

Investigation of features of May, 2001 tropical cyclone over the Arabian Sea through IRS-P4 and other satellite data

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सार – इस शोध पत्र में भारतीय क्षेत्र में उष्ण कटिबंधीय चक्रवातों के बनने / कमजोर पड़ने के संबंध में जारी किए जाने वाले लघु अवधि पूर्वानुमानों में सुधार लाने के लिए उपग्रह से प्राप्त किए गए वायुमंडलीय गति सदिशों तथा भू-भौतिकी प्राचलों की उपयोगिता एवं समुचित संकेतकों का पता लगाने का प्रयास किया गया है। इसमें मई 2001 में अरब सागर में निर्मित चक्रवात के अध्ययन से प्राप्त हुए परिणामों को दर्शाया गया है। इस चक्रवात की पूरी अवधि के गत्यात्मक परिवर्तनों जैसे – भ्रमिलता, अभिसरण एवं अपसरण की जानकारी प्राप्त करने के लिए 850 और 200 हेक्टा पास्कल दाब पर इष्टतम अंतर्वेशन (ओ. आई.) तकनीक के उपयोग द्वारा मेघ गति सदिशों और जलवाष्प पवन सदिशों में संशोधन के साथ पवन क्षेत्र का विश्लेषण किया गया है। इसके साथ-साथ भारतीय क्षेत्र में लघु अवधि पूर्वानुमानों में सुधार के लिए आई.आर.एस.-पी. 4 और टी.आर.एम.एम. उपग्रहों से प्राप्त भूभौतिकीय प्राचलों में भिन्नताओं के आरोही तथा अवरोही नॉड्स की तुलना गत्यात्मक भिन्नताओं से कुछ घनात्मक संकेतों की पहचान करने हेतु की गई है। 26 मई से 28 मई 2001 तक की अवधि में चक्रवात के केन्द्र के चारों तरफ वृहत्त क्षेत्र में 200 हेक्टा पास्कल दाब पर चक्रवाती भ्रमिलता में वृद्धि देखी गई है जो तूफान के कमजोर होने का सकारात्मक संकेत देता है।

ABSTRACT. In this paper, utility of satellite derived atmospheric motion vectors and geophysical parameters is brought out to discern appropriate signals for improving short-range forecasts in respect of development/dissipation of tropical cyclones over the Indian region. Results of a particular case study of May, 2001 cyclone, which formed in the Arabian Sea are reported. Analysis of wind field with input of modified cloud motion vectors and water vapour wind vectors is performed utilizing Optimum Interpolation (OI) technique at 850 and 200 hPa for finding dynamical changes such as vorticity, convergence and divergence for the complete life period of this cyclone. Simultaneously, variations in geophysical parameters obtained from IRS-P4 and TRMM satellites in ascending and descending nodes are compared with dynamical variations for discerning some positive signals to improve short range forecasts over the Indian region. The enhancement of cyclonic vorticity at 200 hPa over larger area surrounding center of cyclone was observed from 26 to 28 May 2001 which gave a positive signal for dissipation of storm.

Key words – Cloud motion vectors, Geophysical parameters, Monsoon depressions, Tropical cyclones.

1. Introduction

The geostationary meteorological satellites have provided lot of upper-air wind data from the tropics to mid-latitudes for global numerical weather prediction. This wind data plays significant role to capture the wind structure at global scale. Global observations of atmospheric winds are very important for atmospheric

science related studies and operational weather forecasting. This is especially true at low latitudes, where the wind field cannot be inferred from the mass field and upper air-soundings from conventional network are sparse. Observations of wind flow over the oceanic areas are important prerequisite for accurate weather forecasts by Numerical Weather Prediction (NWP) models. India is surrounded by vast oceans such as the

