On forecasting tracks of tropical disturbances using ATOVS data over Bay of Bengal

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ABSTRACT. Advanced TOVS (ATOVS), comprising the Advanced Microwave Sounding Unit (AMSU), data obtained from polar orbiting satellites NOAA 15 and 16 during the life cycle of a tropical depression and two tropical cyclonic storms during 2002-03 have been analysed to predict the track of these disturbances. The mid-tropospheric warming due to altostratus outflow from these weather disturbances in the layer 700 – 400 hPa which protrudes about 200 -700 km ahead the storm acts as a pre-cursor to predict the movement of the disturbances with a lead time of about 6 to 24 hours. The disturbance almost follows the axis connecting the centre with the warm tongue that protrudes ahead of the disturbance in the mid-troposphere. While warm core of 7 to 13° C is centered around the upper tropospheric level (250 – 200 hPa) in the case the two moderate intensity tropical cyclones, no significant warmness could be seen in the depression stage.

Key words – Tropical cyclone, Depression, Track forecast, ATOVS, AMSU, Doppler Weather Radar, Mid-tropospheric warmness, Altostratus outflow.

1. Introduction

Tiros Operational Vertical Sounder (TOVS), comprising of 20 channel High Resolution Infra-red Sounder (HIRS), 4 channels Microwave Sounding Unit (MSU) and 3 channels Stratospheric Sounding Unit (SSU), onboard NOAA series of polar orbiters (upto NOAA-14) provides vertical profiles of temperature, humidity and geo-potential heights at standard pressure levels besides columnar ozone, precipitable water vapour and outgoing longwave radiation. The technical details, processing algorithm, retrieval procedures and usefulness and limitations of TOVS data have been excellently documented in Kidder and Vondar Harr (1995) and Cracknell (1997).

1.1. Validation and utilisation of TOVS data in Indian weather conditions

The validation of TOVS derived atmospheric parameters over the Indian region has been done by Khanna and Kelkar (1993), Gupta et al. (1996) and Suresh and Rengarajan (2001). As the Root Mean Squared Error (RMSE) between TOVS derived temperature and that obtained through Radio sonde are smaller than the natural variability (i.e.) the standard deviation of radio-sonde data, satellite soundings can be used in operational weather analysis as they explain a substantial fraction of variance of atmospheric temperature. Hence these data were used to study the thermodynamics of northeast and southwest monsoon by Suresh and Raj (2001) and Suresh et al. (2002). Since the RMSE of less than 2.0° C is quite low to monitor the thermal structure of tropical cyclones (Kidder et al., 2000), TOVS data has been successfully used to study the movement of tropical cyclones over Bay of Bengal and Arabian Sea by Suresh and Rengarajan (2002).

1.2. Advanced TOVS (ATOVS)

The TOVS instrumentation had gone a substantial change from NOAA-15 (launched during May 1998). The
Advanced TOVS (ATOVS) consists of improved HIRS and Advanced MSU (AMSU). The improvement in HIRS sensors include the radiant cooler operation at 95 °K, the reduction in internal field of view to 10 km, the inclusion of a fifth internal warm target temperature sensor and an additional tertiary telescope temperature sensor. The 4 channel MSU and the 3 channel SSU of TOVS have been replaced by a 20 channel AMSU. AMSU has two components, AMSU-A comprising 15 channels (channels 1 to 15) for upper air temperature retrieval and AMSU-B comprising 5 channels (channels 16 to 20) for moisture parameters retrieval. AMSU-A is a cross-track, line-scanned instrument designed to measure scene radiances in 15 discrete frequencies (23.8 to 89.0 GHz). AMSU-A is further classified as AMUS-A1 (channels 3 through 15, with frequencies 50.3 to 89.0 GHz) which is used for the calculation of the vertical temperature profile from the earth’s surface to about 3 hPa (45 km) and AMSU-A2 (K band, channel 1 at 23.8 GHz and Ka band, channel 2 at 31.4 GHz) for the retrieval of all forms of atmospheric water except small ice particles. At each channel frequency, the antenna beam width is 3.3°. Each scan
covers 50° on each side of the sub-satellite path and samples thirty contiguous scene resolution in stepped-scan fashion in eight seconds periodicity. These scan patterns and geometric resolution translate to a 48 km diameter cell at nadir and a 2,179 km swath width from the 833 km nominal orbital altitude.

