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# Impact of ATOVS temperature and moisture profiles on NCMRWF analysis and prediction

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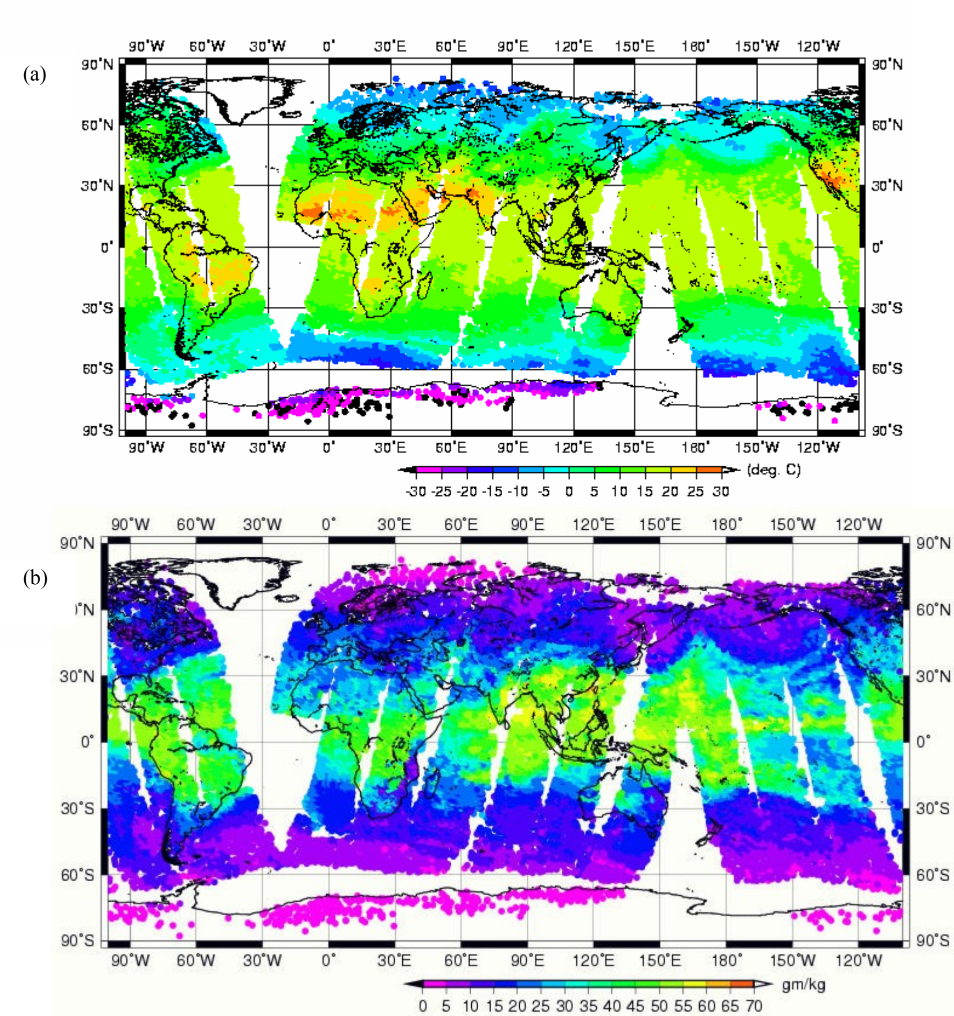
**सार** –एन.ई.एस.डी.आई.एस. (राष्ट्रीय पर्यावरणीय उपग्रह, आँकड़ा और सूचना सेवा) द्वारा हाल ही में उपभोक्ता समुदाय के लिए ध्रुवीय कक्षीय उपग्रहों एन.ओ.ए.ए. 15 और 16 से भूमंडलीय उच्च विभेदन (120 कि.मी.) ए.टी.ओ.वी.एस. तापमान और नमी प्रोफाइल के आँकड़े उपलब्ध कराए गए। राष्ट्रीय मध्यावधि पूर्वानुमान केन्द्र ने भी इन सूचनाओं का अपने प्रचालनात्मक भूमंडलीय आँकड़ा समावेशन पद्धति में उपयोग करना आरंभ कर दिया है। इनके प्रचालनात्मक उपयोग से पहले गहन प्रभाव मूल्यांकन प्रयोग किए गए हैं। भारत में दक्षिणी पश्चिमी मानसून के आगमन के समय भी इनके प्रभाव का अध्ययन किया गया है। इस शोध–पत्र में इन प्रयोगों के परिणामों को प्रस्तुत किया गया है। इस अध्ययन से पता चला कि विशेषकर महासागरीय क्षेत्र में 120 घंटे तक के पूर्वानुमान के लिए ए.टी.ओ.वी.एस आँकड़ों का प्रभाव औसत विश्लेषित और पूर्वानुमानित फील्ड में देखा गया है। इससे यह भी पता चला है कि इन आँकड़ों के उपयोग से भारतीय प्रायद्वीपीय क्षेत्र और उसके समीपवर्ती समुद्रों में वर्षा का 72 घंटे तक का पूर्वानुमान और अधिक बेहतर तरीके से लगाया जा सकता है। इस संबंध में इससे और अधिक सुधार की गुंजाइश नहीं है।

**ABSTRACT.** Global high resolution (120 km) ATOVS temperature and moisture profile data from polar orbiting satellites NOAA 15 & 16 is been made available to user community recently by NESDIS (National Environmental Satellite, Data and Information Service). NCMRWF also has started using these products in its operational global data assimilation system. Extensive impact assessment experiments have been conducted prior to its operational utilization. Impact is also studied during the onset phase of southwest monsoon over India. Results of these experiments are presented in this article. Study show that the impact of ATOVS data is seen on the mean analysed and predicted fields upto 120 hrs prediction specially over the oceanic region. It also reveals that the utilization of these data is able to predict the rainfall over the Indian peninsular region and the adjoining ocean in more realistic manner upto 72 hr forecast, beyond which there is hardly any meaningful improvement.

