

ASSIMILATION OF INSAT-3D SOUNDER RETRIEVED THERMODYNAMIC PROFILES USING WRF MODEL FOR EXTREME RAINFALL EVENT OVER NORTH CENTRAL PART OF INDIA

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Abstract. The impact of Indian National Satellite-3D (INSAT-3D) retrieved thermodynamic profiles (temperature and humidity) on Weather Research Forecasting (WRF) model forecast is examined in this study. The extreme rainfall event which occurred during July 25-26, 2015 over the North central part of India is taken as the case study. The analysis obtained after assimilation is compared with the European Centre for Medium-Range Weather Forecasts (ECMWF) analysis. Obtained results show quite good improvement in humidity and temperature analysis when compared with ECMWF analysis. Positive improvements are observed in 24 h WRF model predicted rainfall on assimilation of INSAT-3D temperature and humidity profiles.

Keywords: INSAT-3D, WRF model, forecast, analysis, rainfall.

1. Introduction

Rainfall is an important parameter that changes in scales from few meters to several of kilo meters. The significance of exact rainfall delineate and forecast are broadly recognized. The precision of Numerical Weather Prediction (NWP) relies on the nature of the initial conditions. Atmospheric observation from various sources (Radar, Satellite, Aircraft, Radiosonde, etc.) are utilized to introduce operational weather prediction models. An evaluation of the nature of the precipitation outline is essential to comprehend the qualities and inadequacies of current forecast/assimilation frameworks and furthermore in perspective of future climate/weather projection. The role of satellite observations in NWP

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models have been growing rapidly due to the increase of number of weather satellites. The NWP models have been developed from the last decades with the continuous process in both data assimilation techniques and numerical model [1]. Data assimilation is the technique in which observations of the original system are incorporated into the model state of a numerical model of that system. The aim of data assimilation is to produce a model state that is as close to the 'original' state as possible, i.e. one that describes the observed reality in the optimum way, which is referred to as the analysis.

Due to their high spatial and transient determination, geostationary satellite instruments give real time data about the advancement of the climate wonders over the observing domain, when contrasted with polar-orbiting satellite instruments. Nonetheless, geostationary satellite instruments have bring down unearthly determination and are accordingly less equipped for giving vertical soundings of the climate than polar-orbiting satellite instruments [2]. India successfully launched on 26th July 2013 INSAT-3D satellite at 82° E. INSAT-3D carried out two meteorological instruments, that is the sounder and the imager [3]. The six channels with imager has, one within electromagnetic range and five inside the infrared (IR) region and nineteen sounder channels, one within visible band of reflected solar energy and eighteen IR channel measures emitted energy. The sounder instrument gives vertical structure of the environment. With the dispatch of INSAT-3D, barometrical soundings are workable interestingly over a moderately information scanty region, for example, the Indian Ocean from a geostationary stage. Atmospheric thermodynamic conditions over the Arabian Sea and the Bay of Bengal impact the climate frameworks over the Indian region. The INSAT-3D data, especially sounder data, can possibly contribute fundamentally to mesoscale climate guaging over the Indian region [2].

Precipitation digestion is considered as one of the essential ways to deal with enhanced the climate figures. Rainfall perception incorporates the atmospheric information as far as winds, temperature and specific humidity and furthermore adds to the model atmospheric spending plan. A few numerical modeling research have demonstrated that precipitation data enhanced the climate estimate [1, 4, 5, 6]. Various affectability examinations for rainfall assimilation have been performed at different forecast/explore focuses like in European Centre for Medium-Range Weather Forecasts (ECMWF) [7] and National Centers for Environmental Prediction (NCEP) [5, 8]. For some reasons, rainfall assimilation is an additional unpredictable issue distinguished to assimilation of convective or on the other hand clear-sky satellite brilliance [10]. Marecal and Mahfouf [11] in 2000, exhibited that nudging of rain rate enhanced the dampness investigation and diminished the turn-up issue. As a result of deficient spread of rain measures and ground-based radars, satellite-recovered precipitation is one of the significant wellspring of precipitation perception. Treadon [8] in 1997, assimilated the satellite-recovered precipitation rate in the NCEP 3D-Var data assimilation framework. Lekhadiya and Jana [9] in 2018, shows the different

physical parameterization options and it has ability to predict rainfall prediction using WRF model.