The AMSU-B is also a cross track, line scanning instrument designed to measure scene radiance frequencies from 89 to 183 GHz. The beam width at each channel frequency is 1.1°. The AMSU-B instrument consists of a scanning parabolic antenna which is rotated once every 8/3 seconds to measure the radiance. Each scan covers 50° on either side of the sub-satellite path and samples ninety contiguous scene resolution in a continuous fashion. These scan patterns and geometric resolution translate to a 16 km diameter cell at nadir at a nominal altitude of 850 km. While channels 16 (89 GHz) and 17 (150 GHz) enable deeper penetration through the atmosphere up to the earth’s surface, channels 18 to 20 (operating at 183.3 ±7 GHz) span the strongly opaque water vapour absorption line. Thus the AMSU-B receives radiation from different geo-physical layers of the atmosphere and helps us to estimate the humidity profiles on a global scale. Technical description of ATOVS is beyond the scope of this paper and interested readers may have it from http://www2.ncdc.noaa.gov/docs/klm.

1.3. Validation and utilisation of ATOVS retrievals

The major advantages of ATOVS are the very high spatial resolution and radiometric accuracy. AMSU is quite capable of measuring / deriving main tropical cyclone parameters of interest such as storm location, liquid water content and thermal anomalies in view of the fact that clouds are well-neigh transparent to microwave radiation. Algorithms for the errors in estimation caused by antenna side lobes (Mo, 1999) and limb adjustment due to increased path length (Wark, 1993) need to be applied to get the best estimation. Details of limb adjustment, temperature retrieval procedure and validation of ATOVS data may be seen from Goldberg(1999) and Jun Li et al. (2000). Validation of ATOVS derived temperature with that obtained through colocated radio sondes in the domain Equator – 30° N during September – November, 1998 indicated a root mean squared error of less than 1.75°C from 1000 to 150 hPa (Kidder et al., 2000).

ATOVS data received from NOAA-15 and 16 satellites at the direct readout ground station at India Meteorological Department (IMD), New Delhi have been used in this paper to study the thermo dynamical structure of two tropical cyclones and one tropical depression over Bay of Bengal during 2002-2003. Moreover, tracks of these tropical disturbances have been studied in this paper using the temperature profile obtained from the AMSU.

Fig. 2. Analysis of 700 – 400 hPa layer mean temperature (°C) at 2001 UTC / 22 October 2002

2. Data

Fig. 1 shows the best tracks of tropical disturbances over Bay of Bengal during 2002 and 2003 as finalised by the apex National Meteorological and Hydrological services of India, viz., IMD, during its Annual Cyclone Review Meetings. Due to technical problems and limitations, ATOVS data were not available in the direct readout ground station at IMD, New Delhi for all the disturbances shown in this figure. The available ATOVS data from NOAA 15 and 16 satellites have been antenna side lobe corrected, limb corrected and processed for two tropical cyclones (Kolkata cyclone, 11-12 November 2002 and Machilipatnam cyclone, 13-16 December 2003) and for a tropical depression on 23 October 2002. AMSU soundings over the domain 6 to 22° N / 72 to 96° E have been used to derive temperatures at 1000, 975, 950, 925, 900 hPa, and thereafter at every 50 hPa interval up to 100 hPa, and then at 70, 50, 30, 20 and 10 hPa. In all as many as 9,500 records have been analysed, of which 1950 pertain to the Bay depression on 23 October 2002, more than 3000 pertain to Kolkata cyclone during 2002 and 4550 correspond to the Machilipatnam cyclone during 2003. Imageries from the geo-stationary satellite (METEOSAT) that had been obtained in real time from Dundee University website (http://www.sat.dundee.ac.uk) during the said period are consulted wherever necessary to identify the intensity of the disturbances. Data obtained by Doppler Weather Radars (DWR) at Chennai and Kolkata have also been considered to identify the structure of the disturbances.

