3DVAR assimilation studies over the Indian region: Results of Impact studies

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Outline

- Overview of 3DVAR Data Assimilation
- 3DVAR results of assimilation of QuikSCAT surface wind vector for several meteorological systems over India.
- 3DVAR results of assimilation of MODIS temperature and humidity profiles for several meteorological systems over India.
- 3DVAR results of assimilation of DWR reflectivity and radial wind for several meteorological systems over India.
- Sensitivity study of the effect of 3DVAR assimilation of observations from various sources both individually and collectively for several meteorological systems over India.
- Acknowledgement

Overview of 3DVAR Data Assimilation

- The evolution of a geophysical system (atmosphere and/or ocean) is governed by physical principles which are written as a set of partial differential equations.
- The governing equations are solved numerically from the knowledge of the initial conditions, which describe the present state of the system, to obtain the future state of the system.
- The preparation of the initial conditions of high quality is a matter that is receiving increasing attention in the field of atmospheric and oceanic sciences.
- In both atmosphere and/or oceans, the prescription of initial conditions require specification of the complete and accurate three-dimensional structure of the initial state of the system.
- About 70 % of Earth surface is covered by oceans and knowledge of the atmosphere over oceans is sparse.

Overview of 3DVAR Data Assimilation (contd)

- There are never adequate number of good observations. The number of degrees of freedom of a typical weather prediction model is about 10^6 -10^7.
- Total number of observations is of the order of 10^4 - 10^5.
- Also, the observations are (i) not regularly distributed in space, (ii) are not available in sensitive areas such as over oceans and ice and (iii) have errors.
- Hence an efficient and novel methodology is needed to combine these irregular observations to provide the initial conditions that are distributed on a regular model grid.
- Such a methodology is provided by “Data Assimilation” method.

Overview of 3DVAR Data Assimilation (contd)

- However, with improvements in the physics and dynamics of the atmospheric model, it was recognized that the model forecast of an atmospheric model can itself serve as the “first guess” or “background”.
- The above “first guess” or “background” can then be blended with the meteorological observations (satellite and conventional observations) using data assimilation methods to yield the optimum initial conditions for a numerical forecast.
- The three-dimensional (3DVAR) and four-dimensional (4DVAR) are the important variational data assimilation methods.
- Purpose of data assimilation is to use all available information (observations) to determine as accurately as possible the state of the atmospheric flow.

3D-VAR

- The equivalence for a scalar variable between minimizing the analysis variance through a least square approach and the variational approach is also true for a full three-dimensional analysis.
- Lorenc showed that minimization of analysis error covariance matrix is equivalent to a variational problem.
- In 3DVAR, we look for the optimal-analysis $\mathbf{x}_a$ field that minimizes a (scalar) cost function J(**x**) is defined as the distance between **x** and $\mathbf{x_b}$, weighted by inverse of background error covariance, plus the distance to the observations $\mathbf{y_o}$, weighted by inverse of observational error covariances, where H(**x**) is an obs. operator

$$J(x) = \frac{1}{2}(x - x_b)^T B^{-1}(x - x_b) + \frac{1}{2}[y_o - H(x)]^T R^{-1}[y_o - H(x)]$$

3DVAR assimilation of QuikSCAT surface wind vector for several meteorological systems over India

- *Two Monsoon Depressions (MD's) formed over the Bay of Bengal region during 02-05 September 2006 and 27-30 September 2006.
- 02-05 September 2006 MD
- A low pressure system formed over the Head Bay of Bengal by late hours of 02 September 2006 which subsequently developed into a depression at 00 UTC 03 September 2006. The east coast and central plains of India recorded a maximum 24 hours rainfall of 35 cm, centered over the Head Bay, the next day and 16 cm on the second day. The depression started dissipating in the late hours of 4th September and by early hours of 5th September 2006.(*Sinha & Chandrasekar, 2010, TOASJ)

Model details and physics options used

- WRF model; 28 vertical layers; 30 km grid spacing, 30 x 118 grid cells in the EW-NS directions.
- Yonsei University scheme: PBL, Kain-Fritsch scheme for cumulus parameterization, the WRF Single-Moment 3-class scheme for microphysics (ice and snow processes), the RRTM scheme for longwave radiation, Dudhia scheme for shortwave radiation, 5-layer thermal diffusion for land surface (soil temperature only) and Monin-Obukhov similarity formulation for the surface layer.

Model details (contd.)

- NCEP GFS data fields available at a grid spacing of 1ºx1º and every three hours were used for the initial & lateral boundary conditions.
- A Control (CTRL) run without any data assimilation and a 3DVAR run in which QuikSCAT observations are assimilated were performed. The CTRL run was performed from 00 UTC of the start date to 60 hrs, while in the 3DVAR run, the QuikSCAT assimilation was performed at 00 UTC of the start date and in two 12 hourly successive cycles. Subsequently the 3DVAR run was integrated in a free-forecast mode.

02-05 September 2006 MD

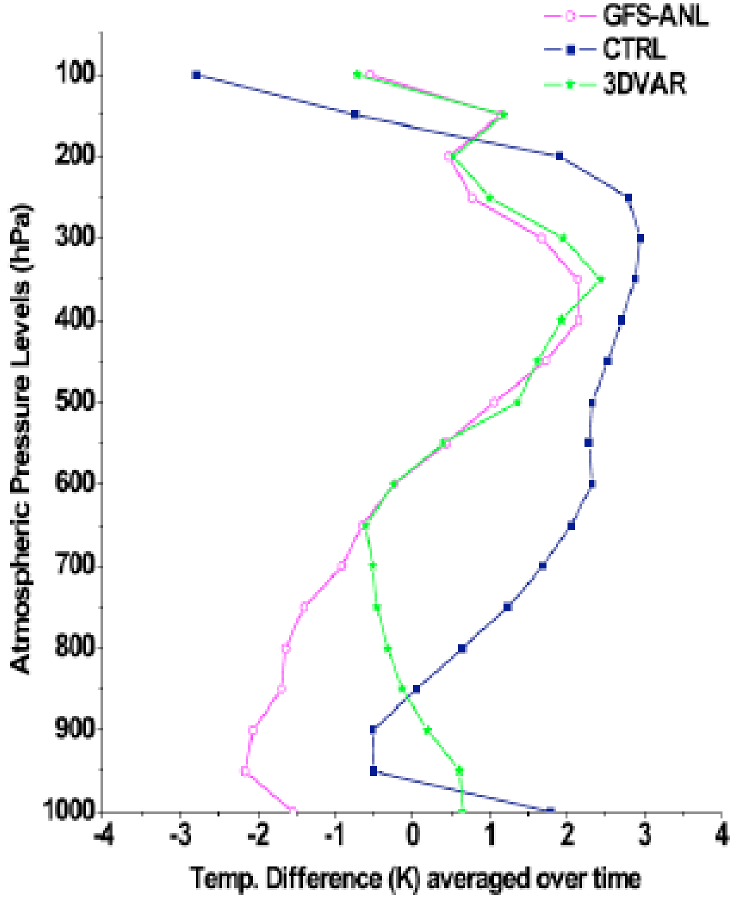


Fig. (5). Difference of Air Temperature over the depression area and the entire domain area, averaged over time, at various pressure levels in K for MD of 02-05 September 2006.

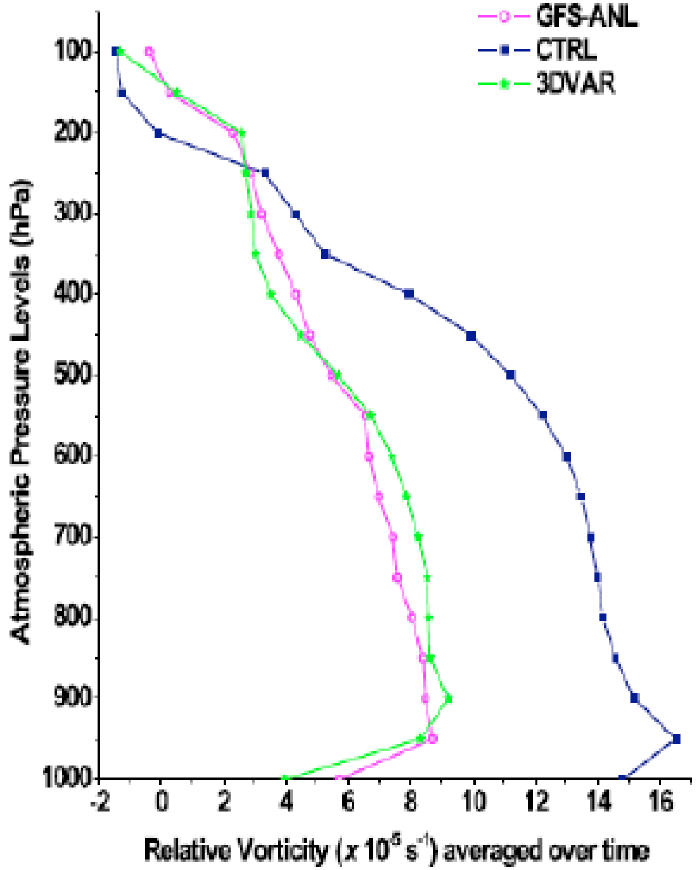


Fig. (6). Relative Vorticity (area averaged over the depression area) at various pressure levels, and averaged over time, for MD of 02-05 September 2006.

02-05 September 2006 MD

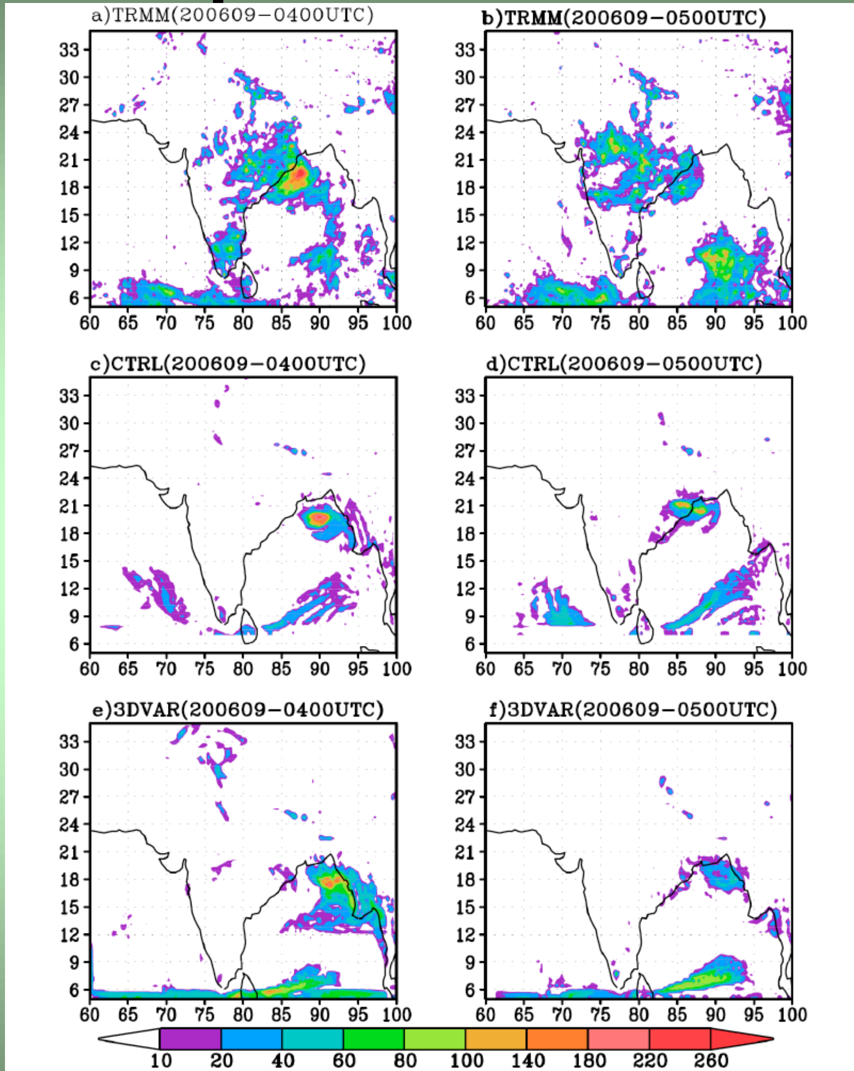


Fig. (7). 24 hrs accumulated precipitation (mm) patterns for the first two days of forecast from TRMM (**a**, **b**), CTRL (**c**, **d**) and 3DVAR (**e**, **f**) for monsoon depression of 02-05 September 2006.

27-30 September 2006 Monsoon Depression

- The monsoon depression of 27-30 September 2006 formed initially as a low pressure system over east-central and NE parts of the Bay of Bengal (BoB) in the late hours of 27th September 2006. This low pressure system intensified into a depression in the early hours of 28th September 2006 and lay centered near 18.0ºN 89.0ºE. On 29th September 2006, the depression moved to the eastern coasts of India near the Orissa coast and was centered near 19.0ºN 86.0ºE. Heavy rainfall of about 24 cm was reported in the Bay of Bengal region and over the Orissa coasts on both days.

