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Satellite data for diagnostics of monsoon disturbances

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सार – इस अध्ययन में भारतीय क्षेत्रों में मानसून विक्षोभों के विभिन्न चरणों से संबंद्ध समुद्र सतह पवन गति, समाकलित जल वाष्प समाकलिक मेघ द्रव जल और वर्षण की दरों जैसे भूभौतिकीय प्राचलों की दैनिक परिवर्तनशीलता का विश्लेषण किया गया है। इस उद्देश्य के लिए भारतीय क्षेत्र में मानसून तंत्रों, विशेष रूप से अवदाबों के मॉनीटरन, विश्लेषण और चित्रण के लिए डी.एम.एस.पी.–एस.एस.एम./आई. और आई. आर एस.–पी. 4 एम.एस.एम.आर. उपग्रह से प्राप्त आँकड़ों का क्रमशः वर्ष 1992 और 2000 में उपयोग किया गया। एस.एस. एम/आई. और एम.एस.एम.आर. आँकड़ों में राष्ट्रीय और अंर्तराष्ट्रीय अनुसंधानकर्ताओं द्वारा विकसित की गई समुचित एलगोरिथ्म विधि का अनुप्रयोग किया गया। इस अध्ययन में बंगाल की खाड़ी में बने मानसून अवदाबों (22–27 जुलाई 1992 और 19–24 अगस्त 2000) के दो विशिष्ट मामलों को उदाहरण देकर समझाया गया है।

यह देखा गया है कि मानसून अवदाबों के बनने से पहले बंगाल की खाड़ी में निम्न क्षेत्र के दक्षिण में सतही पवनें (15–17 ms^{-1}) तीव्र हो गई थीं। एस.एस.एम./आई. और एम.एस.एम.आर. आँकड़ों से प्रेक्षित किए गए समाकलित जल वाष्प समाकलित मेघ द्रव जल और वर्षण की दरों के उच्चतम मान क्रमशः (70–80 kg m^{-2}), (1.8–2.2 kg m^{-2}) और (20–25 mm hr^{-1}) के क्रम में रहे। भूभौतिकीय प्राचलों के उच्चतम मान विशेष रूप से मानसून अवदाबों के दक्षिणी–पश्चिमी क्षेत्र से संबद्ध थे। इस अध्ययन के परिणामों से पता चलता है कि एस.एस. एम./आई. और एम.एस.एम.आर. आँकड़ों से प्राप्त अनुमानित भूभौतिकीय प्राचलों का भारतीय क्षेत्र में विभिन्न मौसम तंत्रों के पूर्वानुमान के लिए विश्वास के साथ उपयोग किया जा सकता है।

ABSTRACT. In this study, daily variations of geophysical parameters such as sea surface wind speed, integrated water vapour, integrated cloud liquid water and precipitation rates associated with different stages of monsoon disturbances have been analyzed over the Indian region. For this purpose, DMSP-SSM/I and IRS-P4 MSMR satellite data have been utilized during the years 1992 and 2000 respectively for monitoring, analysis and depiction of monsoon systems particularly the depressions over the Indian region. Suitable algorithms developed by national and international researchers have been applied to SSM/I and MSMR data. Two typical cases of monsoon depressions (22-27 July 1992 and 19-24 August 2000) developed over the Bay of Bengal are illustrated in this study.

It is observed that prior to the formation of monsoon depressions there was strengthening of surface winds (15-17 ms^{-1}) to the south of low-pressure area over the Bay of Bengal. Highest values of integrated water vapour, integrated cloud liquid water and precipitation rates observed from SSM/I and MSMR data were of the order of (70-80 kg m1.8) ,($^{2-}$-2.2 kg m^{-2}) and (20-25 mm hr^{-1}) respectively. These highest values of geophysical parameters were specially associated with the southwest sector of the monsoon depressions. Results of our study suggest that estimated geophysical parameters obtained from SSM/I and MSMR data can be used with some confidence for prediction of different weather systems over the Indian region.

Key words – DMSP-SSM/I, IRS-P4 MSMR, Monsoon depressions, Geophysical parameters, Remote sensing.

