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On forecasting cyclone movement using TOVS data

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सार - इस शोध-पत्र में, नोआ उपग्रहों से चैन्नै में प्राप्त हुए टी.ओ.वी.एस. आँकड़ों का उपयोग करते हुए वर्ष 1998 के दौरान बंगाल की खाड़ी में आए तीन चक्रवातीय तूफानों और अरब सागर में आए एक चक्रवातीय तूफान के मार्गों का विश्लेषण किया गया। तूफान के 300-700 कि.मी. अग्रक्षेत्र से निकलने वाली, 700 और 400 हैक्टापास्कल के स्तरों की मध्यक्षोभमंडल उष्णता, तूफान की गति के पूर्व संकेत देने का कार्य करती है जिससे तूफान के तट पर पहुँचने से 6 से 24 घंटे पहले ही तूफान के आने का पूर्वानुमान लगा लिया जाता है। इस तकनीक की सहायता से खाड़ी में विशिष्ट प्रकार के दक्षिणाभिमुखी चाल वाले तूफान (28 नवंबर से 7 दिसंबर 1996) का पूर्वानुमान भी सफलतापूर्वक लगाया गया है।

ABSTRACT. The tracks of three cyclonic storms over Bay of Bengal and one over Arabian Sea during 1998 have been analysed using the TOVS data received at Chennai from NOAA satellites. Midtropospheric warmness between 700 and 400 hPa levels which protrudes about 300 to 700 km ahead of the storm acts as precursor to foreshadow the storm movement and predict the landfall about 6 to 24 hrs in advance. This technique has successfully predicted even the peculiar southward movement of Bay storm (28 November to 7 December, 1996).

Key words – TOVS data, Midtropospheric warmness, Cyclone track, Landfall, Forecast.

1. Introduction

Advance Very High Resolution Radiometer (AVHRR) onboard NOAA satellite orbiting from pole to pole at an altitude of about 850 km is capable of transmitting very high resolution (1.1 km) cloud imageries and TIROS operational vertical sounder (TOVS) data using High Resolution Picture Transmission (HRPT) techniques to all ground stations capable of receiving these data. A HRPT direct readout ground station was installed in the Regional Meteorological Centre (RMC), Chennai (13.07° N / 80.25° E) in August 1995 and has been operational since October, 1995. The state of art of the system, its capabilities and limitations have been described in Gupta *et al*. (1996). Technical details regarding TOVS processing have been described elsewhere (Smith *et al*., 1979 & 1981).

1.1. *TIROS Operational Vertical Sounder (TOVS)*

Given the radiance data, the problem of estimating the temperature and trace gas concentration profiles from the observed radiance is often called as inverse problem or retrieval problem. The retrieval problem aims at finding temperature profiles that satisfy the Radiative Transfer Equation (RTE). However, unique solution to the RTE would not be guaranteed, even if we get radiance data at all wavelengths from noise-free radiometer (Chahine, 1970) and infinite number of solutions are quite possible consistent with measured radiances since the radiation measurements are often contaiminated with noise (Eyre, 1990). As the surface and upper air guess profiles have effect on quality of soundings (with larger impact at lower levels and relatively lesser impact over middle and upper troposphere), a judicious initial guess, may be from numerical forecast, regression estimate from microwave and stratospheric level infrared sounding channels data or climatology, has to be made to solve the RTE. It has been reported that a reasonable degree of accuracy is attainable by using the initial guess for surface temperature or 1000 hPa level (Khanna and Kelkar, 1993). However, in the absence of getting efficient numerical upper air forecast in real time for use as initial guess for each satellite pass TOVS retrieval, the climatology is normally used as initial guess in operational mode of TOVS processing at many direct read out HRPT ground stations.

1.2. *One-step physical retrieval scheme*

International TOVS processing package (ITPP) version 4.0 of University of Wisconsin, Madison on one