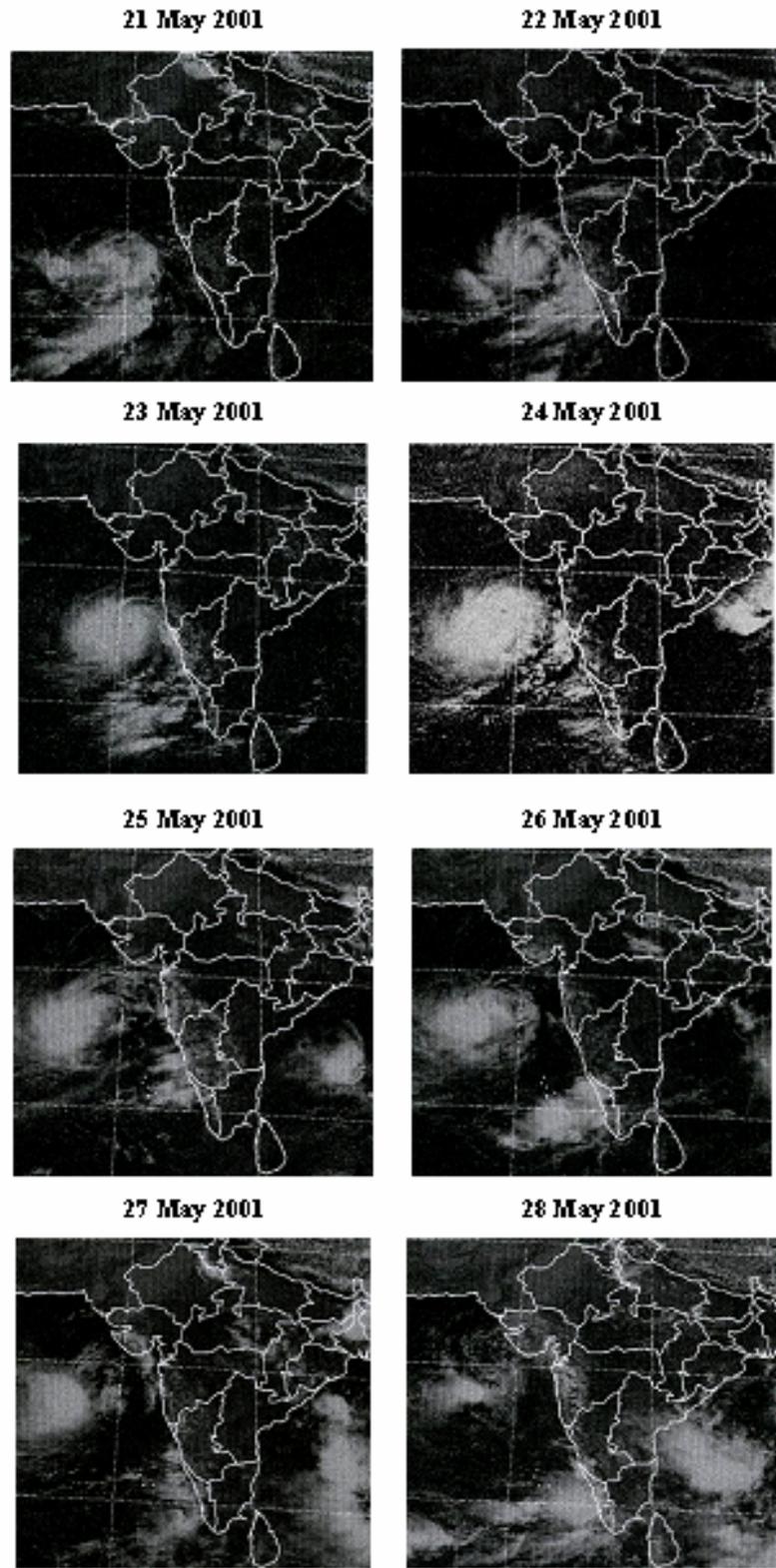


Fig. 1. INSAT imagery for tropical cyclone during 21-28 May 2001

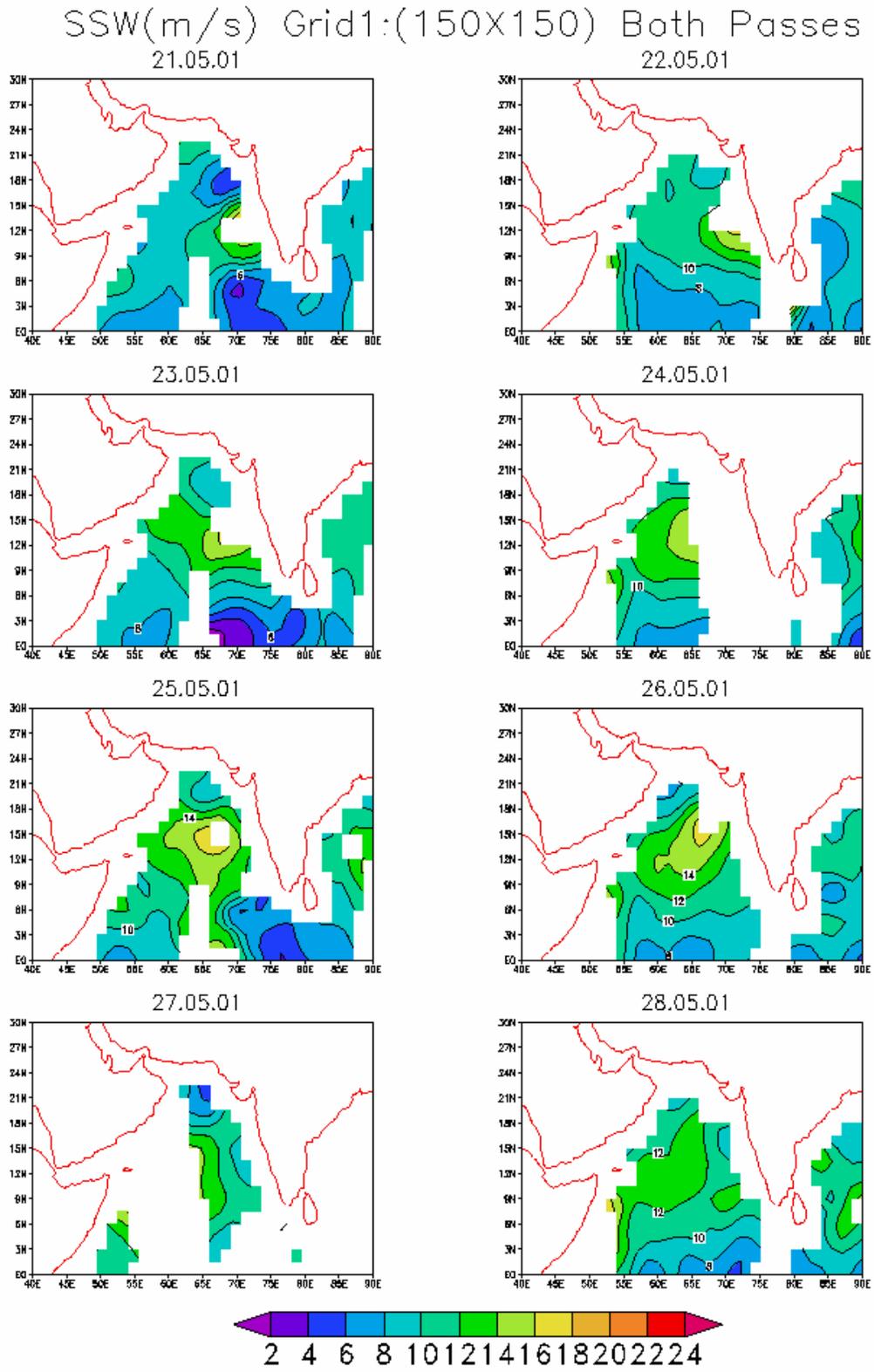


Fig. 2. IRS-P4 MSMR sea surface wind speeds (m/s) during 21-28 May 2001

Arabian Sea, the Bay of Bengal and the south Indian Ocean. Lack of conventional wind data in these areas causes errors in weather forecasts. Therefore, it is worthwhile evaluating the impact of satellite derived winds especially at two standard pressure levels *i.e.*, 850 and 200 hPa for discerning the possible signatures of development/dissipation of weather systems over the Indian region. In this study, better utility of satellite-derived AMVs (Atmospheric Motion Vectors) for improvement of weather forecast of a cyclonic storm over the Arabian Sea is highlighted. Archiving of satellite derived upper-air wind data from INSAT imagery commenced during 1984 at MDUC (Meteorological Data Utilization Centre), in IMD, New Delhi using automated technique developed by Kelkar and Khanna (1986). With subsequent increase in areal coverage of CMVs, interactive quality control procedures were introduced. Some of the earlier investigators carried out impact studies of different observing systems during FGGE period by including satellite-derived winds. Bengtsson *et al.* (1982) concluded that satellite-derived wind data have significant impact on forecasts in the tropics and are more significant for southern hemispheric circulations than for those in the northern hemisphere. However, Rajamani *et al.* (1982) showed that aircraft/ship data have a bigger positive impact in the analysis than satellite-derived wind data. These results were brought out utilizing conventional and non-conventional MONEX-79 data over the Indian region. Joshi *et al.* (1987) suggested that the use of satellite-derived wind data at few intermediate levels would lead to better forecasts over the Indian region. Mahajan *et al.* (1992a) established an empirical relationship between satellite-derived winds obtained from GOES satellite located temporarily over the Indian region during 1979 and conventional winds reported by the research ships at different pressure levels. They showed that satellite-derived wind data could be used for the construction of vertical wind profile over the Indian Ocean. In another study, Mahajan *et al.