3. Methodology

Simpson (1954), using aircraft reconnaissance, has postulated the concept of protrusion of mid-tropospheric warmness due to altostratus outflow far ahead of typhoons. Simpson argued that altostratus outflow from the typhoons is more significant than the
cirrus outflow in causing a significant warmness in the 700-500 hPa layer at a distance from 400 km to as far away as 1000 km ahead of the storm. As opined by Simpson, the altostratus outflow causes the protrusion of warm tongue ahead of the disturbance and the tropical disturbance follows the track obtained by joining the centre of the disturbance with the relatively warm mid-tropospheric locations. This concept has been studied in-depth by Suresh and Rengarajan (2001 and 2002) and they established that the layer mean 700-400 hPa warmness protrudes about 300 to 700 km ahead of the storm and acts as precursor to foreshadow the storm movement and predict the landfall about 6 to 24 hrs in advance over Bay of Bengal and Arabian Sea. They have also demonstrated that this technique could predict the rare southward movement of Bay of Bengal cyclone, 28 November – 7 December, 1996. The 700-400 hPa layer mean temperature computed from ATOVS data have been plotted and isothermal analysis carried out. The average layer mean temperature in the analysis domain varies from –3 to –5.5° C. However, it has been observed that in the vicinity of a tropical disturbance (tropical depression / tropical cyclone), the 700-400 hPa layer is warmer by 0.5 to 4.0° C indicating that adequate warming takes place in the mid-troposphere in association with the disturbance.

3.1. Tropical depression 22-23 October 2002

A tropical depression, with intensity T1.5 in Dvorak’s scale, Dvorak (1975), formed at 0900 UTC on 22nd October 2002 over Bay of Bengal remained practically stationary at 13.5° N / 81.5° E upto 1200 UTC and subsequently intensified into T2.0. It had a very slow northward movement and located at 14.0° N / 81.5° E at 1800 UTC / 22nd. The depression remained practically stationary upto 1200 UTC of 23rd and thereafter weakened in Bay itself. Fig. 2 shows the layer mean temperature of 700-400 hPa obtained from NOAA-16 AMSUs at 2001 UTC on 22nd. A localised mean layer warmness of 3° C (in comparison to the surroundings) was observed at about 50 – 100 km north of the disturbance. The possible direction of movement of the depression (line joining the centre of depression and the protrusion of maximum warmness) was in total agreement with that finalised by IMD. However, there is an eastward shift of about 0.5° in locating the centre of the storm based on ATOVS data albeit the latitude fixation agrees with that of IMD.

3.2. Kolkata cyclone, 11-12 November 2002

A depression formed at 12.0° N / 82.5° E at 0300 UTC on 10 November, 2002 intensified into a cyclonic storm at 1200 UTC on 11th and lay centered at 16.0° N / 84.5° E with intensity T3.0 on Dvorak’s scale. The cyclone intensified further and became a severe cyclonic storm at 0600 UTC on 12th with T4.5 and centered at 21.0° N / 87.5° E. Fig. 3 depicts the plan position indicator (PPI) plots of logarithmic radar reflectivity factor (Z) as tracked by DWR at Kolkata at 0647 and 0649 UTC on 12th when the storm attained T4.5 intensity on Dvorak’s scale and crossed the West Bengal coast. The system had
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Fig. 4. AMSU derived mid-tropospheric (700 – 400 hPa) warmness (°C) that shows the possible track of cyclonic storm on 11th and 12th November 2002