There are two ways to deal with NWP modeling system with different types of observation. The first one is the data-denial approach. It is the effect of different types of observation on forecast and analysis quality of NWP modeling system which is verified by performing two different side-by-side assimilation experiments. i.e. Control run;CNT and experiment run;EXP. In the CNT run all the observation assimilated and in EXP run only particular observation assimilated which gives best appropriate results and the effect of two experiment (CNT and EXP) are performed in different way [12, 13, 14, 15]. In the second approach, the adjoint of the NWP framework is utilized to evaluate the effect of specific types of observation [16, 17, 18]. Be that as it may, we utilized here data-denial Observing System Experiments (OSEs) with different sets of measurements which is computationally extremely costly on the grounds that requires an extensive number of analyses.

The objective of this study is to evaluate the impact of assimilation of INSAT-3D temperature and humidity profiles on WRF model forecast. An extreme rainfall event which occurred on 25th July 2015 in north Madhya Pradesh and adjoining regions is taken as the case study.

2. Model description and assimilation methodology

2.1 WRF model

The model utilized as a part of this study is WRF version 3.7. The WRF model is a cutting edge mesoscale numerical weather prediction model intended to meet both research needs and operational forecasting. The subtle elements of the WRF model can be found on the site (<http://www.wrf-model.org>). WRF is a restricted region, compressible, and nonhydrostatic primitive equation model. It has different physical parameterization schemes [19]. There are two dynamic solvers in the WRF modeling system: the Advanced Research WRF (ARW) solver grew firstly at NCAR (National Center for Atmospheric Research), and the Nonhydrostatic Mesoscale Model (NMM) solver created at National Centers for Environmental Prediction (NCEP). Here we have utilised the ARW dynamic solver. We have used Arakawa C-grid staggering for horizontal grid and the completely compressible system of equations [20]. The territory following hydrostatic weight with vertical framework stretching was utilised in vertical. The time split incorporation utilizes a third order Runge-Kutta scheme with little time ventures for acoustic and gravity wave modes. The parametrization schemes utilized as a part of this experiment comprised of WRF Single Moment (WSM) 6-class graupel conspire for microphysics, the New Kain-Fritsch [21] cumulus convection parameterization scheme and Yonsei University (YSU) planetary boundary layer scheme. The model domain (see Fig. 1) contained

330 × 320 framework focuses with 30 km spatial determination. The model had 36 vertical levels with the highest point level at 10 hPa.

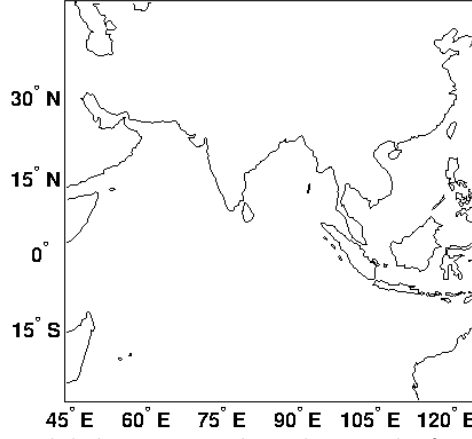


Figure 1: The model domain used in this study for WRF experiment

2.2 Assimilation methodology

The WRF three-dimensional variational (3D-Var) data assimilation framework is utilised as a part of this experiment. It is equipped with assimilating information from a wide range of observational stages got from conventional source as well as satellites. The WRF 3D-Var technique comprises of finding the most likely atmospheric state (i.e. analysis) by limiting a cost function ($J(x)$) given as

$$(1) \quad J(x) = J^b + J^o = \frac{1}{2}(x - x^b)^T B^{-1}(x - x^b) + \frac{1}{2}(H(x) - y^o)^T R^{-1}(H(x) - y^o).$$

