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Satellite analysis of tropical cyclones using NOAA-16 AMSU measurements over Indian region

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सार – 13 मई 1998 को पहला उन्नत सूक्ष्मतरंग परिज्ञापित एकक (ए.एम.एस.यू.) एन.ओ.ए.ए.–15 उपग्रह में छोड़ा गया। ए.एम.एस.यू. के माप अब एन.ओ.ए.ए.–16 और एन.ओ.ए.ए.–17 उपग्रहों से भी उपलब्ध है। उष्णकटिबंधीय चक्रवातों के प्रेक्षण के लिए ए.एम.एस.यू. काफी अच्छे साबित हुए है क्योंकि जो हिम मेघ उष्णकटिबंधीय चक्रवातों को ढक लेते है वे अब इसके मापों को विशेष रूप से प्रभावित नहीं कर पाते हैं। इस शोध–पत्र में ए.एम.एस.यू. का उपयोग करते हुए अक्तूबर 1999, मई और सितंबर 2001 के महीनों में बंगाल की खाड़ी और अरब सागर में बने तीन उष्णकटिबंधीय चक्रवातों की तीव्रता का अध्ययन किया गया है। एन.ओ.ए.ए.–15 और एन.ओ.ए.ए.–16 ए.एम.एस.यू.–ए. के मापों का उपयोग करते हुए उष्णकटिबंधीय चक्रवात क्षेत्रों पर तापमान प्रोफाइलों से ऊपरी क्षोभमंडलीय उष्ण क्रोड तापीय असामान्यताओं का परिकलन किया गया है। यह देखा गया है कि उष्ण क्रोड तापमान असामान्यता का लगभग 250 हैक्टापास्कल का परिमाण, उष्णकटिबंधीय चक्रवातों के इन तीनों मामलों में तीव्रता का द्योतक है। वर्ष 1999 में आए उष्णकटिबंधीय महाचक्रवात के मामले में तापमान असामान्यतों का क्रम लगभग 6° सें. था जबकि वर्ष 2001 में आए उष्णकटिबंधीय सामान्य चक्रवातों के तापमान असामान्यता का क्रम लगभग 3° सें. था। अतः यह कहा जा सकता है कि ए.एम.एस.यू. के आँकड़ें उष्णकटिबंधीय चक्रवात के विश्लेषण और पूर्वानुमान में सुधार के लिए पर्याप्त अवसर प्रदान करते प्रतीत होते हैं।

ABSTRACT. The first Advanced Microwave Sounding Unit (AMSU) was launched aboard NOAA-15 satellite on 13 May 1998. AMSU measurements are now also available from NOAA-16 and NOAA-17 satellites. The AMSU is well suited for the observation of tropical cyclones because the ice clouds that cover tropical cyclones do not significantly affect its measurements. In this paper the intensity of three tropical cyclones formed over Bay of Bengal and Arabian Sea in the month of October 1999, May and September 2001 were studied using AMSU measurements. The upper tropospheric warm core thermal anomalies over the tropical cyclone areas were computed from temperature profiles using the NOAA-15 and NOAA-16 AMSU-A measurements. It has been observed that the magnitude of the warm core temperature anomaly at about 250 hPa was an indicator of the intensity of tropical cyclones in all three cases. The order of the temperature anomaly was about 6°C in case of super tropical cyclone, 1999 while in other two cases the order of the temperature anomaly were of about 3°C for moderate tropical cyclones, 2001. Therefore, it may be stated that the AMSU data appeared to offer substantial opportunities for improvements in tropical cyclone analysis and forecasting.

Key words – AMSU, Tropical cyclone, Warm core anomalies.

