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Assimilation of special observations taken during the INDOEX and its impact on the global analysis-forecast system

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RESUMEN

Para la determinación precisa de la estructura tridimensional de la circulación atmosférica es muy importante asimilar cada observación de todas las fuentes de variables, especialmente sobre las regiones oceánicas escasas de datos. Durante la fase intensiva de campo de 1999 del experimento del Océano Índico (INDOEX-IFP 99), se hicieron varias observaciones particulares sobre el Océano Índico que dieron la oportunidad de estudiarlo más exhaustivamente. En este estudio, estas observaciones particulares se han asimilado, junto con otras observaciones convencionales y no convencionales recibidas en el Centro Nacional para el Pronóstico Meteorológico de Rango Medio (NCMRWF), a través del Sistema Global de Telecomunicaciones en sus sistema de análisis global de pronóstico. El propósito de este estudio es determinar el impacto de los datos adicionales sobre el Sistema Global de Asimilación de Datos del NCMRWF, así como generar mejores condiciones iniciales para su uso futuro en estudios de modelado.

Se ha estudiado el impacto de los grupos de datos en análisis y pronósticos subsecuentes de 5 días en los campos medios mensuales. El campo medio de viento muestra el fortalecimiento de las tendencias de los vientos en los niveles bajos y el fortalecimiento del viento alrededor del anticiclón subtropical en los niveles altos. Se ha encontrado que el impacto es mayor sobre las regiones oceánicas escasas de datos y en los niveles altos en comparación con los niveles bajos. Se ha estudiado el impacto de estos grupos de datos sobre diferentes condiciones iniciales así como sobre el pronóstico. Se han observado impactos significativos sobre aquellas regiones oceánicas donde persisten sistemas sinópticos bien definidos.

ABSTRACT

For accurate determination of the three-dimensional structure of atmospheric circulation, it is very important to assimilate every observation from all available sources, especially over the data sparse oceanic regions. During the Indian Ocean Experiment Intensive Field Phase -1999 (INDOEX-IFP 99) several special observations were taken over the Indian Ocean region, which gave an opportunity to study this region more thoroughly. In this study these special observations, along with atmospheric motion vectors that form METEOSAT-5(63^{o}E), have been assimilated along with other conventional as well as non-conventional observations received at the National Centre for Medium Range Weather Forecasting (NCMRWF) through the Global Telecommunication System (GTS) in its global analyses-forecast system. The aim of this study is to assess the impact of the additional data on the Global Data Assimilation system of NCMRWF as well as to create better initial conditions for its future use in modeling studies.

Impact of INDOEX data sets on analyses and subsequent 5-day forecast has been studied on the monthly mean fields. Mean wind field shows the strengthening of trade winds in the lower levels and the strengthening of the wind around sub-tropical anticyclone in the higher levels. It is found that the impact is stronger over the data sparse oceanic region and in the higher levels compared to the lower levels. The impact of these data sets is studied on different initial conditions as well as forecast as part of case studies. Significant positive impacts, specially on analysis, are noticed over those oceanic regions where some well-defined synoptic system persisted.

Key words: Data assimilation, INDOEX, forecasting.

1. Introduction

Atmospheric data assimilation is the process to determine a consistent four-dimension atmospheric state by objectively analysing the various meteorological parameters using several information such as meteorological observations, background fields, dynamical constrains (like mass-motion relationship), various types of statistical information about the observations, etc. It is well known that the quality of any objective analysis of the atmospheric fields depends upon the density and the quality of the observations assimilated to produce the analysis. Data scarcity over the tropical oceanic region is one of the major problems associated with numerical weather prediction (NWP) over the tropics. So the assimilation of any additional information over this region is likely to provide better initial conditions (Basu and Das Gupta, 2001), which in turn would show a positive impact on subsequent forecasts. Several studies have been carried out to assess the impact of various types of meteorological observations on the analysis-forecast system. Impact of Network wind profiler data across the United States of America on the Mesoscale Analysis and Forecast system has been studied by Smith and Benjamin (1993), revealing that the profiler data improved the overall short range forecast in the study area. Tuleya and Lord (1997) studied the impact of dropwindsonde data on tropical storms over the Atlantic, indicating a positive impact of data on track forecasting. Impact of satellite data on 35 years of reanalysis has been assessed by Mo *et al.* (1995) The study found that the analyses in the Northern Hemisphere (NH) are basically unaffected by the satellite data though the satellite data impact on the forecasts in NH is positive but very small, about 1% a in 5-day forecast. However, the impact is greater over the tropics and the Southern Hemisphere. Velden *et al.* (1992) studied the impact of satellite derived wind on track prediction of hurricanes, and found it to be positive. Most of these studies used additional data (except satellite) over the extra tropical region of Northern Hemisphere and emphasized the impact mainly over that region. INDOEX intensive field phase experiments was carried out in the Tropical Indian Ocean region from January to March 1999. A large number of scientists from India, Europe, the U S and the Indian Ocean region participated in INDOEX. India deployed an oceanic research vessel (ORV), Sagar-Kanya. The U S deployed the research vessel Ron Brown. The European Space Agency (ESA) specially shifted one geo-stationary satellite, METEOSAT-5 along 63°E to monitor the weather phenomenon over the Indian Ocean region. Special observations were taken at Male Airport (Maldives) for the February to March 1999 period. All these especially collected observations gave us an opportunity to study the impact of these data over the Indian Ocean region.

A pilot study (Basu and Das Gupta, 2001) was undertaken to assess the impact of ORV Sagar-Kanya observations for 1st-8th February 1998 on NCMRWF analysis-forecast system, which shows positive impact on the analysis and subsequent forecasts. In this study the cloud motion vectors from METEOSAT-5, the rawinsonde observations from two ships viz. Sagar-Kanya and Ron Brown, surface and rawinsonde observation from two island stations viz. Maldives and Diego Garcia and the dropsonde data from the UCAR (University Corporation for Atmospheric Research) C-130 (aircraft) have been assimilated along with other conventional as well as non-conventional observations received on real time at NCMRWF via GTS during 1st February-10th March 1999. During this period there was one tropical depression over the south Indian Ocean region from 3rd-8th February 1999, and another tropical storm, Davina, from 3rd-12th March 1999. The impact of the data sets on these tropical systems has been examined. The impact on the analysis-forecast system are examined with respect to the analysed mean circulation fields for February 1999 and through statistical scores computed over various regions. A brief description of NCMRWF's operational Analysis-Forecast system is given in section 2. The various types of special data sets, other than the operational one, assimilated to study the impact are described in section 3. The results of the experiments have been presented and discussed in section 4, and conclusions can be found in section 5.

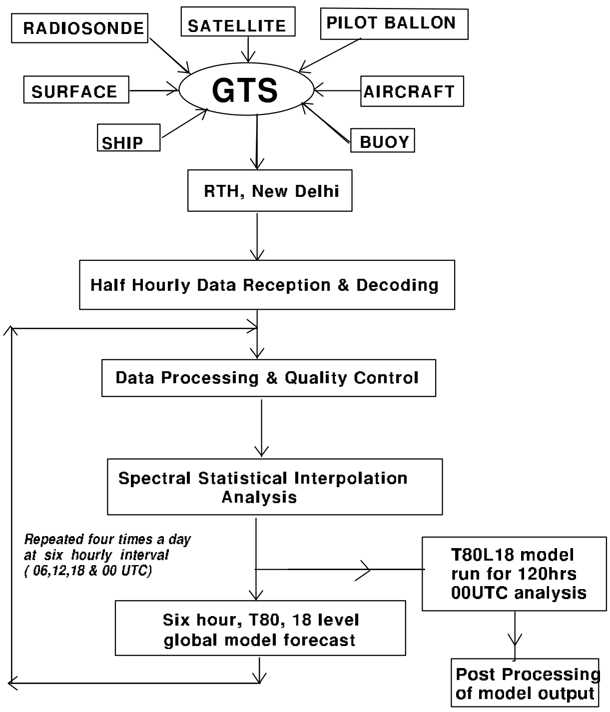


Fig. 1. The schematic diagram showing the flow of Global Data Assimilation and Forecasting system operational at NCMRWF.