* (1992b) used these winds in objective analysis of the wind field and showed that constructed winds are of potential use for depicting major circulation features over the seas surrounding India. Later, for utilization of INSAT winds, Mahajan *et al.* (1995) developed another regression relationship between INSAT winds and the radiosonde winds of island stations over the Indian seas. They utilised modified INSAT CMVs as an input in objective analysis of the wind field and showed that they are of potential use in depicting better monsoon circulation features over the Indian region.

However, the same empirical relationship may not hold good for the winds derived from the European METEOSAT-5 satellite which was located over the Indian region. Therefore, in this study, another relationship is

used which was earlier developed between METEOSAT-5 winds (CMVs and WVVVs) and radiosonde winds obtained at Minicoy and Port Blair island stations, Mahajan (2003). In this study, potential utility of atmospheric motion vectors is explored to obtain some signal of development/dissipation of a tropical cyclone for improving very short-range forecasts over the Indian region. Simultaneously, variations in geophysical parameters and modulation in convective activity obtained from IRS-P4 and INSAT satellites are highlighted showing its consistency during development/dissipation of the system under study.

2. Data

Cloud Motion Vectors (CMVs) at 800-950 hPa and water vapour wind vectors (WVVVs) at 100-250 hPa obtained from METEOSAT-5 at 1200 UTC are utilized for computing dynamical changes in lower and upper troposphere especially at 850 and 200 hPa for the complete life period of May 2001 cyclone. INSAT satellite imageries at synoptic hour observations (Fig.1) are used to depict variations in convective activity in the region of tropical cyclone. IRS-P4 MSMR grid mode data in ascending and descending nodes are utilized for the computation of sea surface temperature, sea surface winds, integrated water vapour and cloud liquid water content over the Arabian Sea. Radiosonde wind data of Minicoy and Port Blair island stations are used for its comparison with satellite-derived winds with METEOSAT-5 satellite. NCEP wind field analyses at 1200 UTC for 850 and 200 hPa are used for performing objective analyses of wind fields with inputs of satellite derived winds.