1. Introduction

Tropical cyclones are marine events that are often poorly observed by conventional data sources. Remote sensing from geostationary meteorological satellite platforms is frequently the only method available to determine or estimate Tropical Cyclone (TC) characteristics. Infrared (IR) imagery is routinely employed in a subjective way to analyze storm position, movement, development and evolution. Accurate intensity estimates are of utmost importance for marine warnings, landfall, evacuation planning and decision making. The most widely used satellite technique was developed by Dvorak (1982). This technique employs image pattern recognition and empirically based rules to derive an estimate of TC intensity in 'T numbers'. This parameter was developed to be representative of a simple model of hurricane evolution such that T-number increments correspond to typical observed changes in intensity. In certain situations, an image enhancement curve is used with the IR data to isolate discrete temperature levels and derive a T number from a combination of two satellite measured temperatures at the storm center usually a relatively warm eye and the temperature of the cold convective cloud that surrounds the eye.

Scientific progress often comes as a result of new instruments for making scientific observations. The AMSU is one such new instrument. The first AMSU was flown on the NOAA-15 satellite on 13 May 1998. Two more new satellites NOAA-16 and NOAA-17 also carried

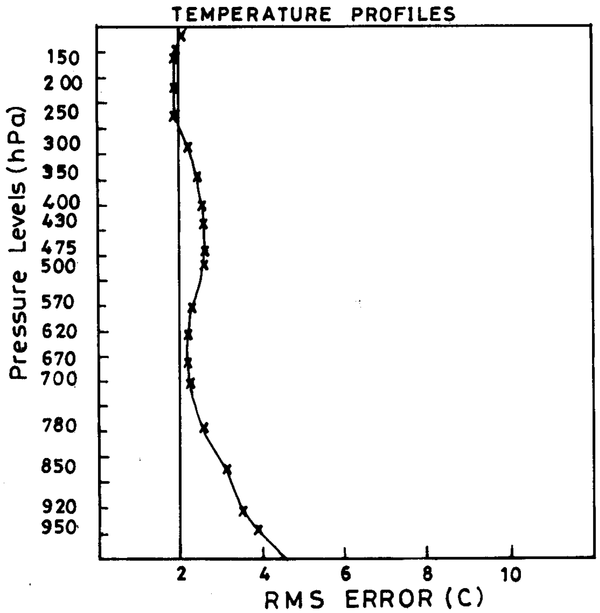
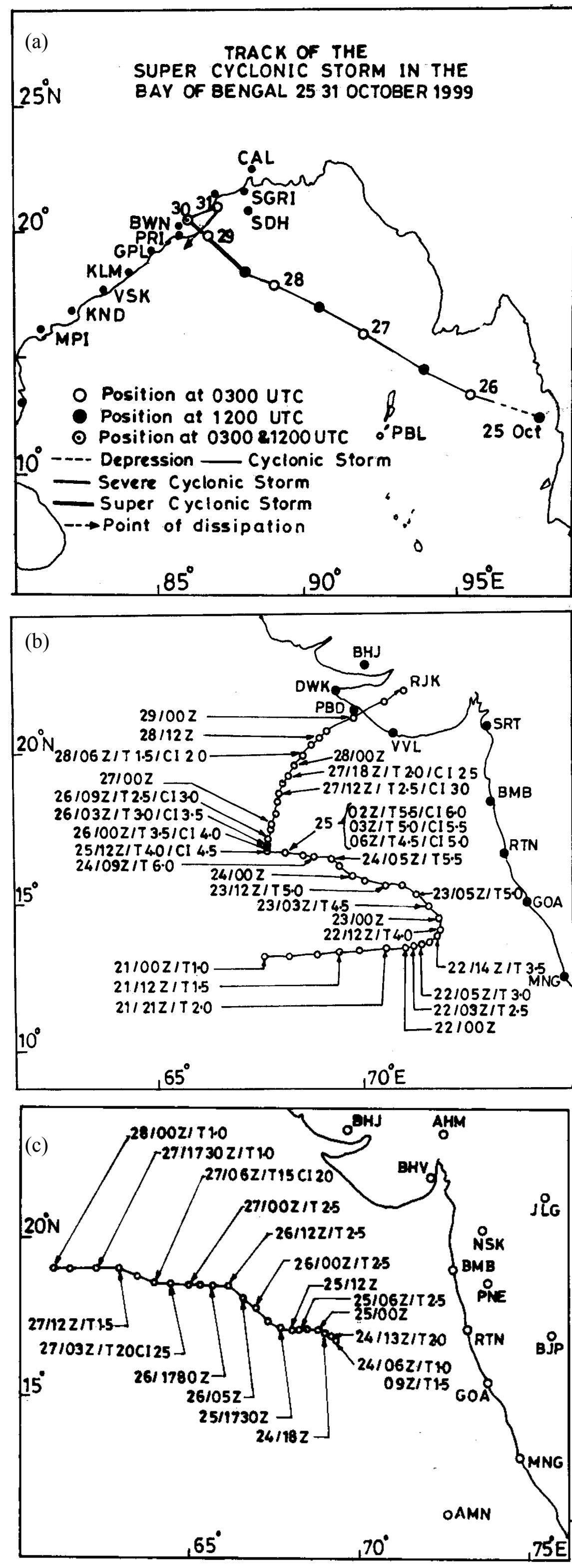