2. Analysis-Forecast system

The Global Data Assimilation system (GDAS) operating at NCMRWF is a six-hourly intermittent three-dimensional scheme. At the NCMRWF, meteorological observations from all over the globe are assimilated four times a day viz. 0000, 0600, 1200 and 1800 UTC. The assimilation scheme utilizes all data collected within 3 hours of the assimilation time and received within a specific cut-off period ($\sim$ 12 hours for 0000 UTC). A six-hour prediction from the Numerical Weather Prediction (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 analysis. A brief description on analysis-forecast system of NCMRWF is depicted in Figure 1.

Data used in the operational assimilation system of NCMRWF include:

(1) surface observations from land stations and voluntary observing fleet over sea (SYNOP/SHIP),
(2) drifting and moored buoy observations (BUOY),
(3) upper air profiles of temperature, moisture and wind by radio theodolite (TEMP),
(4) upper wind profiles by optical theodolite (PILOT),
(5) satellite observed cloud motion vectors (SATOB) from INSAT(Indian Satellite), METEOSAT-6(0^o) GMS and GOES,
(6) satellite observed temperature and total precipitable water (SATEM) from NOAA series of satellite,
(7) upper level wind and temperature reported by aircrafts (AIREP/AMDAR),
(8) surface wind direction and speed over oceanic region from ERS-2 satellite.

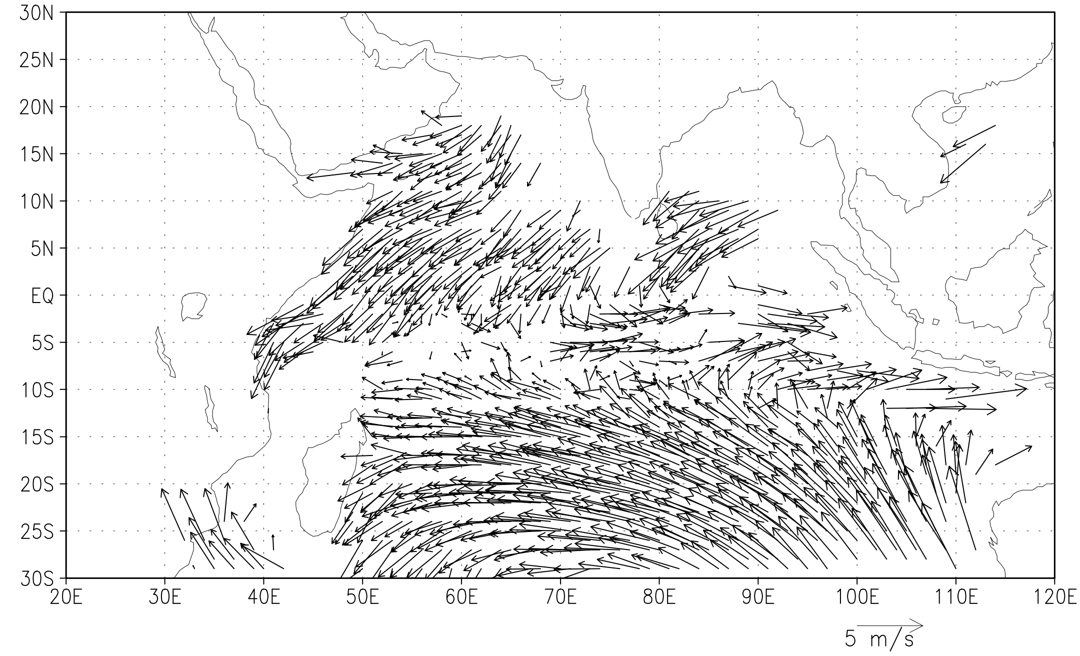
Keeping in view global observations pertaining to different types of instruments, highly heterogeneous in nature, proper processing is performed to separate them out into different categories. This is very essential as different types of observations may have different error characteristics which accordingly would have to be given due weightage in the analysis. The entire data set is passed through a comprehensive quality control procedure (Collins and Gandin, 1990), before entering them into the analysis system.

The analysis scheme used in GDAS is based on the concept of Spectral Statistical Interpolation (SSI), a technique originally developed at the National Center for Environmental Prediction (NCEP), US (Parrish and Derber, 1992). It is based on the concept of minimizing a cost function J consisting of mainly two parts J=Jges + Jobs (Lorenc, 1986), where Jges and Jobs are related to the fit of analysis with first guess and observation, respectively. J is minimized using conjugate gradient algorithm with respect to analysis variable in such a way that the analysis is best fitted with both the first guess and observations. The analysis is performed in spectral space at vertical sigma level, the analysis variables are the sigma level spectral coefficients of the empirical orthogonal functions (EOF's) of vorticity, mixing ratio, unbalanced part of divergence, temperature and log of surface pressure. The balanced parts of the various variables are computed using a quasi-geostrophic linear balance relationship (Haltiner and Williams, 1979).

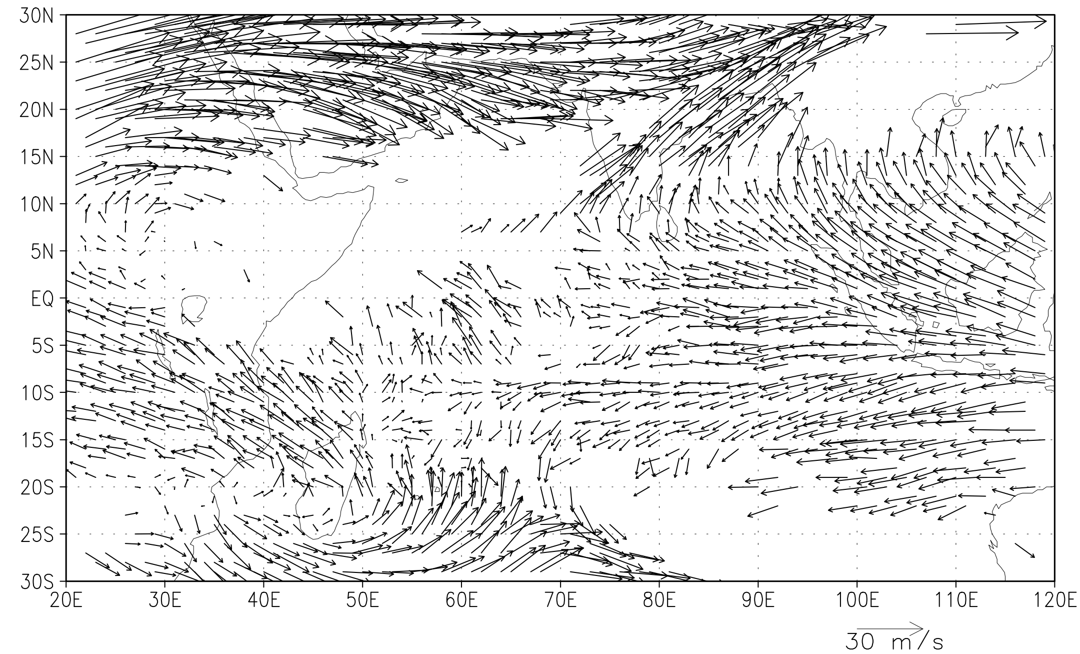
The forecast model (Kanamitsu, 1989) operating at NCMRWF is a global model, which uses the spectral method for expansion of variables in a series of spherical harmony. The forecast model variables are surface pressure, layer temperature, specific humidity, divergence and vorticity, all of which are at present expanded in a series of up to 80 waves. In the vertical, the atmosphere is sliced into 18 unequally spaced sigma layers, out of which about 12 are within the troposphere and the rest are placed above. The physical processes are computed on a Gaussian grid (128×256), which corresponds to 160 km roughly in the east-west and north-south direction. The brief description of the model is given in Table 1.