3. Methodology

METEOSAT-5 derived CMVs (800-950 hPa) and WVVVs (100-250 hPa) over the Arabian Sea and the Bay of Bengal were utilized for the year 2000. This was done for an independent data to establish relationship between CMVs (800-950 hPa) and RS winds at 850 hPa and between WVVVs (100-250 hPa) and RS winds at 200 hPa. Here radiosonde wind data are considered from Minicoy and Port Blair island stations. There were few occasions when CMVs and WVVVs were not exactly available over the locations of island station. In such cases mean wind in a 5° square keeping the island station at the center is used as a representative wind. This procedure is adopted because autocorrelation coefficients of satellite derived wind vectors remain highly significant within a 5° square, Wylie and Hinton (1981). In order to generate satellite - derived winds at 850 hPa and 200 hPa, above recorded winds of CMVs and WVVVs are compared with radiosonde winds at 850 and 200 hPa of Minicoy and

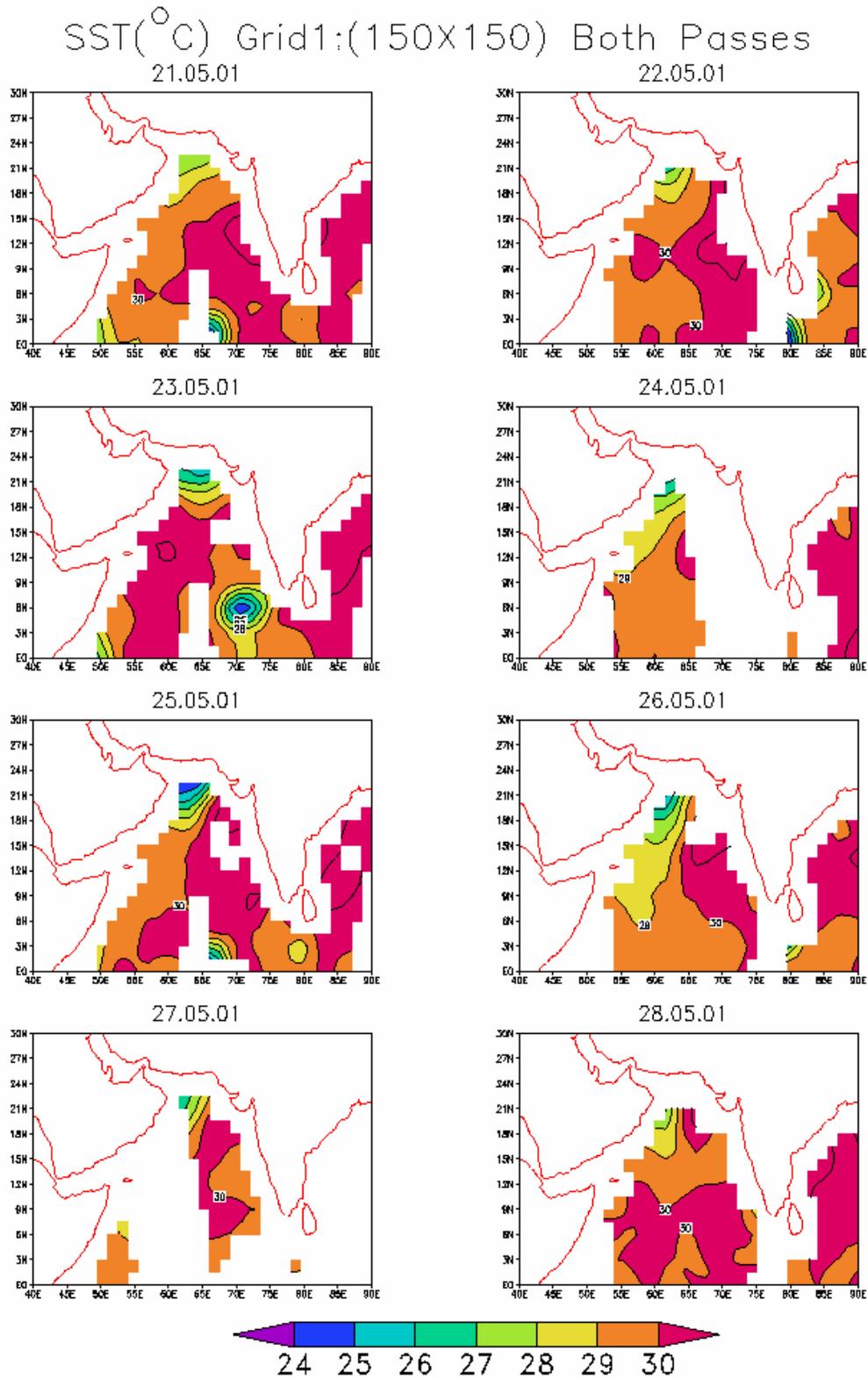


Fig. 3. IRS-P4 MSMR sea surface temperature (°C) during 21-28 May 2001

TABLE 1
Range and retrieval accuracy of parameters

Parameter	Range	Retrieval Accuracy (Approx.)
SST (°K)	281-305	1.5
SSW (mps)	0 – 24	1.6 *
IWV (gm/cm ²)	0.3 – 8.2	0.20
CLW (mg/cm ²)	0 – 132	13.0