Fig. 1. RMS errors of vertical profile of temperature

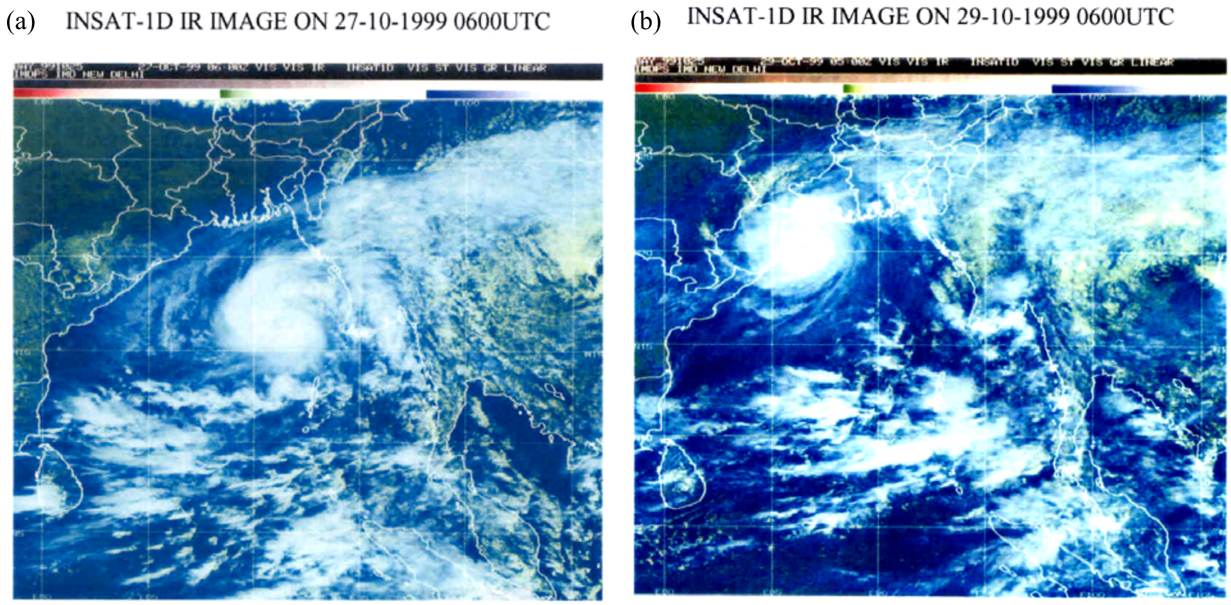
the AMSU payload. The AMSU has significantly improved spatial resolution, radiometric accuracy and the number of channels over the previous MSU. The AMSU complements the much more frequent and higher resolution observations of the geostationary satellite to give more complete description of the atmosphere. Since clouds are nearly (but not completely) transparent to microwave radiometer, the AMSU can measure the above parameters even through the central dense overcast that prevents visible and infrared satellite instruments from making these measurements. The main parameters of interest to the forecaster are storm location and movement, thermal anomalies, wind speed and rain rate. While other satellite instruments can be used to estimate these parameters, the AMSU is the first satellite instrument that has potential to measure all of them very accurately. In order to receive and process the data from these two new satellites, a new High Resolution Picture Transmission (HRPT) system consisting two ultra sun micro computer work stations have been commissioned in India Meteorological Department (IMD), New Delhi. The improved instrumentation onboard NOAA-15 and NOAA-16 and selection of better retrieval approach have made it possible to retrieve the temperature profiles of desired accuracies (Singh *et al.*, 2002 and 2003b).