Table 1. Brief Description of the Global Spectral Model

Model Elements	**Components**	**Specifications**
GRID	HORIZONTAL	Global Spectral-T80 (256X128
	TOPOGRAPHY	Mean
DINAMICS	HORIZONTAL TRANSFORM	Orzag's Technique
	VERTICAL DIFFERENCING	Arakawa's energy conserving scheme
	TIME DIFFERENCING	Semi-implicit with 900 seconds of time step
	TIME FILTERING	Robert's method
	HORIZONTAL DIFFUSION	Second order over quasi-pressure surfaces, scales selective
PHYSICS	SURFACE FLUXES	Monin - Obukhov Similarity
	TURBULENT DIFFUSION	K-Theory
	RADIATION	Short Wave-Lacis & Hansen
		Long Wave- Fels and Schwarzkopf
	DEEP CONVECTION	Kuo scheme modified
	SHALLOW CONVECTION	Tiedtke method
	LARGE SCALE CONDENSATION	Manabe-modified Scheme based on saturation
	CLOUD GENERATION	Slingo scheme
	RAINFALL EVAPORATION	Kessler's scheme
	LAND SURFACE PROCESSES	Pan Scheme having 3-layer soil model for soil temperature and bucket hydrology of Manabe for soil moisture prediction
	AIR-SEA INTERACTION	Roughness length over sea computed by Charnock's relation. Climatological SST, bulk formulae for sensible and latent heat fluxes
	GRAVITY WAVE DRAG	Lindzen and Pierrehumbert Scheme



(a)



(b)

Fig. 2. (a) Monthly composite wind observations (lower level) from METEOSAT-5 for 00UTC of 1st-28th February 1999. (b) Monthly composite wind observations (higher level) from METEOSAT-5 for 00UTC of 1st-28th February 1999.

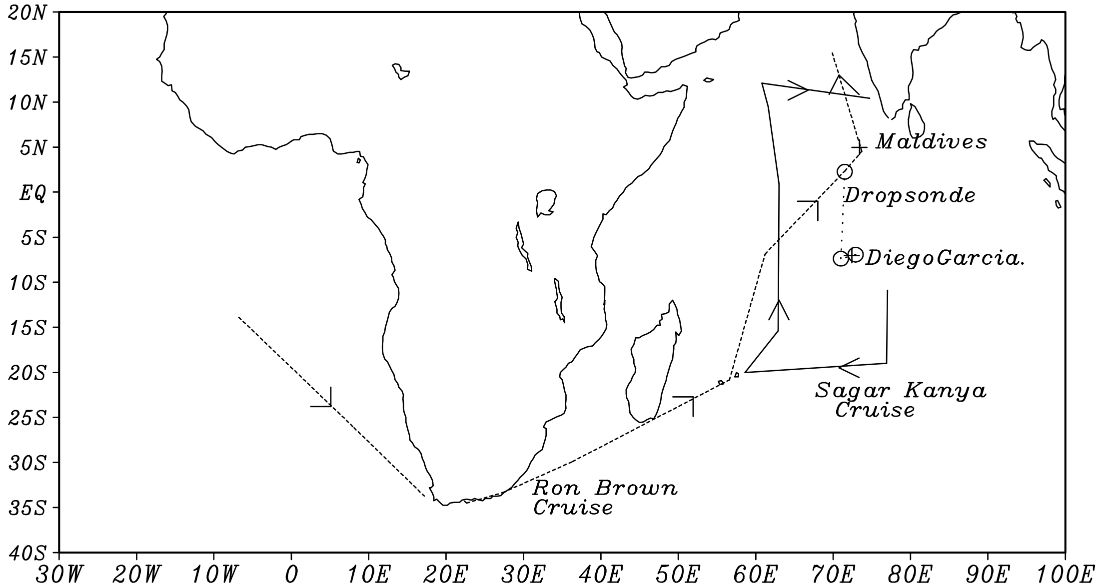


Fig. 3. Geographical location of different types of observations during INDOEX-IFP 99 (1st February-10thMarch 1999)

3. INDOEX data set

The special data set collected for INDOEX, in addition to various kinds of regular observations taken all over the globe, and received through GTS are described below.

METEOSAT data: The classical cloud motion vectors (CMW-product) from METEOSAT-5 have been assimilated for the entire period. The frequency of the observations is 16 per day, at an interval of 90 minutes. The winds were derived from all the three channels, i. e., visible (VIS), infrared (IR) and water vapour (WV) channel. Figure 2 depicts the monthly composite (1st-28th February 2000) METEOSAT-5 winds, around 0000 UTC ($\pm$ 0300 UTC) for (a) lower level (1000-700 hPa), and (b) higher level (300-100 hPa). It may be noted that in the lower level a good coverage of wind is seen over the region, 0^o to 30^oS and 40^oE to 110^oE. In contrast, the upper level winds are seen over the mid latitude and also over the tropical region along the sub-tropical anticyclones of both the hemispheres.

ORV Sagar-Kanya data: this data set consists of rawinsonde observations comprising pressure, temperature, humidity and wind from the Oceanographic Research Vessel (ORV) Sagar Kanya with a frequency of 2-3 observations per day. The track of the ship is shown in Figure 3.

ORV Ron Brown data: this data set consists of rawinsonde data collected during the INDOEX cruise of the NOAA Ship Ron Brown, comprising pressure, temperature, humidity and wind at different vertical levels of atmosphere with a frequency of 2 observations (around 1100 and 2300 UTC) per day. The track of this ship is shown in Figure 3.

Maldives data: this data set consists of rawinsonde data collected during INDOEX from the Kaashidhoo Climate Observatory at Maldives (73.47^{o}E and 4.97^{o}N). Generally there are 2-3 observations per day, but on some days there were four observations around 0600, 1200, 1800 and 2300 UTC. This data set consist of the vertical profiles of pressure, temperature, humidity and wind.

Diego Garcia data: this data set consists of rawinsonde mandatory/ significant level data in TEMP/PILOT code from the Diego Garcia station (72.40^{o}E and 7.30^{o}S) at 12-hour intervals (0000 and 1200 UTC) per day.

Dropsonde data: this dataset consists of dropsonde data from the UCAR C-130 research aircraft. Dropsondes were taken as requested on the 20th, 24th and 28th February 1999. There were 8-12 observations per day. This data set also consisted of the vertical profiles of pressure, temperature, humidity and wind. The positions of the aircraft on various dates are shown in Figure 3.

Except for the Diego Garcia data, which was available at mandatory and significant pressure levels, all other data were assimilated at an interval of 10 hPa in the vertical. Although most of the data sets described above had undergone quality control at their source along with other conventional and non-conventional data, they were also passed through the operational quality control procedure. This resulted in rejection of a very nominal amount ($\sim$ 0.01 %) of data at various levels. Reanalysis for the 1st Feb.-10th March 1999 period has been carried out using all conventional and non-conventional data that are regularly obtained at NCMRWF along with the above-mentioned INDOEX data set. Five-day forecasts are prepared using 00UTC each day as initial conditions for the whole period. The salient features of operational (OPER) analysis (without INDOEX data) and re-analysis (REAN) (with INDOEX data) and the forecasts from both sets of analyses are briefly discussed in the following section.

4. Results and discussion

The main objective of the present paper is to study the impact of additional data over the circulation pattern and related weather phenomenon over the Indian Ocean region. The results are presented in two parts: the first part focuses on the impact on individual case studies, and the second part is devoted to the analysed mean monthly features over the Indian Ocean region.