The gradient of the cost function $J(x)$ with respect to x is given as

$$(2) \quad \nabla_x J(x) = B^{-1}(x - x^b) + H^T R^{-1}(H(x) - y^o).$$

As shown in Eq. (1), the cost function is characterised as the summed squared separation of the present state (x) to the background state (x^b) and to the perceptions (y^o) in which the agitators are weighted by the inverse of error covariance matrices. In Eq. (1), H is the (forward) perception administrator that maps model state to perception space. The covariance matrices of background error (B) and perception error (R) are expected Gaussian. These errors are additionally expected impartial and uncorrelated to each other. The setup of the WRF 3D-Var framework depends on an incremental plan turning in a multivariate incremental research inside the WRF model space. The incremental cost function minimization is accomplished in a preconditioned control variable space. The preconditioned manipulate variables applied as a part of this experiment are humidity, velocity potential, stream-function and unbalanced pressure.

Information of contrasts between 24 h and 12 h forecasts are utilised to evaluate background error covariances matrix by the National Meteorological Center (NMC) technique [22, 23]. Portrayal of the horizontal aspect of historical past blunders on a level plane homogeneous and isotropic recursive channels. The vertical component is hooked up through projection onto climatologically arrived on the midpoint of eigenvectors of vertical error evaluated by the NMC strategy [24]. Within WRF 3D-Var, all perception errors are thought to be uncorrelated in space and time. The corner to corner components of those covariance matrices are contrast for perceptions (in present case, temperature and humidity).

3. Data used

The temperature and humidity profiles are retrieved from INSAT-3D data at 43 pressure levels and the retrieved data is available at L2B product from Meteorological & Oceanographic Satellite Data Archival Centre (MOSDAC) (www.mosadc.gov.in). The spatial resolution of data is 10 km at nadir. The data is available hourly. The retrieved temperature and humidity profiles for 25th July, 2015 are taken and data file is in the form of Hierarchical Data Format-5 (HDF5) which is dumped for the variable temperature, specific humidity, latitude, longitude and pressure levels in binary form. Combining all binary files to a single file and converting it into American Standard Code for Information Interchange (ASCII) format, which is readable for OBSPROC and subsequently for 3D-Var. Using them with GFS data file and processed through WRFDA. Model initial conditions and lateral boundary conditions are taken from NCEP analysis at every six hours with $0.5^\circ \times 0.5^\circ$ horizontal resolution and 26 vertical levels. The lateral boundary conditions must first be modified to reflect difference between background forecast and analysis. The model forecast verification is done with temperature and humidity profiles from ECMWF analysis. For rainfall forecast verification Global Satellite Mapping of Precipitation (GSMaP) data is used.

4. Case study

An extreme rainfall event which occurred on 25th July, 2015 in North-Madhya Pradesh, central India is taken as the case study. The 24 h accumulated rainfall from GSMaP during 0000 UTC 25 - 0000 UTC 26 July 2015 is shown in Fig. 2. From Fig. 2, we can see that there was 160 mm rainfall in 24 h over North-Madhya Pradesh.

4.1 Experimental setup

Two experiments were performed for this study, the Control (CNT) and the Experiment (EXP). In the CNT run, only GFS analysis is taken as the model initial condition, while in EXP run, the INSAT-3D retrieved temperature and