2. Retrieval of temperature profiles

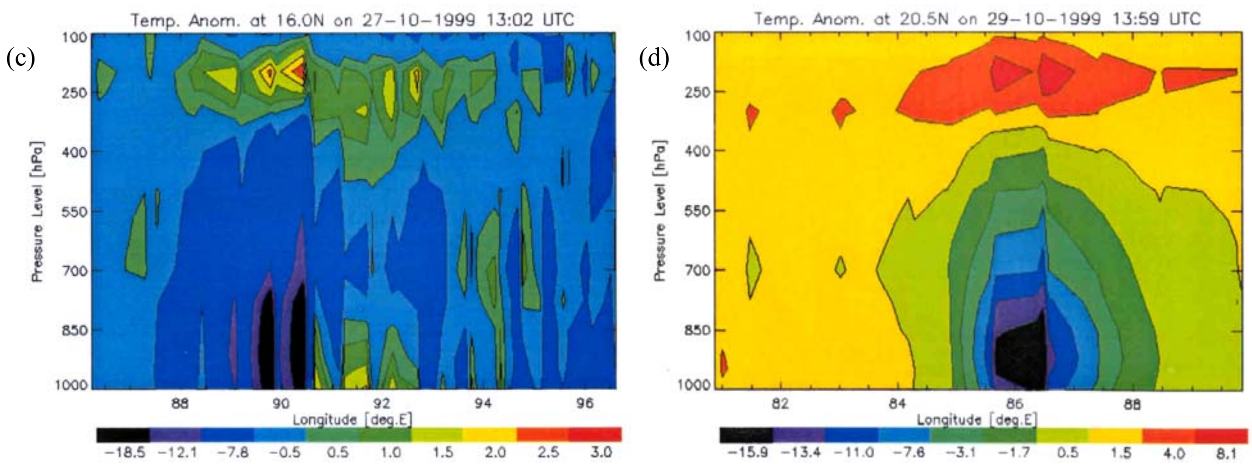
The retrieval of atmospheric temperature profiles using AMSU data has several steps, but is straightforward. Before the temperature retrieval itself can be



Figs. 2(a-c). Track of (a) supercyclonic storm in the Bay of Bengal during 25-31 October 1999, (b) Arabian Sea cyclone during 21-29 May 2001 and (c) Arabian Sea cyclone during 24-28 September 2001



Figs. 3(a&b). INSAT-1D IR image on (a) 27 October 1999 at 0600 UTC and (b) 29 October 1999 at 0600 UTC