4.1 Case studies

As mentioned earlier there were two well-defined cyclonic circulations formed over the South Indian Ocean during this period. The tropical disturbance formed on 3rd-8th February 1999, was located close to 67.0^{o}E/8.0^{o}S on 3rd February 1999. Figure 4 depicts the analysed height and wind field around this location on 00UTC of 3rd February 1999, at 1000, 850 and 700 hPa level respectively for both OPER and REAN. At 1000 hPa in OPER the center of the circulation in wind field is located northwest of the observed location and a broad east-west oriented trough is seen over that region. The same features are seen at 850 and 700 hPa in OPER. Moreover, the center of the circulation in wind field and center of the contour low in the height field do not coincide with OPER in any levels. In contrast, REAN could capture the tropical disturbance with its center at about 65^{o}E and 8.5^{o}S in 1000, 850 and 700 hPa level. In REAN the cyclonic circulation is well-organised around the center of the disturbance, and in 700 hPa level there is a difference of 20 gpm in the geopotential height field compared to OPER. Analyses of this tropical system on the subsequent dates also show improvements with INDOEX data. The system is better analysed in REAN, but there is not a significant impact on prediction of the track of the system. One of the reasons for this may be attributed to the basic flow pattern in the neighbouring region, which mainly comes from the first guess and as there are very few conventional observations over this region, basic flow does not differ much in OPER and REAN.

The tropical storm Davina that formed over the south Indian Ocean during 3rd-10th March was located at 89.6^{o}E and 11.8^{o}S on 00UTC of 4th March 1999. The storm has been captured in the analysis of both OPER and REAN. Figures 5(a) and 5(b) show wind analysis at 850 hPa for OPER and REAN for 00UTC of 4th March 1999 respectively. In OPER two cyclonic circulations are seen, one centered at 85^{o}E, 11^{o}S and other at 72^{o}E and 10.5^{o}S. In contrast, in REAN there is only one cyclonic circulation centered at 87^{o}E and 11^{o}S, and the winds around the circulation are stronger ($\sim$3m/sec) compared to OPER. South-easterly winds ahead of the system, i.e., over 50^{o}E-75^{o}E and 15^{o}S-30^{o}S are quite strong($\sim$ 12m/sec.) in OPER. A well developed northwest-southeast oriented ridge is seen in OPER and has been replaced by a feeble trough in REAN. However, the intensity of the storm could not be maintained in the subsequent forecasts using both REAN and OPER. Figures 5(c) and 5(d) show the 48-hour forecasts of wind field at 850 hPa based on initial condition 00UTC, 4th March 1999 for OPER and REAN respectively. The 48-hour forecast based on OPER shows the storm lagging behind the observed position, in contrast with the forecasts based on REAN that shows better agreement. Figures 5(e) and 5(f) show the 96-hour forecasts of wind field at 850 hPa based on the same initial condition for OPER and REAN. As seen, the storm is maintained up to

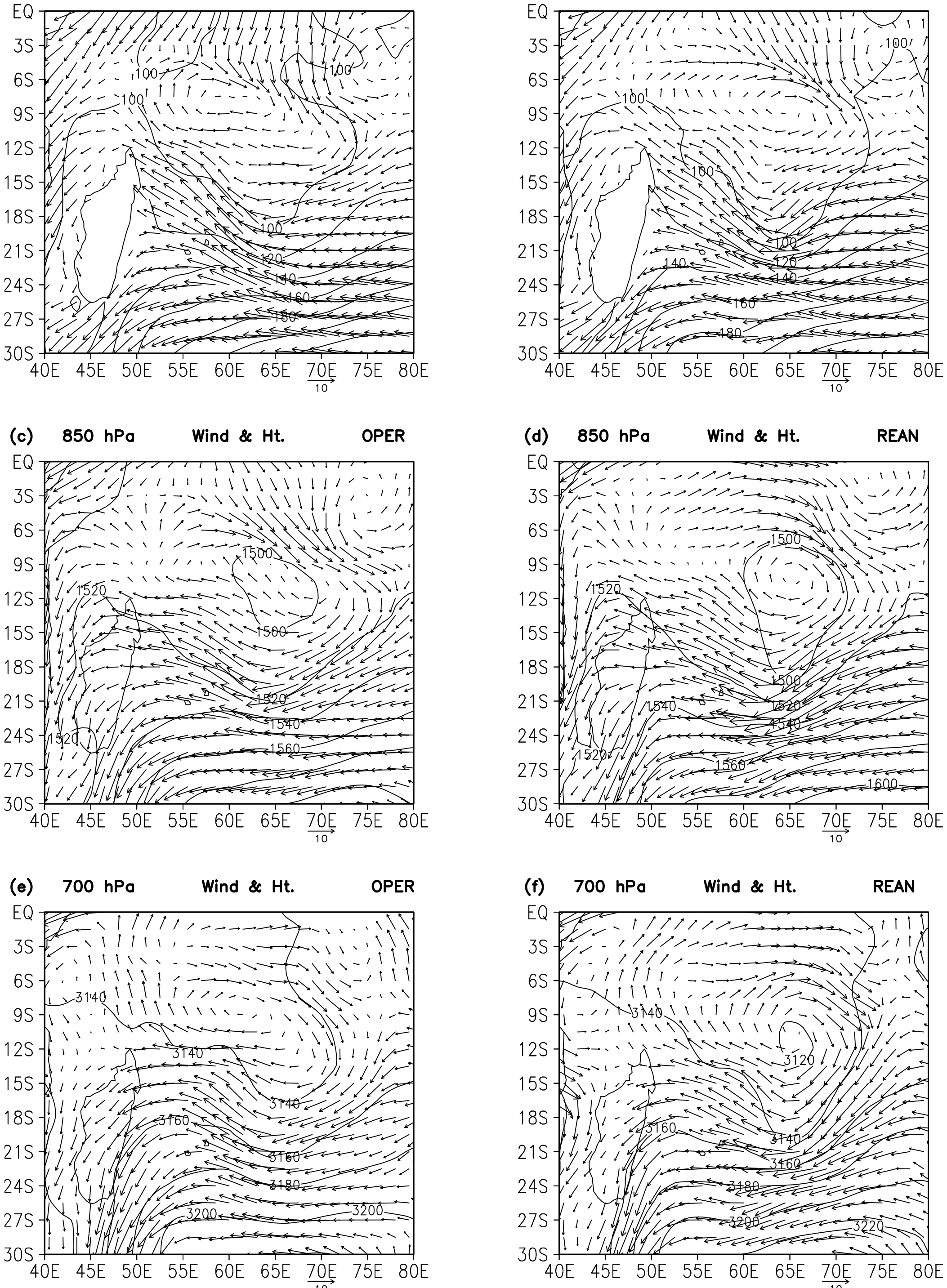


Fig. 4. Analysed Wind (m/s) and Geopotential (m) field at 1000, 850 and 700 hPa level for both OPER and REAN on 00UTC, 3rd Feb. 1999.