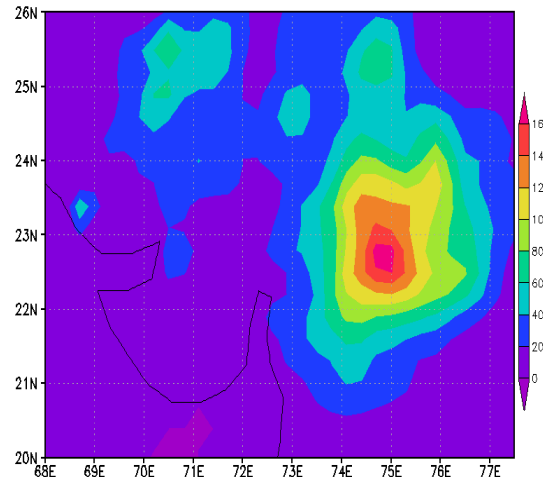
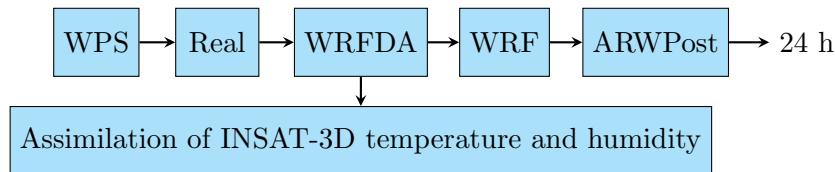


Figure 2: 24 h accumulated rainfall(mm) map from GSMaP during 0000 UTC 25 July 2015 - 0000 UTC 26 July 2015

humidity profiles are assimilated and GFS analysis are taken as model boundary conditions. The WRF model then run with the obtained analysis from CNT and EXP run to provide 24 h forecast.



Flowchart 1: Control Run



Flowchart 2: Experiment Run

5. Results and discussion

5.1 Impact on analysis

5.1.1 Overview of the fit to observations

The principal correlation that we made can be portrayed as an once-over to verify everything seems to be good or sanity check i.e. it is basic test to rapidly assess whether a claim or the after-effect of a figuring can be valid. The INSAT-3D analysed temperature and humidity data are plotted as a function of observed temperature and humidity respectively and compared with the first guess. In an effective assimilation, the investigation called as analysis departure (O-A) are smaller than the first guess departure (O-B); subsequently the analysis better matches the perceptions. The histogram plots of the first-guess and analysis

departures for temperature and humidity are shown in Fig. 3 and Fig. 4 respectively. The first-guess departures (O-B) for temperature has a Root Mean Square Deviation (RMSD) of about 0.4063 while the analysis departures (O-A) has the RMSD of about 0.6831. The first-guess departure for humidity is found to have RMSD of about 0.2899 while analysis departures have the RMSD of about 9.2491e-04. The analysis bias and RMSD are altogether lower than their background counterparts. From Fig. 3 and Fig. 4, it is clear that the analysis is closer to the observations than the background.

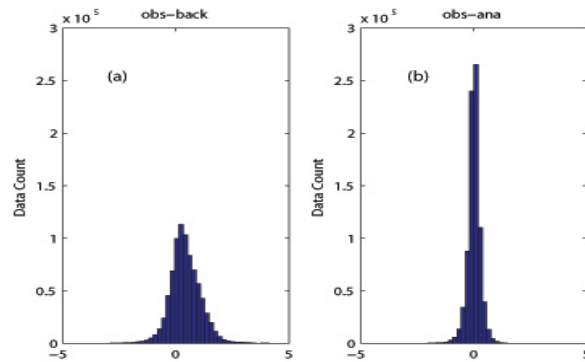


Figure 3: Histogram of the Temperature(K) (a) first guess departures (O-B) and (b) analysis departures (O-A)

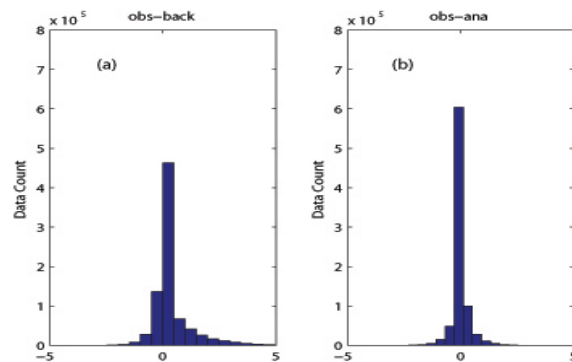


Figure 4: Histogram of the Humidity(gm/kg) (a) first guess departures (O-B) and (b) analysis departures (O-A)