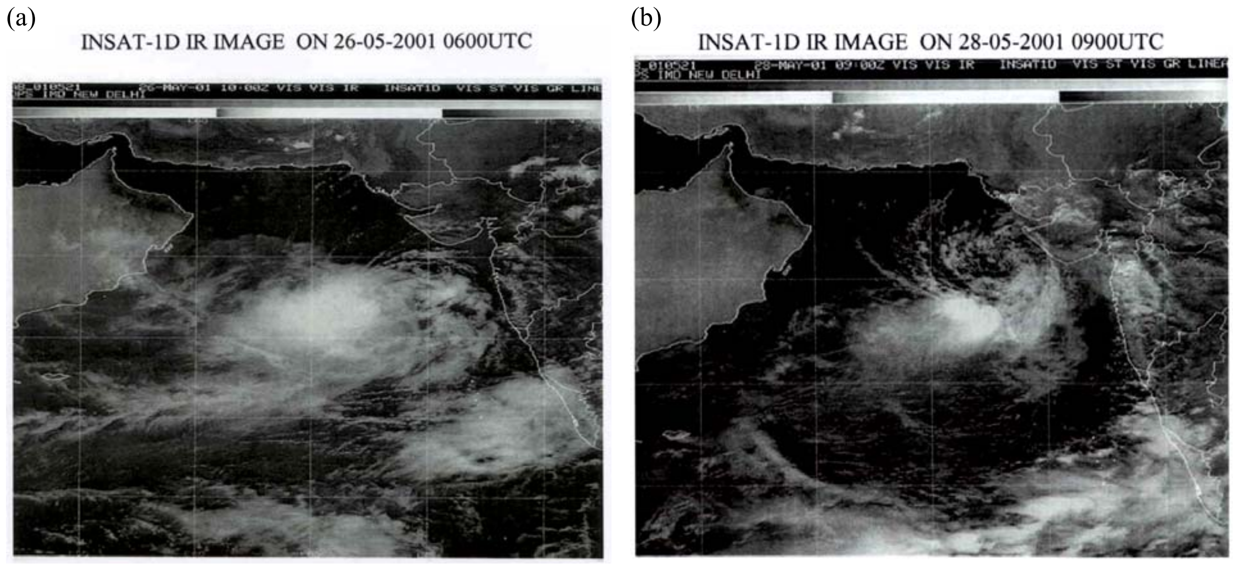


Figs. 3(c&d). Vertical profile of temperature anomaly at (c) 16.0° N on 27 October 1999 at 1302 UTC and (d) 20.5° N on 29 October 1999 at 1359 UTC

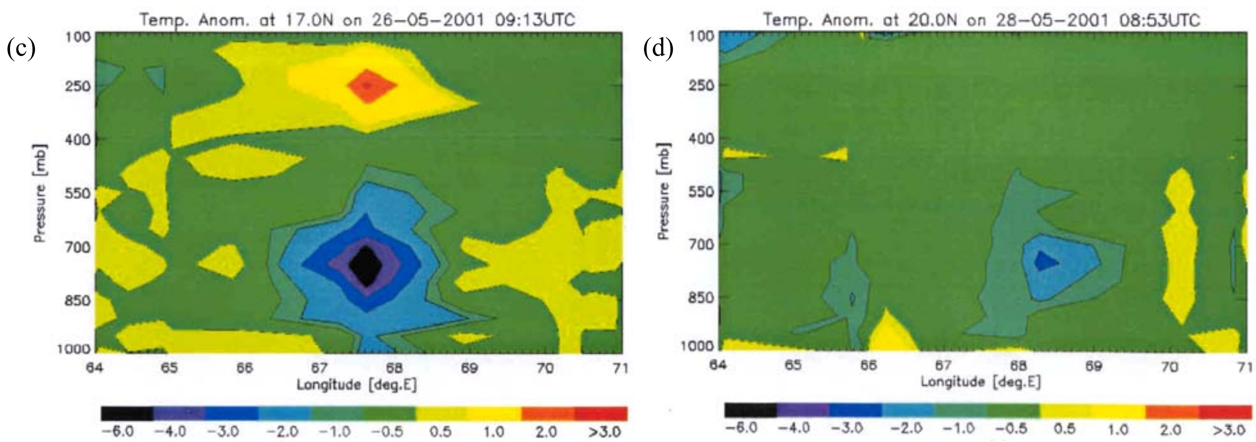
accomplished, two corrections to the data are made. The first correction is for antenna lobe points at the earth, but side lobes can point at different points on the earth, cold space, and at the spacecraft itself. The raw measurements called antenna temperatures are converted into brightness temperature to remove the side lobes contributions based on model pattern on the spacecraft geometry. The second and large correction adjustments in the brightness temperatures from thirty different view angles are called limb adjustments. As the instrument scans away from nadir, the atmospheric levels being sensed by a particular channel rise due to increased path length through the upper level of atmosphere. If there are no limb adjustments, the brightness temperature for the particular channel could vary by almost 15° K along a scan line due to vertical variation of atmospheric temperature. Limb adjustment removes this effect. Different channel combinations are used for different atmospheric levels. For example, channels 1-7 are not used for retrievals above 100 hPa in order to reduce contamination from precipitation. The root mean square (rms) difference between AMSU-A temperature retrievals and collocated radio sonde over Indian regions are about 2.0° C except below 850 hPa where it is about 3° C. Fig. 1 shows the plot of rms error of vertical profile of temperature (Singh and Singh 2003a).