* In the present study 8 channels are used for wind speed retrieval

Portblair island stations. Considering satellite derived wind as independent variable, linear regression equations are developed for both u and v wind components. These equations are statistically tested for their significance, Mahajan (2003). IRS-P4 MSMR data for both descending and ascending nodes are combined for each day and plotted on the chart to see the complete variation in geophysical parameters over the Indian seas. All the geophysical parameters such as sea surface wind speed, sea surface temperature, integrated water vapour and cloud liquid water available only at 150×150 km grid are used for uniformity. Moreover, wind speed values are more accurate for this resolution as compared to 75×75 km resolution, Ali *et al.* (2000). Therefore, in the present study, the data of 150×150 km resolution for cloud liquid water content are plotted for the above tropical cyclone to analyse variations of geophysical parameters associated with modulation of convective activity during various stages of development and dissipation. The range of different geophysical parameters derived from IRS-P4 data and their accuracies over tropical region are shown in Table 1 (Gohil *et al.* 2000).

Regression equations developed for both u and v components have been used to modify the wind fields of METEOSAT-5 data during the life period of May 2001 tropical cyclones. This was done for two important standard pressure levels *i.e.*, at 850 and 200 hPa where, generally we get maximum low level convergence and maximum upper tropospheric divergence. NCEP daily wind field analyses at 1200 UTC are used as a priori for carrying the objective analyses of wind field at 850 and 200 hPa by including modified METEOSAT-5 winds. The technique used is optimum interpolation (OI) method. Later, using these analyzed data; vorticity fields at 850 and 200 hPa were computed for the entire life period of tropical cyclone. Main emphasis is to monitor the vorticity fields, especially in the region of tropical cyclone. It is then compared with the cloudiness pattern obtained by INSAT, METEOSAT-5 and NOAA satellites. TRMM-derived daily rainfall is used to analyze the major rainfall

activity in the thick convective areas for the complete life cycle of the tropical cyclone. Considering that during pre-monsoon and post-monsoon seasons, genesis of tropical cyclones is supported by transport of large amount of moisture over the Arabian Sea and the Bay of Bengal. An accurate analysis of moisture fields over these areas plays an important role in understanding the mechanism and the dynamics of development of intense atmospheric systems. Satellite data, however, make it feasible to study the distribution of moisture and cloud liquid water content over large and remote oceanic areas because of their wide spatial and temporal coverage. Here, in this study IRS-P4 MSMR derived geophysical parameters are used for finding their variations during genesis, development, mature stage and dissipation of the tropical cyclone. Results for 1200 UTC show similar variations in geophysical and dynamical parameters highlighting how intensification/dissipation of system took place. Here, as an example the details of 1200 UTC are shown to give better understanding of development and dissipation of very severe tropical cyclone over the Indian region.

4. Results and discussion

Results based on the analysis of different parameters for the case study under consideration are brought out as follows.

(a) IRS-P4 derived surface wind speed increased from 4-6 mps to 16-18 mps in the region surrounding center of tropical cyclone for the period 21 to 26 May and then drastically decreased from 12-10 mps to 8-6 mps on 27 and 28 May giving signatures that dissipation is likely to occur for tropical cyclone (Fig. 2).

(b) On 21st and 22nd May SSTs were around 29-30°C in the vicinity of the system. During the weakening stage on 27th and 28th May, the area with SSTs above 30°C is reduced considerably. The gradient on northwestern side was increased showing SST about 26-27°C (Fig. 3).

(c) Integrated water vapour (IWV) was 5 to 6.5 gm/cm² at the time of formation of low on 21st May. During the formation of severe cyclonic storm IWV reached its maximum value of 7.5 gm/cm² (Fig. 4).

(d) At low stage, maximum cloud liquid water (CLW) varied from 10 to 50 mg/cm² in the vicinity of the low. It increased to 70-80 mg/cm² on 23rd when the system developed into very severe cyclonic storm (Fig. 5).

(e) Cyclonic vorticity surrounding the center of the storm at 850 hPa was well established and it was varying from 2 to 6×10^{-5} /s during 23 to 28 May 2001 (Fig. 6).