27-30 September 2006 MD

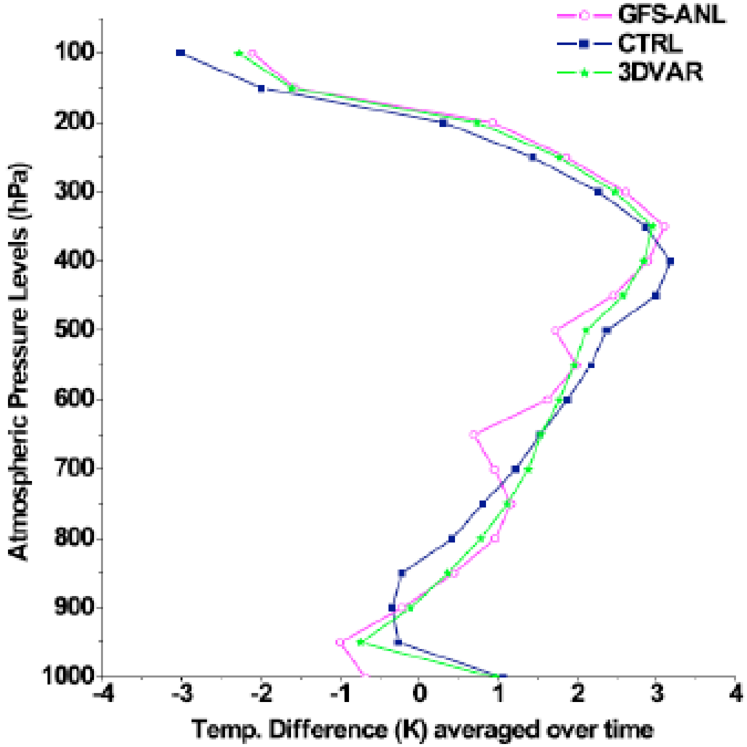


Fig. (15). Difference of Air Temperature over the depression area and the entire domain area, averaged over time, at various pressure levels in K for MD of 27-30 September 2006.

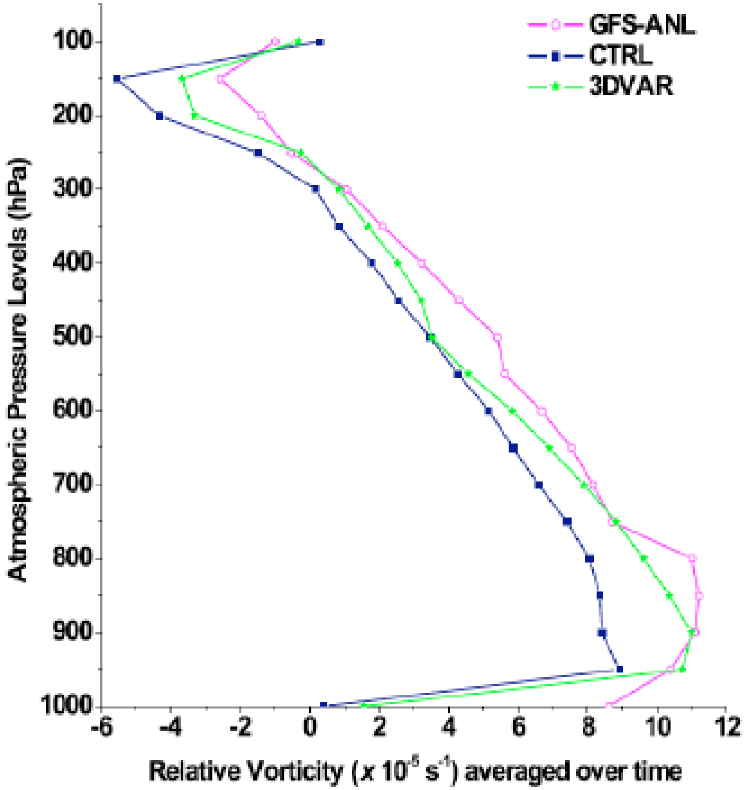


Fig. (16). Relative Vorticity (area averaged over the depression area) at various pressure levels, and averaged over time, for MD of 27-30 September 2006.

27-30 September 2006 MD

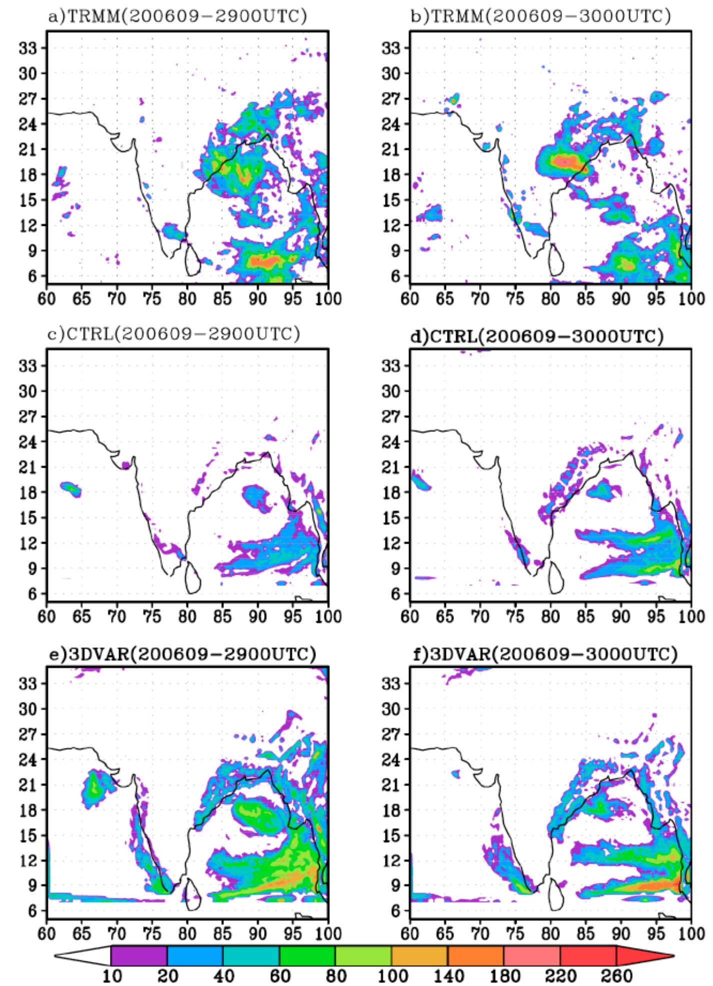


Fig. (17). 24 hrs accumulated precipitation (mm) patterns for the first two days of the forecast from TRMM (**a**, **b**), CTRL (**c**, **d**) and 3DVAR (**e**, **f**) for monsoon depression of 27-30 September 2006.

Results and discussions

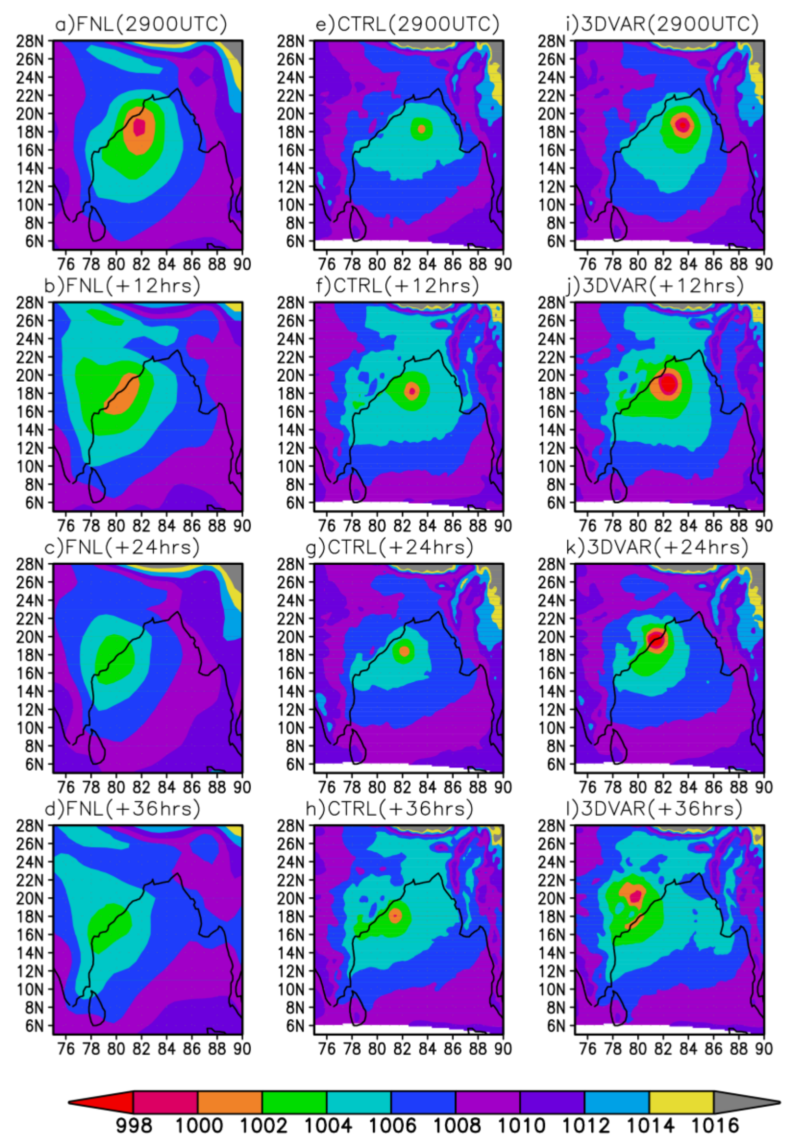
- The vertical profiles of relative vorticity over the monsoon depressions indicate that the 3DVAR run is in good agreement with GFS-ANL as compared to the CTRL run.
- The well-known temperature structure of a monsoon depression (cold core at low levels and warm core at upper levels) is better simulated by the 3DVAR run.
- Ingesting QuikSCAT data shows good impact in terms of precipitation for the 27-30 September 2006 depression; however, the impact is less for the other depression.

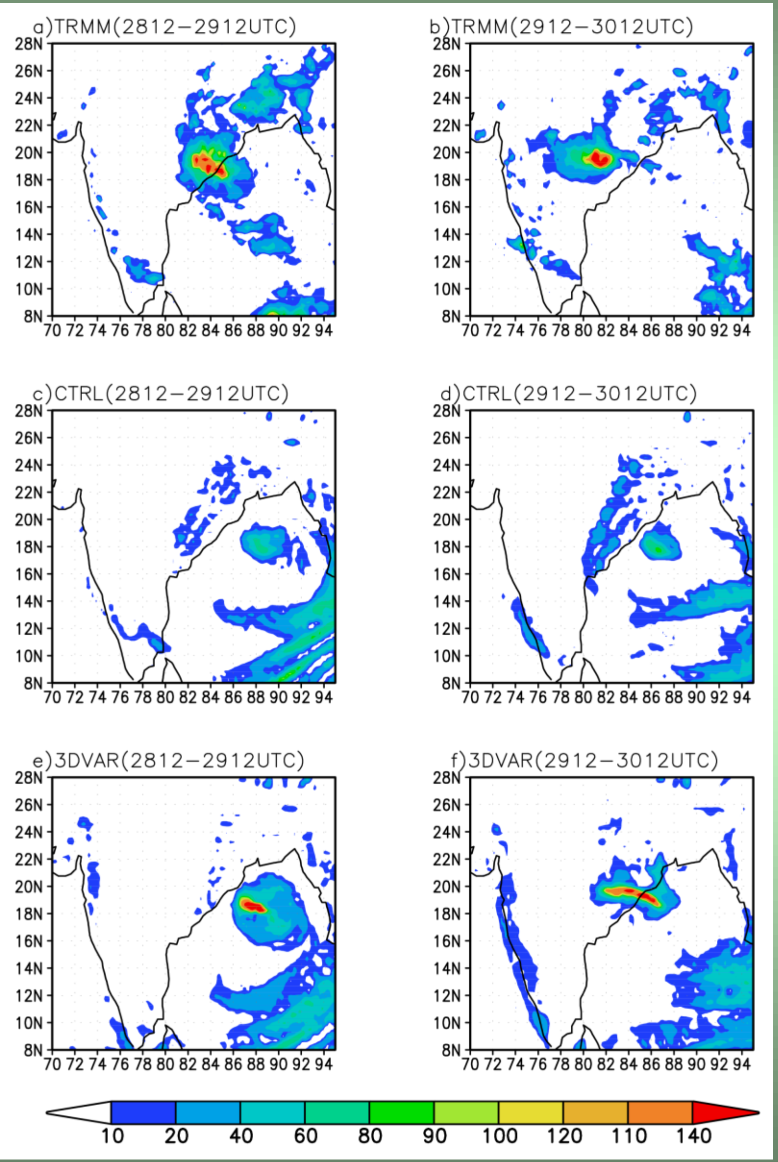
*3DVAR data assimilation of MODIS temperature and humidity profiles for a depression over the Indian region (27-30 September 2006)

- The system was first seen as a low-pressure area which formed over the east central and adjoining northeast Bay off Arakan coast on 27 Sep 2006. The system intensified into a depression at 0900 UTC over east central Bay and lay centered near 18º N 89º E on 28 Sep 2006. Moving in westerly direction, the depression crossed the Orissa coast close to Gopalpur in the afternoon of 29 Sep and lay near 19º N 84.5º E around 1200 UTC of the same day. Subsequently the depression weakened into a well marked low pressure area, moved westward and became less marked over Vidarbha on 1 October 2006.