3. Data and methodology

In the present study AMSU data points from NOAA-15 and NOAA-16 satellites relative to the tropical cyclone center were used to derive temperature soundings. The



Figs. 4(a&b). INSAT-1D IR image on (a) 26 May 2001 at 0600 UTC and (b) 28 May 2001 at 0900 UTC



Figs. 4(c&d). Vertical profile of temperature anomaly at (c) 17.0° N on 26 May 2001 at 0913 UTC and (d) 20.0° N on 28 May 2001 at 0853 UTC

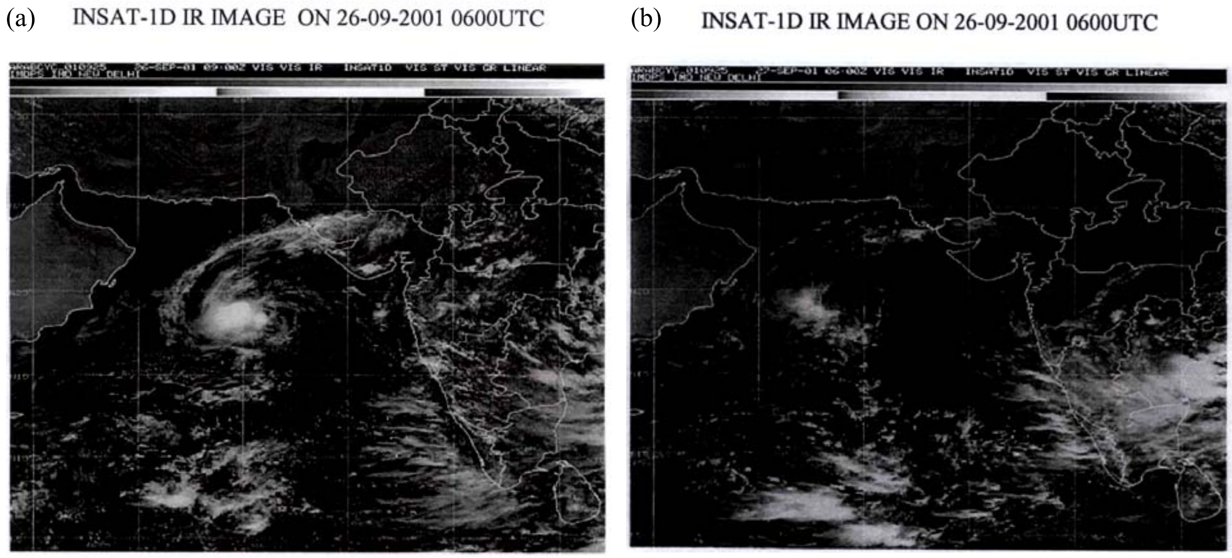
AMSU temperature profiles were azimuthally averaged at each vertical level (0 to 20 km) in a cylindrical coordinate system (radius from 0 to 600 km) centered on the storm. The temperature at a radius of 600 km, at each level is subtracted to give the temperature anomaly.