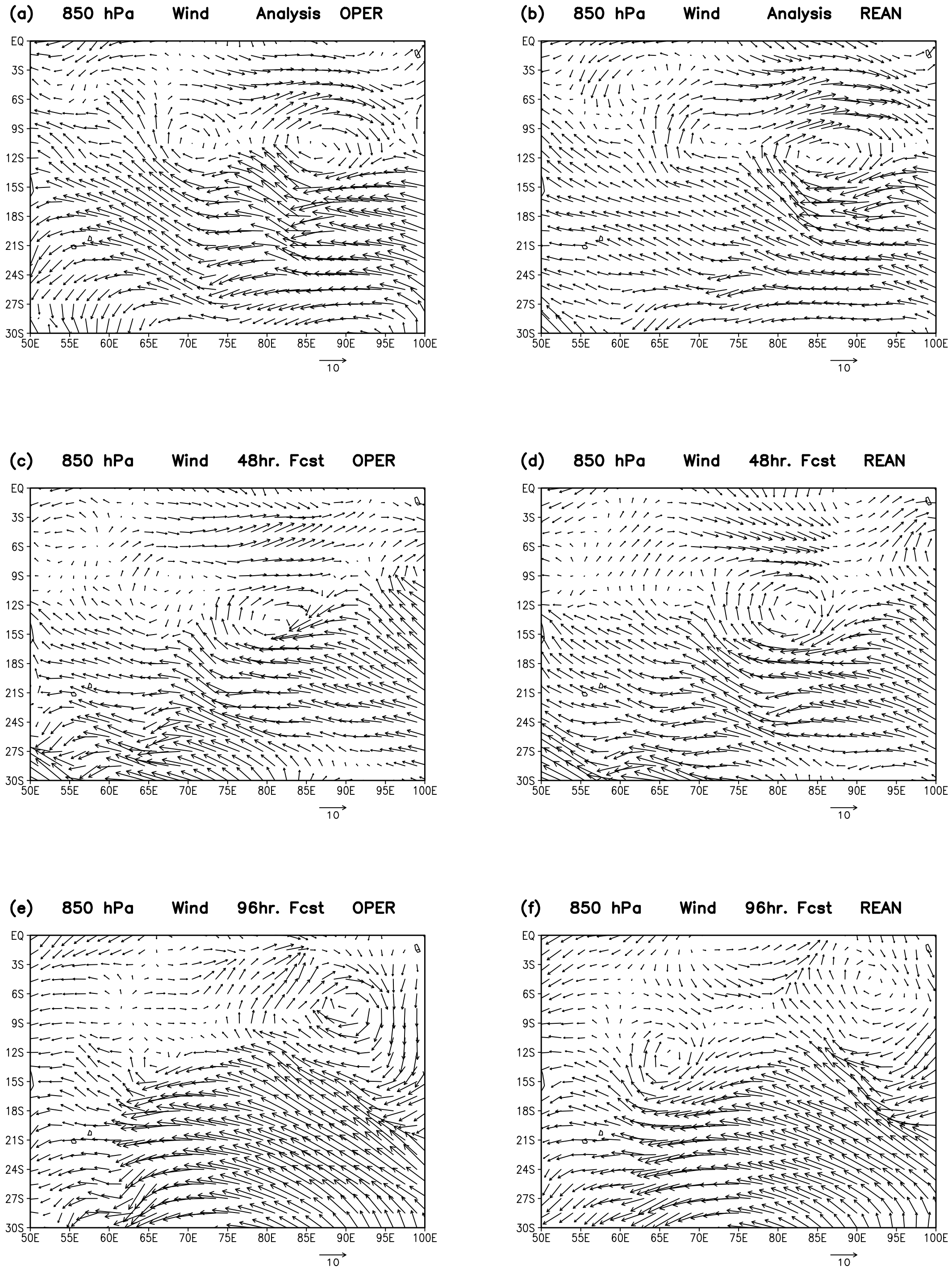


Fig. 5. Analysis, 48-hour forecast and 96-hour forecast winds(m/s) at 850 hPa for OPER and REAN with initial condition on 00UTC 4th March 1999.

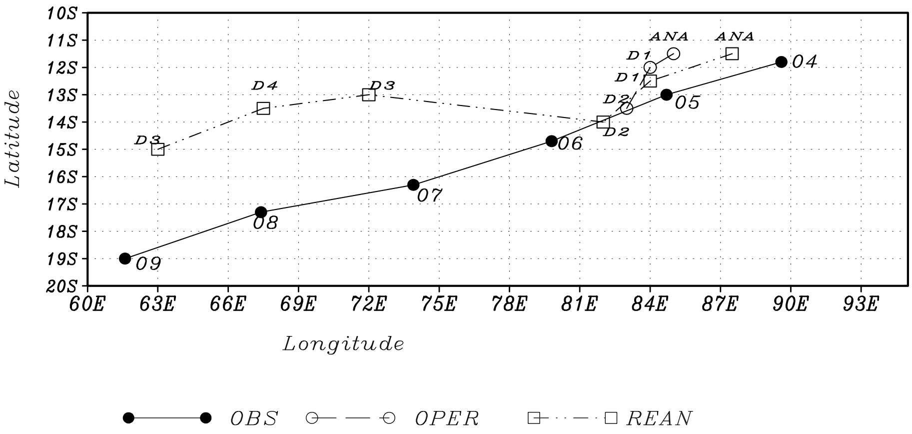


Fig. 6. Observed track of storm Davina along with the forecasted tracks for OPER and REAN based on analysis of 00UTC 4th March 1999.

Table 2. Mean Positional vector error (km) of the storm DAVINA

	REAN	**OPER**
Analysis	200	450
24hr. Forecast	70	122
48hr. Forecast	230	340
72hr. Forecast	380	460

96-hour forecast based on REAN, whereas it is mainly seen as a trough in OPER. The analyses of the storm and track predictions on subsequent days are also better represented in REAN compared to OPER. For brevity, the observed track of the storm along with the predicted by REAN and OPER, based on the initial condition of 00UTC of 4th March, 1999 are shown in Figure 6. Since the storm was simulated only as a trough beyond 48 hours, track of the storm is only shown up to 2 days by OPER in Figure 6. The positional vector error of the center of the storm for OPER and REAN averaged over 5 initial conditions (00UTC 4th March to 00UTC 8th March 1999) as presented in Table 2.

The predicted rainfall (24 h accumulated) from both sets of analyses, with initial condition of 00UTC of 4th March 1999, valid for 03UTC of 6th March and 8th March 1999, are compared with the rainfall analysis and the same is presented in Figure 7. The rainfall analysis/observation (Mitra *et al.*, 1997) are prepared by merging conventional rain gauge data with satellite (INSAT) estimated rainfall. As seen, the analysed rainfall associated with the storm for both days is about 4 cm. Predicted rainfall from both REAN and OPER are under-predicted compared to observed. However the geographical distribution of rainfall for REAN matches better with the analysed rainfall than OPER.

Figure 7(a) shows the rainfall analysis for 03 UTC of 6th March 1999. Figure 7(c) and 7(e) show the predicted, 24-hour accumulated rainfall valid for 03UTC of 6th March, with initial condition of 00UTC of 4th March 1999 from OPER and REAN respectively. Shaded portions on analysed and forecasted rainfall plot depict the region with rainfall less than 1 cm. Figure 7(a) shows the center of rainfall maxima with well spread rainfall over all the sectors around 80^{o}E and 15^{o}S. As seen, OPER (Figure 7(c)) shows practically no rainfall, particularly in the north-west sector, around that location. In contrast, REAN (Figure 7(e)) shows more wide spread rainfall in all the sectors with about 1 cm of rainfall. In addition there is practically no rainfall seen in the analysis in the region 65^{o}E-75^{o}E, north of 25^{o}S. As seen, OPER produces rainfall over this region, which is not observed. REAN in contrast shows that except for a narrow band of less than 1 cm rainfall there is practically no rain over this region. However, a rainfall patch around 80^{o}E and 24^{o}S by both OPER and REAN seems to be spurious. Figure 7(b) shows the rainfall analysis for 03 UTC of 8th March 1999. Figures 7(d) and 7(f) show the predicted, last 24-hour accumulated rainfall valid for 03UTC