1. Introduction

There are many types of monsoon disturbances *viz*. lows, depressions, off shore vortices, mid tropospheric cyclones etc. forming over the Indian region during monsoon season. Monsoon disturbances, particularly depressions forming in a quasi-stationary planetary scale monsoon trough over the Bay of Bengal and crossing the east coast of India before moving further in westerly/northwesterly direction and giving widespread rain over the central parts of India are the most important synoptic scale disturbances during the monsoon period. Indeed, according to Rao (1976) monsoon depressions account for most of the monsoon rains over the central part of Indian region. He presented extensive surface and upper air analysis, satellite and radar imagery for various synoptic case studies but deplored that the existing network does not provide sufficient details about the structure of the monsoon depressions at upper levels. Sikka (1977) had made a complete review of the depressions in respect of their life history, structure and movement over the Indian region. In his study, the climatology of depressions with regard to cyclogenesis, horizontal scale, tracks and life expectancy are discussed. Similarly, rainfall aspects are discussed and role of local, dynamical and sub-synoptic scale factors are brought out. In the conclusion he stressed the need for better data sets for understanding the dynamics and the structure of the depression. The present study is an effort in that direction using remote sensing data obtained from DMSP-SSM/I and IRS-P4 MSMR for improved understanding of monsoon depressions over the Indian region.

During the summer monsoon season, genesis of monsoon disturbances is caused by the transport of large amounts of moisture over the Arabian Sea and the Bay of Bengal. Hence, accurate analysis of moisture fields over these oceanic areas play an important role in understanding the mechanism and the dynamics of the monsoon systems. Satellite data, however, make it feasible to study the distribution of moisture over large and remote oceanic areas because of their wide spatial and temporal coverage. With the advent of satellite carrying microwave sensors, the sample of monitoring moisture over oceans has become well established (Stelin *et al*. 1976, Grody *et al*. 1980, Prabhakara *et al*. 1982, Pandey, 1992, Kilham *et al.* 1992a and Kilham *et al*. 1994b). Krishnamurty and Kanamitsu (1973) have illustrated that for short-range numerical weather prediction (NWP) modelling over tropical region, a detailed definition of moisture fields is extremely important. Ruprecht and Gray (1976) have also emphasized the importance of precipitable water for understanding the development of weather systems over the oceanic regions. Convection is the main source of precipitation in the global tropics. Latent heat released from convective precipitation is considered as one of the major forcings of the general circulation of the atmosphere. Rasmusson and Carpenter (1982) have shown that large-scale anomalies in tropical precipitation are closely associated with the global scale circulation anomalies. Therefore, knowledge of accurate precipitation estimates is essential. Mintz (1981) suggested that information on precipitation is important for both NWP and General Circulation Models (GCM).

Some of the earlier researchers have used SSM/I data for monsoon studies over the Indian region, but in their studies mostly broad scale aspects of monsoon activity have been highlighted. Hong and Lim (1994) have demonstrated 30-60 day oscillations in rainfall estimates obtained from SSM/I data over the Indian region for the year 1989. Nair and Mohan Kumar (1994) have computed mean monthly latent heat fluxes using SSM/I data over the Arabian Sea and the Bay of Bengal for the year 1988. In their study, latent heat fluxes exhibited a semi-annual oscillation and attained a peak value just before the onset of monsoon and reached lower values during active phase of monsoon. Juri *et al*. (1994) have studied the variability of the ITCZ using SSM/I over the southwest Indian Ocean. They inferred that the shape and intensity of ITCZ was modulated by the strength of the northwest monsoon and by standing vortices over the southwest Indian Ocean. Chiu *et al*. (1993) have made a comparative study of monthly rain rates derived from the infrared-based GPI (GOES Precipitation Index) and SSM/I data over the Indian Ocean. This illustrated that SSM/I rain rates were smaller than GPI rain rates over north Indian Ocean. Nair *et al*. (1995) in another study found that latent heat fluxes computed from SSM/I data were higher over the Arabian Sea than over the Bay of Bengal during pre-monsoon and monsoon months. Basu *et al*. (1995) demonstrated the potential use of satellite microwave measurements of total precipitable water for deriving humidity profiles over the Indian Ocean. The objective of the present study is to understand structural features of monsoon disturbances particularly depressions forming over the Indian oceanic regions using both DMSP and IRS-P4 satellite data.

2. Data

SSM/I measurements at four frequencies *viz*. 19.35, 22.235, 37 and 85.5 GHz and MSMR measurements at 6.6, 10.65, 1800 and 2100 GHz frequencies were used for monitoring the areal coverage of monsoon disturbances, particularly lows and depressions formed over the Arabian Sea and the Bay of Bengal. DMSP-SSM/I and IRS-P4 MSMR data were used for July 1992 and August 2000 respectively. Daily weather reports obtained from India Meteorological Department were used for selecting synoptic situations over the Indian region involving the complete life cycle of monsoon disturbances. DMSP, IRS-P4, INSAT and METEOSAT imageries were used to locate and monitor the advancement of the monsoon systems over the Indian region. ECMWF and IMD surface and upper air charts were used to identify and inspect the surface pressure patterns and upper air circulations associated with the monsoon systems.