Fig. 5. Possible track predicted by AMSU compared with track as finalised by IMD

Due to scan geometry limitations of the polar orbiters, only a portion of the storm could be detected by the day time NOAA 16 passes, viz., 0712 UTC on 11th and 0839 UTC on 12th. The core region of the storm was missed by these passes. Hence analyses of data obtained from these passes have not been presented in this paper. The land fall was predicted from the mid-tropospheric warmness (based on 0126 UTC of 12th NOAA15 data) about six hours in advance. The possible track of the storm as derived from AMSU data (based on 1951 UTC/10th, 0123 UTC/11th and 0126 UTC/12th satellite passes) compared with that finalised by IMD has been shown in Fig. 5. For this purpose, the first warmest mid-tropospheric location ahead of the storm (i.e., the southern most point of the warm tongue, ahead of the storm) has been joined with the known storm centre just prior to and/or at the time of the satellite pass and the track thus obtained has been extended along the warmest locations of the warm tongue. While the direction of storm’s movement can be predicted from the track thus obtained, the speed of the storm can be estimated from persistence/immediate past movement.

Since the mid-tropospheric warmness protrudes 200-700 km ahead of the storm (Simpson, 1954; Suresh and Rengarajan, 2002) and the tropical cyclones move over the oceanic area at an average speed of 10-30 kmph (IMD, 2003 and 2004), forecast based on ATOVS analyses can be issued with 9 to 24 hrs lead time depending on the nearest warm tongue location.

The nearest warmer location at 0123 UTC / 11th was at 16.18° N / 84.54° E with a layer mean temperature of...
–2.0°C which is 1.5 to 2.0°C warmer than the surrounding. This location is about 300 km ahead of the storm. Based on persistence, the forecast position at 1200 UTC has been fixed as this location. The IMD’s track position at 1200 UTC / 11th was 16.0° N / 84.5° E. The forecast is in good agreement with the best track finalised by IMD. The warmest locations were 17.65° N / 84.4° E (with -1.15°C mean temperature) and 17.55° N / 85.3° E (with -1.48°C mean temperature). These locations are warmer than the surroundings by more than 3.0°C and they are at a distance more than 420 km from the storm centre. By assuming the past speed of 20-25 kmph, the forecast positions at 2100 UTC / 11th and 0000 UTC / 12th have been made. In a similar way, the forecast position at 0600 UTC / 12th based on ATOVS data of 0126 UTC / 12th was fixed at 21.68° N / 87.2° E, having the layer mean temperature of – 1.85°C, which is in close agreement with IMD’s 0600 UTC position, viz., 21.0° N / 87.5° E. Forecast position at 0900 UTC, viz., 22.2° N / 88.2° E was almost tallying with the landfall location near Sagar island around 0900 UTC / 12th. The positional errors with reference to the IMD’s finalised track have been tabulated in Table 1. The storm, according to IMD(2003), had moved with a extremely rare and high speed of about 120 kmph from 16.5° N / 84.0° N at 2100 UTC / 11th to 19.0° N / 86.5° E at 0000 UTC / 12th. Hence the error in track prediction based on persistence, climatology and climatology and persistence (CLIPER) are not available for this storm in IMD (2003) for comparison. However, going by the available records the

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**Fig. 6.** Bay storm with severe cyclonic storm intensity (T3.5) at 2026 UTC and 2056 UTC on 14 December, 2003 as tracked by Doppler Weather Radar, Chennai

**TABLE 1**

| Forecast position valid at (time / date) | Forecast position based on ATOVS | IMD’s finalised position | Error in estimation (km) | Forecast lead time |
|----------------------------------------|---------------------------------|--------------------------|-------------------------|-------------------|
| 1200 UTC / 11th *                      | 16.18° N/ 84.54°E              | 16.0° N/ 84.5°E         | 18                      | 10 hrs 30 min    |
| 2100 UTC / 11th *                      | 17.60° N/ 84.85°E              | 16.5° N/ 84.0°E         | 139                     | 19 hrs 30 min    |
| 0000 UTC / 12th *                      | 18.20° N/ 85.30°E              | 19.0° N/ 86.5°E         | 144                     | 22 hrs 30 min    |
| 0600 UTC/12th *                        | 21.68° N/ 87.20° E             | 21.0° N/ 87.5° E        | 74                      | 04 hrs 30 min    |
| 0900 UTC / 12th *                      | 22.20° N/ 88.20° E             | 22.5° N/ 88.5° E        | 42                      | 07 hrs 30 min    |