**Key words** – ATOVS, NOAA-15&16, Temperature profile, Total precipitable water, Data assimilation, Observing system experiments, RMSE, Systematic error, Remote sensing.

## 1. Introduction

Quality of weather forecasting has improved immensely over the last century and one of the major reasons for the improvement is significant achievement in our ability to observe global atmosphere more thoroughly both in space and time. Conventional observations over the oceanic region are inadequate to determine the initial structure of the atmosphere and hence continuous efforts are on at different numerical weather prediction (NWP) centers to utilize various other types of data. Technical advancement to collect and process the wide variety of space based observations and the cost effectiveness of the space-based system has opened an opportunity to assimilate all these new information. Temperature and moisture profile data from polar orbiting satellite is one of such data set. The vertical profiles of temperature and humidity from TIROS Operational Vertical Sounder (TOVS) system, on board NOAA series of satellite were available to scientific community since 1979. NCMRWF was using global coarse resolution (500 km) TOVS temperature and moisture data from NOAA –11, 12 and later NOAA-14 received through global telecommunication system (GTS) since its existence. The distribution of 500 km SATEM data on GTS has been discontinued from May 2001. Now days NESIDS processed global ATOVS (advanced TOVS) temperature and moisture profile data from NOAA 15 & 16 at 120 km resolution in BUFR code is been made available to user community.




**Figs. 1(a&b).** (a) Temperature at 850 hPa (ATOVS NOAA 15 & 16) received at NCMRWF 0000 UTC 29 September 2001 and (b) Total precipitable water content (TPWC) (ATOVS NOAA 15 & 16) received at NCMRWF 0000 UTC 29 September 2001

The positive impact of assimilation of ATOVS data on global analysis-forecast system was reported by many operational NWP centers. The incorporation of ATOVS level-1b radiance in the global variational assimilation system of National Centre for Environmental Prediction (NCEP), USA has resulted in a significant improvement in the forecast models skill mainly in the upper levels and over the southern hemisphere (Derber, 1999). The positive impact over the southern hemisphere and tropics also reported (Okamato, 1999) after incorporating NESDIS derived ATOVS temperature and moisture in Optimum Interpolation(OI) analysis of Japan Meteorological Society (JMA). English *et al.* (2000) have compared the impact of TOVS and ATOVS satellite sounding data on the accuracy of numerical weather forecasts and found the reduction of forecast error by 20% over the southern hemisphere and 5% in the northern hemisphere after utilizing ATOVS temperature information.

Impact of global coarse resolution (500 km) TOVS data on global data assimilation-forecast system (GDAFS) of NCMRWF has been studied by Bohra *et al.*, 1998. The study show that, though the TOVS data is beneficial to the GDAFS system but the coarse resolution data is not sufficient to enhance the quality of the initial condition to the desired extent. Another study (Prasad *et al.*, 1999) was carried out using high-resolution (80 km) TOVS temperature-sounding data locally derived at India Meteorological Department (IMD), New Delhi. This high-resolution data is able to bring out the impact in the synoptic scale prediction associated with tropical easterly wave activity over the north Indian Ocean. The impact of NESDIS derived global high resolution (120 km) TOVS temperature sounding were studied for a limited period 21-29 August 1998 (Prasad *et al*., 2000) which also showed positive impact associated with subtropical westerlies over the south Indian ocean(~20º S).

In this study, an attempt has been made to assess the impact of the NESDIS derived ATOVS global high resolution (120 km) temperature profiles and total precipitable water (TPWC) in the global data assimilation system of NCMRWF. Assimilation cycles have been rerun using these data for one-month period (September 2001). The impact was also studied for monsoon onset period, 20th May-20th June 2002. Salient features of ATOVS data and operational analysis-forecast system of NCMRWF are described in section 2 and section 3 respectively. Numerical experiments carried out to assess the impact are described in section 4. Results of the experiments are discussed in section 5. Conclusions are presented in section 6.

## 2. ATOVS data

NOAA-15 and 16(K&L) are the latest operational satellites in advance TIROS-N series. NOAA-15 is the first satellite to support dedicated microwave instruments for the generation of temperature, moisture profiles in cloudy region where visible and infrared sensors have reduced capabilities. In NOAA 15 and 16, Advanced Microwave Sounding Units(AMSU-A&B) have been used in place of the Stratospheric Sounding Unit (SSU) and the Microwave Sounding Unit (MSU) of the other TIROS-N series. Infrared High Resolution Radiation Sounder (HIRS) and Advanced Very High Resolution Radiometer (AVHRR) remained nearly unchanged in the new series of satellites. Atmospheric temperature and moisture profiles, total ozone and other parameters in both clear and cloudy atmospheres are being retrieved from ATOVS radiance measurements by NESIDS, using the International ATOVS Processing Package (Li *et al*., 2000). ATOVS data is being downloaded operationally at NCMRWF from August 2001 onwards in BUFR code. This data set mainly contains atmospheric temperature for 40 levels (1000-10 hPa), mixing ratio for 15 levels (1000–300 hPa), ozone amount, cloud amount and total precipitable water content etc.

