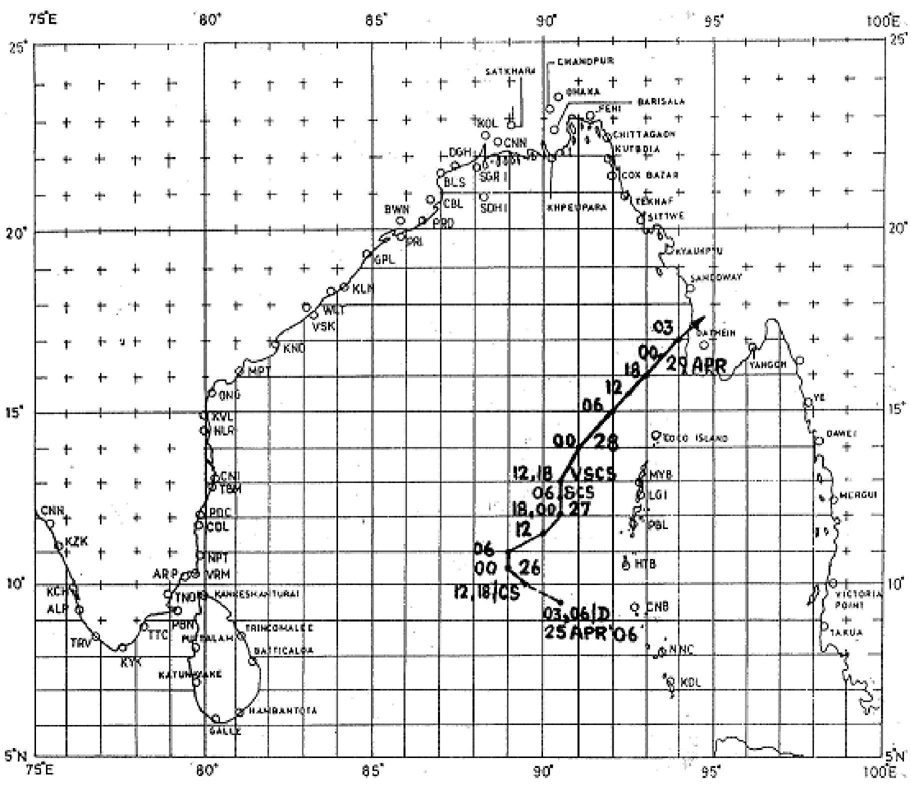


Fig. 2. Track of Very Severe Cyclonic Storm, "MALA" over the Bay of Bengal (25-29 April, 2006)

TABLE 1(a)

Best track positions and other parameters for Bay of Bengal very severe cyclonic storm, 'MALA' (April 25-29, 2006)

Date	Time (UTC)	Centre Lat. °N/ Long. °E	C.I. NO.	Estimated central pressure (hPa)	Estimated maximum sustained surface wind (kt)	Estimated pressure drop at the Centre (hPa)	Grade
25 April 2006	0300	9.5/90.5	1.5	996	25	4	D
	0900	9.5/90.0	2.0	996	30	4	DD
	1200	10.0/89.5	2.5	996	35	5	CS
26 April 2006	0300	10.5/89.0	3.0	994	40	6	CS
	1200	11.5/90.0	3.0	994	40	6	CS
27 April 2006	0300	12.5/90.5	3.5	984	50	8	SCS
	1200	13.0/90.5	4.0	980	65	14	VSCS
28 April 2006	0300	14.5/91.5	4.5	954	80	30	VSCS
	1200	15.5/92.5	5.5	954	100	52	VSCS
29 April 2006	0300	17.0/94.0	5.5	954	100	52	VSCS
	0600	17.5/94.5	5.0	966	90	40	VSCS
	Crossed Arakan coast about 100 km south of Sandoway (48080) as very severe cyclonic storm around 0700 UTC						
	0900	18.0/95.0					SCS
	1200	18.5/95.5					SCS
	1800	19.0/96.0					CS

TABLE 1(b)

Best track position for the south Indian system during 25 -29th April 2006

Date	Centre Lat. °S/Long. °E
25 April 2006	03.0/89.0
26 April 2006	07.0/90.0
27 April 2006	4.0/87.0
28 April 2006	4.0/86.0
29 April 2006	4.0/84.5
30 April 2006	4.0/83.0

Tamilnadu/south Andhra Pradesh coast. The intensification of a cyclonic storm to very severe cyclonic storm stage during the period of recurvature in the month of April is not very common. During the period of 1891-2006 only 13 such cases are available when the system intensified during the recurvature.