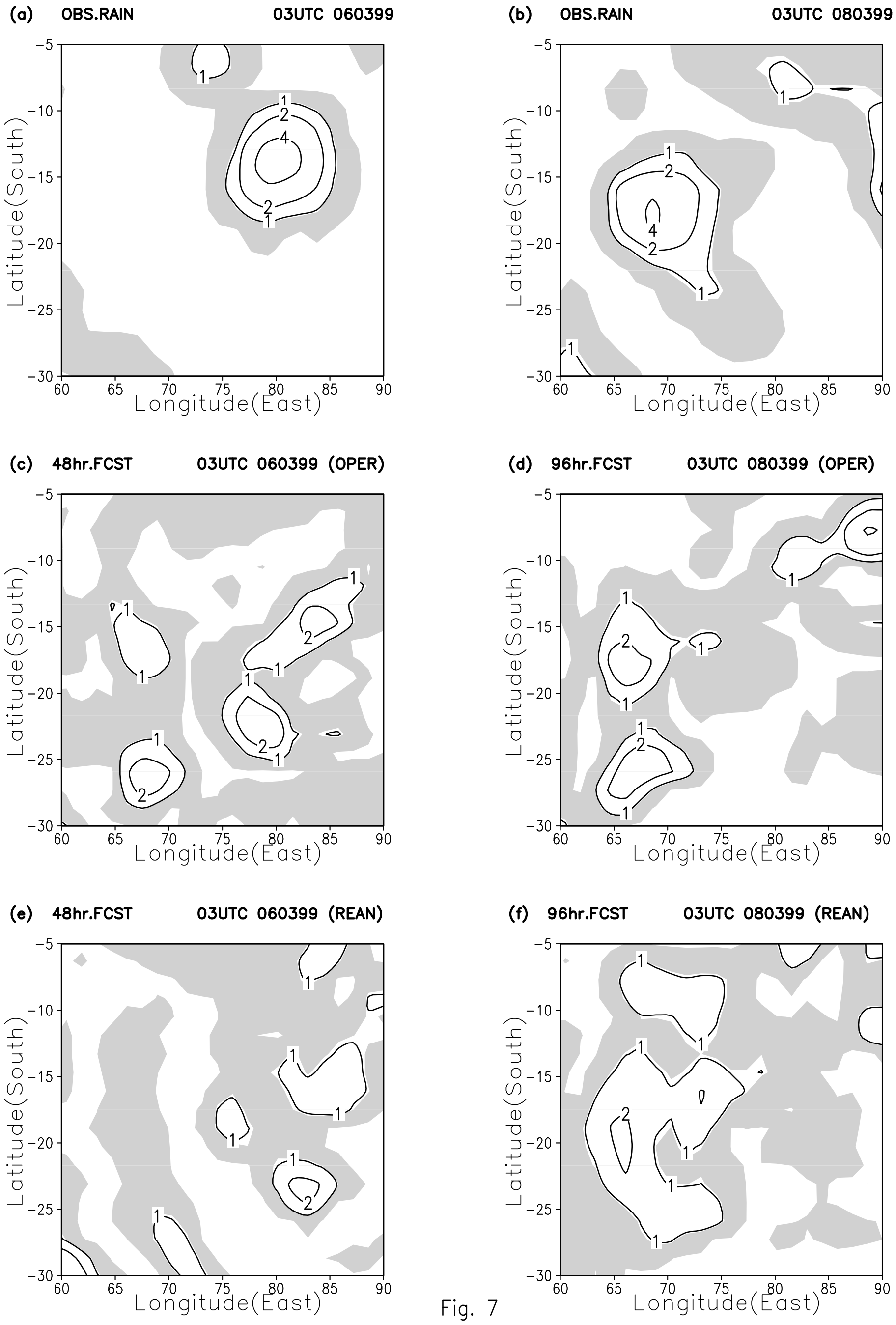


Fig. 7. Rainfall analysis (cm) and 24 hour accumulated rainfall valid for 03UTC of 6th and 8th March 1999 based on initial condition 00UTC 4th March 1999, for OPER and REAN.

of 8th March, with the initial condition of 00UTC of 4th March 1999 from OPER and REAN respectively. The rainfall analysis (Figure 7 (b)) shows a maxima of 4cm around 67°E and 17°S, and has horizontal extent of about 10 degrees (65°E -75°E) in the east-west direction. OPER (Figure 7 (d)) shows two distinct maximas of 2cm, each around 65°E,17°S and 67°E,27°S, which are not seen in the observations. Moreover the rainfall belt is confined to a narrower longitudinal extent viz. 65°E-70°E. In addition, there is a rainfall maxima around 88°E and 7°S, which is not seen in the analysis. As far as rainfall from REAN (Figure 7 (f)) is concerned, there is a rainfall maxima of 2cm seen around 66°E and 17°S, which is closer to the observation. The horizontal spread of rainfall extends from 65°E-75°E, as seen in the analysis. However, there is some rainfall extending north of 12°S and south of 5°S, which is not observed. In contrast to OPER there is no rainfall maxima east of 85°E by REAN. Hence, overall, the rainfall predicted by REAN is closer to observation compared to OPER, which shows a tendency to produce spurious rainfall over some oceanic regions.

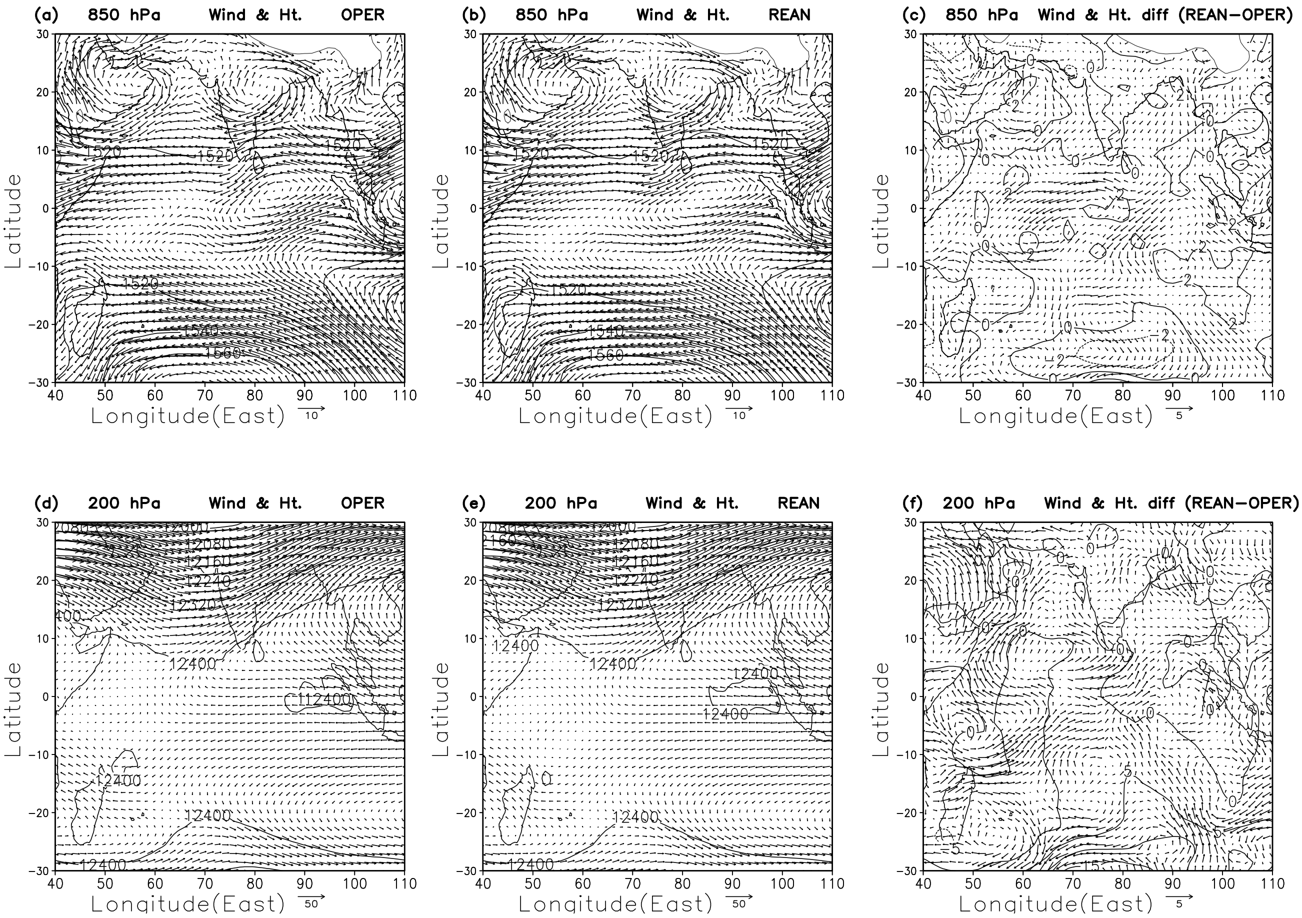


Fig. 8. Mean monthly analysed Wind (m/s) and Geopotential (m) filed for OPER and REAN and their difference (REAN-OPER) at 850 and 200 hPa for 00UTC 1st -28th February 1999.