5.1.2 Comparison with ECMWF analysis

The 24 h analysed specific humidity and temperature from both the experiments (CNT and EXP) are verified against the ECMWF analysis valid at 0000 UTC 25th July, 2015. The vertical profiles of the domain averaged RMSD of the temperature and specific humidity with respect to the ECMWF analysis. Temperature and Humidity for both EXP and CNT runs are shown in Fig. 5(a)

and Fig. 5(b) respectively. The RMSD values for the EXP runs for both temperature and humidity are less than the corresponding CNT values suggesting that the assimilation of the INSAT-3D temperature and humidity profiles have improved the analysis in EXP run.

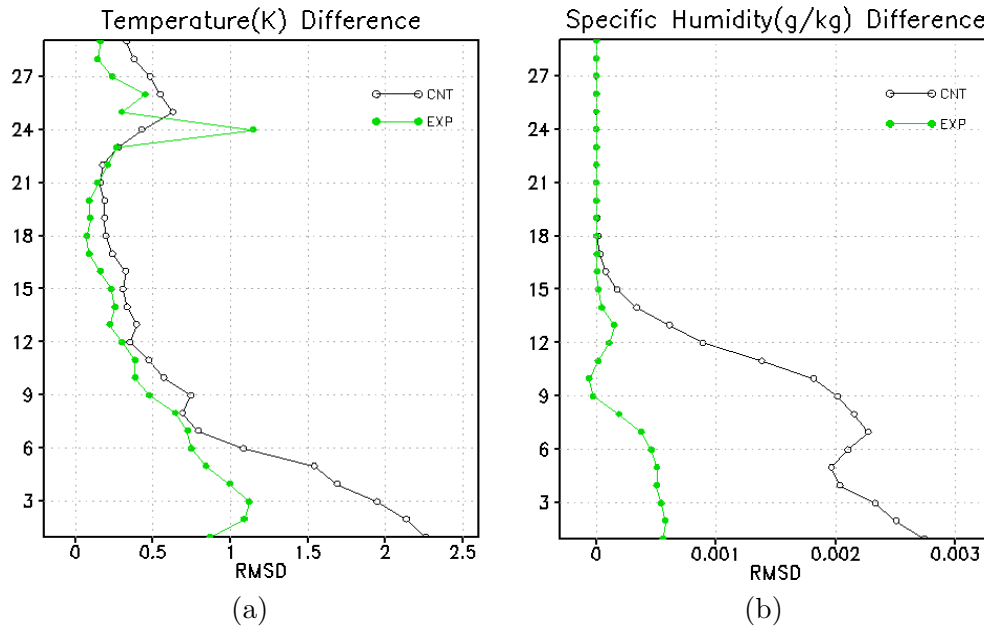


Figure 5: Domain averaged vertical profiles of the RMSD of (a) temperature and (b) humidity for CNT and EXP runs calculated with respect to the ECMWF analysis valid at 0000 UTC 25th July 2015

5.2 Impact on forecast

5.2.1 Comparison with ECMWF analysis

The 24 h predicted temperature and specific humidity from both the experiments (CNT and EXP) are verified against the ECMWF analysis. The spatial distribution of the forecast improvement for the 24 h forecasted temperature and specific humidity on 26th July 2015 are shown in Fig. 6 and Fig. 7 respectively. The assimilation of INSAT-3D temperature and specific humidity profiles show significant improvement in temperature and specific humidity throughout the domain. A few pockets of negative improvement are also observed. The vertical profiles of RMSD, for both CNT and EXP run, in 24 h forecast of specific humidity and temperature are shown in Fig. 8(a) and Fig. 8(b) respectively.