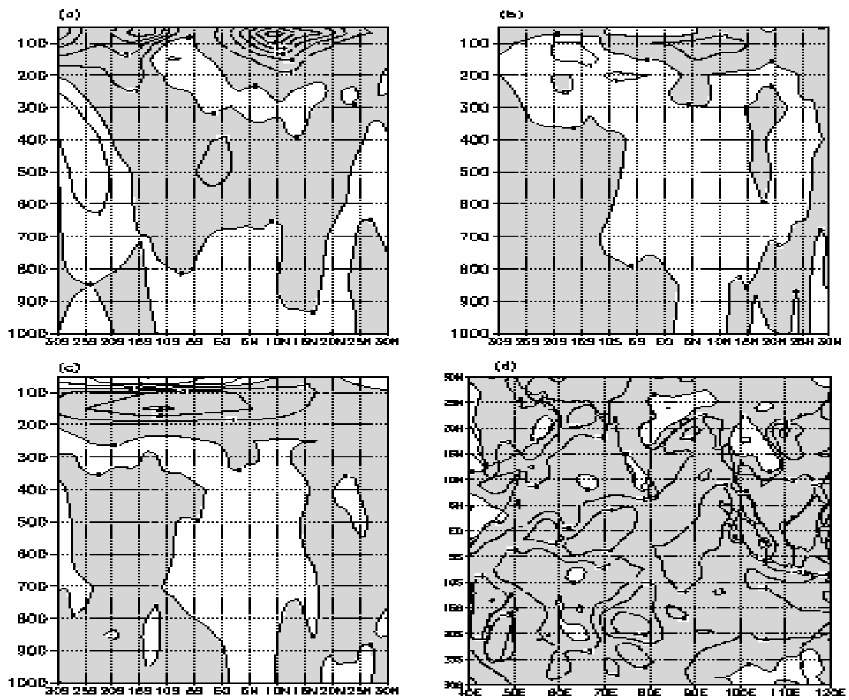
Geographical distribution of global ATOVS temperature at 850 hPa and TPWC for 00UTC ±3 hours, on 29 September 2001 are depicted in Figs. 1(a&b) respectively. In the temperature field the high temperature (heat low) over Rajasthan and adjoining Pakistan region, central African region and over Arabian region are clearly brought out, as seen in Fig. 1(a). TPWC data [Fig. 1(b)] is also able to brought out the variation as expected. The high TPWC are seen over the northern hemispheric equatorial trough region as expected. On 29th there was a cyclonic circulation extended upto 500 hPa level situated over Orrisa and adjoining Bay of Bengal region, causing heavy rainfall over that region. One can see the high value of TPWC over this region also.

## 3. Global Data Assimilation – Forecast System (GDAFS)

Impact assessment studies have been carried out using the operational GDAFS of NCMRWF. Global Data Assimilation system (GDAS) operational at NCMRWF is a six-hourly intermittent three-dimensional scheme. Main components of GDAS are, (*i*) data reception and quality Control (*ii*) data Analysis and (*iii*) short range (6 hr) prediction of a NWP model. Meteorological data from various observing platforms from all over the globe is received at Region Telecommunication Hub (RTH), New Delhi through Global Telecommunication System (GTS) and same is made available to NCMRWF. At NCMRWF, meteorological observations from all over the globe is assimilated four times a day *viz*. 0000, 0600, 1200 and 1800 UTC of everyday. Data used in the operational assimilation system of NCMRWF are SYNOP/SHIP, BUOY, TEMP, PILOT, AMDAR/AIREP, SATOB from INSAT, METEOSAT at 0° & 63° E, GMS and GOES. The observations falling within ±3 hours of the respective hour of assimilation are being used in the corresponding hour assimilation. A six-hour prediction from NWP model (T80L18), with a previous initial condition, valid for the current analysis time is used as the background field, or the first guess for the subsequent analysis. The analysis scheme used in GDAS is based on the concept of Spectral Statistical Interpolation (SSI) technique developed at NCEP, USA (Parrish and Derber, 1992). The forecast model at NCMRWF is a T80/L18 spectral global model, the initial version of which is developed at NCEP (Kanamitsu, 1989).