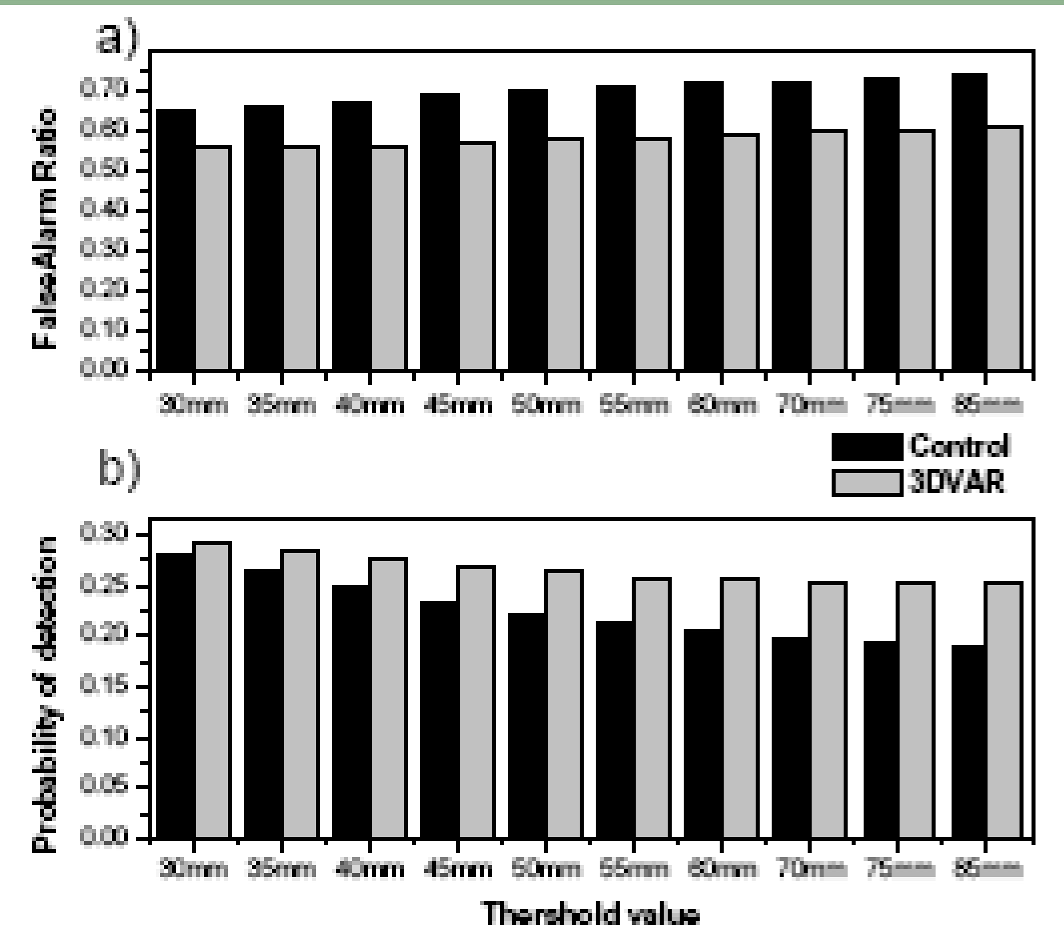
(*Govindan Kutty, Chandrasekar et al. TOASJ, 2008)

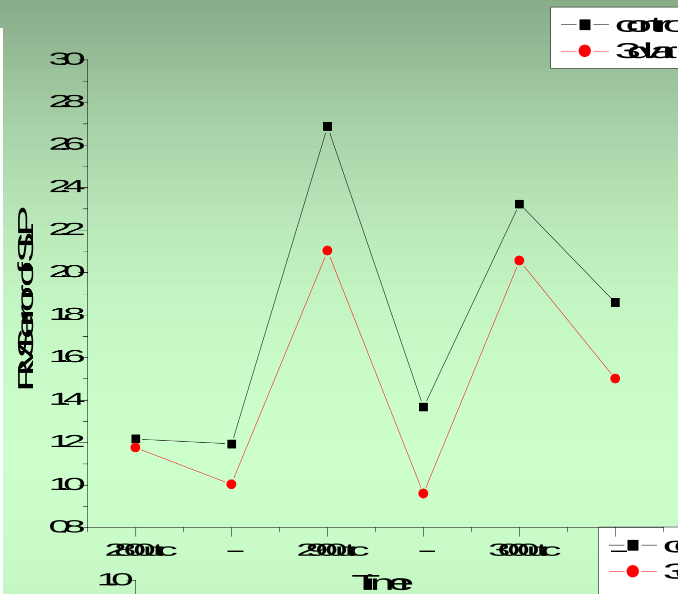
Sea level pressure (hPa) and 24 hr rain

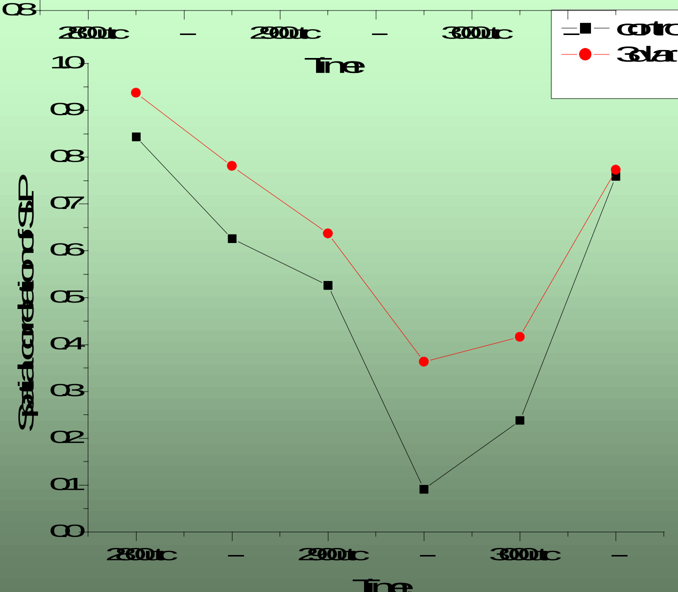




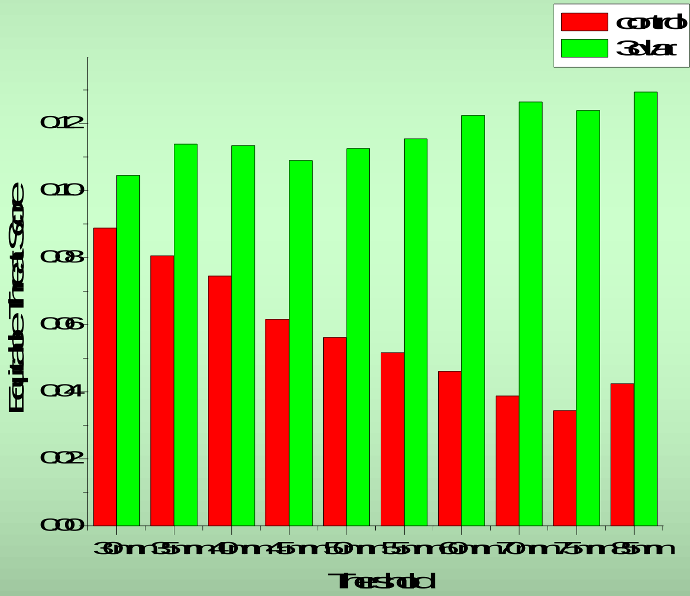
Spatial corr. of SLP & RMSE of SLP in a 10 º x 10 º box about depression center. Also FAR & POD shown

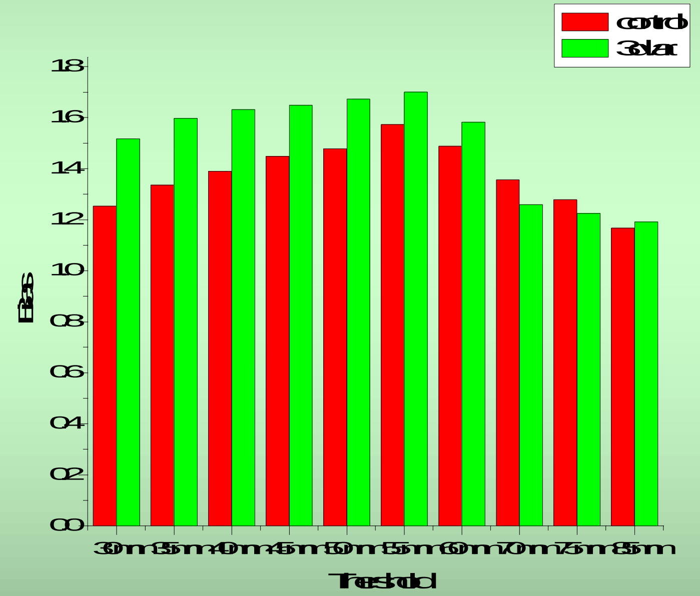




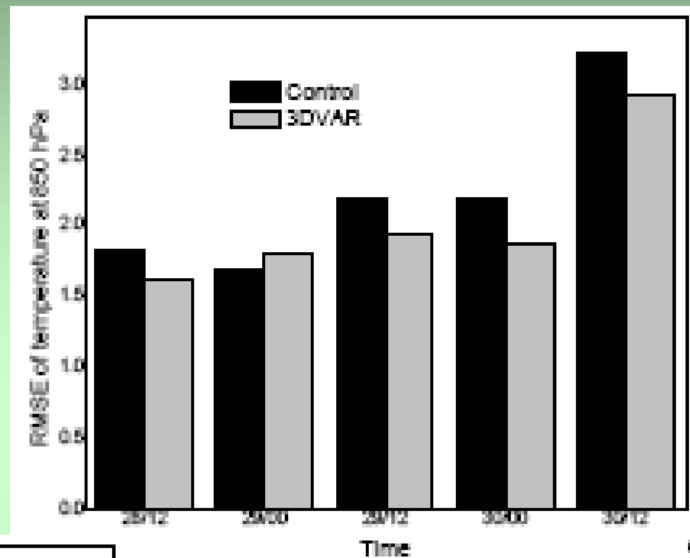


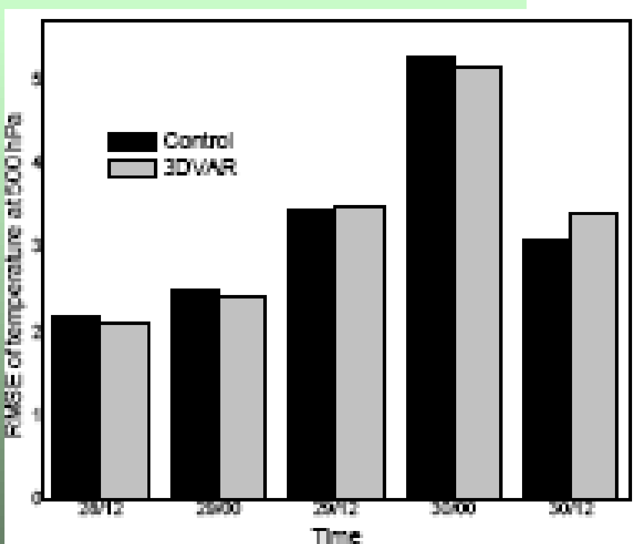
ETS and bias of 48 hour precipitation.

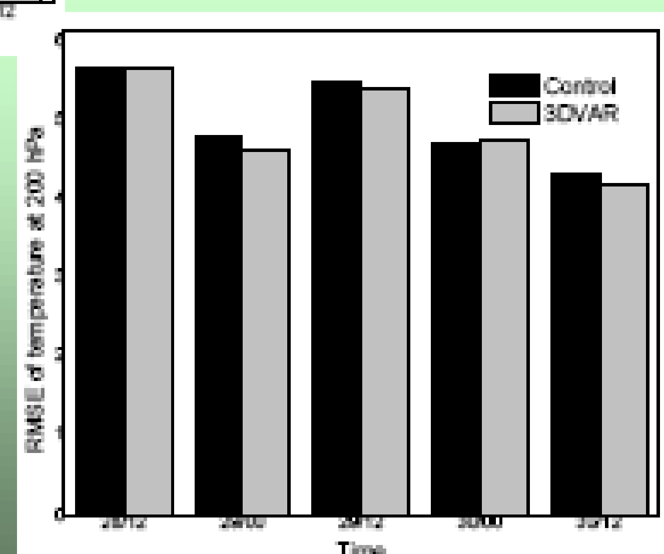




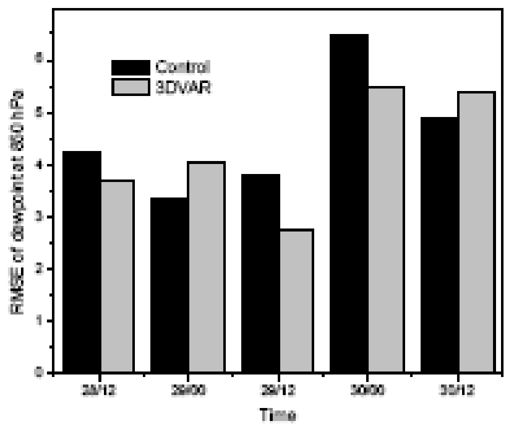
RMS Errors of temperature (850, 500 and 200 hPa)

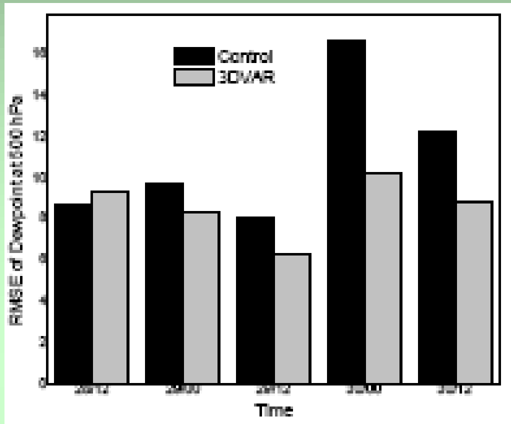


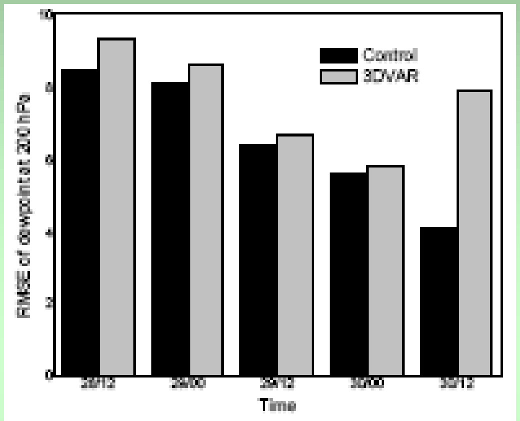


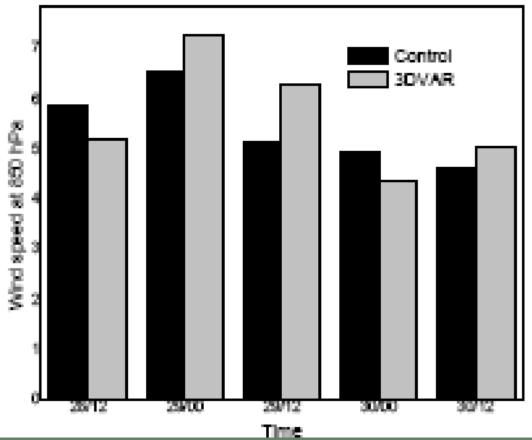


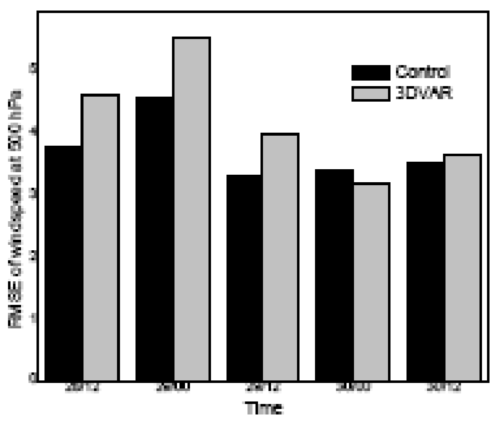
RMS Errors of dew point temp. & wind speeds at 850, 500 and 200 hP)