5.2.2 Rainfall Comparison with GSMaP rainfall

The 24 h precipitation forecast is verified against the observation from GSMaP. Here we examined the spatial distribution of 24 h accumulated rainfall. The

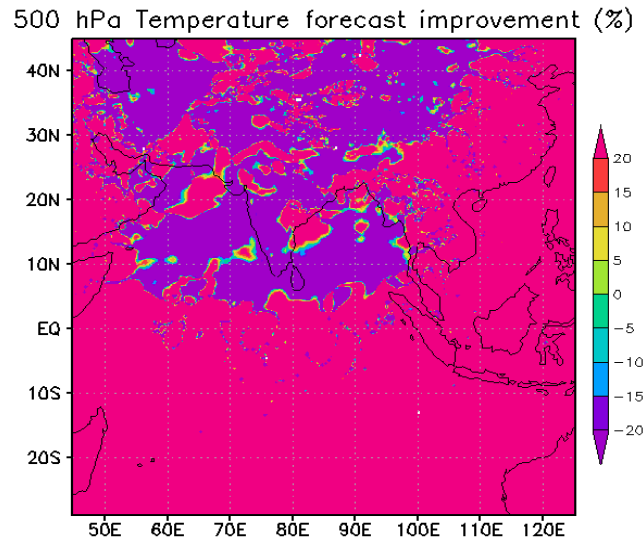


Figure 6: Spatial distribution of the temperature forecast improvement during 0000 UTC 26th July 2015

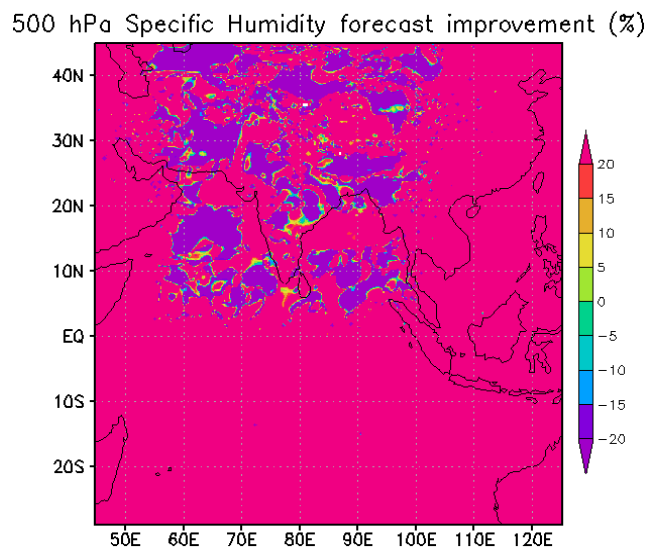


Figure 7: Spatial distribution of the specific humidity forecast improvement during 26th July 2015

CNT minus GSMaP rainfall map is shown in Fig. 9(a), while EXP minus GSMaP rainfall map is shown in Fig. 9(b). The spatial distribution of the rainfall improvement parameter Fig. 9(c), clearly shows that the assimilation of temperature and specific humidity profiles from INSAT-3D data improved the accumulated rainfall prediction over whole Madhya Pradesh and its adjoin-