Prediction of track and intensity of cyclonic storm is one of the most difficult and challenging problems of current tropical cyclone research. The focal point is to minimise the forecast error, to the extent that the forecast can be used effectively for issuing appropriate warning for disaster manangement. It has been also established on many studies that the landfall forecast error is higher in case of recurving cyclones than the cyclones following northwesterly track (Rama Rao *et al.*, 2007). The twentyfour hours landfall operational forecast error by IMD in case of the very severe cyclonic storm (VSCS) Mala has been approximately 125 km. Considering all the above, a diagnostic study has been undertaken to find out

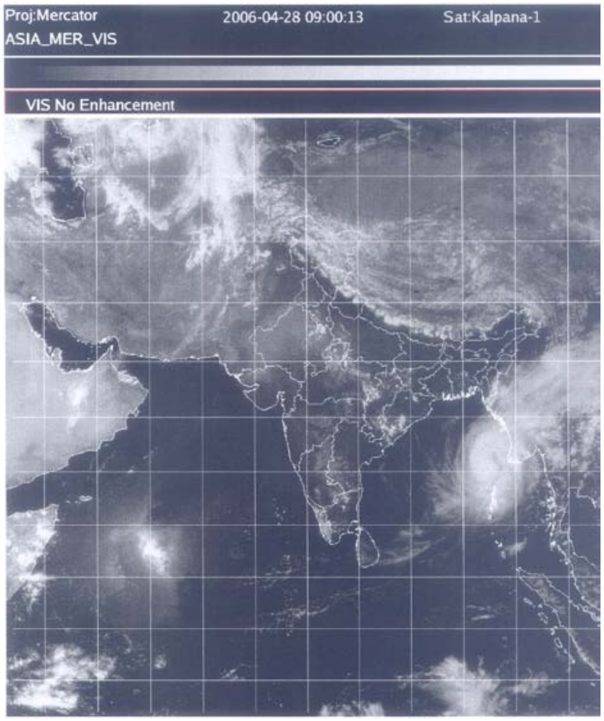


Fig. 3. INSAT visible imagery of very severe Cyclonic Storm Mala at 0900 UTC of 28 Apr 2006

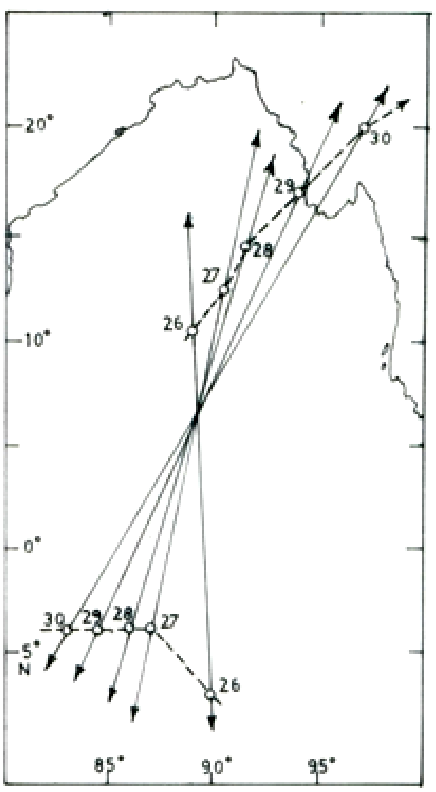


Fig. 4. Interaction between "MALA" and vortex over South Indian Ocean (26th - 30th April 2006)

TABLE 2

Thermo dynamical and dynamical parameters considered in the study

Parameters	Levels (hPa)
Geopotential	850
Vertical Velocity	850
Air Temperature	300
Precipitable water	Surface

TABLE 3

The location of maximum vertical velocity (Pascal/Sec) with respect to the storm centre

	Date				
Level	25	26	27	28	29
1000	00	00	00	+0.010	+0.01
850	-0.2	-0.2	-0.10	-0.125	0.150
500	-0.24	-0.175	-0.175	-0.27	-0.275
200	-0.24	-0.250	-0.225	-0.30	--

the various synoptic, thermodynamic and dynamic features associated with a recurving very severe cyclonic storm, Mala. The present study may help in reducing the landfall error and in predicting the intensity of a recurving cyclone.