Note: * Forecast based on ATOVS data of 0123 UTC / 11th November 2002.
# Forecast based on ATOVS data of 0123 UTC / 12th November 2002.
* Forecast lead time = Time at which the forecast is valid – Time of availability of processed HRPT data.
error in forecasting of the storm track through ATOVS is much comparable to that obtained using Quasi Lagrangian Model, persistence, climatology and CLIPER, viz., 150 to 330 km.

3.3. Machilipatnam cyclonic storm, 13 – 16 December 2003

The depression formed at 1200 UTC on 11th December 2003 (4.5° N / 90.5° E) had a long northwestward sea travel to become a cyclonic storm with intensity T 2.5 (9.5° N / 87.0° E) at 1200 UTC on 13th. It gained intensity as a severe cyclonic storm (T 3.5) at 1200 UTC on 14th and lay centered at 12.0° N / 83.5° E. Mosaic of two PPI(Z) displays obtained from DWR at Cyclone Detection Radar station, Chennai at 2026 and 2056 UTC / 14th has been presented as Fig. 6. Maximum Z was around 50 dBZ only corresponding to a rain rate (R) of 48 mm/hr using the well known Marshall – Palmer’s original Z – R relationship. The severe cyclonic storm intensity was

TABLE 2

| 0817 UTC / 13 December 2003 | 2049 UTC / 13 December 2003 |
|-----------------------------|-----------------------------|
| Latitude (°N) | Longitude (°E) | 700-400hPa layer mean temperature (°C) | Latitude (°N) | Longitude (°E) | 700-400hPa layer mean temperature (°C) |
| 12.4 | 87.4 | - 0.44 | 13.7 | 83.6 | - 0.37 |
| 13.4 | 87.4 | - 0.60 | 13.8 | 83.1 | - 0.69 |
| 09.8 | 86.6 | - 0.70 | 11.3 | 83.0 | - 0.50 |
| 13.8 | 87.1 | - 1.10 | 11.4 | 82.6 | - 0.58 |
| 10.0 | 87.5 | - 1.30 | 11.0 | 82.4 | - 1.07 |
| 08.9 | 86.9 | - 1.40 | 10.8 | 83.5 | - 1.13 |
| 13.2 | 86.7 | - 1.50 | 11.3 | 83.6 | - 1.24 |

Note: The mean layer temperature about 300 – 500 km away from the disturbances are of the order of –3 to –5° C.

TABLE 3

| Forecast position valid at (time / date) | Forecast position based on ATOVS | IMD’s finalised position | Error in estimation (km) | Forecast lead time |
|----------------------------------------|---------------------------------|--------------------------|-------------------------|--------------------|
| 1800 UTC / 13th @ 10.0° N / 88.0° E | 10.0° N / 87.0° E | 100 | 09 hrs 30 min |
| 2100 UTC / 13th @ 10.5° N / 87.3° E | 10.5° N / 86.5° E | 80 | 12 hrs 30 min |
| 0000 UTC / 14th @ 10.6° N / 87.0° E | 10.5° N / 86.0° E | 104 | 15 hr 30 min |
| 0600 UTC / 14th @ 11.5° N / 85.5° E | 11.0° N / 85.0° E | 71 | 09 hrs |
| 0900 UTC / 14th @ 11.8° N / 84.6° E | 11.5° N / 84.5° E | 32 | 12 hrs |
| 1200 UTC / 14th @ 12.2° N / 84.2° E | 12.0° N / 83.5° E | 73 | 15 hrs |
| 1800 UTC / 14th @ 13.0° N / 82.9° E | 12.8° N / 82.5° E | 45 | 09 hrs 40 min |
| 2100 UTC / 12th @ 13.5° N / 82.8° E | 13.4° N / 82.2° E | 61 | 12 hrs 40 min |
| 0300 UTC / 15th @ 13.8° N / 82.0° E | 14.0° N / 81.5° E | 54 | 06 hrs 10 min |
| 0900 UTC / 15th @ 14.2° N / 81.2° E | 15.0° N / 81.0° E | 82 | 12 hrs 10 min |
| 1200 UTC / 15th @ 14.7° N / 80.8° E | 15.5° N / 81.0° E | 75 | 15 hrs 10 min |
| 1500 UTC / 15th @ 15.2° N / 81.1° E | 15.8° N / 81.0° E | 61 | 18 hrs 10 min |
| 1800 UTC / 15th @ 16.1° N / 81.4° E | 16.0° N / 81.0° E | 43 | 21 hrs 10 min |