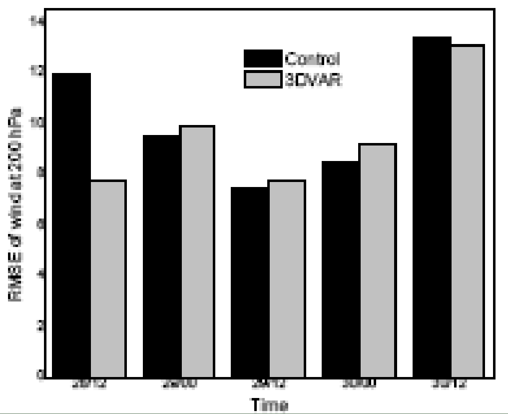












Results and discussions

The SLP field for the 3DVAR run is in good agreement with respect to the NCEP FNL analysis as compared to CTRL.

The MODIS 3DVAR run also shows increased rainfall over a larger land area on the eastern coast of India as compared to the control run. 3DVAR run had higher spatial correlation, lower RMSE of SLP and higher ETS values as compared to CTRL.

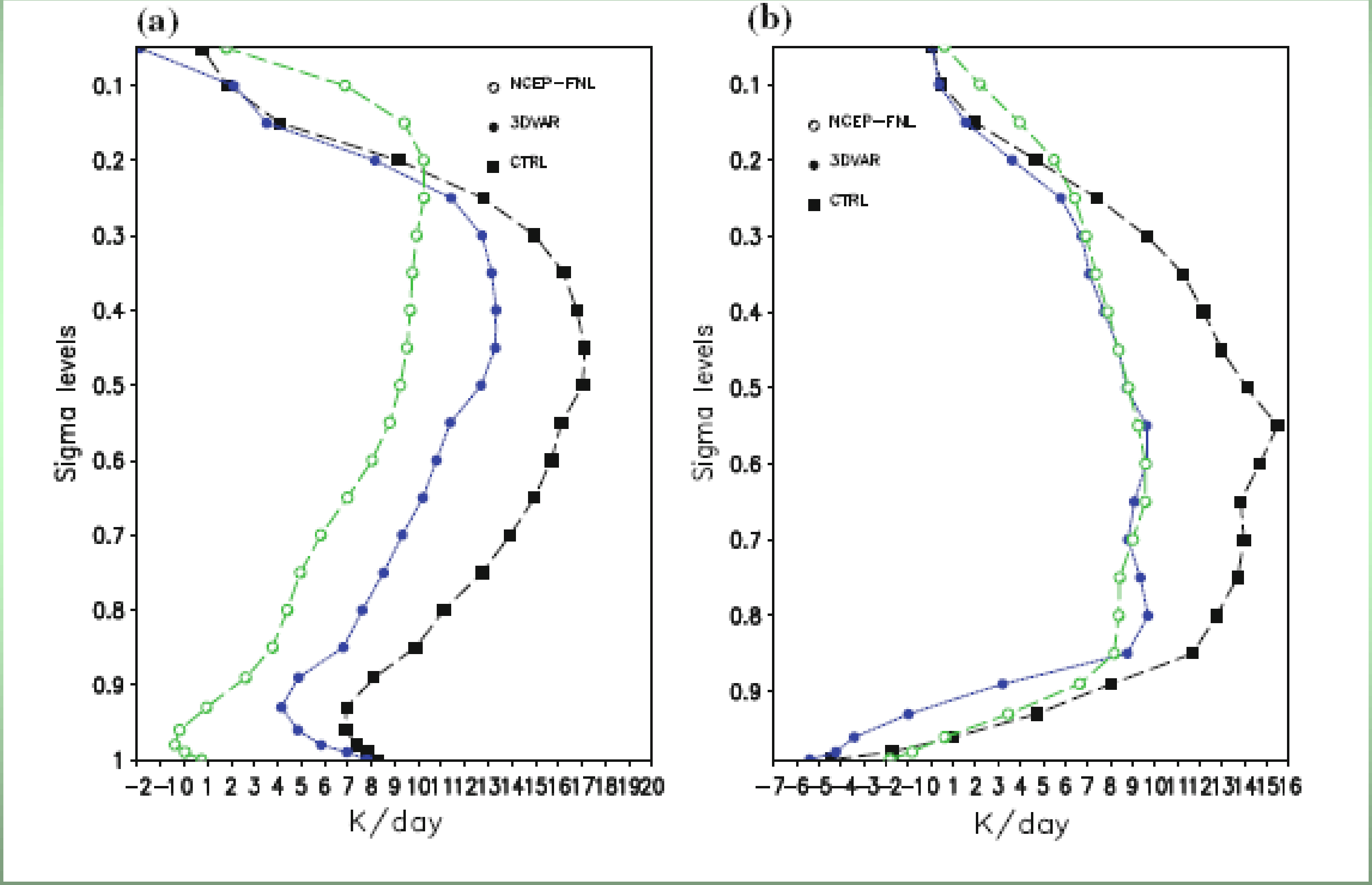
Overall there is a positive impact of the 3DVAR assimilation of the MODIS temperature and humidity profiles in simulating the monsoon depression of 27-29 September 2006.

*3DVAR data assimilation of MODIS temperature and humidity profiles for depressions over India

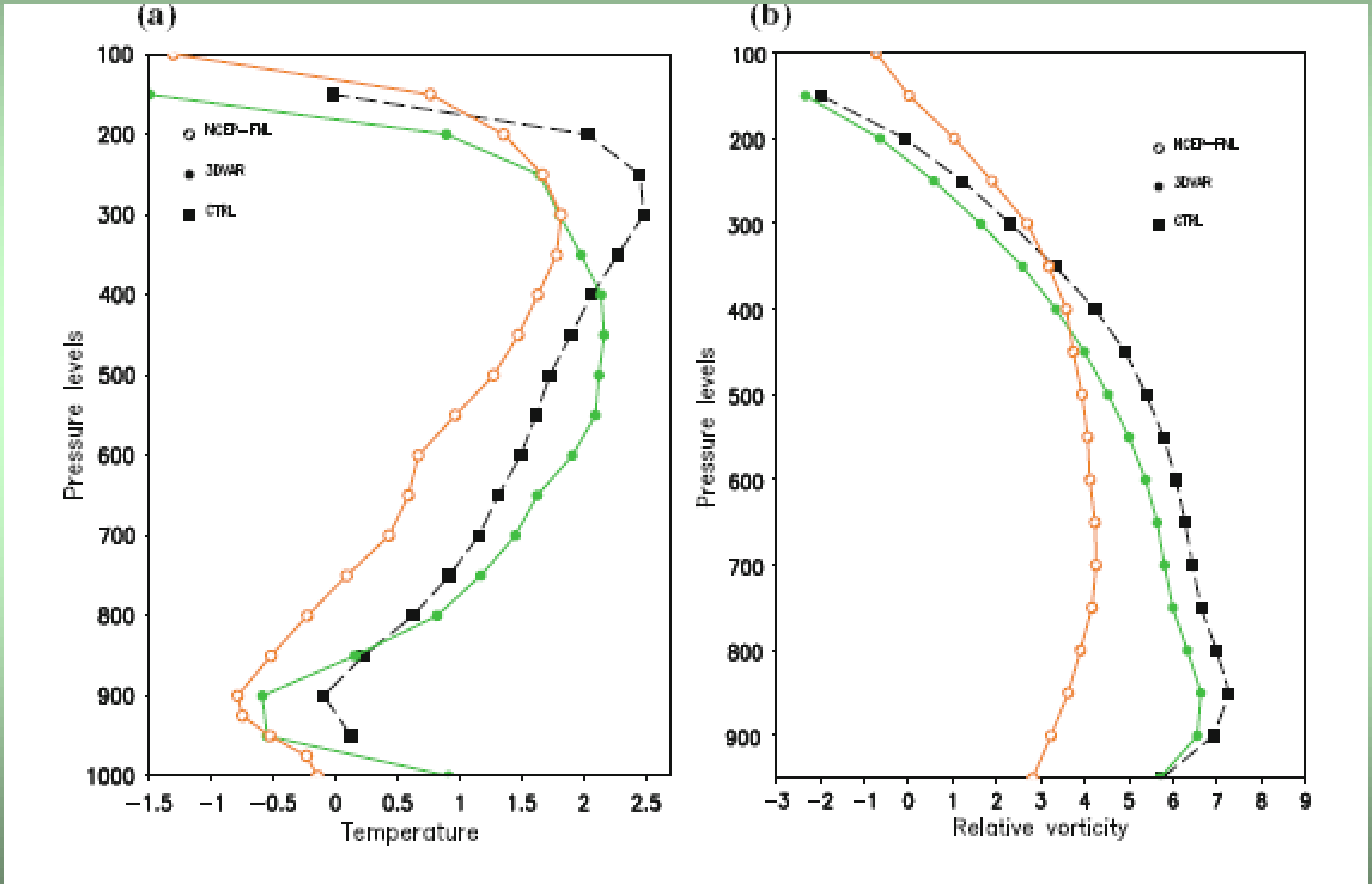
- Three monsoon depressions were investigated (2-5 September 2006, 19-22 September 2006), 18-22 June 2007) for 3DVAR assimilation of MODIS temperature and humidity profiles using WRF model.
- WRF model employed two domains (36 km and 12 km grid spacing) with 24 vertical levels. Used NCEP-GFS fields for initial and lateral boundary conditions.
- Investigated the effect of the heat and moisture budgets of the simulated depressions over the Indian region.
- Utilized CTRL (Control) run with no assimilation and 3DVAR run which ingested MODIS temperature and humidity profiles for a pre-forecast period; subsequently the 3DVAR run was run in a free forecast mode only.

(*Govindan Kutty & Chandrasekar, MAP, 2010)

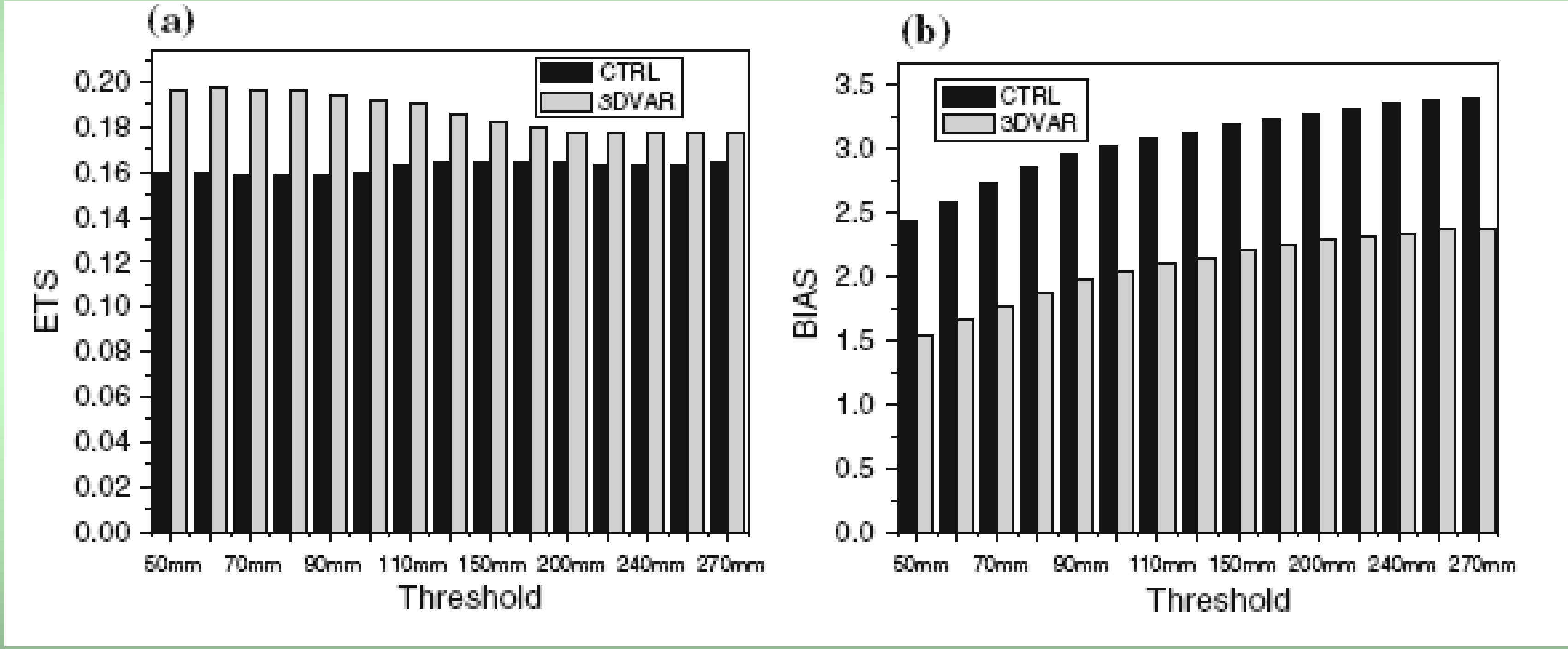
Time-area averaged profiles for Q_1/c_p and Q_2/c_p for 20-22 Sep 2006 depression