A brief life history of VSCS, Mala is presented in Sec. 2. The data and methodology followed in the study are discussed in Sec. 3. The results and discussion are presented and analysed in Sec. 4 and the broad conclusions of the study are presented in Sec. 5.

2. Brief history of very severe cyclonic storm "Mala"

Fig. 2 shows the track of very severe cyclonic storm, "Mala" and Table 1 (a) presents the track position, intensity and other parameter of Mala. Table 1(b) presents the position of Vortex over south Indian Ocean during 25-29th 2006. An area of convection persisted over the south Bay of Bengal since middle of April and organized into a low level cyclonic circulation on 23rd April. Under low vertical wind shear, convection built around the system and consolidated around the center. The convective clusters continued to organize, resulting into the formation of a depression at 0300 UTC of 25th April. Moving in a westerly direction, it intensified into a deep depression at 0900 UTC of 25th April and lay centered about 370 km southwest of Port Blair. It intensified into a cyclonic storm at 1200 UTC of the same day. The system continued its

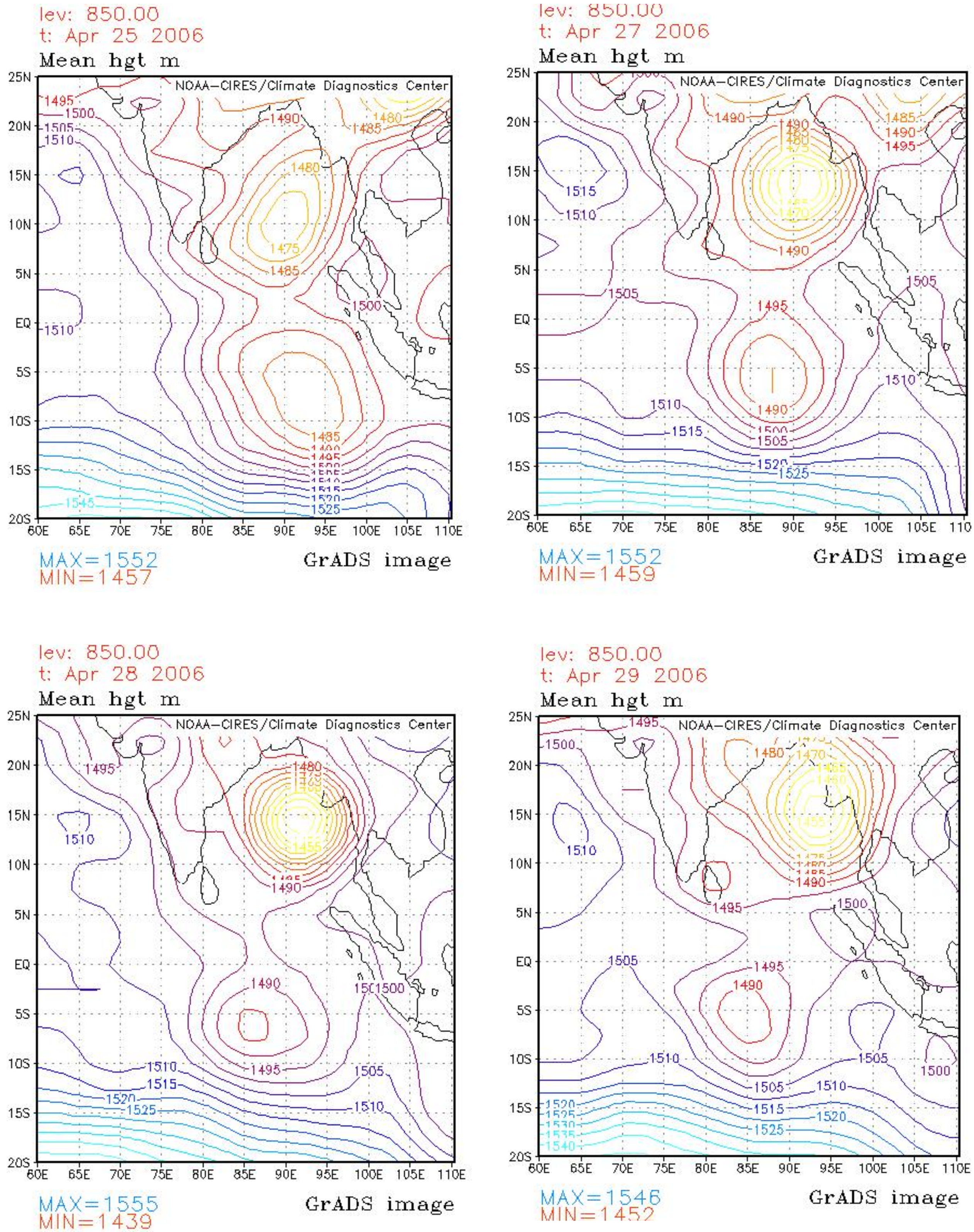


Fig. 5. The spatial distribution of geopotential height over the region under consideration at 850 hPa on 25th, 27th, 28th, 29th April 2006

west north westward movement till 0300 UTC of 26th while maintaining cyclonic storm intensity. It then took northerly track and finally northeasterly track till its landfall. The system intensified into severe cyclonic storm at 0300 UTC of 27th and into a very severe cyclonic storm at 1200 UTC of the same day. The system crossed Arakan coast, about 100 km south of Sandoway (48080) as a very severe cyclonic storm around 0700 UTC of 29th causing large damage to lives and properties in Myanmar (RSMC Tropical Cyclone, New Delhi, 2007).

The T-number according to Dvork's intensity scale (Dvork, 1984) went on increasing and reached maximum (T5.5) at 1200 UTC of 28th (Table 1). The maximum intensity continued till 0300 UTC of 29th and then the intensity slightly decreased to 5.0 at 0600 UTC of 29th before the landfall. The sustained maximum wind speed was 100 kts with maximum pressure drop of 52 hPa and lowest estimated central pressure of 954 hPa. A representative INSAT imagery of the system at 0900 UTC of 28th is shown in Fig. 3.