4.2 *Mean Fields*

Mean monthly (00UTC, 1st-28th February 1999) analysed wind and height fields for REAN, OPER and their differences for 850 and 200 hPa are shown in Figure 8. In the lower level (850 hPa) the zonal component of wind from the Northern Hemisphere over the equatorial region (within 60°E to 90°E) has strengthened by 3 m/sec in the REAN, whereas the same from the Southern Hemisphere has weakened by 2m/sec. Mean monthly reanalysis (REAN) at 850 hPa level also shows strengthening of the northerly flow by 2 m/sec east of the subtropical anticyclone and weakening in the Southern Hemisphere. Similar features are noticed in the middle level. In the upper level (200 hPa), a considerable difference is seen over the 50°E to 110°E and 20°S to 30°S region along the subtropical anticyclone of the Southern Hemisphere, which is mainly caused by METEOSAT-5 data over that region.

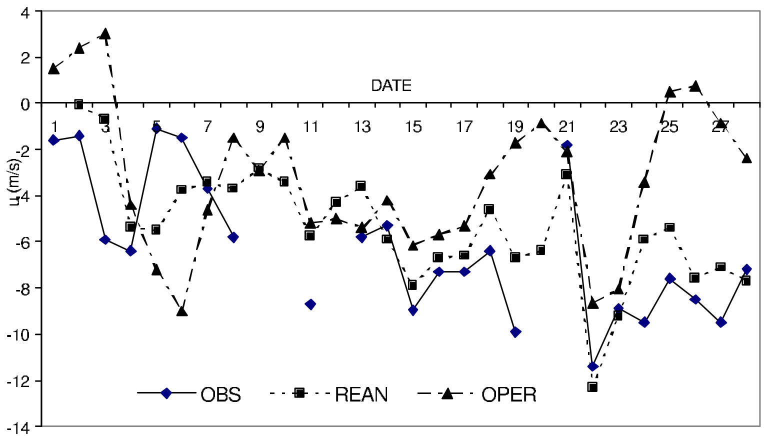


Fig. 9. Daily variation of u-component of wind (m/s) for analysis of OPER and REAN along with the RS/RW observations (u) at 850 hPa at Maldives (74.47E/4.97N) for 00UTC analysis 1st-28th Februray 1999.

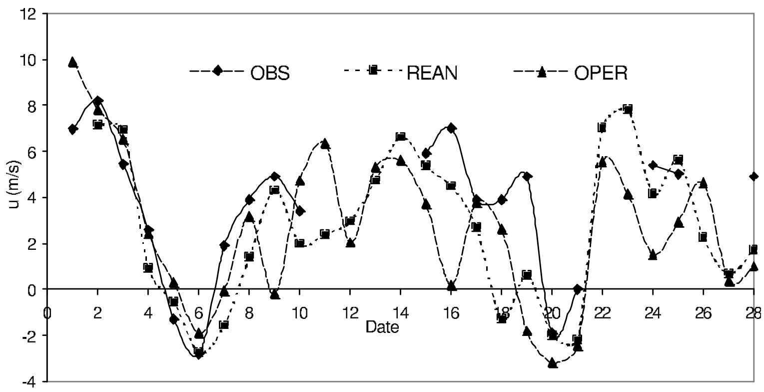


Fig. 10. Daily variation of u-component of wind (m/s) for analysis of OPER and REAN along with the RS/RW observations (u) at 850 hPa at Diego Garcia (72.47E/-7.3S) for 00UTC analysis 1st-28th Februray 1999.

The strengthening and weakening of the zonal component of wind in the equatorial region is examined by comparing the u-component of analysed wind with raidosonde observation for two island stations, one situated north and the other south of the equator. The analysed u-component of wind at 850 hPa, for OPER and REAN on 00UTC of 1st-28th February, 1999 have been plotted along with the observations for two stations: Maldives (74.47°E/4.97°N) and Diego Garcia (72.47°E/7.3°S) in Figures 9 and 10 respectively. There are few gaps in the observation plot (solid line), which are mainly due to non-availability of observations on those dates. Wind observations at 850 hPa for Maldives at 00UTC of 1st-28th February 1999 shows predominate easterly component with average speed of 6.5 m/s. In OPER, in the first and later part of the month, westerly components have been noticed instead of easterly at 850 hPa level with an average wind speed of 3.3 m/s, whereas in REAN zonal component of wind at 850 hPa level throughout the month is easterly with average speed of 5.8 m/s. Analysis of the zonal component of wind for both OPER and REAN at 850 hPa over Diego Garcia compare well with the observation. The monthly averaged zonal component wind speed observed 00UTC of February 1999 at 850 hPa in Diego Garcia is 3.9 m/s, and the same is seen as 2.5 m/s by OPER and 2.7 m/s by REAN. By far, in both stations REAN has shown better agreement with the observations in most days, showing the positive impact of the upper air observations of these two stations.

The mean monthly moisture field (specific humidity) for both sets of analysis and their differences (REAN-OPER) at 850 and 700 hPa are shown in Figure 11. The shaded regions in the difference plots indicate the negative difference. The mean specific humidity at 850 hPa shows an increase of 1 gm/kg in