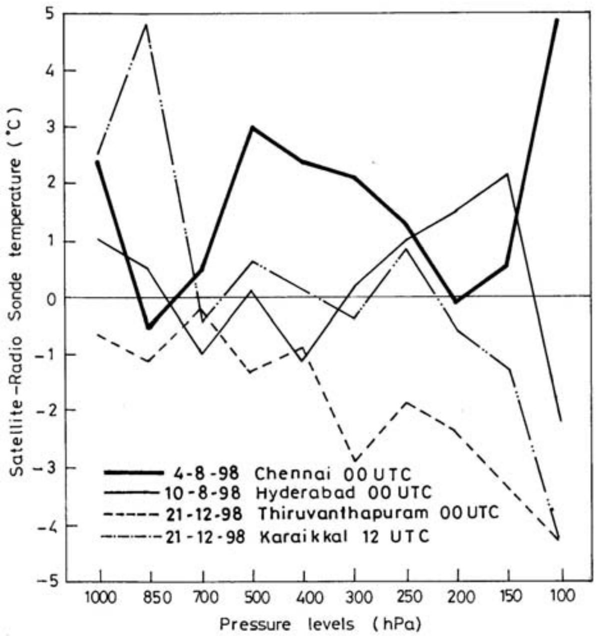


Fig. 1. Plot of temperature bias (satellite-radio sonde temperature) during 1998

step physical retrieval scheme has been used at Chennai to retrieve the TOVS products as this scheme uses data from all channels and has the provision for incorporating guess profiles to improve the quality/accuracy of the retrievals. Since microwave sounding unit (MSU) undergoes calibration in every scan and microwave radiation is wellnigh unaffected by the cloud contaminations, the MSU channels data are considered, potentially, as a sensitive indicator of the atmospheric heating and cooling processes (Kidder and Vonder Harr, 1995). As stratospheric high resolution infrared radiation sounder (HIRS) and microwave sounding unit (MSU) channels are almost unaffected by the clouds, regression estimates obtained from these channels have been used as first guess profile to retrieve atmospheric temperature at various levels. As the airmasses change with season, the regression coefficients have to be updated at frequent intervals for different categories of airmasses. The regression coefficents have been estimated for each TOVS retrieval in order to fix this problem, as a matter of routing.

However, in respect of satellite passes during 0700 – 0900 and 1900 – 2100 hrs UTC (in the case of NOAA 14 satellite), we do not have radio-sonde data (at 0600 and 1800 UTC) for intercomparison. As such, for the passes during these period, upper air climatology of 1200 and 0000 UTC respectively has been used as first guess profile to solve RTE. It is desirable to use regression estimates since these are generated using *in-situ* measurement of satellite data, Moreover the warm/hot lower levels generally prevailing almost throughout the year and high seasonal variability of moisture in the equatorial latitudes during afternoon offer varying transmittances which lead to increase in temperature at lower and mid tropospheric level. Hence an empirical estimation of temperature correction profiles, based on the upper air climatological data of 0000 and 1200 UTC data (IMD, 1988), has been made for validation of TOVS data obtained from NOAA 14 satellite passes.

1.3. *Validation of TOVS data and limitations*

Validation of TOVS derived upper air temperature data for the Indian region has been done by Khanna and Kelkar (1993) and Gupta *et al*. (1996). Validation of TOVS products has been carried out as a routine from October, 1996 to December, 1998 by HRPT station, Chennai with colocated RS/RW stations in Chennai region. Though the differences between satellite and RS/RW upper air data, called biases, have been observed to be within 1 to 1.5° C at various levels on many days, Fig. 1 depicts at random the biases during typical monsoon and post-monsoon season, 1998. It may be seen even in this random sampling that biases at 1000 and 850 hPa on two retrievals were slightly more than the other two presumably due to either poor quality of initial guess (climatology in this case) or due to time lag between the soundings (more than two hours in these cases) and/or due to meso ν scale variations that might have taken place on that day which were not readily known to us. In general, validation of TOVS retrievals, during 1996-98 indicate that there is good agreement between the satellite and RS/RW data from 700 to 200 hPa with root mean squared biases, of less than 2.5° C in respect of temperature and less than 100 meters in respect of geopotential height.

As the root mean squared biases are smaller than the natural variability [standard deviation of radio-sonde data (IMD, 1988)], satellite soundings can be used in weather analysis and forecast as they explain a substantial fraction of variance of atmospheric temperature. It should be noted that the biases are over estimates in view of the fact that the timings and sounding techniques of satellite and radio-sonde are different and instrumental errors from radio-sondes have also been taken into account. As such it may be concluded that satellite soundings are complementary and not competitive to RS/RW soundings (Cracknell, 1997). Though these inherent problems with satellite soundings may indicate that the satellite soundings cannot be direct substitutes for radio-sonde soundings, satellite soundings contain a wealth of information on spatial and temporal scales which conventional radio-sondes do not have. Hence the satellite soundings can be independently used as the errors confine to observations by a single system.