3. Data and methodology

The best track information and other significant characteristics like intensity, sustained maximum wind, pressure drop etc. have been collected from the report on cyclonic disturbances over North Indian Ocean published by Regional Specialized Meteorological Centre (RSMC) Tropical Cyclone New Delhi (RSMC New Delhi 2007).

The NCEP/NCAR reanalysis (Kalnay *et al*., 1996) over the region of 20° S and 25° N and 50° E to 110° E have been considered to analyze different dynamic and thermodynamic parameters associated with intensity fixation and movement of the system. The details of the parameters considered in the study are shown in Table 2. The highest values over its region of location in respect of different parameters for each day during the storm period has been calculated and analyzed to find out their relation with intensification and movement of the system.

4. Results and discussion

4.1. *Geopotential*

The spatial distribution of geopotential height over the region under consideration at 850 hPa level is shown in Fig. 5. The spatial distribution clearly demonstrates the interaction between the Vortex over South Indian Ocean (SIO) and Mala, throughout the life period of Mala. It is observed that the intensity of Mala increased rapidly while the intensity of the vortex over SIO near about 7.5° N and 95.0° E on 25th April showed no significant change in intensity throughout the period. As Mala recurved and moved north-northeastwards, the vortex over SIO moved west north westwards. All these observations endorses the earlier findings of Kuettener (1967), Muralker (1950), Mukherjee and Padmanabhan (1977) on interaction between two vortices on both sides of the equator. To illustrate the above feature the tracks of Mala and the Vortex in South Indian Ocean are shown in Fig. 4. It is dictated that while track was a clockwise path of Mala during 26-29 April, there was anticyclonic path in case of Vortex over South Indian Ocean, like the Fujiwara effect, the lines joining the centers of both the vortices had common point of centers of intersection (6.5° N / 79.0° E). Over the period of time, the intensity of Mala increased and that of Vortex over SIO decreased.