Note: @ Forecast based on ATOVS data of 0817 UTC / 13th December 2003.
* Forecast based on ATOVS data of 2049 UTC / 13th December 2003.
# Forecast based on ATOVS data of 0805 UTC / 14th December 2003.
& Forecast based on ATOVS data of 2034 UTC / 14th December 2003.
 Forecast lead time = Time at which the forecast is valid – Time of availability of processed HRPT data.
maintained up to 1800 UTC of 15th and crossed coast near Machilipatnam as a cyclonic storm around 1800 UTC on 15th. The storm weakened into a deep depression at 0300 UTC on 16th and gradually weakened over north coastal Andhra Pradesh.

Fig. 7 shows the analyses of mid-tropospheric warmness at 0817 and 2049 UTC of 13th. Based on 0817 UTC of 13th AMSU data, the maximum mid-tropospheric warmness of more than 2.5°C was concentrated over two regions suggesting that the storm may move towards northwest initially and then may change its path towards northnortheastward. Similarly, the 2049 UTC analysis also revealed that the mid-tropospheric warmness concentrated into two localised regions suggesting that the storm may move towards either of them or in between these two warm pools. The peak values of 700 – 400 hPa layer mean temperatures at various sounding points have been tabulated in Table 2.

The maximum warmness was observed more in the northern pool than the southern one suggesting that the storm had a tendency to move towards northwestward rather than westnorthwestward. Since the storm was away from the coast by more than 600 km during this period, ground based radars were of no help in tracking the storm. Satellite imageries from the METEOSAT at 1500, 1800 UTC / 13th could not suggest any clear cut movement of the storm since the storm centre was obscured by the dense overcast cloud mass.

Based on the maximum mid-tropospheric warmness and persistence, the track position at 1800 UTC / 13th has been estimated (from 0817 UTC/ 13th ATOVS analysis) at 10.0° N / 88.0° E wherein the 700-400 hPa layer mean temperature was – 0.16°C. The positions at 2100 UTC / 13th and 0000 UTC /14th have also been estimated from the 0817 UTC / 13th ATOVS analysis. In a similar way, from the 2049 UTC / 13th ATOVS derived mid-tropospheric temperature analysis, storm’s positions at 0600, 0900 and 1200 UTC / 14th have been estimated. The estimated positions reasonably agrees with the IMD’s finalised track. The errors in estimation have been tabulated in Table 3.

The 0805 UTC / 14th ATOVS data revealed northwestward movement of the storm. The forecast position at 1800 and 2100 UTC / 14th estimated from this analyses agreed well with the finalised track. Fig. 8 shows the 700-400 hPa layer mean temperature at 2034 UTC on 14th. This analysis clearly indicates the northwestward movement of the storm and its likely heading towards Machilipatnam (16.2° N / 81.15° E) coast. Fig. 9 depicts
the track of the storm estimated from ATOVS compared with the track finalised by IMD.