Time and area averaged profiles for difference in air temp and relative vorticity



ETS and bias for 19-22 Sep 2006 depression



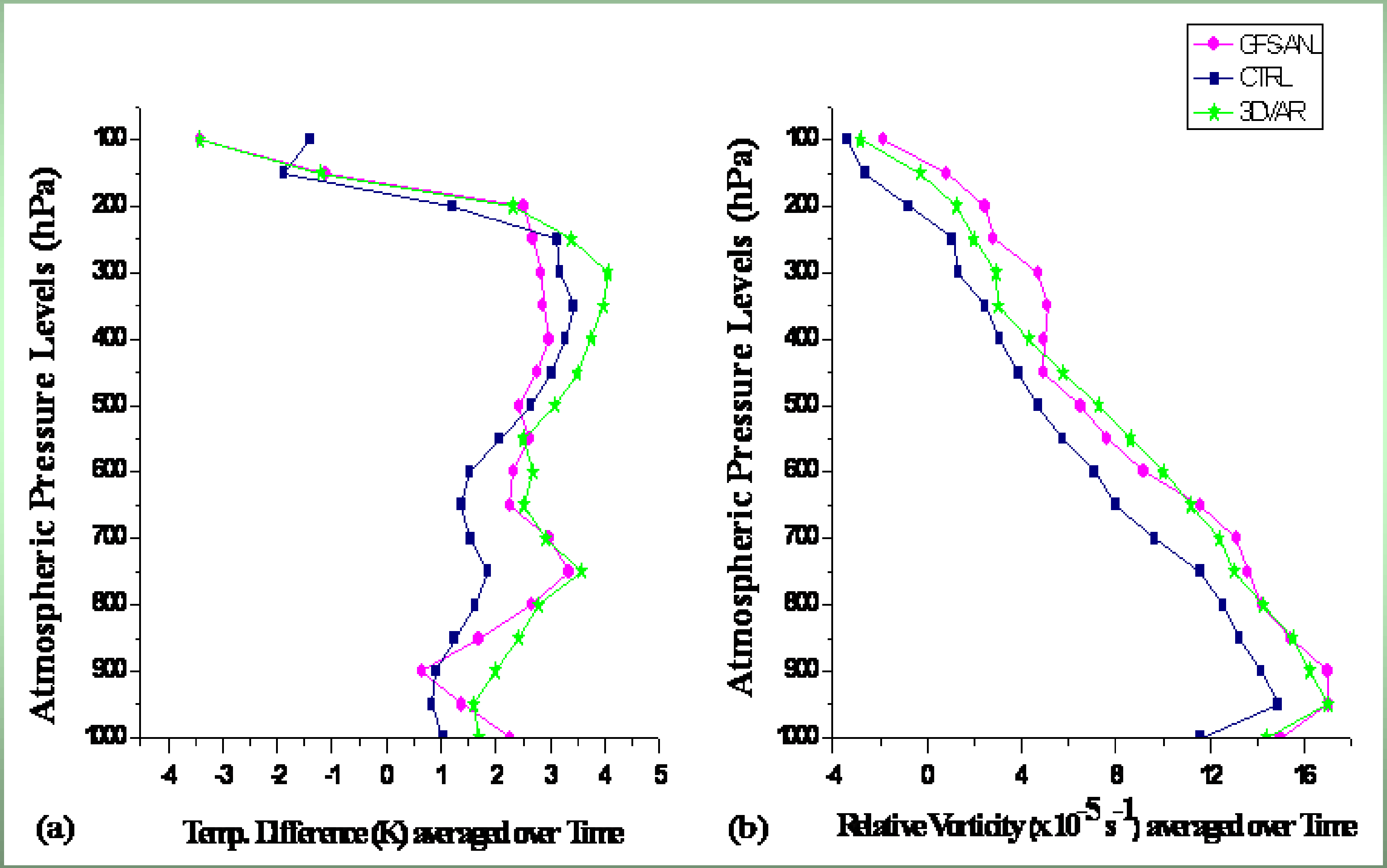
Results and discussions

- ETS for the 3DVAR run for all the three monsoon depression cases show higher values as compared to the CTRL run.
- The bias values for the 3DVAR run are lower as compared to the CTRL run for all the three monsoon depression cases, indicating that the 3DVAR run is not over predicting the precipitation.
- The above indicates that assimilation of MODIS temperature and humidity profiles results in improved quantitative rainfall forecasts.

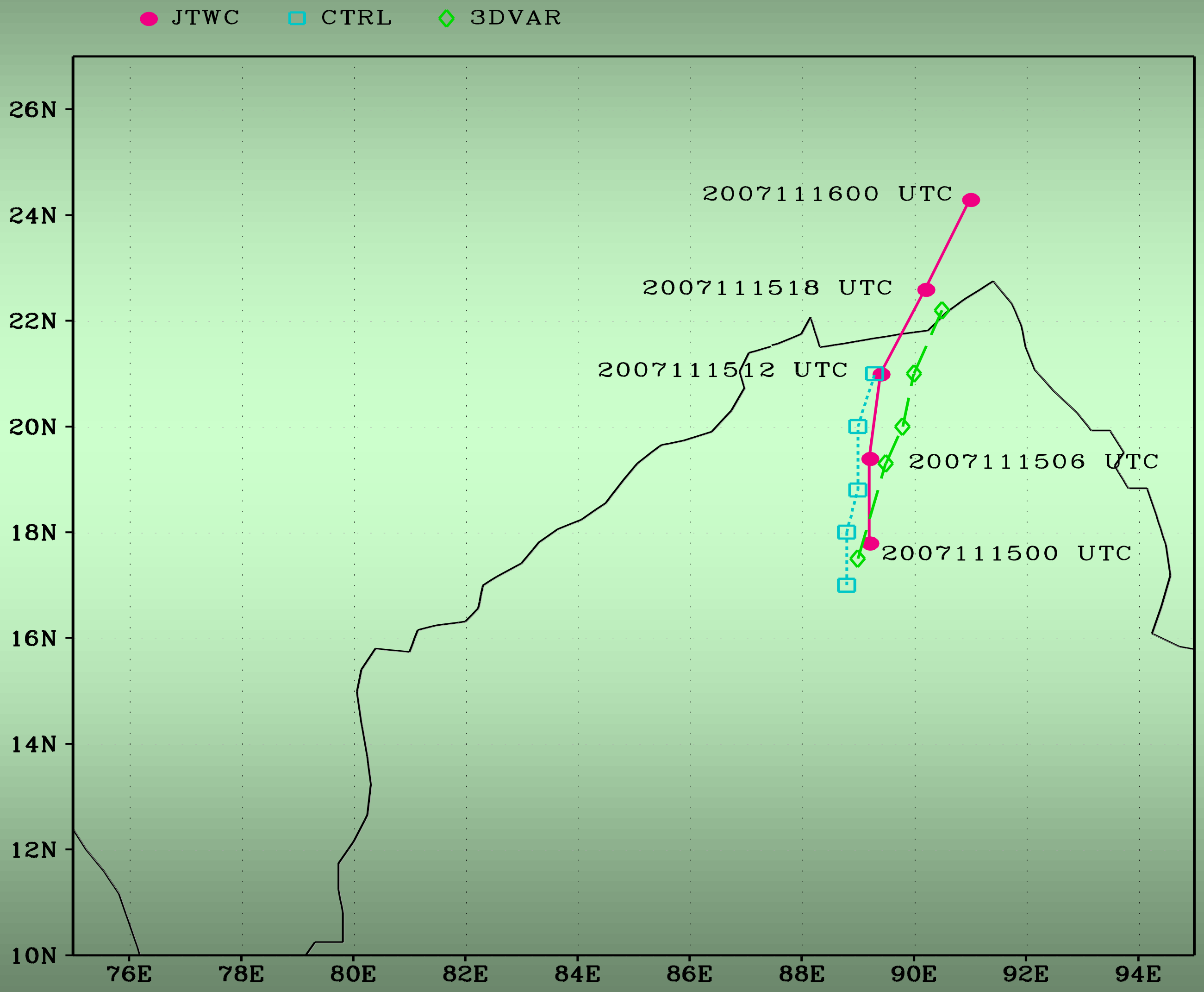
3DVAR results of assimilation of DWR reflectivity and radial wind for several meteorological systems over India

- One monsoon depression (19-21 September 2006), and two tropical cyclones (Cyclone SIDR 15-16 November 2007 and Cyclone AILA 25-26 November 2007) were investigated for 3DVAR assimilation of Doppler Weather Radar (DWR) reflectivity and radial wind using WRF model.
- WRF model domain of 30 km grid spacing with 28 vertical levels. Used NCEP-GFS fields for initial and lateral boundary conditions.