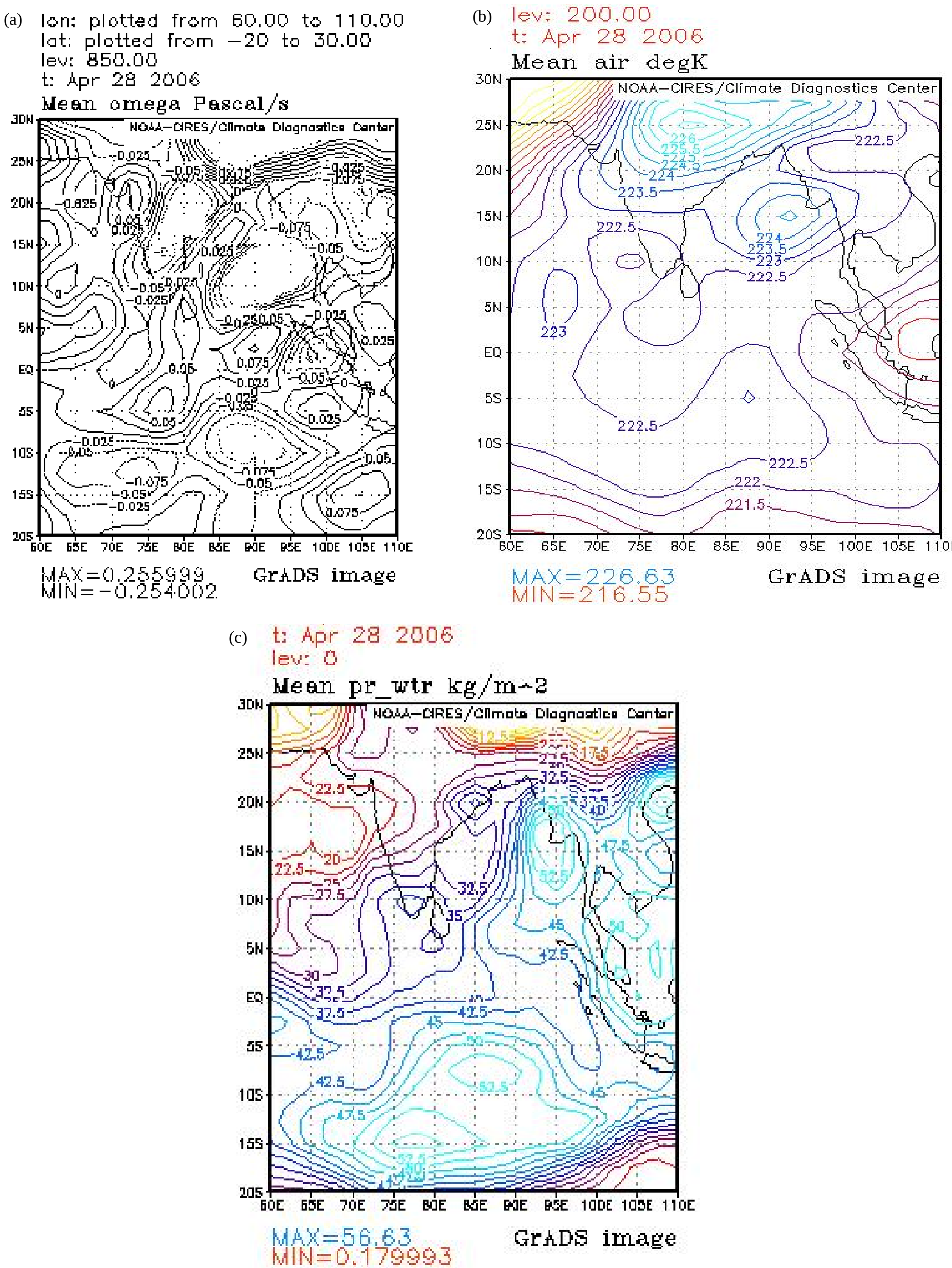
Considering the geopotential at 500 hPa levels, the interaction was also evident (not shown) similar to that observed at 850 hPa level.