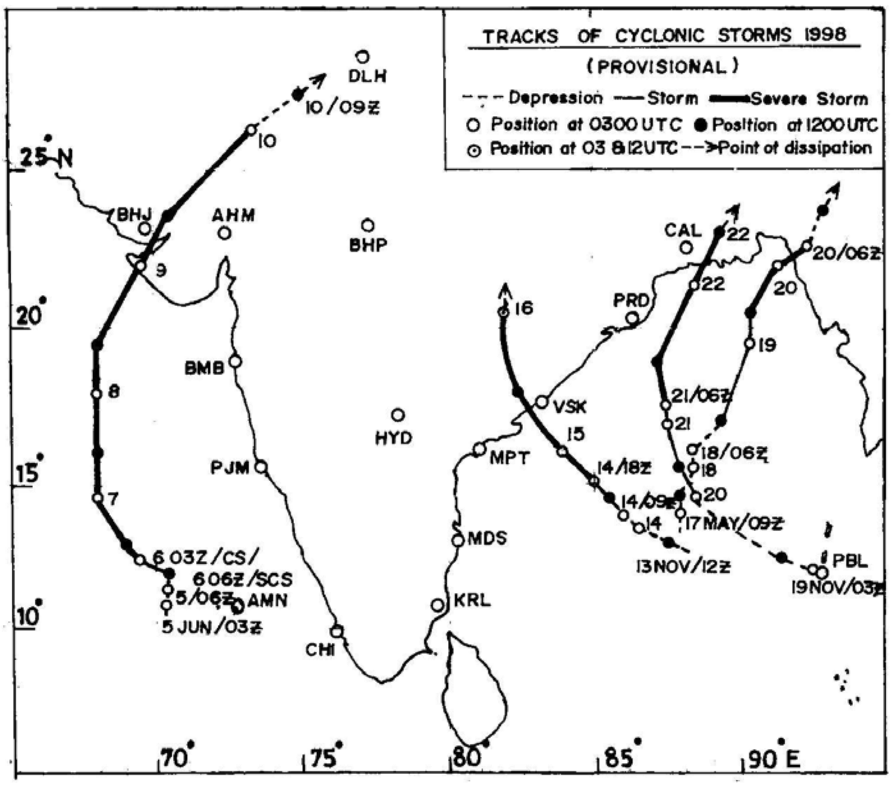


Fig. 2. Tracks of cyclonic storms during 1998

2. Data

TOVS derived temperature data in the region (Equator to 26° N; 64° E to 90° E) during May, June and October to December, 1998 have been used in this study to foreshadow the cyclonic storms which formed over the Bay of Bengal and Arabian Sea. Nearly 400 to 500 soundings from each satellite pass (NOAA 12 and 14 satellites) during the cyclonic storm period have been considered. This voluminous data, especially over the data sparse oceanic area has been of tremendous use in analysing the cyclonic field and to foreshadow the track of the cyclone. Climatological normals of radio-sonde data for the Indian region published by the India Meteorological Department (IMD, 1988) and annual cyclone review report of IMD for the period 1998 have been consulted. TOVS data during the period November-December 1996 has also been used in this study to verify the technique developed on a peculiar cyclone movement in the Bay of Bengal.

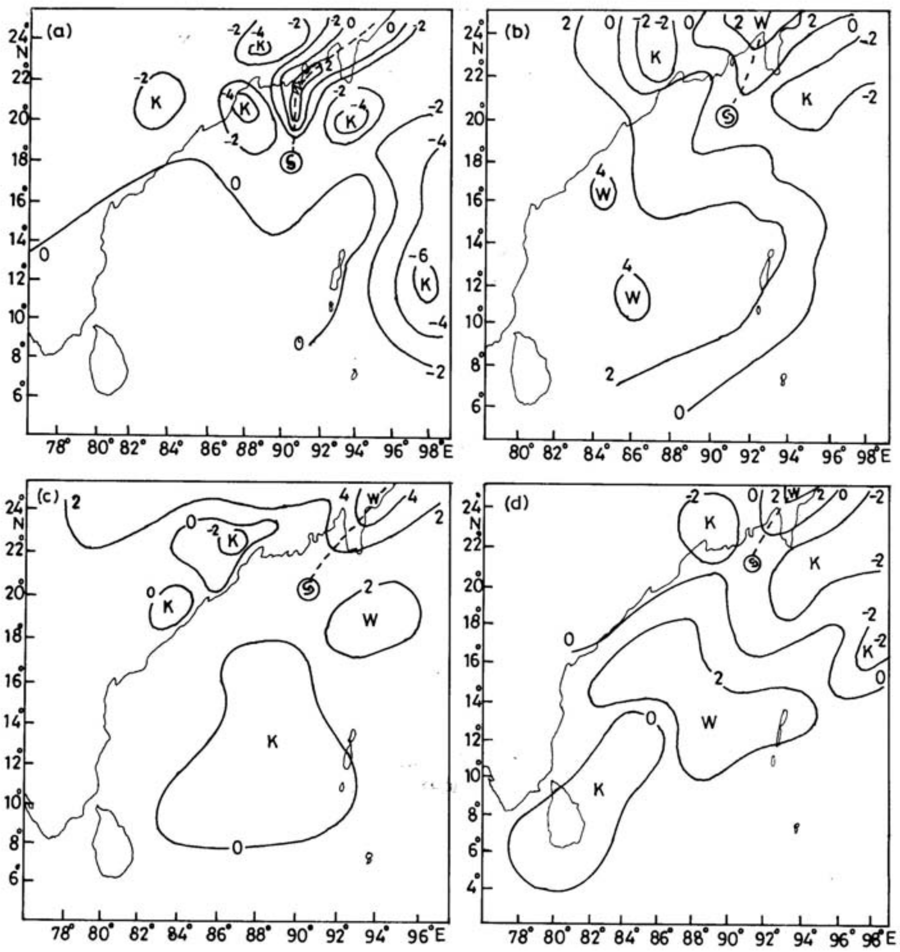
3. Methodology

3.1. *Analysis of mid-tropospheric warmness*

In one of the earlier studies on the structure of tropical cyclones using aircraft reconnaissance, Simpson (1954) has postulated the concept of midtropospheric warmness due to altostratus outflow. He argued that altostratus outflow is more significant than the cirrus outflow from the tropical cyclonic storm 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.