4. Results and discussion

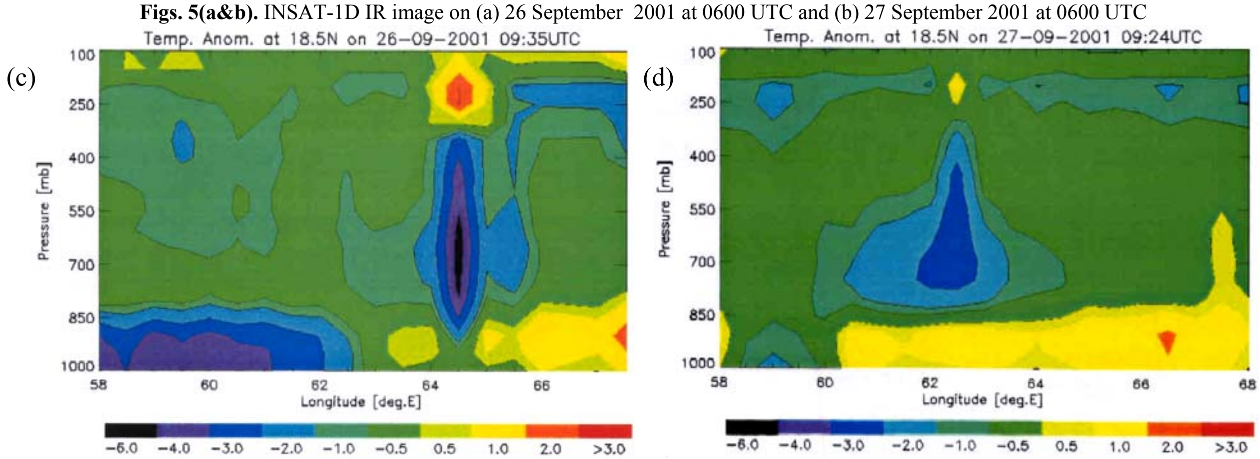
The Advanced Microwave Sounder Unit (AMSU) that was included on the NOAA-15 satellite has an increased number of channels (15 on AMSU-A and 5 on AMSU-B), and increased horizontal resolution (48 km and 15 km at nadir for AMSU-A and B, respectively) relative to the previous generation Microwave Sounder Unit (MSU). Kidder *et al*. (2000) have shown that the AMSU-A instrument, which was designed for temperature sounding can observe the upper-level warm core of tropical cyclones. The tropospheric temperature anomalies were computed using the above mentioned methodology for the study of tropical cyclones formed over Bay of Bengal in October, 1999, Arabian Sea in the month of May and September, 2001. The Bay cyclone was very severe cyclone of intensity T-number 6 while other two tropical cyclones were of moderate intensity of T- number 3.0 considered in the present study. The tracks of these three tropical cyclones are given in Figs. 2(a-c). The development and intensification of these three tropical cyclones have been studied simultaneously using microwave and infrared satellite data in the following section. The satellite data particularly the microwave data was not sufficient due to its limitation of being polar orbiting characteristics to monitor the continuous growth and decay of tropical cyclones over the area.

4.1. *Bay of Bengal tropical cyclone*

The development of the Bay of Bengal super tropical cyclone was very intense and larger in size. This came as



Figs. 5(a&b). INSAT-1D IR image on (a) 26 September 2001 at 0600 UTC and (b) 27 September 2001 at 0600 UTC



Figs. 5(c&d). Vertical profile of temperature anomaly at (c) 18.5° N on 26 Sep 2001 at 0935 UTC and (d) 18.5° N on 27 Sep 2001 at 0924 UTC

a significant disturbance from the Gulf of Thailand and soon after crossing the Malay Peninsula it could be spotted as a vortex in the satellite imagery. While moving northwestwards it intensified through several stages on 28 October. The eye contracted and became more organized late in the afternoon on 28 October. This was again accompanied with rapid intensification of this tropical cyclone. Figs. 3 (a&b) show INSAT-1D images of 27 October 1999 and 29 October 1999 indicating the rapid intensification of this tropical cyclone that took place in October 1999.