4.2. *Vertical velocity*

The vertical velocity at 850 hPa level over the storm region clearly indicates that the upward vertical motion was higher in the northeast sector of the VSCS Mala. The region of upward vertical motion corresponds to the region of maximum low level vorticity and convergence. The regions of maximum upward vertical motion also suggest likely direction of movement of the system. Hence the distribution of vertical velocity suggested northeastward movement of the system. The location of maximum vertical velocity with respect to the storm centre also suggest the same (Table 3). The analysis of vertical velocity over the region also shows gradual increase of vertical velocity as the system intensified during 25th to 27th. A representative distribution of vertical velocity is shown in Fig 6(a). The distribution of vertical velocity also suggested the occurrence of two velocity maxima on either side of the equator in association with Mala and vortex over SIO. However, the interaction between them was not as evident as in case of geopotential heights.

4.3. *Air temperature*

The air temperature at 850 hPa level was higher (>17° C) (not shown) over the Bay of Bengal with stronger north-south temperature gradient on 25th. Then the gradient decreased and a colder region (<17° C) developed over south east Bay and neighborhood on 26th. It was >17° C over recurving path of Bay of Bengal. On 27th the temperature gradually increased with colder temperature over the storm region. This pattern prevailed also on 28th and 29th. It may be due to the fact that the lower level temperature over the storm region decreases due to enhanced convection and rainfall. However the



Figs. 6(a-c). (a) The vertical velocity at 850 hPa level over the storm region, (b) Air Temp. at 200 hPa level on 28th April 2006. (c) The values of precipitable water on 28th April, 2006 temperature gradient from the centre of colder region was directed towards the northeast during all the days.

Considering the temperature at 500 hPa level (not shown), the storm region was also colder and the maximum temperature gradient was oriented towards the northeast. It further showed the interaction of the system with another vortex over SIO which was located near 02° S and 90° E on 27th and moved southwest wards during this period. While the temperature maxima in association with Mala moved northeastwards, that associated with Vortex over southern hemisphere moved northwestwards till 28th and become less marked on 29th.

The analysis of air temperature at 200 hPa level showed a warmer region to the west of system on 25th and to the north-northeast of the system centre thereafter after till 29th. The location of the warmer region hence clearly indicated the north northeastward movement of the system. A representative distribution of air temperature at 200 hPa is shown in Fig. 6 (b).

4.4. *Precipitable water*

The highest value of precipitable water lay towards southwest on 25th, towards south on 26th and then towards northeast on 27th (figure not shown). The precipitable water also suggested the system to move in a northeasterly direction from 27th. The precipitable water was maximum on 28th (56.6 kg/m^2) increasing from 50 kg/m^2 during 25-27th. It maintained almost same intensity (56 kg/m^2) on 29th. The distribution of precipitable water also indicates the existence of two maxima on either side of the equator corresponding to the location of Mala and the vortex in SIO under consideration. A representative distribution of precipitable water is shown in Fig. 6 (c).

If we compare the observed centre of the system with the centre of highest values of Relative Humidity at 850 hPa level, mean values of precipitable water content, air temperature at 300 hPa level and vertical velocity for the previous day, we observe that the tendency of movement was highly correlated with this parameter. The system moved towards the region of higher values of precipitable water and temperature at 300 hPa levels and upward vertical motion at lower levels. These favorable conditions were associated with increase in convection with the system.

5. Conclusion

(*i*) This study reveals that region of occurrence of higher precipitable water content, higher air temperature at 300 hPa level and higher upward vertical velocity in lower levels may be indicator of future movement of the system. All these parameters are associated with increase in convection due to the system.

(*ii*) The study supports the earlier findings that if a vortex develops in SIO within lower latitudinal belt, it interacts with the system over the Bay of Bengal. The stronger one intensifies and weaker one becomes weaker or filled up with time. The vortex over the southern hemisphere moved west-northwestward as Mala moved northeastwards revealing the impact of interaction between the two vortices and its effect on the movement of the system.

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