Using the above concept, an attempt has been made in this study to identify precursor (s), if any, for the direction of movement of the system. However on critical examination of the imageries of systems tracked through polar orbiters, it was found that no altostratus cloud outflow could be seen at any stage of the system. In order to find out whether any significant warming in the mid troposphere ahead of the storm has taken place, mean temperature and gpm thickness in the layers 500-850 hPa, 500-700 hPa & 400-700 hPa were computed, plotted and analysed. In addition to the above, the temperature drop from 850 to 500 hPa has also been worked out to find out pre-cursor (s), if any, to forecast the cyclone track over Bay of Bengal and Arabian Sea during 1998.

The analysis clearly demonstrate the presence of a midtropospheric warmness protruding about 400 to 700 km in advance of the storm centre especially in 400-



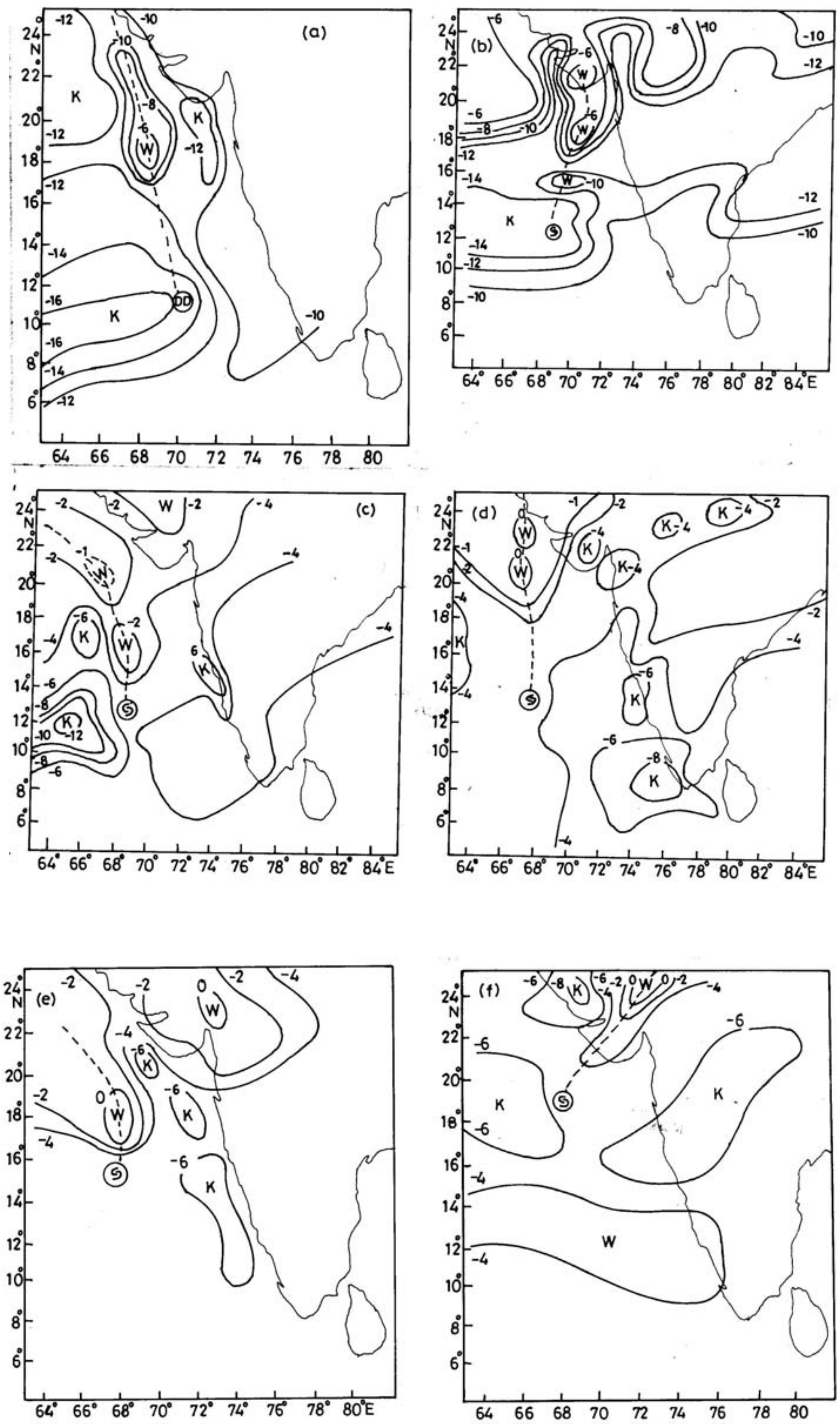
Figs. 3(a-d). Analyses of 700-400 hPa layer mean temperature during 17 – 20 May, 1998

700 hPa mean temperature and gpm thickness analysis. As the mean temperature and thickness are directly correlated, we restrict our discussion only to the mean temperature analysis between 700 and 400 hPa. Also it has been observed that when the storm was very close to the coast (within 300 to 350 km from the coast), the axis connecting the warm tongue and storm centre almost coincided with the actual track of the system. This warm tongue and the axis can probably be used as pre-cursors for the movement of storm especially matured ones.