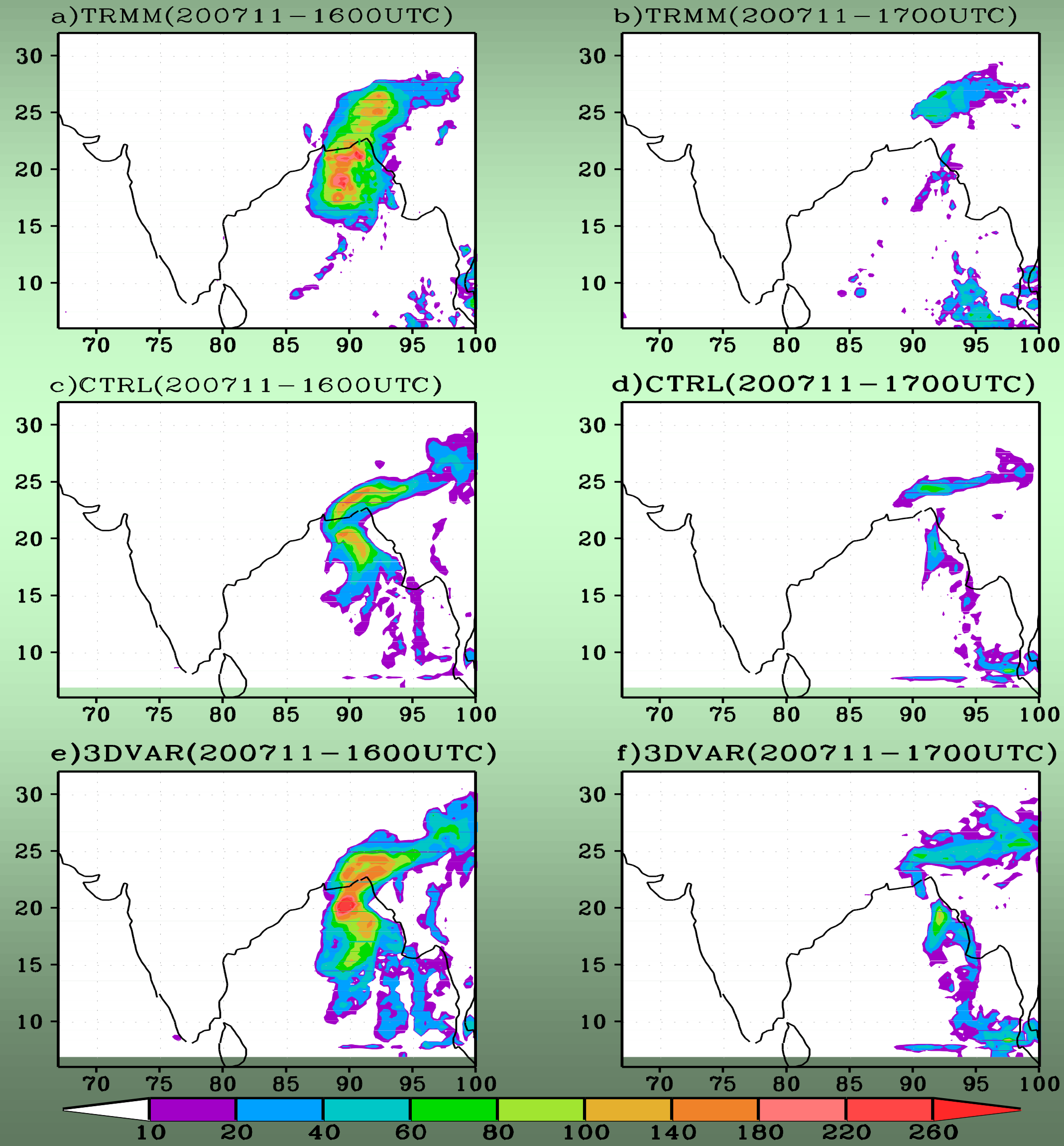
Cyclone SIDR



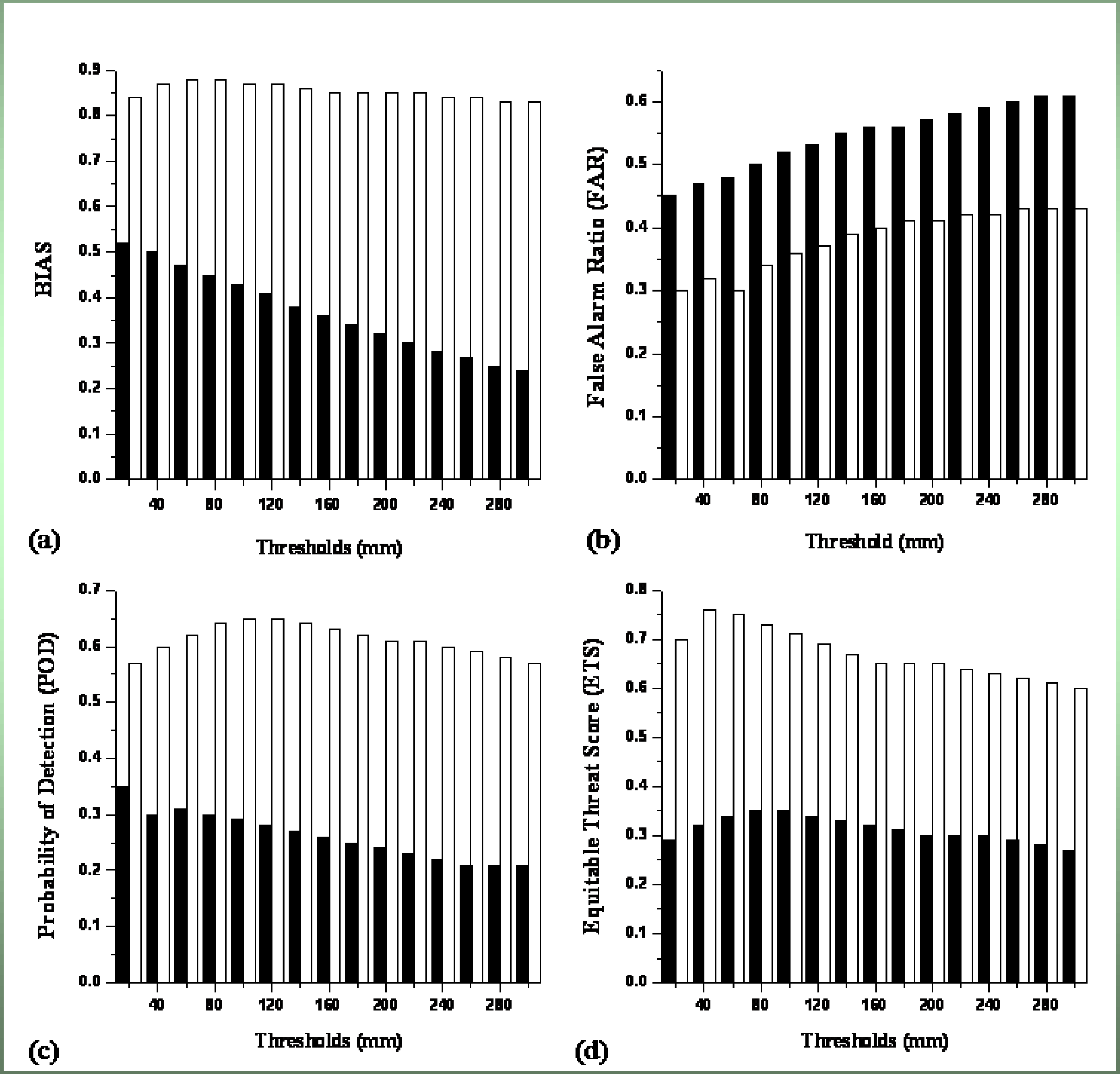
Track of Cyclone SIDR



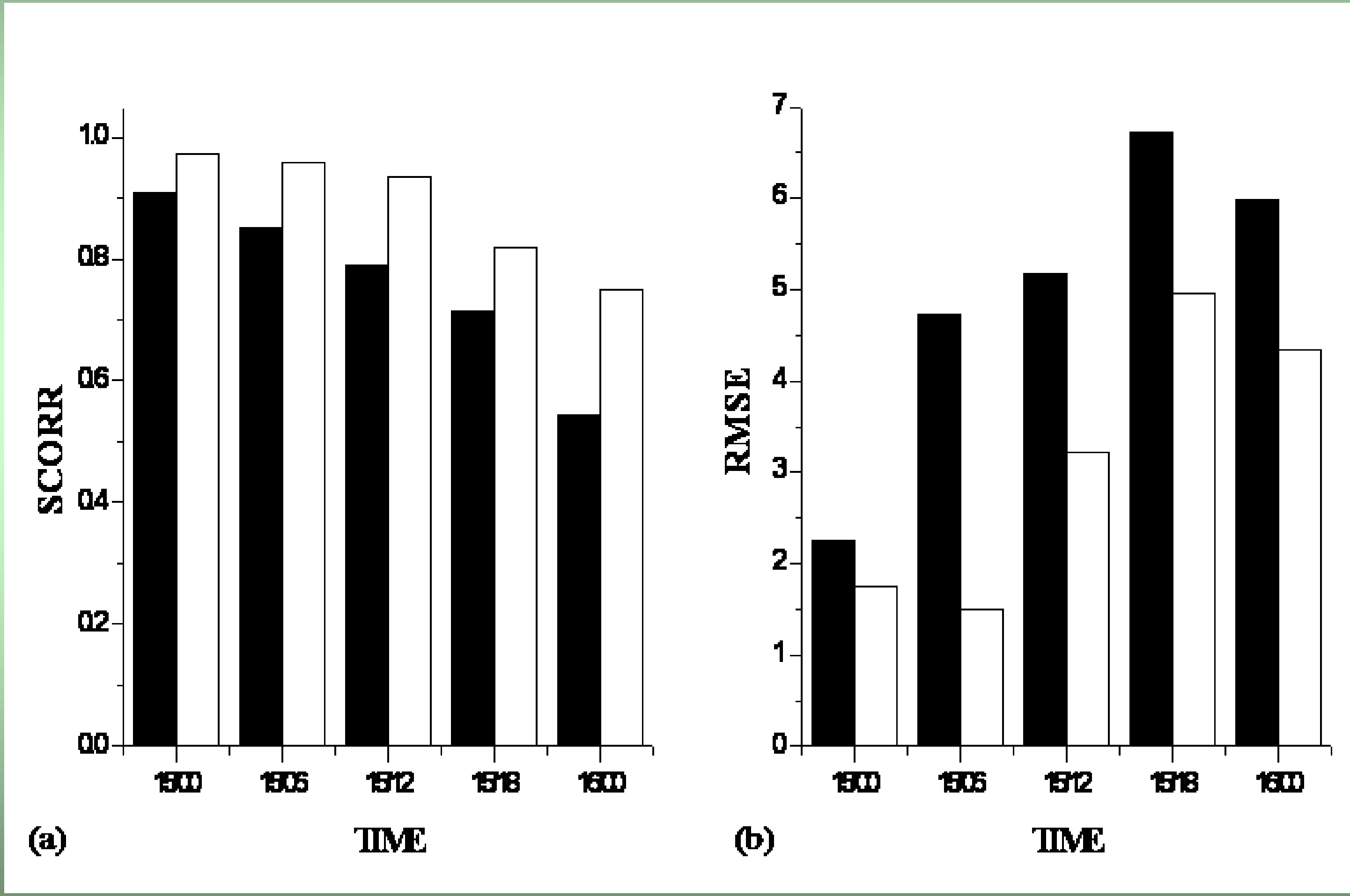
Cyclone SIDR



Cyclone SIDR



Cyclone SIDR (space corr. and RMSE of 950 hPa wind)



Results and Discussions

- For cyclone SIDR, the 3DVAR runs clearly reproduces a warm mid troposphere layers between 600 hPa and 300 hPa.
- For cyclone SIDR, the profile of relative vorticity for the 3DVAR run consistently matches with the GFS-ANL profile for all atmospheric layers, capturing the sharp maximum of the cyclonic vorticity at 900 hPa.
- The precipitation patterns for both days of forecast are reasonably well simulated by the 3DVAR run and is in agreement with the TRMM.

Sensitivity study of the effect of 3DVAR assimilation of observations from various sources both individually and collectively for several meteorological systems over India

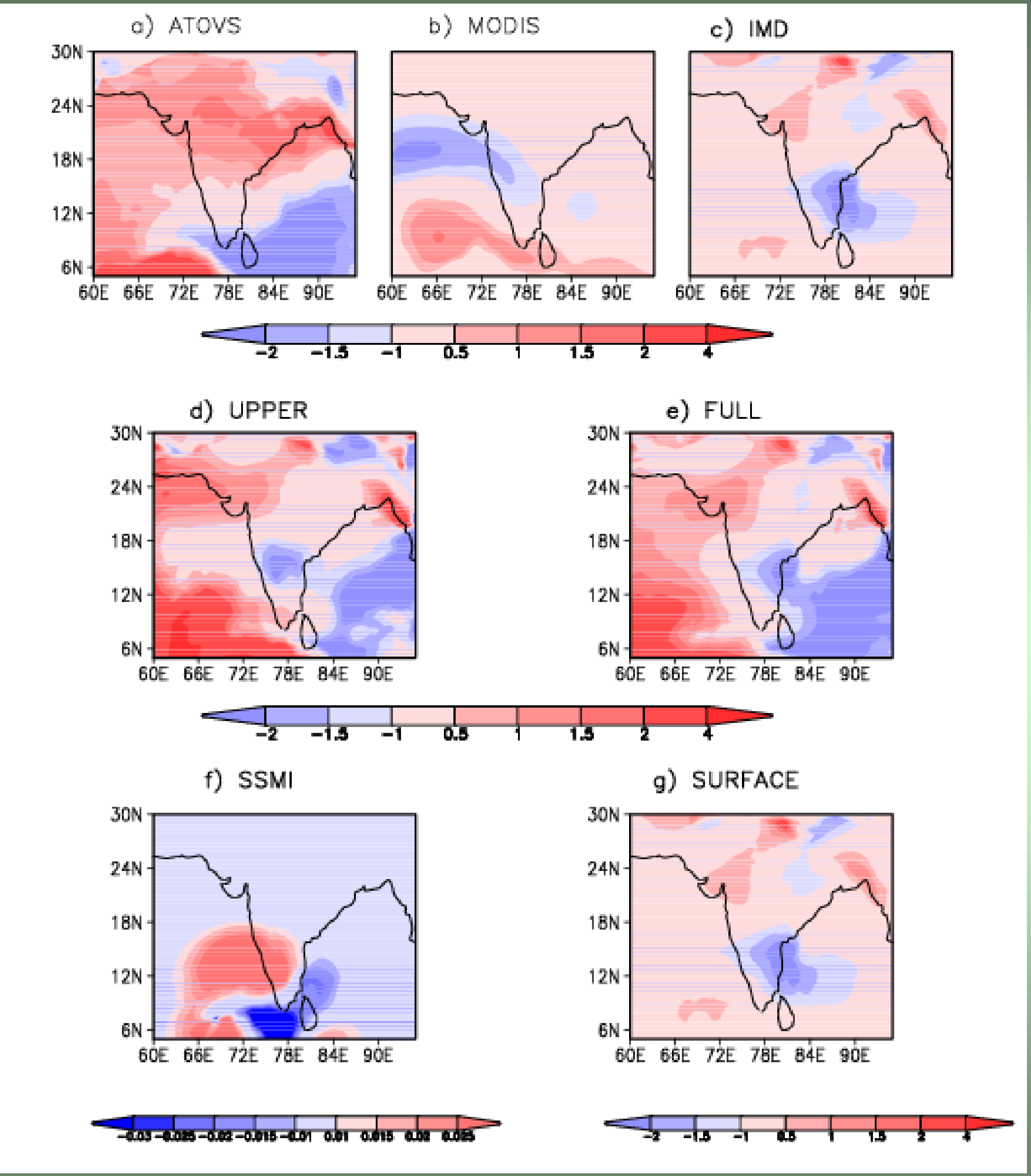
- Monsoon depression of 1-3 August 2006 is studied. The low pressure area was formed over the north Bay off West Bengal coast on 1 August of 2006. The depression drifted south westwards and intensified into a deep depression.
- The deep depression crossed the south of Orissa coast between Puri and Gopalpur around 03 UTC of 3 August 2006.
- This deep depression caused heavy to very heavy rainfall over the coast of the Orissa and eastern Indian region

Numerical experiments

- The letters M, A, G and S denote model experiments assimilating MODIS, ATOVS, conventional (GTS) and SSMI observations respectively with the initial time of forecast being 31 July 2006 18 UTC.