## 4. Numerical experiments

Assimilation-forecast cycles were rerun utilizing TPWC and temperature profile of ATOVS for 25 August - 30 September 2001. During the this period the operational assimilation cycle was using TPWC and ocean surface wind speed of SSM/I along with other operationally available data sets described in section 3. The temperature profiles for 16 standard pressure levels (1000 –10 hPa) mainly over oceanic region and TPWC of ATOVS over land and sea both within 60º N-60º S have been assimilated in place of SSM/I TPWC along with other data sets in the first experiment. The temperature



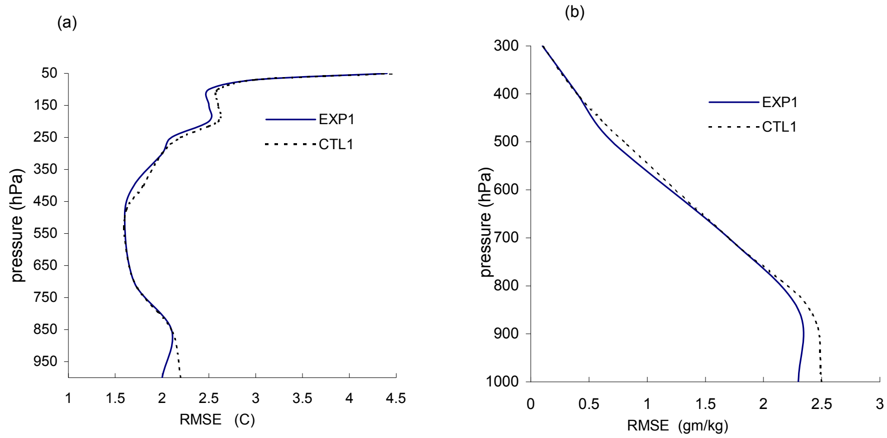

**Figs. 2(a-d).** Vertical cross section or sectoral mean difference (CRTL-EXP) for (a) zonal wind, (b) meridional wind, (c) temperature and (d) geographical distribution of TPWC difference

profiles in the higher level (above 50 hPa) over land also have been assimilated, as there are very few radiosondes, which go beyond 50 hPa over the tropical region. The operational run is been assumed as the control run and the analyses and forecast field generated by inclusion of these new data sets (EXP1) are compared with the corresponding operational archive (CTL1).

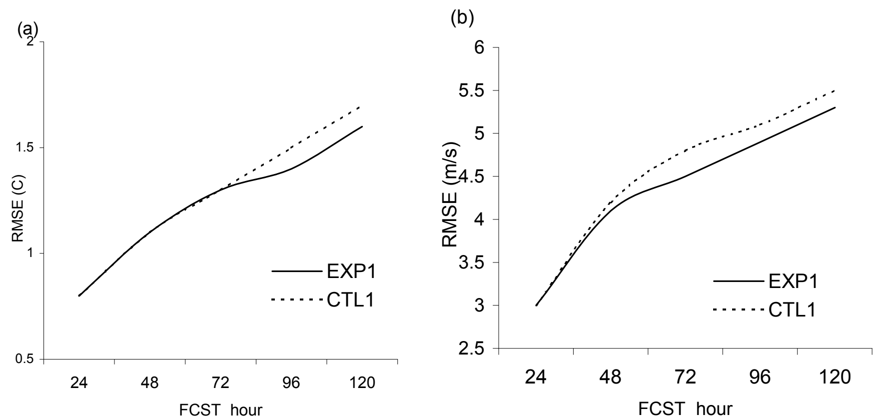
To assess the impact of ATOVS data on the large-scale circulation features during the southwest monsoon onset phase, another set of experiment was carried out for 25 May-15 June 2002. During this period, the operational assimilation cycle (OPER) was using ATOVS temperature profile and TPWC as described earlier. The assimilation-forecast system were rerun (NOATOVS), without ATOVS data form the operationally used data sets.

## 5. Results and discussion

Assimilation of ATOVS data has resulted in some significant changes to the mean analysed fields. Earlier studies by various scientists referred above have discussed the impact of the data over both hemispheres in detail. Though in general, positive impact is seen in the present study throughout the globe but for brevity the detail discussion will be mainly confined on the impact over India and adjoining region. Figs. 2 (a-c) show the vertical cross-section of the sectoral mean (40º E - 120º E) difference (EXP1-CTL1), computed for the monthly mean(1 – 30 September 2001) analysed zonal component of wind, meridional component of wind and temperature respectively. The shaded region in the plots depicts the negative difference. The sectoral mean difference of zonal wind (*u*), over the equatorial region in the lower tropospheric level [Fig. 2(a)] shows the positive difference, revealing the marginal strengthening of lower tropospheric cross-equatorial flow in EXP1 compared to CTL1. But in the higher level, the tropical easterly jet stream (core ~10º N) has shown a strengthening of 6m/s in EXP1. The difference in the sectoral mean meridional wind (*v*) of two sets of mean analysis is less compared to *u*, though a slight strengthening in the southerly component of cross-equatorial flow is noticed just north of equator in EXP1. The difference in temperature field is prominent (~3º C) over the southern hemisphere, specially in the higher levels, as there are very few radiosonde observations over this region. The temperature at almost all levels upto 200 hPa along equator is marginally higher in EXP1. Fig. 2(d) shows the geographical distribution of analysed TPWC difference (EXP1-CTL1). As seen in the plot, analysed TPWC in EXP1 is less than that of CTL1




**Figs. 3(a&b).** Mean monthly RMSE of analysis computed against radiosonde observations over Indian region (a) temperature and ( b) specific humidity for 0000 UTC, September 2001