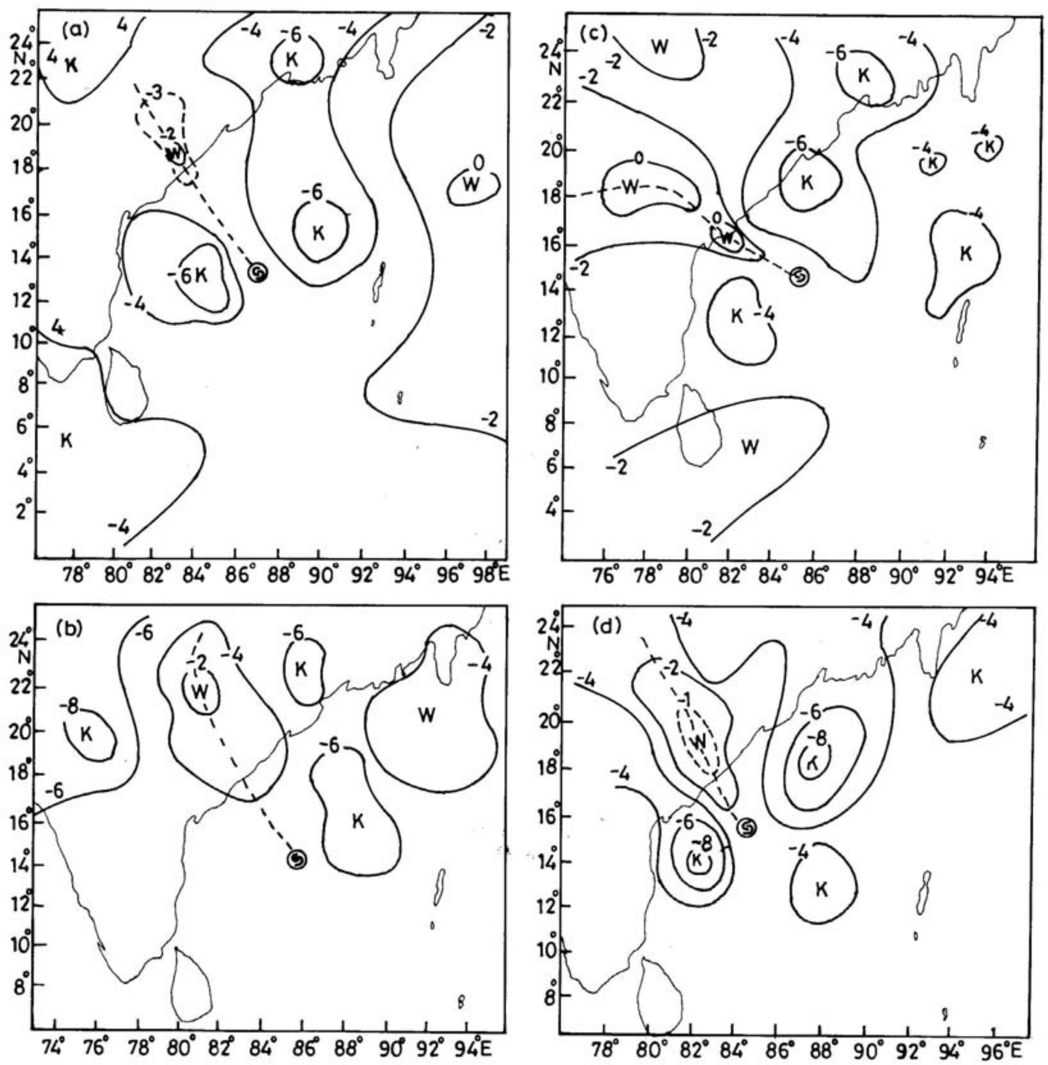
As has been mentioned in paras 1.2 and 1.3, the analyses revealed that NOAA 14 data over estimates the midtropospheric warmness, ofcourse uniformly, over Bay and Arabian Sea. Hence empirical correction for the data obtained through this satellite for the layer averaged temperature has been made for the area under study (including profiles over Bay of Bengal and Arabian Sea) to have comparability with RS/RW climatology and NOAA 12 data. These correction factors (8° C over Bay and 10° C over Arabian Sea) have been subtracted to have realistic comparison with NOAA 12 data and RS/RW climatology. The individual cases are discussed below.

3.2. *Forecasting storm tracks*

Tracks of cyclonic storms during 1998 have been taken from the published records of IMD and shownin Fig. 2.