3. Methodology

3.1. *Wind speed*

The oceans are recognized as the most energetic, dynamic and undulating bodies of the earth-atmosphere systems. Various random motions that occur in the ocean vary both spatially and temporally. Frictional motion between atmospheric motion and ocean surface is related to the kinematics of the atmospheric boundary layer and the resulting transfer of energy emerges as wind stress. The passive microwave emissivity of the ocean surface varies in response to deformation to it caused by wind stress. Due to increase in wind speed, the ocean becomes rough causing changes in brightness temperature. These changes in microwave brightness temperature are measured by SSM/I & MSMR, and are analysed to retrieve wind speed over the oceanic region. There are several wind speed algorithms based on SSM/I measurements. The recent ones are Goodberlet *et al*. (1989), Goodberlet and Swift (1992), Schluessel and Luthardt (1991), Petty (1993a) and Kilham *et al*. (1995a). Out of these algorithms it is found that algorithm based on Petty (1993a) fits well over the Indian region (Ramesh Kumar *et al*. 1995, Mahajan 2002). Hence, this algorithm is used for a case of monsoon depression that formed over the Bay of Bengal during 22-27 July 1992. Another similar case of monsoon depression that formed over the Bay of Bengal during 19-24 August 2000 is analyzed using finished product of MSMR sea surface wind speed obtained from NRSA.

3.2. *Integrated water vapour*

The following algorithms were considered for the study. They are Alishouse *et al*. (1990), Petty and Katsaros (1990), Schluessel and Emery (1990), Petty (1993b) and Kilham *et al*. (1995b). Of all the above algorithms, the algorithm of Schluessel and Emery (1990) was found to give good description of integrated water vapour over the Indian region (Mahajan, 2001). Hence, in our study the same algorithm is used for monitoring monsoon depression over the Indian region. Similarly, finished product of MSMR in respect of integrated water vapour is used for a case of monsoon depression that formed over the Bay of Bengal during August 2000.

3.3. *Integrated cloud liquid water*

There are several integrated cloud liquid water (CLW) algorithms based on SSM/I measurements. The validation of SSM/I CLW estimates is quite complex and may represent the stiffest challenge of SSM/I atmospheric retrievals, since it involves uncertainties. Other SSM/I geophysical parameters can be more easily related to routine conventional measurements on synoptic basis for calibration and validation. This is not applicable for CLW. At present, there are different approaches for validation of SSM/I estimates of CLW, with each having its merits and demerits. First includes upper looking microwave radiometer to view the atmospheric liquid water. Alishouse *et al*. (1990b) selected this technique for CLW calibration/validation campaign. Kilham and Barrett (1993) and Petty (1993c) explained its limitations with respect to wind speed and water vapour respectively. The second method is related to CLW *in situ* from aircraft flights through stratiform cloud layers. This approach has been used by Petty and Katsaros (1992), but on a very much smaller scale. The reason is that while generating *in situ* data, a very large number of aircraft flights are required to cover a wide range of possible CLW values. The third is to use humidity values from radiosonde ascent to model the CLW. Five recent algorithms for CLW namely Alishouse *et al*. (1990b), Hargens *et al*. (1992), Petty, (1993c), Wentz (1992) and Weng and Grody (1994) have been considered for the present study. Of these, the algorithm developed by Weng and Grody (1994) has been used in this study. The major improvement of this algorithm over many previous studies are due to (*i*) It detects the liquid water in optically thin stratus and low level clouds very well, (*ii*) It measures liquid water in highly convective clouds, (*iii*) It can be applied to any climate regime because some of the coefficients are derived using a comprehensive training SSM/I data set obtained from various clear sky conditions and (*iv*) The liquid water derived from this algorithm agrees well with that derived using ground based microwave radiometer measurements. In the same line, finished product of MSMR data for cloud liquid water produced by NRSA is used for getting associated characteristic features for a case of monsoon depression that formed during August 2000.