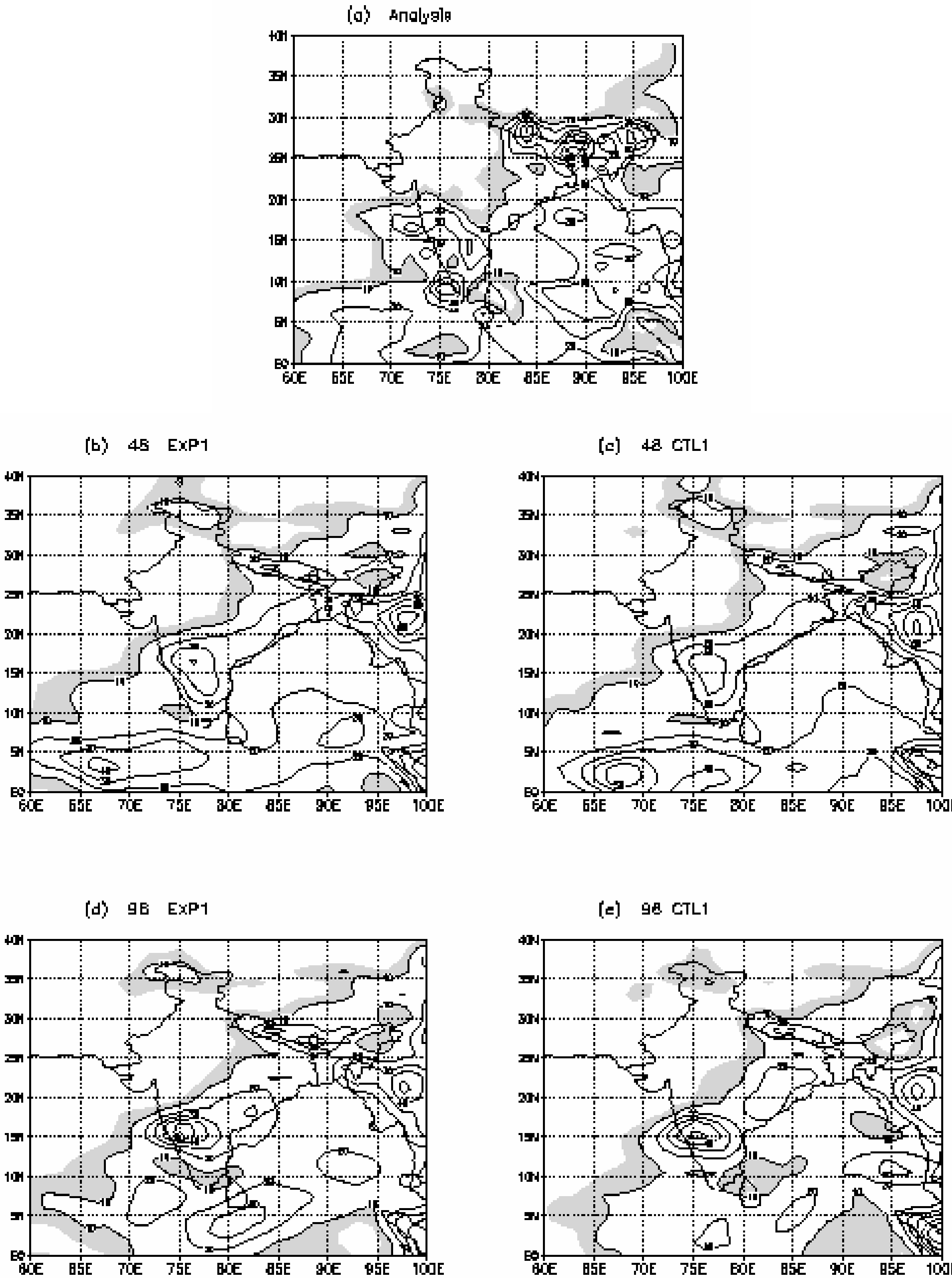



**Figs. 4(a&b).** Mean monthly RMSE of forecast computed against respective analysis at 850 hPa over Indian region (a) temperature and (b) vector wind for 0000 UTC September 2001

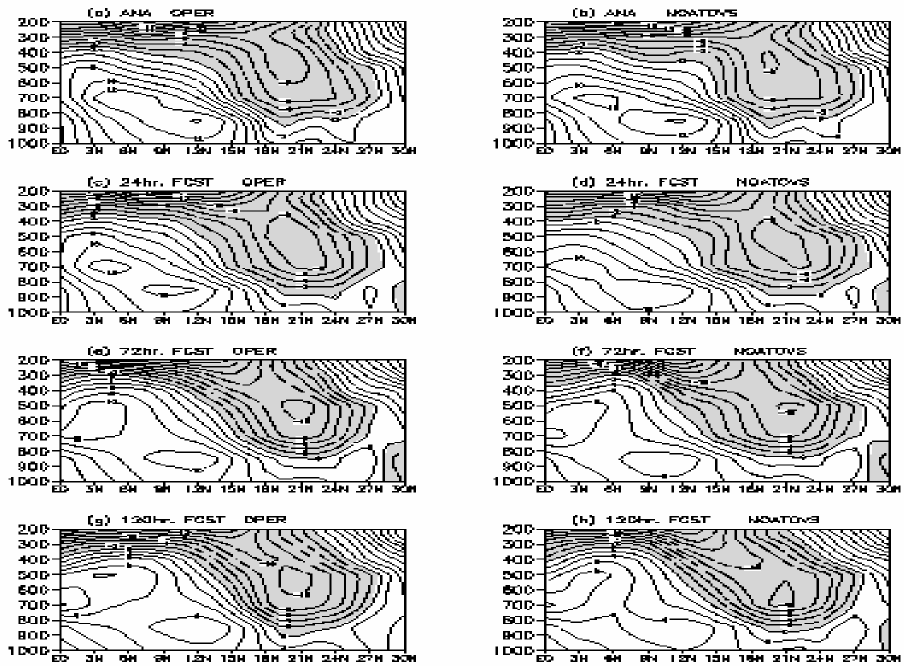
almost all over the region. The difference is generally more over the oceanic region. Nevertheless there are some areas specially over the land, where the analysed TPWC in EXP1 is more than that of CTL1. These regions, such as (*i*) peninsular Indian region along the west coast, (*ii*) central Indian region covering Orissa, east M.P. and adjoining monsoon through region, and (*iii*) Myanmar and adjoining Thailand region. All these regions generally are the regions of heavy precipitation during monsoon season.