Figs. 4(a-f). Analysis of 700-400 hPa layer mean temperature during 5-10 June, 1998



Figs. 5(a-d). Analysis of 700-400 hPa layer mean temperature during 13-16 November, 1998

(a) *Pre-monsoon cyclonic storm (17-20 May, 1998)*

A depression formed over central Bay at 0300 UTC on 17 May 1998 and intensified into a cyclonic storm at 1200 UTC on 18. Analysis of the mean temperature between 700 and 400 hPa level at 2045 UTC on 18 indicates that the storm will move in northerly to north northeasterly direction and the actual movement of the storm confirmed this till 19. Further analyses based on 2336 UTC of 18 (analysis not shown) and 0757, 1224 and 2032 UTC of 19 also confirmed the cyclone movement atleast 24 hrs in advance and the landfall was also predicted within 20 km from the actual landfall. Fig. 3 depicts the mean temperature analysis.

(b) *Cyclonic storm during monsoon season (5-10 June, 1998)*

The deep depression observed over Arabian Sea at 0300 UTC on 5 June 1998 intensified into a cyclonic storm at 1200 UTC and moved in northwesterly direction initially. 700-400 layer mean temperature analysis of 0142 UTC on 5 (Deep Depression stage), 0118 and 0937 UTC on 6 and 0056 and 0928 UTC on 7 clearly foreshadowed the storm

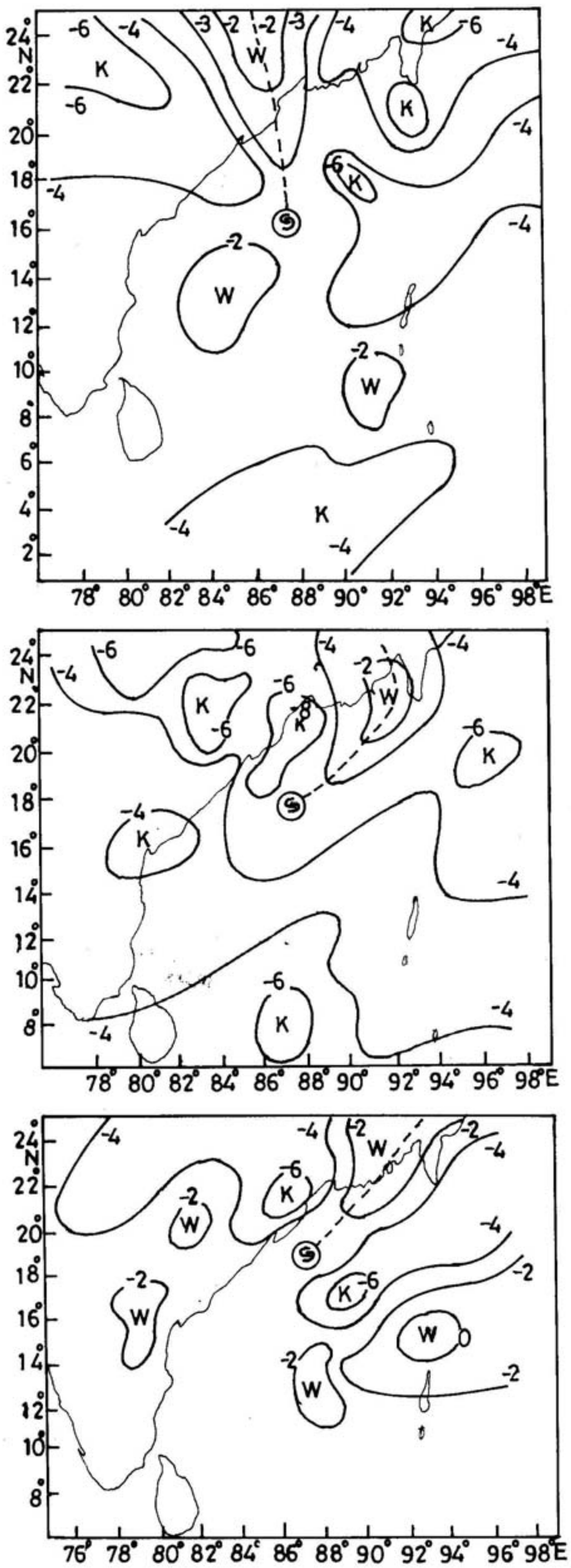


Fig. 6. Analysis of 700-400 hPa layer mean temperature during 19 November - 22 November, 1998

track. Fig. 4 shows the analysis. The analysis predicted correctly the possible landfall over Gujarat when the storm was away from the coast by 350 km based on 0917 UTC soundings of 8.

(c) *Post monsoon cyclonic storm (13-16 November, 1998)*

A depression formed over central Bay on 13 intensified into a cyclonic storm at 0900 UTC of 14 and moved on NW direction and crossed close to Visakhapatnam on 15 A/N. The 700-400 layer mean temperature analysis of 0028 UTC on 14 indicates that the storm will move towards north Andhra coast and most likely cross the coast close to Visakhapatnam (17.5° N; 82.7° E). This prediction has been done when the storm was away from the coast by atleast 450 km. 0823 UTC analysis of 14 reconfirms the movement of the storm towards north Andhra coast. The exact landfall had been predicted based on 1136 and 2058 UTC analyses on 14 when the storm was about 300 and 200 km away from the coast. Fig. 5 shows the 700-400 hPa mean temperature analysis.