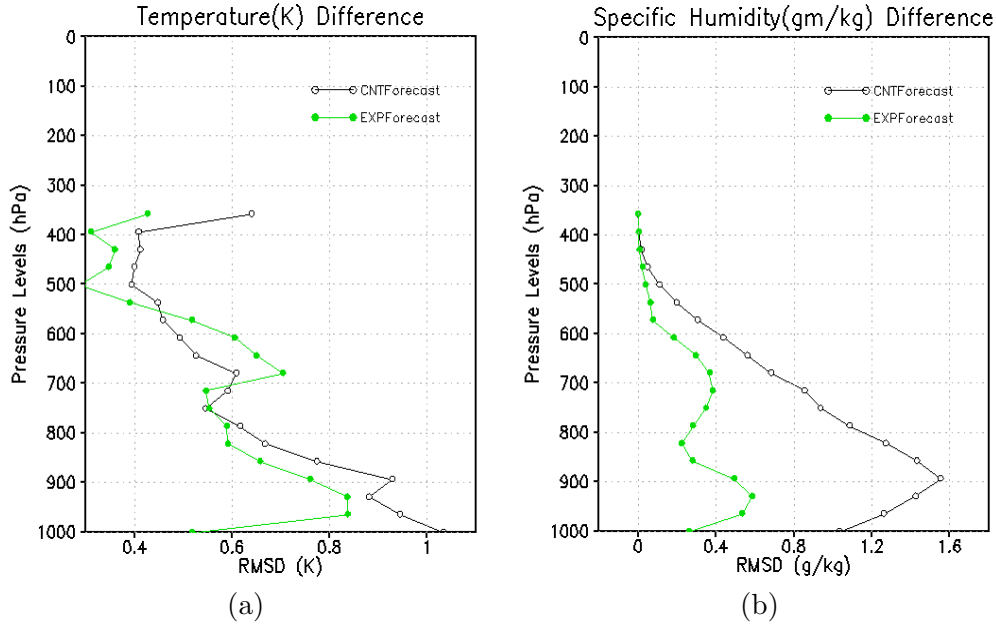


Figure 8: Domain averaged vertical profile of the RMSD of 24 h (a) Temperature and (b) Humidity forecast for CNTForecast and EXPForecast runs calculated with respect to the ECMWF analysis valid at 0000 UTC 26th July 2015

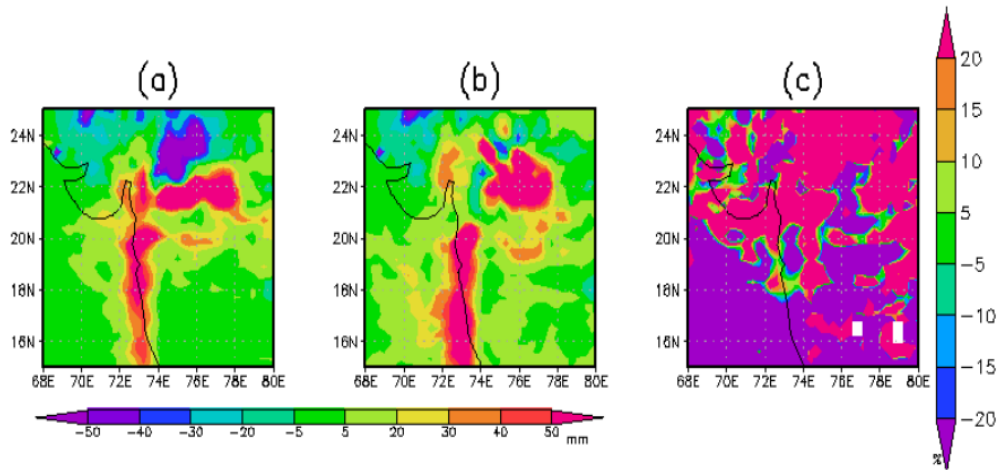


Figure 9: Spatial distribution of 24 h accumulated rainfall forecast improvement parameter in the form (a) CNT minus GSMaP rainfall map, (b) EXP minus GSMaP rainfall map and (c) rainfall improvement

ing regions. Overall, the plots suggests that accumulated rainfall prediction is improved on assimilation of thermodynamic profiles from INSAT-3D.

6. Conclusion

In this investigation, WRF model has been utilized to assimilate the precipitation information during 25 - 26 July, 2015 over North central part of India. Assimilation have been done to compare GFS analysis with ECMWF rainfall, GFS forecast with ECMWF rainfall as well as compared with GFS analysis and GSMaP rainfall. The results shows quite good improvement in temperature and specific humidity forecasts. It demonstrate that rainfall assimilation enhances the rainfall forecast. Thus, assimilation of rainfall observation in the NWP model can be seen as a positive advancement for enhancing the accuracy of numerical modeling for short-range weather forecast.

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