Root mean square errors (RMSE) of analysed field (*z*, *u*, *v*, *t*, *q*) against observations have been computed for various regions such as, global, northern hemisphere, southern hemisphere, tropics, Indian region (66º E- 96º E & 6º N- 36º N) etc. for EXP1 and CTL1 at different vertical levels. Though there is almost no improvement or negligible improvement of RMSE of EXP1 compared to CTL1 over northern hemisphere, but slight improvement is seen over southern hemisphere and Indian region. RMSE of temperature(*t*) and specific humidity(*q*) of EXP1 and CTL1 computed against radiosonde observations over Indian region averaged over the month for 0000 UTC, September 2001 at different vertical levels are plotted in Figs. 3(a&b) respectively. As seen from the plot, the RMSEs of temperature and specific humidity of EXP1 are less compared to that of CTL1 specially below 850 hPa and above 500 hPa levels.

Impact of data on forecast is examined through forecast RMSE computed against the respective analyses for both EXP1 and CTL1. In general there is a marginal




**Figs. 5(a-e).** Analysed and predicted total rainfall for September 2001 (a) Analysis, (b) 48 hr Prediction EXP 1, (c) 48 hr Prediction CTL1, (d) 96 hr Prediction EXP1 and (e) 96 hr Prediction CTL1

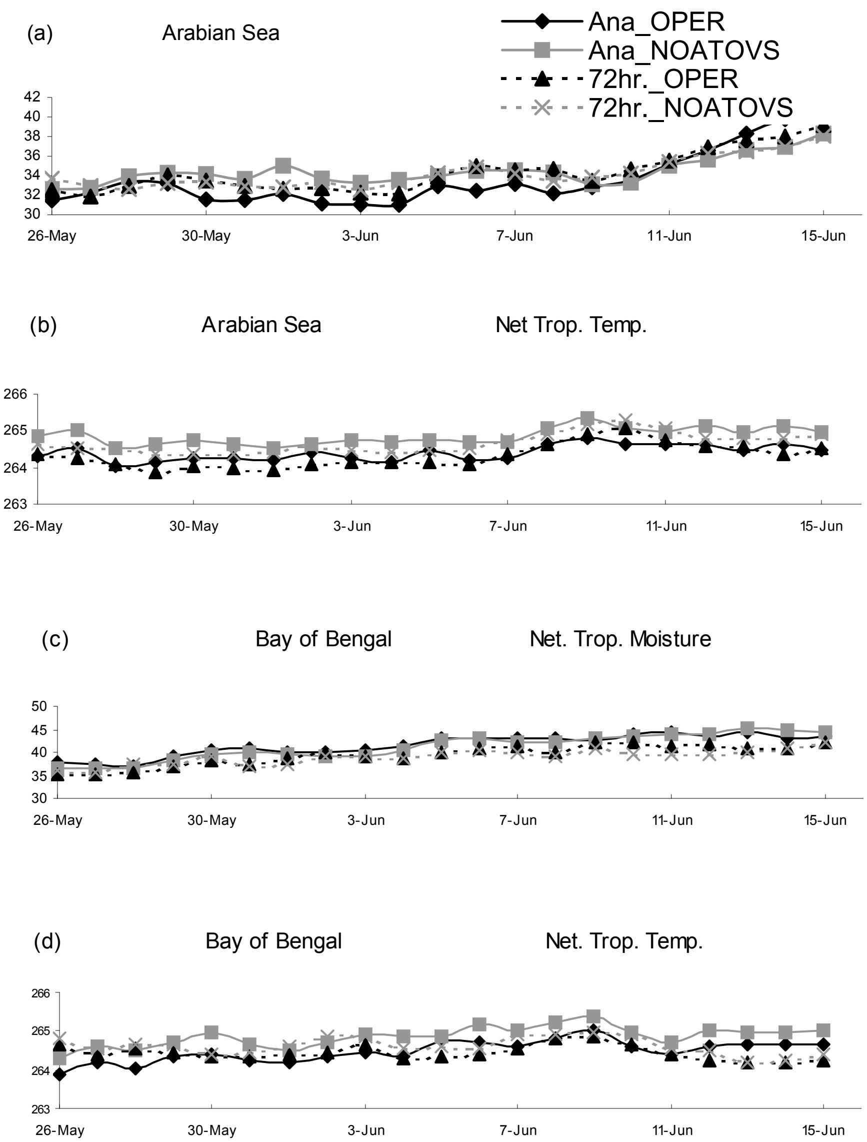


**Figs. 6(a-h).** Height latitude cross section of zonal wind at 80° E at different latitude analysis, 24 hr, 72 hr & 120 hr forecast for OPER and NOATOVS averaged for 0000UTC, 1-15 June 2002