3.4. *Precipitation rates*

Estimation of precipitation over the oceanic areas is of great importance not only from the point of view of its practical utility but also as an input to various atmospheric studies. Some of the earlier researchers (Arkin, 1979, Stout *et al*., 1979, Griffith *et al*., 1981, Bhandari *et al*., 1987, Rao *et al*., 1989) have devised and tested several diagnostic methods to estimate precipitation using satellite data. Martin and Scherer (1973), Barrett and Martim (1981) and Manikiam (1986) made comprehensive review of these methods. Basically, precipitation measurements from space rely on three types of electromagnetic radiation *viz*. visible, infrared and microwaves. Measurements of precipitation using the first two types of radiation are relatively indirect methods based on cloud top observations while data in microwave region of electromagnetic spectrum provide more physically direct information on precipitation (Barrett and Beaumont, 1994). Four recent algorithms for precipitation estimation developed by different researchers namely (*i*) Olson, (*ii*) Berg, (*iii*) Petty and (*iv*) Smith *et al*., (1998) have been considered for the present study. The details of the

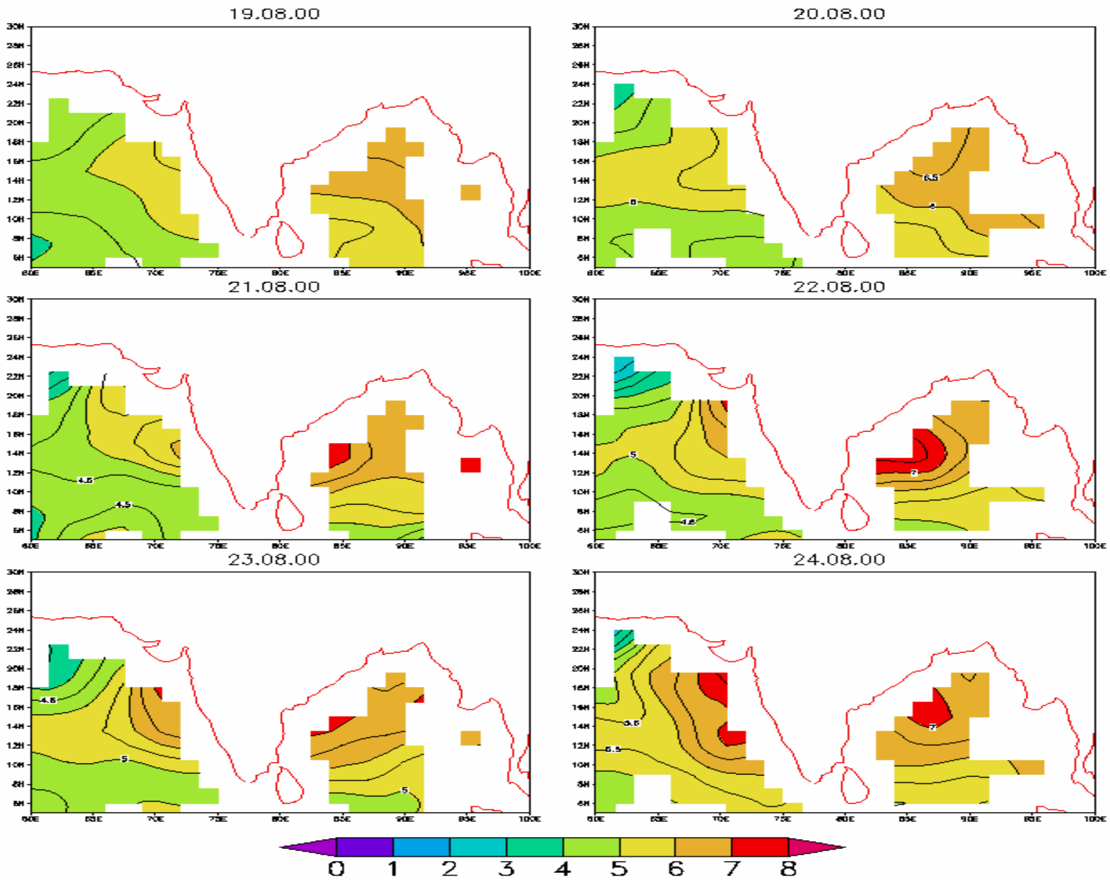

Fig. 1. IRS-P4 MSMR derived integrated water vapour distribution during complete life cycle of monsoon depression

algorithms by Olson, Berg and Petty can be seen in Wilheit *et al*. (1994). Of these, the algorithm developed by Smith *et al*. (1998) is found to be suitable over the Indian region because of following reasons. (*i*) In this technique the error caused by spatial and temporal variation of surface temperature, emissivity and atmospheric effects are minimized by modelling the non-raining brightness temperatures with half degree latitude and half degree longitudes region based on statistics of satellite data. (*ii*) Displacement of data from modelled relationship by more than threshold value calculated from standard deviation of the non-raining data is detected as rainfall. (*iii*) The algorithm is able to detect rainfall over land, sea and coast. (*iv*) Collocation errors are drastically reduced by matching radar rainfall pixels with appropriate satellite data. (*v*) The algorithm is sensitive to light rainfall less than 0.5 mm hr^{-1} and shows large dynamic range suitable for measuring heavy rainfall.