Expn.	0hr	6hr	12 hr	18hr	24hr	30hr
MODIS	M		M		M	
ATOVS		A		A		A
SSMI		S		S		S
IMD	G	G	G	G	G	G
SURFACE	G	ASG	G	ASG	G	ASG
UPPER	M	AG	M	AG	M	AG
FULL	MG	ASG	MG	ASG	MG	ASG

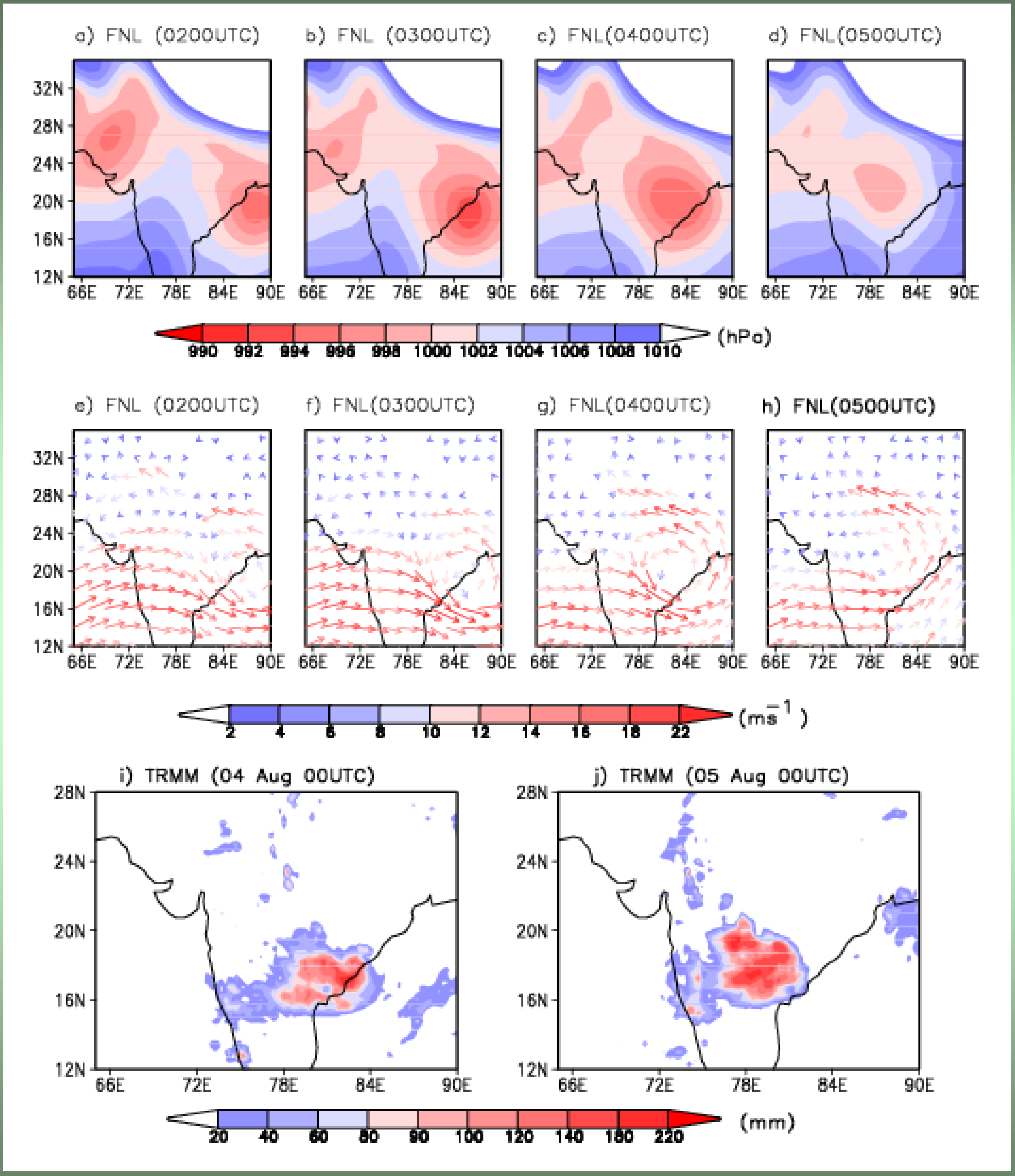
Analysis Increments for 850 hPa wind speed



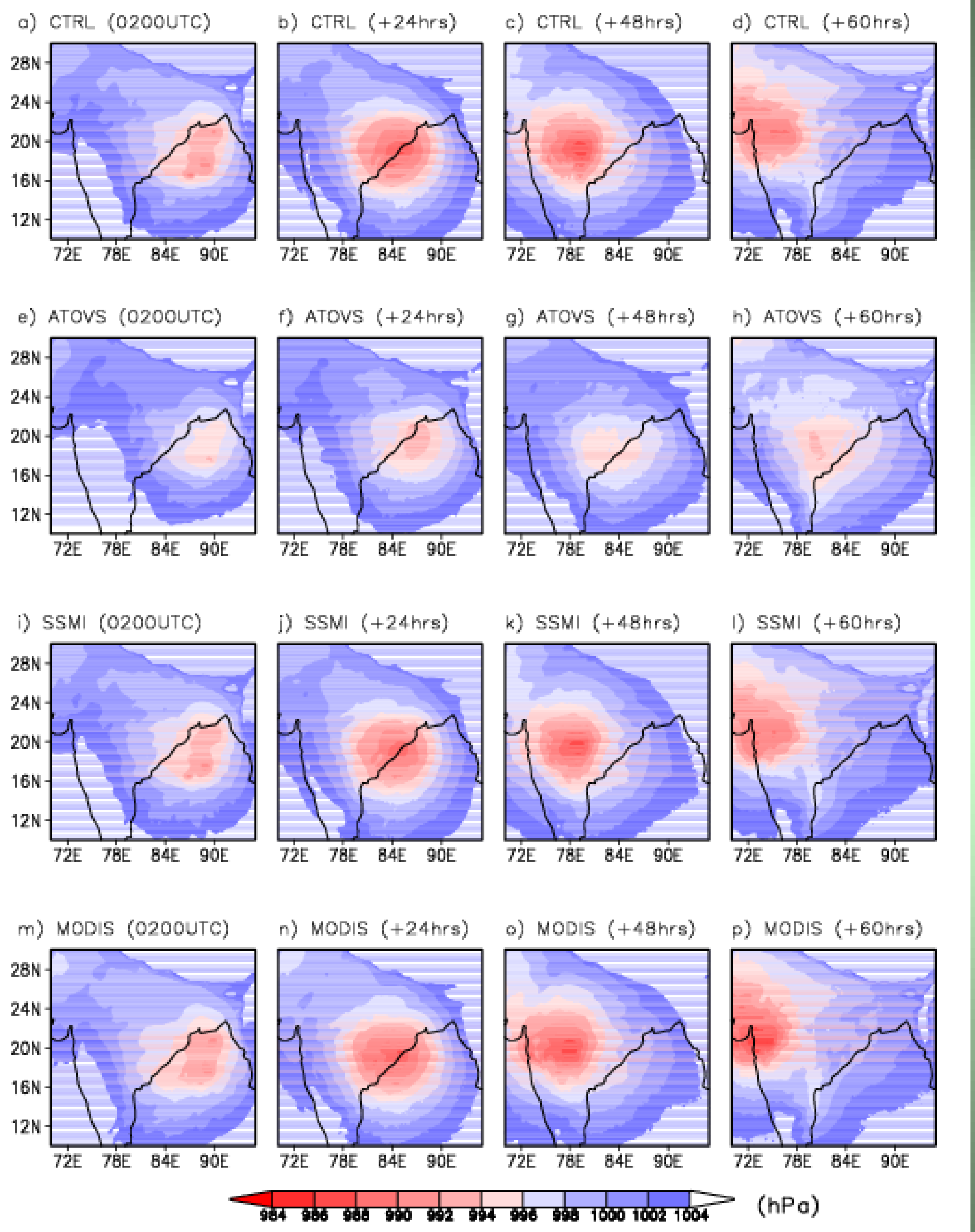
NCEP-FNL SLP

NCEP-FNL Wind speed (850 hPa)