improvement in forecast RMSE of EXP1 compared to that of CTL1. The forecast RMSE averaged over 0000 UTC forecast for 1 – 30 September 2001 for temperature and wind speed at 850 hPa over the Indian region are shown in Figs. 4(a&b) respectively. RMSEs of both the fields for EXP1 are less than that of CTL1 beyond 48 hour forecast onwards.

Impact on forecast is also examined through the precipitation forecasts. The total predicted precipitation for the month of September 2001 for different lengths of forecast are compared to that of the satellite and rain gauge merged observed rainfall analysis (Mitra *et al.*, 1997). Fig. 5 shows the total analysed and predicted (48 hr & 96 hr) rainfall over India and adjoining region for EXP1 and CTL1. 48hr predicted total rainfall for September 2001 has computed by adding all the accumulated predicted rainfalls from 24hr to 48hr of forecast, based on run of all the days (30 days 0000 UTC) initial conditions. Similarly 96 hr total rainfall has been computed by adding all the rainfall predictions accumulated for 72 hr to 96 hr. There are two regions of rainfall maxima in the rainfall analysis, one over sub-Himalayan West Bengal region of India and adjoining Nepal, and another along the west coast of India. Since the rainfall over both the regions are basically dominated by topography, the ATOVS data have almost no impact on the rainfall over this region, though EXP1 shows a marginal increase of rainfall amount over both the regions. However, the impact of data is seen on the precipitation forecast over the oceanic region. The rainfall over the north Indian Ocean between 60º E to 80º E is over predicted in 48 hr and under predicted in 96 hr forecast of CTL1. Over this region the rainfall prediction of EXP1 better matches with the analysed rainfall compared to that of CTL1. Similarly over the Andaman Sea region (~ 90º E/8º N) the predicted rainfall of EXP1 better matches with the analysed rainfall.

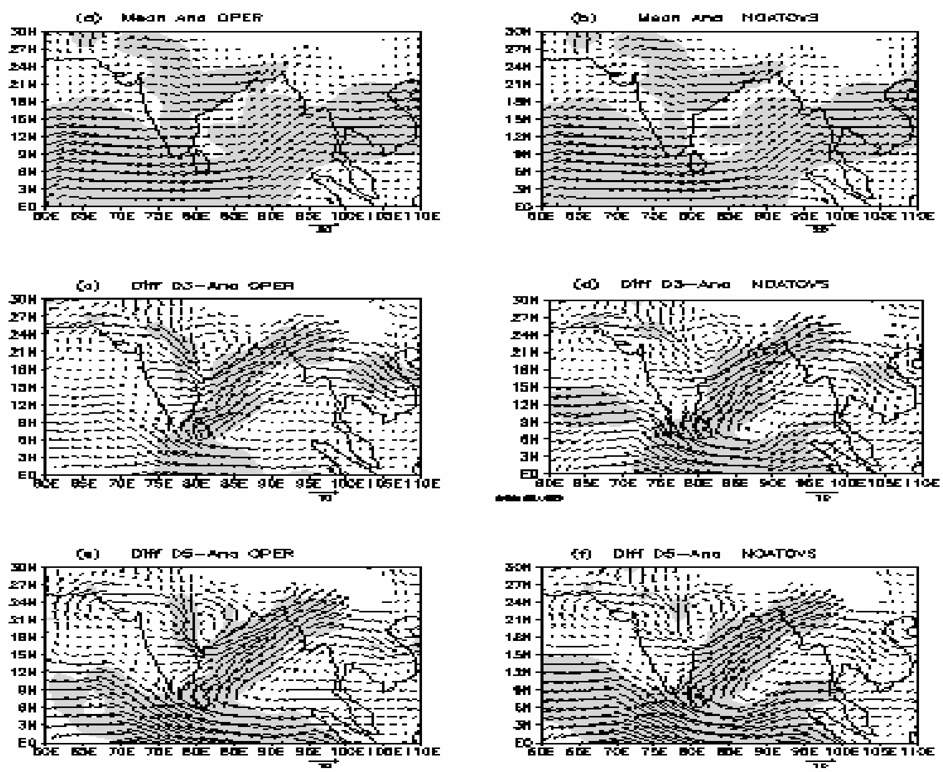
For the second experiment (NOATOVS), the emphasis was given to examine the impact of ATOVS data on the large-scale circulation and other related features during onset phase of southwest monsoon. The analysis and subsequent predictions of the strength of lower level jet, tropospheric moisture content, mean tropospheric temperature etc. of OPER are compared with that of NOATOVS over the Arabian Sea (55.5º E-75º E, 0º-19.5º N) and Bay of Bengal (BOB) region (78º E-96º E, 0º-19.5º N). The latitude-height cross-sections of mean (0000 UTC, 1-15 June 2002) analyzed and predicted zonal wind along 60° E, a longitude where the core of lower level jet (LLJ) was seen during this period are shown in Fig. 6. Operational T80 model has a tendency to weaken the strength of LLJ with forecast time. Mean analysed strength of LLJ was 14 mps at 850 hPa level, centered around 12° N, both in OPER and NOATOVS.