4. Results and discussion

The following are the important results of the study.

(*i*) Surface wind speed obtained from SSM/I gradually increased from 6-10 ms^{-1} to 12-15 ms^{-1} to the south of low pressure area over the Bay of Bengal during the complete life cycle of the monsoon depression (22-27 July 1992). Similar characteristic features are also observed in case of another monsoon depression with intensification of MSMR wind speed from 10-12 ms^{-1} to 15-17 ms^{-1} during 19-24 August 2000.

(*ii*) Highest values of integrated water vapour (SSM/I, 60-70 kg m^{-2}) and (MSMR, 70-80 kg m^{-2}) were observed in southwest sectors of monsoon depressions during July 1992 and August 2000 respectively. Fig. 1 shows the integrated water vapour distribution during the complete life cycle of depression (19-24 August 2000).

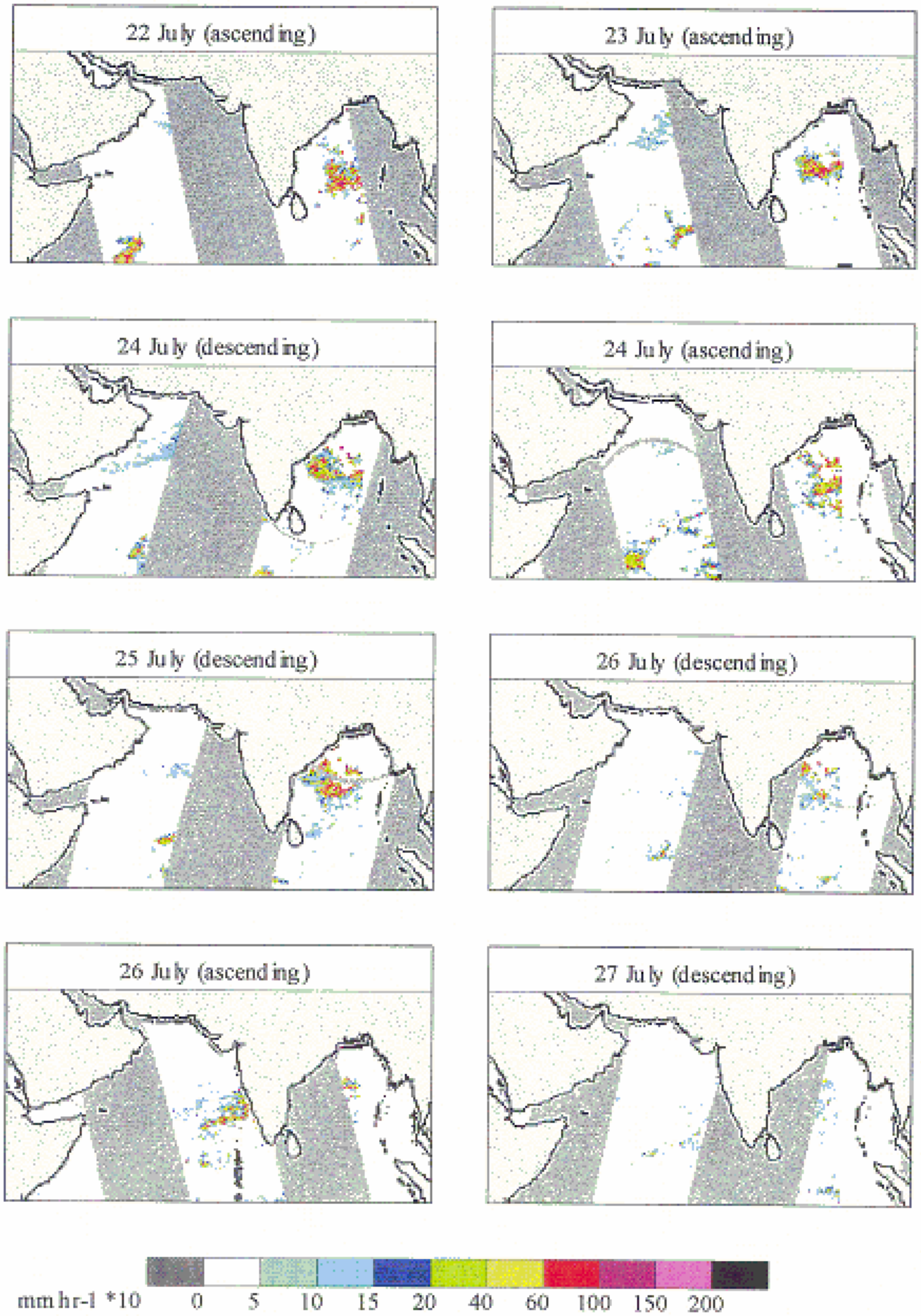

Fig. 2. SSM/I derived precipitation rates for the period 22-27 July1992

(*iii*) Highest values of integrated cloud liquid water (SSM/I, 1.8-2.2 kg m^{-2}) and (MSMR, 0.6-0.7 kg m^{-2}) were observed in specific area of the southwest sectors of the depressions during July 1992 and August 2000, where major convective activity was prevailing.

(*iv*) Highest values of precipitation rates (SSM/I, 20-25 mm hr^{-1}) were observed in the southwest sector of monsoon depression during July 1992 (Fig. 2).

For a case of July 1992 depression strong surface winds (12-15 ms^{-1}) were found to be dominant over southwest, central and southeast Arabian Sea stretching from 10° to 15° N for almost all days of the study. During 22 to 26 July a low level jet was persisting over the Arabian Sea. As demonstrated by earlier investigators (Mahajan and Deshpande, 1986; Mahajan and Nagar, 1987 and Mahajan *et al.*1992) there exists a strong relationship between the wind speed at low level jet and the wind speed at the surface over the Indian Ocean. In the present study, strong surface wind speed (12-15 ms^{-1}) observed in large areas over the Arabian Sea seems to be due to the effect of low level jet. In another case of monsoon depression during August 2000 again similar excitation of strong surface winds (10 to 17 ms^{-1}) to the south of low-pressure area was observed. Building up of the large area of strong surface winds over the central and south Bay prior to the formation of low pressure system, followed by gradual increase of wind speed over the head Bay after the formation of well marked low and later depression are the important features observed in the study.