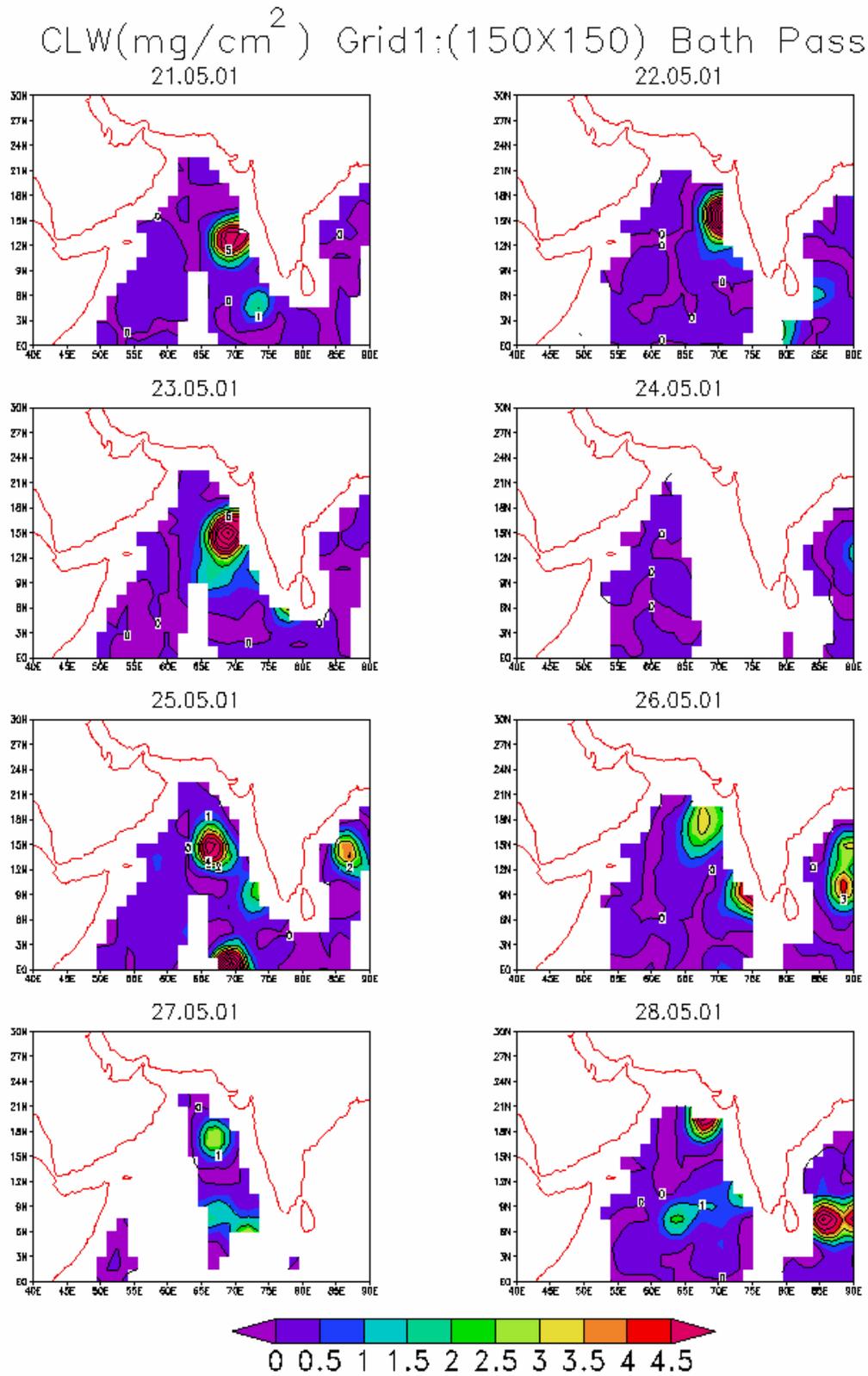


Fig. 5. IRS-P4 MSMR cloud liquid water (mg/cm^2) during 21-28 May 2001