(d) *Post monsoon cyclonic storm (19-22 November, 1998)*

The depression formed over east central Bay on 19 initially moved in NW direction and changed its path to NNW over central and north Bay during 20–21 and finally recurved and had its landfall close to Calcutta on 22 F/N. 2335 UTC/20 midtropospheric analysis indicated that the storm was heading towards little north of Paradip and the actual track was also confirming this prediction upto 1200 UTC/21. The recurvature was predicted based on 0844 UTC/21 NOAA 14 pass. The landfall was predicted based on 1223 UTC/21 NOAA 12 pass when the storm was away from the coast by more than 300 km. The analysis have been depicted in Fig. 6.

3.3. *Bay storm 28 November – 7 December, 1996*

The Bay storm during 28 November – 7 December, 1996 has two peculiarities. One, it had a loop in the central Bay and two, it had southward movement before its landfall. The track of this storm is shown in Fig. 7. This storm could not be forecast correctly either by synoptic or by numerical weather prediction (NWP) methods. As such an attempt has been made to study the movement of this storm through the technique developed in this paper. 0758 UTC/3 satellite pass prediction was very much agreeing with the storm movement till 1200 UTC/4 (Fig. 8). However, 2035 UTC/3 TOVS data indicated southwestward movement of the storm which may be quite strange and/or puzzle to the forecaster. Analysis of 0024

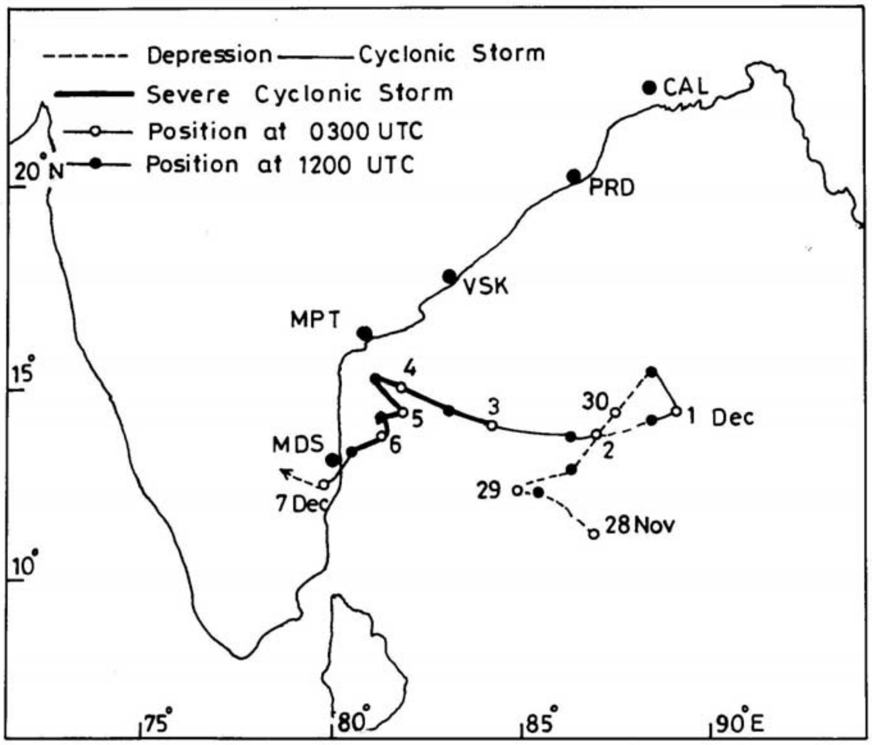


Fig. 7. Track of cyclonic storm during 28 November - 7 December, 1996 over Bay of Bengal