Before the formation of monsoon depression the oceanic area north of 8° N was dominated by higher values of WV (55-70 kg m^{-2}) and south of 8° N it was associated with lower values of WV of the order of 45-55 kg m^{-2}. With the formation of low pressure system and its subsequent intensification into depression more moisture incursion was brought out over the Bay of Bengal. This caused increase in WV values (from 45-55 kg m^{-2} to 50-70 kg m^{-2}) over the Bay of Bengal during 26 and 27 July 1992. Similar development of highest values of integrated water vapour (70-80 kg m^{-2}) was observed during 19-22 August 2000.

Convective activity was observed building up over the central Bay on 22 and 23 July 1992. This activity was increased in larger area in association with dipping of monsoon trough over the east central Bay on 24 July 1992. Formation of low-pressure area and its intensification into depression on 25 and 26 July gave rise to increase in convective activity off the Orissa coast. This convective activity was seen to be more concentrated in the southwest sector of the monsoon depression. With the crossing of monsoon depression over land no major convective activity was observed over Head Bay *i.e.* on 27 July 1992. In relation to major convective activity, higher values of CLW (1.8-2.2 kg m^{-2}) were observed during different stages of the monsoon depression. In the similar way highest values of integrated cloud liquid water (0.6-0.7 kg m^{-2}) were developed in the southwest sector of monsoon depression on 22 August 2000.

As depicted in INSAT-1D visible imagery, the central and northwest Bay were completely dominated by convective cloud clusters associated with monsoon trough, low and depression on 24, 25 and 26 July 1992 respectively. In the developing stage of monsoon depression the precipitation distribution over the central Bay was of scattered nature. But when the depression was formed, it was well organized with highest intensity (20-25 mm hr^{-1}) especially in the southwest sector of the depression.

5. Conclusions

In this study DMSP-SSM/I and IRS-P4 MSMR satellite data have been used for monitoring, analysis and depiction of monsoon systems particularly depressions over the Indian region. Suitable algorithms developed by various national and international scientists have been used for finding the geophysical parameters during different stages of monsoon depressions over the Indian region. Excitation of sea surface winds to the south of low pressure area prior to the formation of depression and development of highest values of integrated water vapour, integrated cloud liquid water and precipitation rates in the southwest sector of the depression are special features observed in the study.

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