The AMSU data was available for few passes of NOAA-15 covering the area of super tropical cyclone formed in the Bay of Bengal. The color contour plot of vertical cross section of temperature anomaly profiles are shown in Figs. 3 (c&d) for 27 October and 29 October 1999 respectively. It may be clearly seen that order of the warm core temperature anomaly at about 250 hPa was larger on 29 October [Fig. 3(d) compared to 27 October 1999 Fig. 3(c)] indicating the positive relationship of tropical intensity with warm core temperature anomaly. The magnitude of the temperature anomaly at about 250 hPa was around 6°C in this super tropical cyclone, 1999 [Fig. 3(d)].

4.2. *Arabian Sea tropical cyclones*

Figs. 4 (a&b) show the INSAT-1D infrared images of 26 and 28 May 2001 respectively. The signature of tropical cyclone was clearly observed on 26 May 2001 and these were disappeared on 28 May, 2001. The similar situation could also be observed from microwave satellite data from Fig. 4 (c). The warm core temperature anomaly of the order of 3° C for this cyclone was centered at about 250 hPa with central location of 17.0° N and 67.4° E on 26 May 2001 while on 28 of May 2001 the tropical cyclone is weakened and moved to 20° N and 69.4° E with no sign of warm core temperature anomaly indicated in Fig. 4(d).

Similar behavior of tropical cyclone formed in the month of September 2001 has also been observed. The Figs. 5 (a& b), which show the INSAT IR images of 26 and 27 September 2001 indicating the convergence of cloud mass on 26 September 2001 and disappeared on 27 September 2001 as cyclone moved northwest and weakened. The warm core anomaly is located at the central position of tropical cyclone 18.5° N and 66.0° E about 250 hPa depicted in Fig. 5(c). Next day on 27 September 2001 the cyclone has moved to 18.5° N and 62.5° E with no sign of warm core temperature anomaly observed in Fig. 5 (d).

The Advanced Microwave Sounder Unit (AMSU) on the NOAA-15 Polar Orbiting Satellite provides data for atmospheric temperature soundings. The horizontal resolution of the AMSU data is about 50 km near nadir, and about 100 km on the limb of the satellite scans. Because of the limited resolution, the inner core of intense tropical cyclones is not fully resolved. However, the data may still provide horizontal and vertical structure information that is not usually available by any other means. The AMSU senses the atmospheric temperature even in the presence of clouds, except when liquid water is present. Intense tropical cyclones at this level have shown AMSU measured warm anomalies of several degrees Celsius, however the level of the maximum warm core is typically at about 250-300 hPa, where the anomaly is 10-12° C for intense hurricanes (Demuth, *et al.* 2000, Kidder, *et al*., 2000). If one assumes that the atmosphere is hydrostatic and in gradient wind balance, then the maximum cyclonic vorticity is located at the level where the cyclone is cold core below and warm core above. With tropical cyclones this is very near the surface but with subtropical cyclones, it is in the upper troposphere. Therefore, with AMSU temperature retrievals alone in the tropics and subtropics can deduce the vertical structure of winds as well as temperature with individual weather systems (Kidder, *et al*., 1978 and 1980).

5. Conclusion

Tropical cyclones are also known as tropical depressions, tropical storms or hurricanes, depending on their wind speed. Early detection of these systems will help determine those that warrant further examination by more traditional methods, and allow investigators to study the genesis of tropical cyclones by watching the full development of a storm from its very beginning using satellite data. Three tropical cyclones that developed over Indian Ocean in last three years were classified by using the latest NOAA satellite series AMSU data. The results obtained by using the satellite data were found more impressive and critical. The warm core temperature anomaly about 250 hPa could be used as an indicator of tropical cyclone intensity. With fewer weather stations and search aircraft, the use of the satellite data can greatly improve tropical cyclone identification and prediction. For a system developing close to land, this earlier prediction could mean the difference between life and death for those living in the region.

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