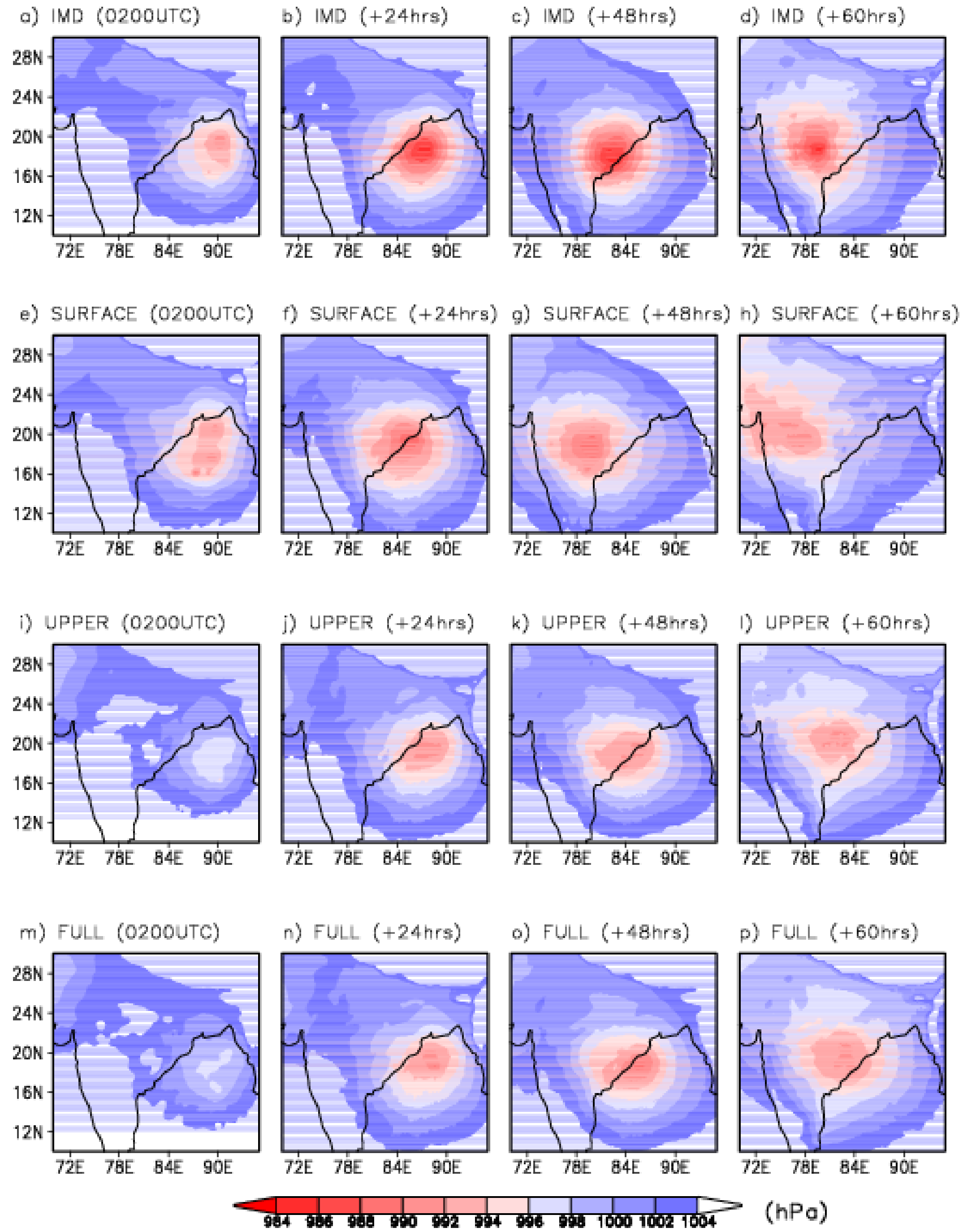
TRMM rainfall



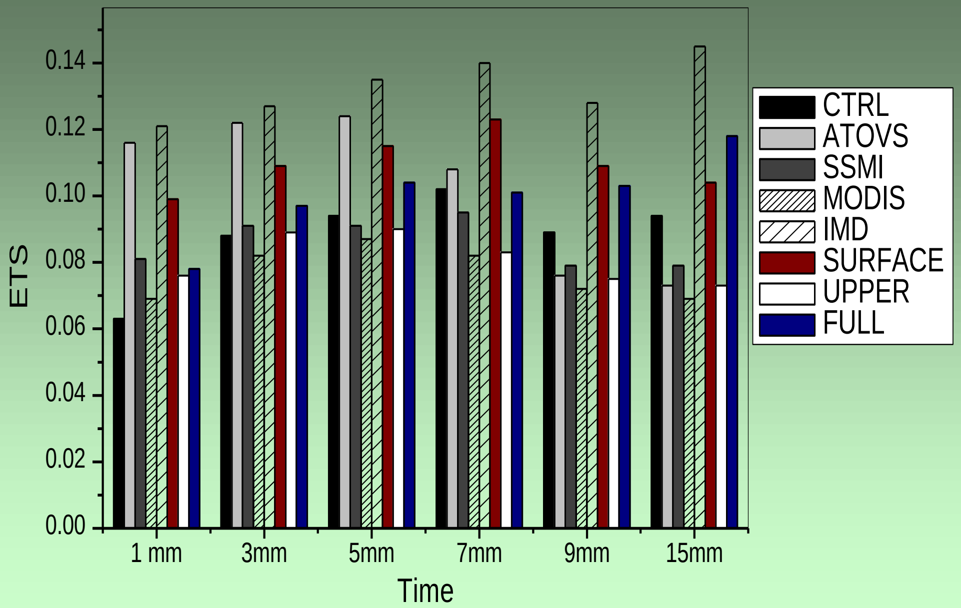
Mean Sea Level Pressure

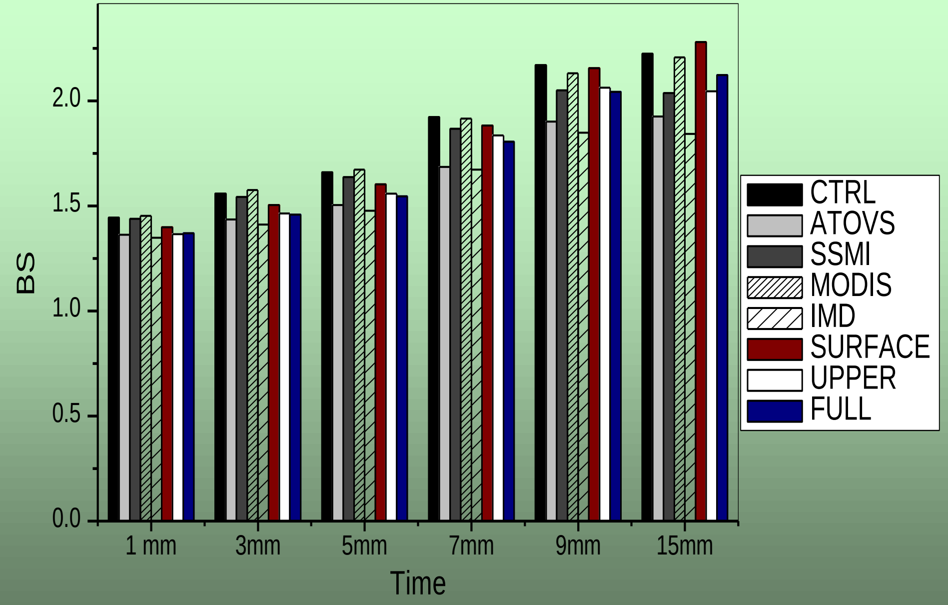


Mean Sea Level Pressure

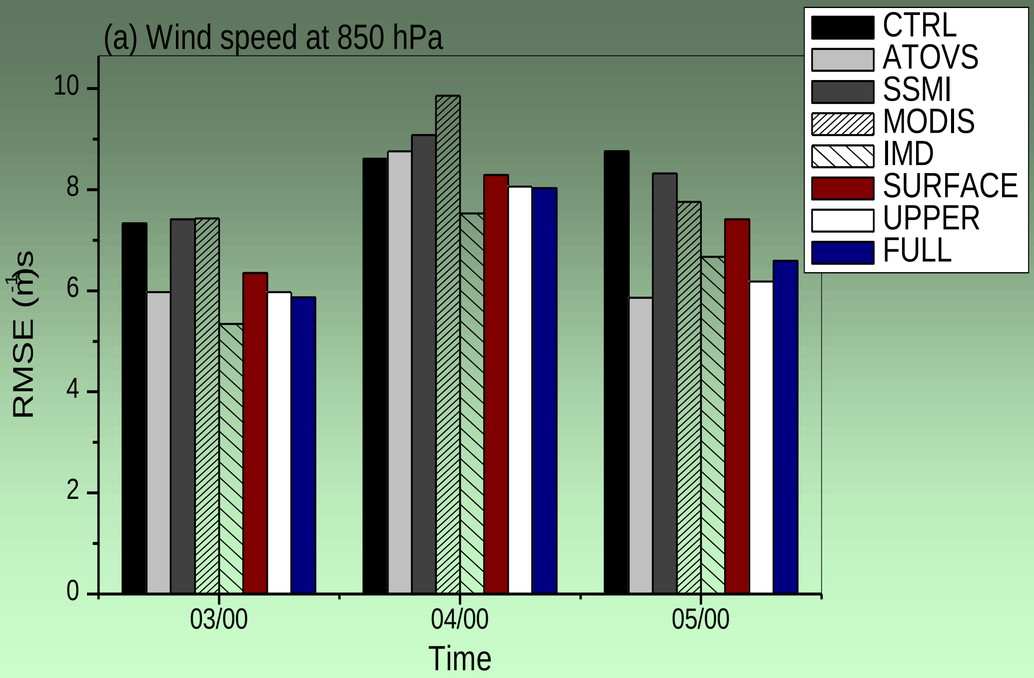


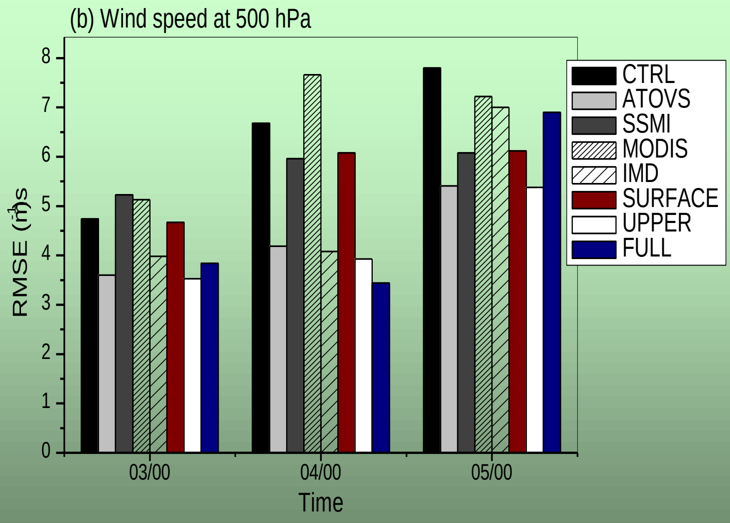
ETS &
Bias score

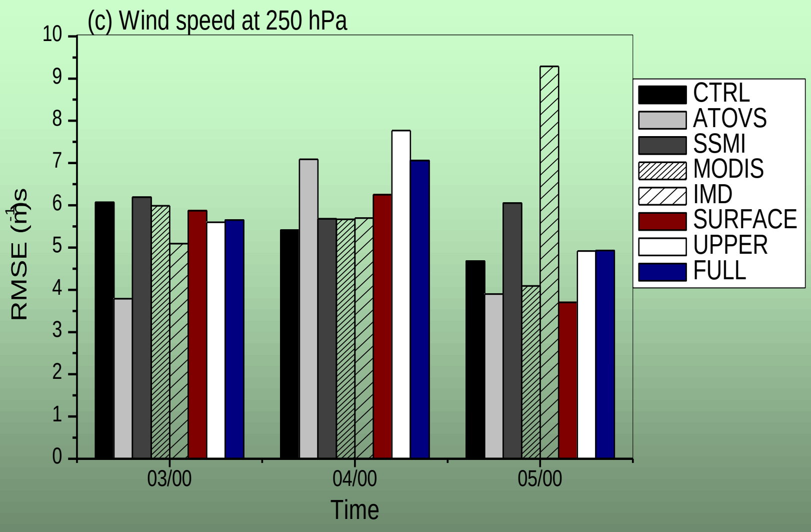




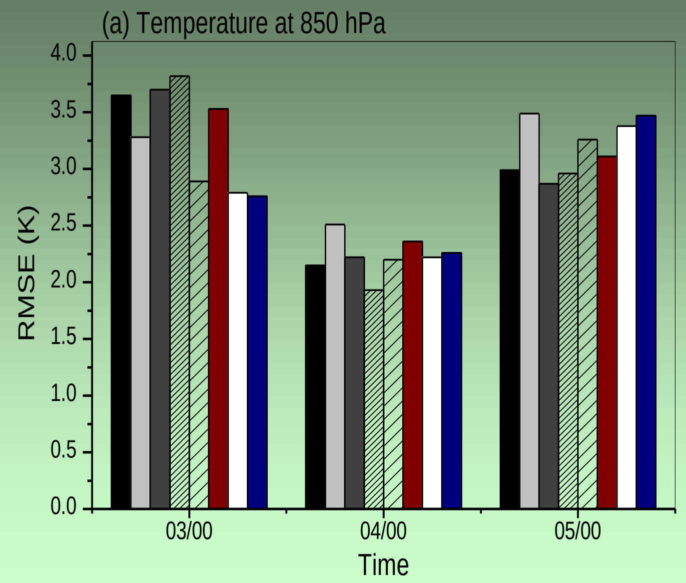
RMSE of wind speed (ms^{-1})

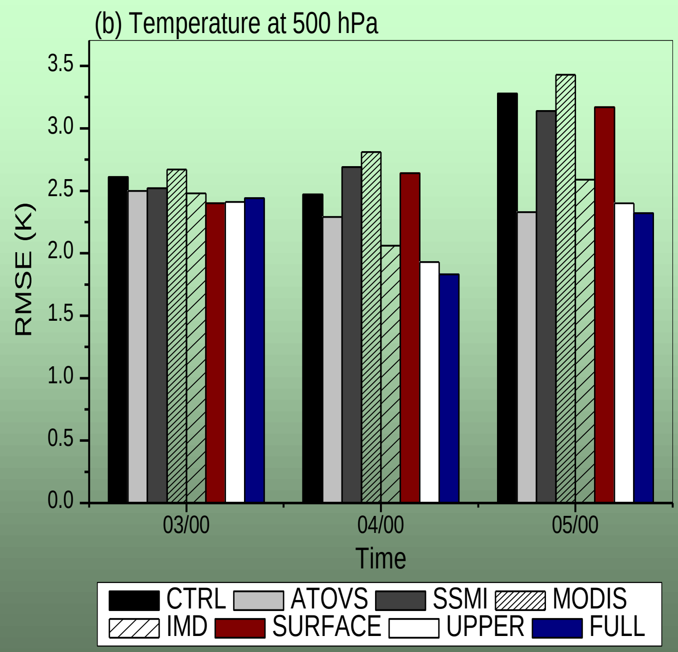


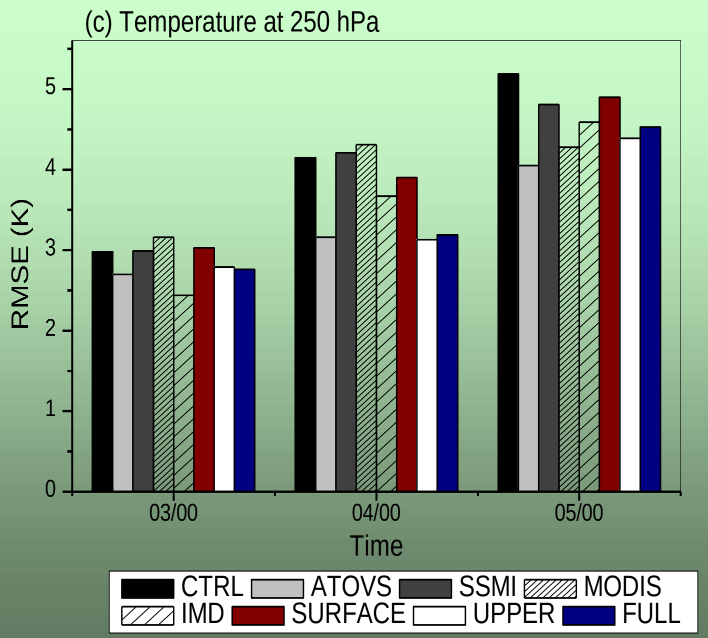




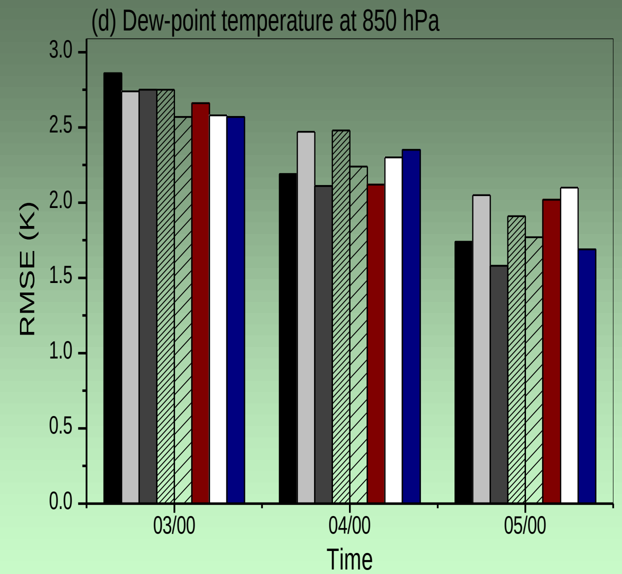
RMSE of temperature (K)

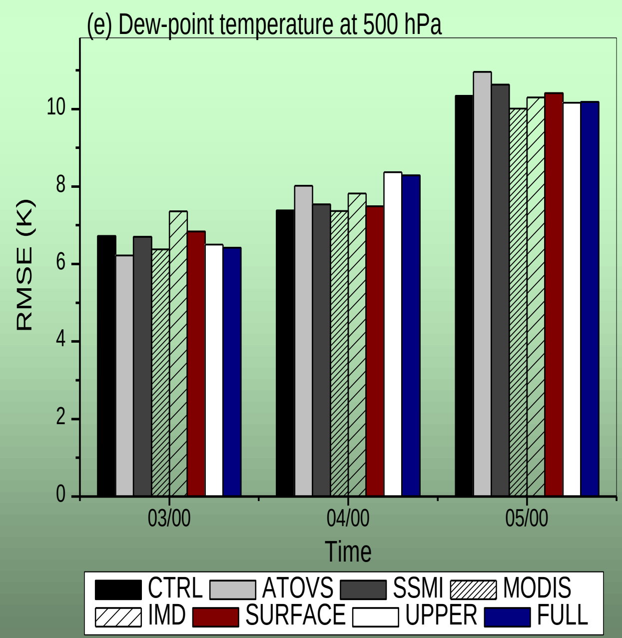


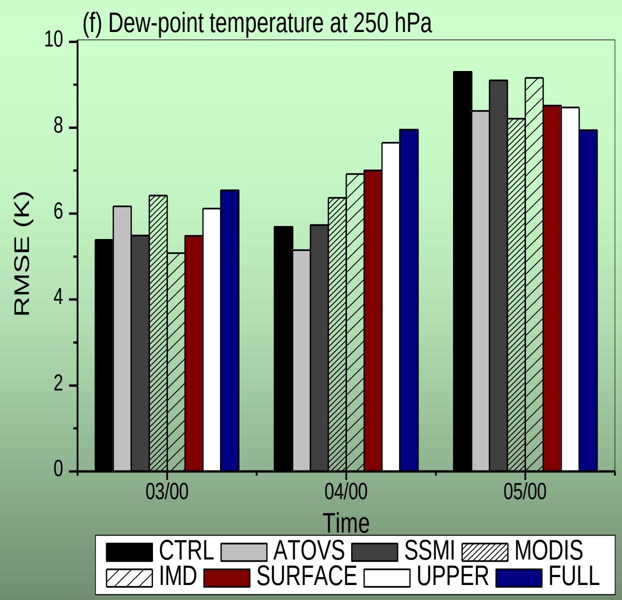




RMSE of dew-point temperature (K)







Results and Discussions

- Reduced error values for the field variables (temperature, dew-point temperature and wind speed) especially for the ATOVS, UPPER and FULL experiments are observed.
- Statistical skill scores (ETS and Bias score) suggests enhanced forecast skill for assimilation experiments.
- The model run which incorporated all the satellite observations (FULL) has shown significant reduction in the error values of the field variables and also has enhanced forecast skill for precipitation

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