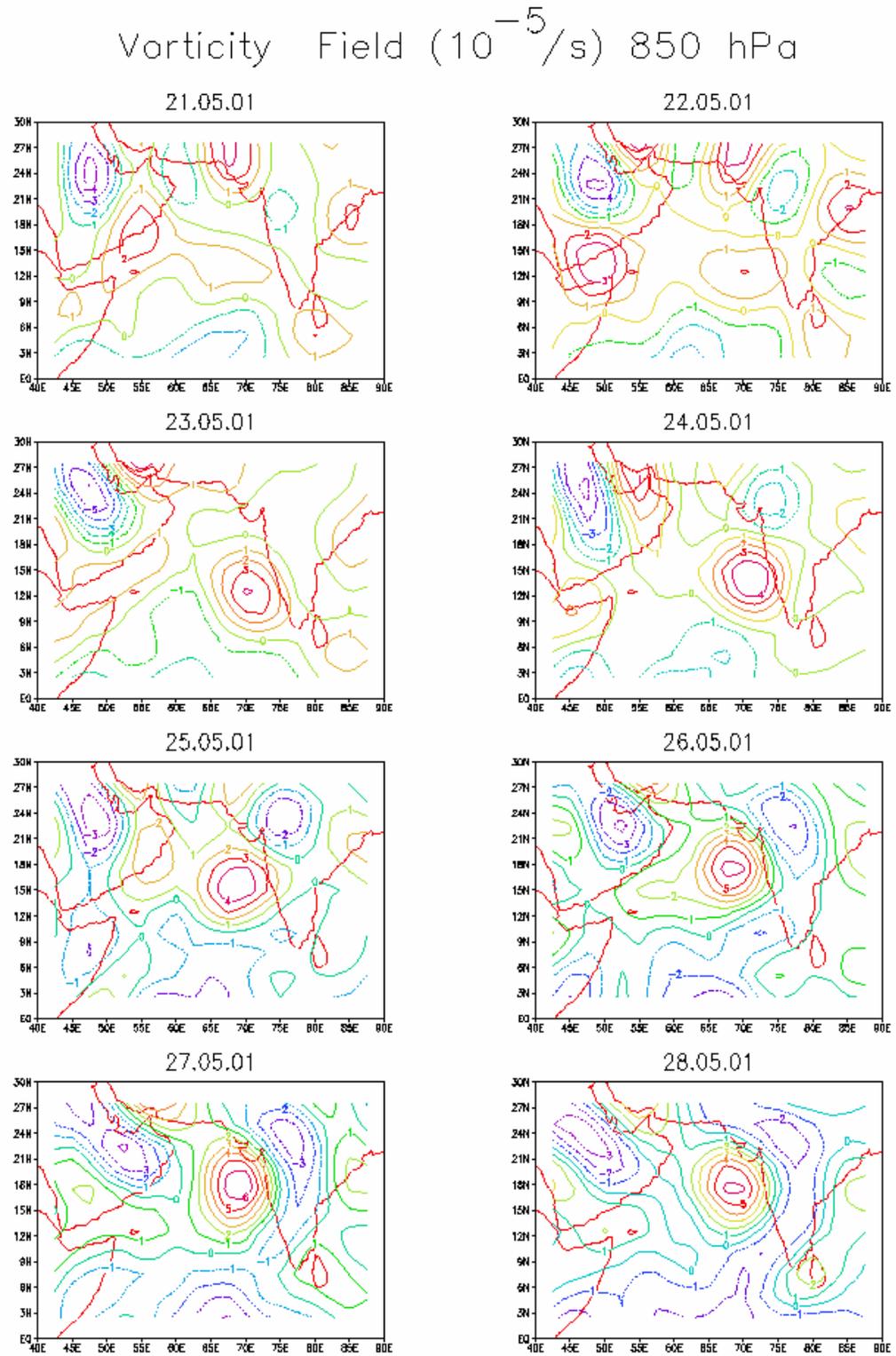


Fig. 6. Vorticity ($10^{-5}/\text{sec}$) analyses for 850 hPa at 1200 UTC during 21-28 May 2001