**Figs. 7(a-d).** Net tropospheric moisture and net tropospheric temperature Analysis and 72 hr forecast for OPER & NOATOVS over Arabian Sea and Bay of Bengal

The strength of equatorial westerlies in the middle troposphere is marginally increased (~2m/s) in mean analysis of OPER compared to that in NOATOVS. Though both the runs show the weakening of LLJ with forecast time, but the strength of LLJ is better maintained in the subsequent predictions of OPER compared to NOATOVS. However no significant differences are seen in upper level easterlies for both sets of analyses and subsequent predictions.

Net tropospheric moisture (1000-300 hPa) build up and mean tropospheric temperature (1000-100 hPa) are two parameters closely associated with the onset of monsoon. The daily variation of these two parameters, in analyses and subsequent predictions over Arabian Sea and Bay of Bengal are shown in Figs. 7(a-d) for analyses, 72hr and 120 hr predictions for both OPER and NOATOVS during 26 May - 15 June 2002. Though one can see the similar trend in the variation of these parameters for both the runs, but their absolute values are different. Arabian Sea is less moist in OPER run compared to NOATOVS, where as BOB is less moist in OPER. The mean tropospheric temperature over both Arabian Sea and BOB are less in OPER compared to NOATOVS. Over




**Figs. 8(a-f).** Mean analysis and difference of 72 hr and 120 hr forecasts from respective analysis for OPER and NOATOVS at 850 hPa wind 0000 UTC, 1-15 June 2002

Arabian Sea net tropospheric moisture shows a steep rise in OPER from 10 June onwards associated with an active monsoon phase over the west coast of India where as the rise in NOATOVS is not that steep. However, 72 hr forecasts of both the parameters are generally better verified with respective analyses in OPER compared to NOATOVS.

Finally the impact of the ATOVS data is seen on the systematic error of the model prediction also. Systematic errors of any model are mainly due to the constraints associated with the formulation of the forecast model *e.g.* large observational data gaps, uncertainties in the parameterization of various physical processes, representation of orography, the reliable surface boundary conditions, etc. Though the nature of the systematic error in the wind field has not changed after utilisation of ATOVS data, but the magnitude, specially over the oceanic region have been reduced drastically, almost at all the levels. For brevity the geographical distribution of mean analysed wind field for 0000 UTC 1-15 June 2002, at 850 hPa only, over India and adjoining region, along with the differences of 72 hr forecast and 120 hr forecast from the respective analysis are shown in Fig. 8. Shaded region in the plot delineate the region with wind speed more than 5m/sec. As seen from Figs. 8(a&b), there is hardly any noticeable difference between the mean analysed wind fields at 850 hPa of OPER and NOATOVS. The comparison 72 hr forecast error of OPER [Fig. 8(c)] and NOATOVS [Fig. 8(d)] shows that weakening of cross equatorial flow, LLJ and south easterly trade wind, which are some of the systematic errors of the model at lower level (Ramesh & Iyengar, 1999) are present in both sets of forecasts but the magnitude of weakening is decreased considerably in OPER compared to NOATOVS. However the formation of anomalous cyclonic circulation over east coast of India north of 15° N persist in both OPER and NOATOVS, and there are marginal deterioration of forecast error, in some regions specially over the land OPER. Systematic errors in 120 hr predictions of OPER [Fig. 8(e)] also show the same type of improvement over the oceanic region and slight deterioration over land when compared to that of NOATOVS [Fig. 8(f)], though the magnitude of improvement is less than that in 72 hr forecast.

## 6. Conclusions

An overall improvement is noticed in the analysis-forecast system after utilization of ATOVS data. However the broad conclusions drawn based on the above described experiments are as follows:

(*i*) Impact of ATOVS temperature and TPWC data are seen on the monthly mean analysis of different meteorological parameters.

(*ii*) There is an improvement in RMSE of various analysed parameters, when RMSE computed against radiosonde observations at different levels over southern hemisphere, tropics and especially over Indian region.

(*iii*) Utilisation of these data sets in GDAFS is able to bring some meaningful improvement in the precipitation forecast upto 72 hr TPWC of SSM/I had a tendency to over predict the precipitation amount over the north Indian Ocean and adjoining Arabian Sea region in the initial days of forecast, which has been rectified realistically after using ATOVS data. ATOVS data has very less impact on the precipitation forecast over the topographically induced region of high precipitations.

(*iv*) Forecast RMSEs computed against the respective verifying analysis suggest some improvement over the Indian region.

(*v*) ATOVS data found to be helpful to maintain the strength of LLJ, cross equatorial flow etc. upto 120 hr predictions during monsoon onset phase.

NESDIS derived ATOVS temperature profile and TPWC have been used in this study, however it is generally found that model dependent locally derived (1D-Var) gives further better impact on Analysis and subsequent forecast. Efforts are on at NCMRWF to utilise 1D-var retrieved profiles, which may produce more realistic forecast in near future.

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