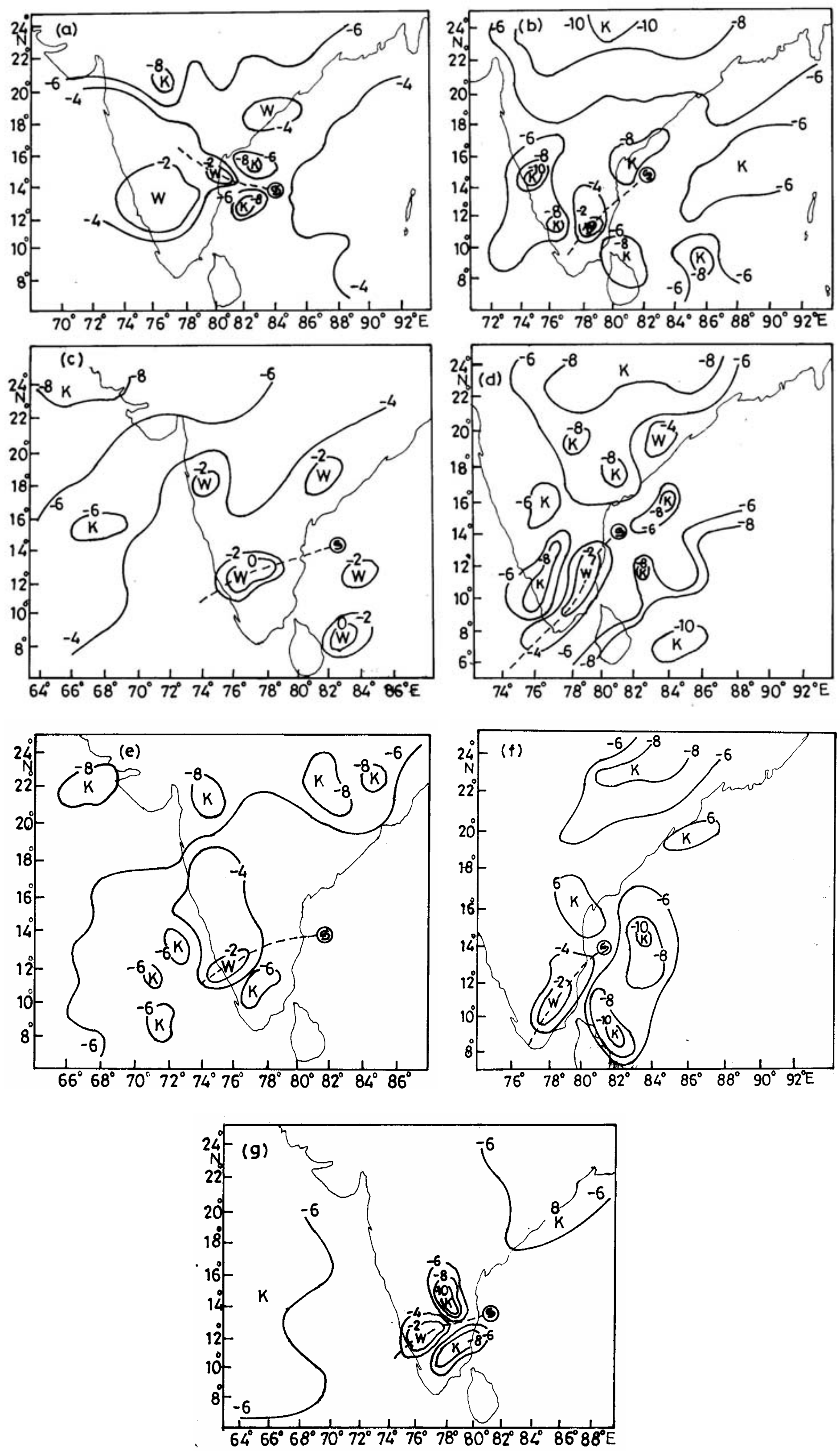
and 0205 UTC/4 passes TOVS data also reconfirmed the SSW ward movement of the storm which had actually taken place from 1200 UTC/4. 0747 UTC/4 pass (analysis not shown) predicted even the SE ward movement of the storm about 6 hours in advance. The landfall was very well predicted based on 2024 UTC/4, 0738 & 0918 UTC and 2014 UTC/5 and 0728 UTC/6 satellite passes.

4. Limitations and scope for future research

The above analysis were carried out using the TOVS retrievals obtained from NOAA 12 and 14 satellites. NOAA 15 satellite launched on 13 May 1998 has advanced microwave sounding (AMSU) as a component of advanced TOVS(ATOVS) which has 20 channels compared to 4 channels in MSU of TOVS (Kidder and Harr, 1995). NOAA 15 is on operational mode from the latter half of 1998. The resolution of ATOVS is 2 to 6 times higher than that of TOVS (48 km in AMSU-A and 16 km in AMSU-B of ATOVS as compared to 110 km in MSU). The salient features of AMSU is that besides improved spatial resolution and quality of sounding, it measures the tropical cyclone parameters of interest such as thermal anomalies, wind speeds and rain rates and open a new horizon to estimate the central pressure of a cyclonic storm through statistical methods. Since the AMSU complements the much more frequent and high resolution geostationary satellite observations, it gives almost complete description of tropical storms (Kidder *et al*., 2000). On receipt of ATOVS retrievals, further analyses of storm will be conducted to understand the finer details of the storms.

5. Summary and conclusions

Since the forecaster is deprived of the radio-sonde data over the vast oceanic area where the genesis of the storm takes place and the storm has major sea travel before landfall, TOVS data can conveniently be used to forecast the storm movement. Moreover, as the TOVS data is available from atleast four soundings a day over any given area, the volume and quantum of data are very high in comparison to radio-sonde data. The question of compatibility with radio-sonde does not arise if we restrict only to TOVS analyses. The method outlined in this paper can be tried, initially, as a parallel forecasting tool till such time the forecaster is satisfied with the suitability of the technique in conformity with the climatology and



Figs. 8(a-g). Analysis of 700-400 hPa layer mean temperature during 28 November - 7 December, 1996 persistence methods. The method can easily be made operational, if found suitable, thanks to the rapid advancement in computing technology.

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