4. Warm core of the cyclonic storms

Temperature anomaly for the AMSU retrievals at various pressure levels have been worked out based on the method followed by Kidder et al. (2000) to estimate the extent warmness over the eye or core region of the storm. For this purpose the environmental temperature at 500 - 600 km away from the centre of the storm has been subtracted from the sounding temperature over the eye or core region of the storm for each pressure level. No significant warmness was observed over the core region of the tropical depression at 2001 UTC on 22 October, 2002. However in the case of the Kolkata cyclonic storm, at 250 hPa, a warming of 12.1° C at 62 km and 13.3° C at 124 km were observed at 0123 UTC on 12 November, 2002 during which period the storm had gained intensity T 3.5. Warming over the eye of the storm could not be estimated in view of non-availability of AMSU soundings for this storm. In the case of Machilipatnam cyclone, two soundings at 28 and 40 km from the storm centre at 0806 UTC on 14 December, 2003 revealed a 7.7° C warmness at 200 hPa. When the storm was having its peak intensity of T 3.5 at 2037 UTC on 14th, a sounding at 45 km from the storm centre indicated a 9.1° C warmness at 200 hPa. In the absence of sounding data from reconnaissance flights, the above inference from the two cyclonic storms of marginal intensities supports the established facts that the tropical cyclones are warm core systems and the warmness of the core region extends from 10 to 16° C in the 200-250 hPa level [Hawkins and Rubsam (1968) and Asnani (1993)]. It may also be seen that the lower tropospheric warmness of about 2° C was also captured by the AMSU soundings over the region very close to the core / eye of the storm.

5. Limitations and challenges

Though the AMSU data provides us a wealth of information for understanding the thermodynamic features of the cyclonic storms and help us to predict the movement of the storm, it does have the following limitations.

(i) Since the eye of the cyclone is ordinarily far less than the highest 48 km AMSU resolution obtainable at nadir, thermo-dynamic features of the core region or eye of the cyclonic storm can not be completely understood with the ATOVS data.

(ii) Significant changes in the tropical disturbances can take place between two successive passes of polar orbiters viewing almost the same area with twelve hour periodicity.

(iii) Contiguity is not maintained in AMSU observations between two successive passes due to scan geometry limitations. Hence the disturbance may, at times, go unnoticed which is usually termed as ‘storms fall in the crack’ (Kidder et al., 2000).

The above limitations to certain extent have been addressed by scanning a little farther towards the limb and thereby making the ‘gap between passes’ as small as possible. Though this is being attempted from NOAA-16 onwards, gap between two passes still exists. In order to avert the ‘gap’ in sounding retrievals and to keep continuity, more number of polar orbiting satellites are needed to have a close watch for the analyses of tropical disturbances. More over, with the contemplated introduction of microwave payload in geo-stationary satellites, it is hoped that the temporal resolution as well the ‘data gap’ problem would be solved.

6. Conclusions

The mid-tropospheric warmness, about 200 to 700 km ahead of the tropical disturbances (tropical storm / depression) caused by the Altostratus outflow between 700 and 400 hPa may be used as a tool to forecast the tracks of these disturbances. The disturbance follows the axis connecting the centre of the disturbance with the warm tongue that protrudes ahead of it. The disturbance essentially passes through the location having maximum mid-tropospheric warmness. Based on the persistence / speed of past movement, forecast position of the disturbance can be estimated over a time period of 6 to 24
The prediction accuracy is better than the other methods, viz., climatology, climatology and persistence, numerical methods, that are in operational use. The two moderate intensity cyclonic storms that have been analysed in this paper showed upper tropospheric (250 to 200 hPa) warmth of 7 to 13° C over the core region than the surrounding atmosphere at a distance of about 500-600 km from the storm centre. However, such an upper tropospheric warmth could not be seen in the depression stages. Since the AMSU retrievals are not obtained from a regularly placed grid locations and they have varying resolution (at the sub satellite points and at the edges of the swath) and it may take considerable time to plot the thousands of retrievals, objective analysis can be attempted to place the 700 – 400 hPa layer mean temperature values at regular grids, say, 1° Lat. × 1° Long., over the area of interest in an operational set up to issue the forecast.

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