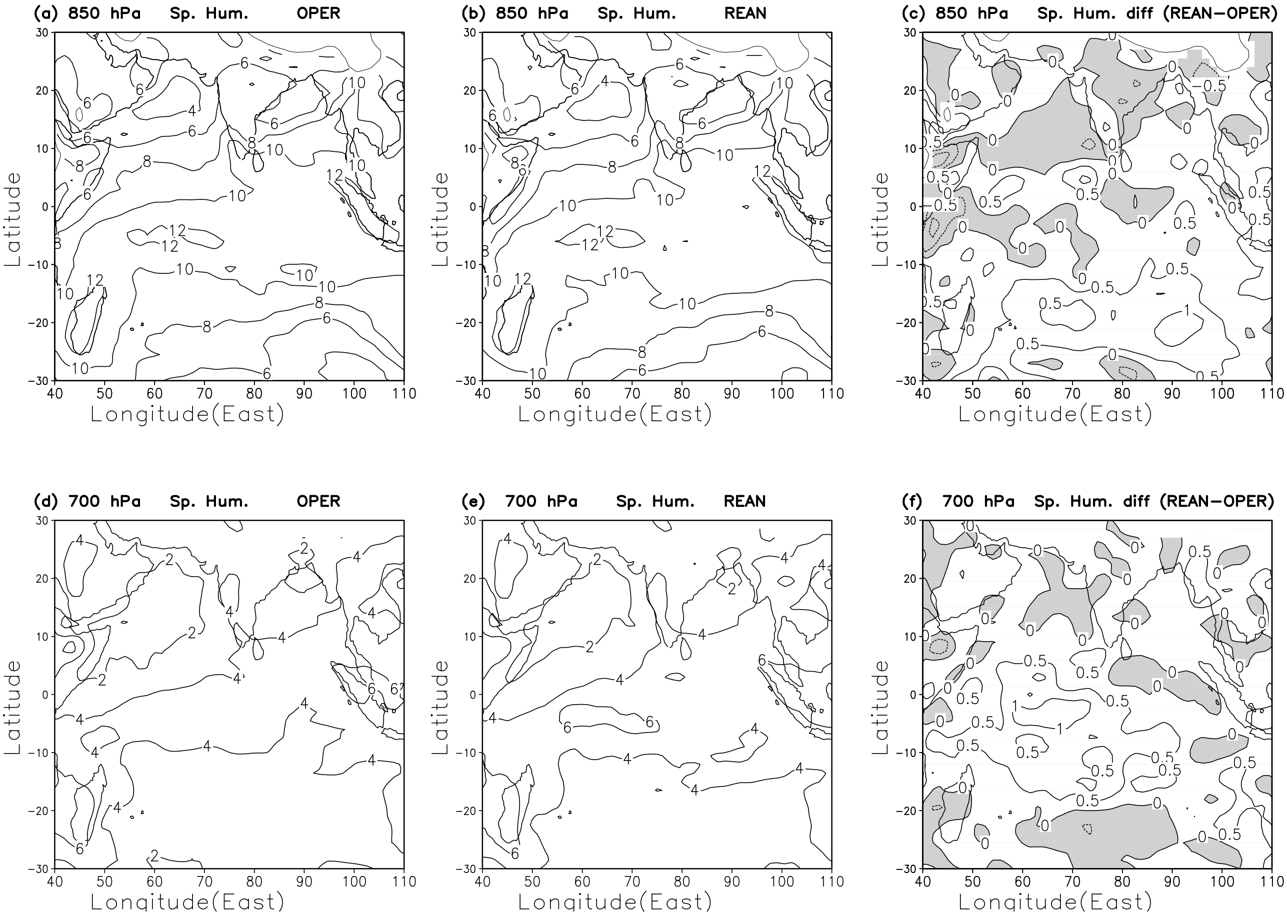


Fig. 11. Mean monthly analysed specific humidity (gm/kg) filed for OPER and REAN and their difference (REAN-OPER) at 850 and 700 hPa for 00UTC 1st -28th February 1999.

REAN compared to OPER, just north of the equator along 70^{o}E, which could be due to the strengthening of the wind in that region. The increase in specific humidity by 1.2 gm/kg is also noticed in REAN over the South Indian Ocean, south of 10^{o}S at 850 hPa level whereas, a decrease in specific humidity is noticed over the Arabian Sea. At 700 hPa the maximum increase (1.4 gm/kg) in specific humidity in REAN compared to OPER is seen between 60^{o}E and 80^{o}E along 5^{o}S latitude.

The root mean square error (RMSE) of the analysis and first guess computed against RS/RW observations, at various pressure levels for different parameters viz. z, u, v, t, q, have been computed for OPER and REAN over different regions. On average, there are about 580 RS/RW observations all over the globe and 60 RS/RW observations over the tropical region (30^{o}N to 30^{o}S), per cycle of assimilation (00UTC). RMSE for REAN are mostly less compared to that of OPER at various levels for all parameters over both regions. For brevity only the RMSE for deviation of the analysis, computed over tropical region for u, v, t and q, are shown in Figure 12. It may be noted that for u, v, and t, the improvement in RMSE for REAN over OPER is mostly seen in the middle and upper tropospheric level (700 - 200 hPa). For u and v component of wind, the maximum improvement in RMSE ($\sim$12%) for REAN over OPER is seen between 500-400 hPa level. Marginal improvement in RMSE for parameter T is seen in the lower level viz. between 925-600 hPa and the upper tropospheric level above 200 hPa. The improvement in RMSE for parameter q is mainly confined to the lower tropospheric level below 700 hPa.

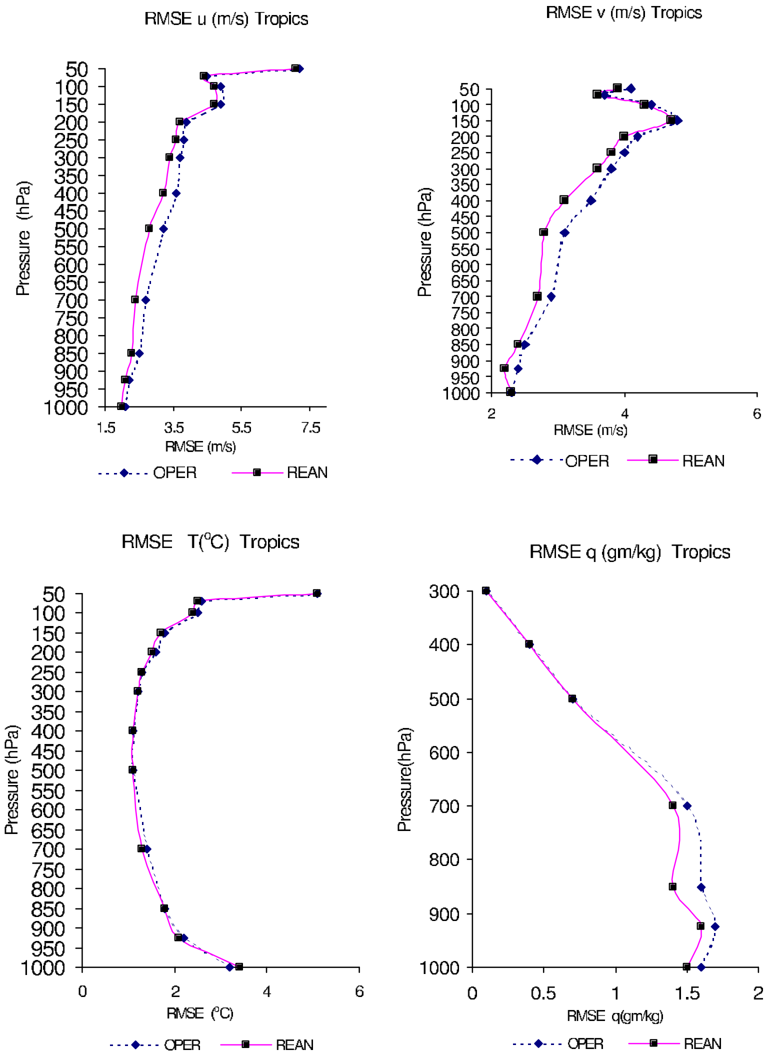


Fig. 12. Root Mean Square Error (RMSE) for deviation of analysis form observations for OPER and REAN at various pressure levels for u, v, T, q computed over tropics for 00UTC 1st-28th February 1999.

5. Conclusions

Based on the results presented in section 4, the following broad conclusions are drawn.

(1) The mean monthly reanalyses using all the special observations do not differ much from the operational analysis. Whatever differences have come in the mean wind field are mainly due to the assimilation of METEOSAT-5 winds.
(2) The difference in the mean specific humidity near the equatorial region and over the South Indian Ocean are the effect of both special observations and METEOSAT winds.
(3) The mean monthly RMSE of analysis from observation are always lower for REAN than for OPER. So it may be concluded that the analysis (REAN) is also better than OPER in terms of mean monthly.
(4) On day to day basis both analyses show considerable differences, particularly over the data sparse oceanic region. These differences are greater when there are some well defined activities over that region and in such cases the reanalysis (REAN) is closer to the actual observations than OPER.
(5) The impact of the assimilated special observations is also seen on the subsequent forecast, specially

over the region of well-defined activity.

Reanalyses using special observations taken during various other experiments over the Indian Ocean region are being done for other seasons as well. These will enable a better understanding of the impact of data at various scales.

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