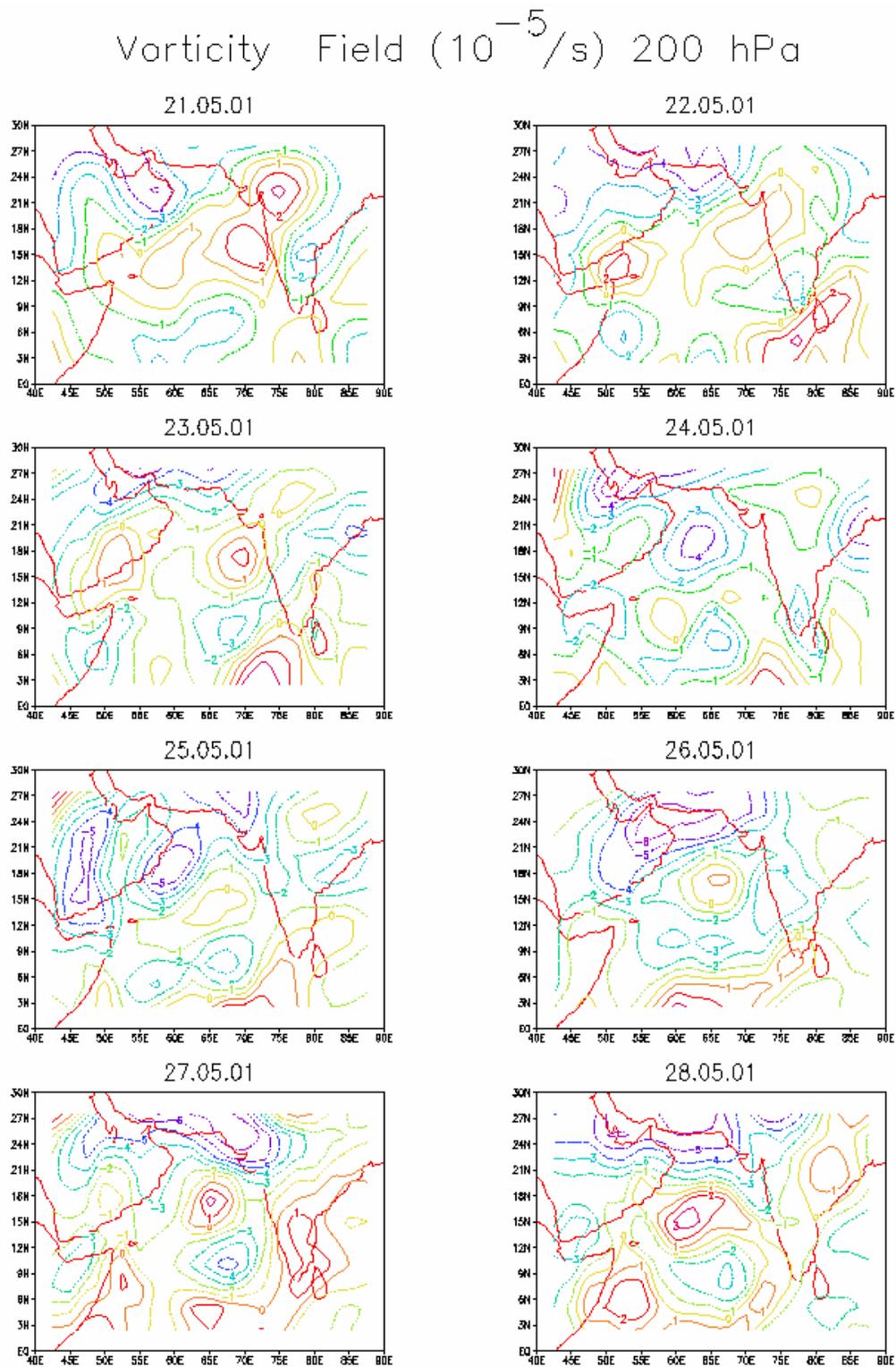


Fig. 7. Vorticity ($10^{-5}/\text{sec}$) analyses for 200 hPa at 1200 UTC during 21-28 May 2001

(f) Anticyclonic vorticity in the storm field at 200 hPa started increasing from 21 May and reached a substantially high value of $-3 \times 10^{-5}/s$ on 24 May 2001 (Fig. 7).

(g) Neither cyclonic nor anticyclonic vorticity was developed at 200 hPa in the region of tropical cyclone on 25th May 2001, except a very small area at the centre showing beginning of development of cyclonic vorticity.

(h) Adverse development *i.e.*, enhancement of cyclonic vorticity in larger area surrounding center of cyclone at 200 hPa was observed from 26 to 28 May 2001.

As per Indian Daily Weather Report (IDWR) of IMD, it was mentioned that on 24th and 25th May 2001 a very severe cyclonic storm is likely to intensify further thereby implying the probability of reaching to super cyclonic storm stage. IRS-P4 MSMR derived geophysical parameters during the development of different stages of the tropical cyclone (21-25 May) also showed greater enhancement indicating likelihood of intensification to super cyclonic storm. But, instead of developing into super cyclonic storm it started dissipating and came down to well-marked low pressure area from 26 May to 28 May 2001. Cyclonic vorticity at 850 hPa in the region of tropical cyclone started increasing from 22 May onwards and it was more in the following days up to 28 May. It gradually developed from 2 to $6 \times 10^{-5}/s$ during 23 to 28 May 2001. This was a positive sign for the development of tropical cyclone into its peak intensity. But it did not develop into super cyclonic storm. Vorticity field at 200 hPa was thoroughly examined in order to understand observed non-development to the super cyclonic storm from very severe cyclonic storm stage on 24th May. Later, neither cyclonic nor anticyclonic vorticity area at 200 hPa was developed in the region of tropical cyclone surrounding the eye on 25th and 26th May.

Further, more intense cyclonic vorticity area at 200 hPa was developed on the 27th and 28th May which gave a signal of dissipation of tropical cyclone. With these adverse developments at 200 hPa, tropical cyclone dissipated into depression on 28th May. It further dissipated into well-marked low-pressure area on 29th May and hit the coast of Gujarat without much disastrous impacts.

If satellite derived humidity, along with modified CMVs and WVVVs, are used as an input in the atmospheric model then certainly there is improvement in the forecast of atmospheric systems prevailing over the Indian Seas. Utilizing satellite derived modified wind field and humidity Kulkarni *et al.* (1992) showed improvement in track of cyclonic circulation and the rainfall rates in the

region of monsoon vortex. In the present situation, efforts are required first to use modified CMVs and WVVVs in data assimilation and then in atmospheric models to get better results. Such efforts are being made at different weather forecasting centers all over the world, including India.

5. Conclusions

In this specific case study, it has been highlighted how inputs of geophysical parameters derived from IRS-P4 data and CMVs & WVVVs obtained from METEOSAT-5 data gave signatures for the development/dissipation of severe tropical cyclone formed over the Arabian Sea during May 2001. It is revealed from the study that apart from proper variations in geophysical parameters and cloud features, the improved analysis of vorticity, convergence and divergence of the wind field based on inputs of modified CMVs and WVVVs in objective analysis of the wind field at 850 and 200 hPa gave a signal of dissipation of very severe tropical cyclone into well marked low pressure area 2-3 days before its hitting the west coast of India. On the basis of this encouraging result more studies could be undertaken to explore possibility of utilizing this methodology in future for improving the forecasts of tropical cyclones.

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