The Effect of Assimilating Clear-Sky INSAT 3D Radiances on Heavy Rainfall Prediction over Indian Region

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Absract

Early mitigation of natural hazards like flash floods, cyclones etc. has been the focus of much of mainstream meteorological research. This study looks at the problem of heavy rainfall over the Indian ocean and ways and means to improve the forecast skill of such events. In this study, clear-sky infrared radiances from INSAT 3D, a geo-stationary sounder, are assimilated with a view to determine its impact on improving the skill in heavy rainfall prediction. In order to eliminate cloudy radiance observations, an adaptive threshold based cloud screening algorithm is used. Initial ensembles required for the assimilation are generated using an iterative EOF (Empirical Orthogonal Function) based perturbation technique, wherein the perturbations were made 24 hours prior to the proposed analysis time in order to allow for the model spin-up. The Local Ensemble Transform Kalman Filter (LETKF) assimilation strategy is adopted. The assimilation of cloud free window channel radiances from INSAT 3D show improvements in the analysis especially for atmospheric layers between 850 - 1000 hPa. The assimilation shows considerable improvements in the forecast of moderate rainfall whereas for the heavy rainfall it shows no improvement when compared with the control run.

INSAT 3D

INSAT 3D, a geostationary satellite launched on 25 July 2013, carries a 6 channel multi-spectral imager and a 18 channel infrared sounder. The channel specifications of the infrared sounder is given in table 1.

Table 1 : INSAT 3D channel specifications

Channel	Frequency (μm)	Type	Channel	Frequency (μm)	Type
1	14.71	CO2 band	10	7.43	Water vapor
2	14.37	CO2 band	11	7.02	Water vapor
3	14.06	CO2 band	12	6.51	Water vapor
4	13.96	CO2 band	13	4.57	N2O
5	13.37	CO2 band	14	4.52	N2O
6	12.66	Water vapor	15	4.45	CO2
7	12.02	Water vapor	16	4.13	CO2
8	11.03	window	17	3.98	window
9	9.71	ozone	18	3.74	window

In this study, only clear-sky radiances were assimilated into NWP model. Hence the cloudy pixels were removed using the observed radiances. A Bispectral Composite Threshold (BCT) method illustrated by Jedlovec et al. [1] is employed. Wherein the clouds were detected using an adaptive threshold based screening procedure as illustrated in figure 1. The cloud detection methodology was applied to several observation datasets and it was validated with the operational cloud mask product derived from INSAT 3D. Qualitative metrics were calculated for different times (Table 2). It can be observed that the BCT method is very consistent in terms of the Hit Rate (HR).

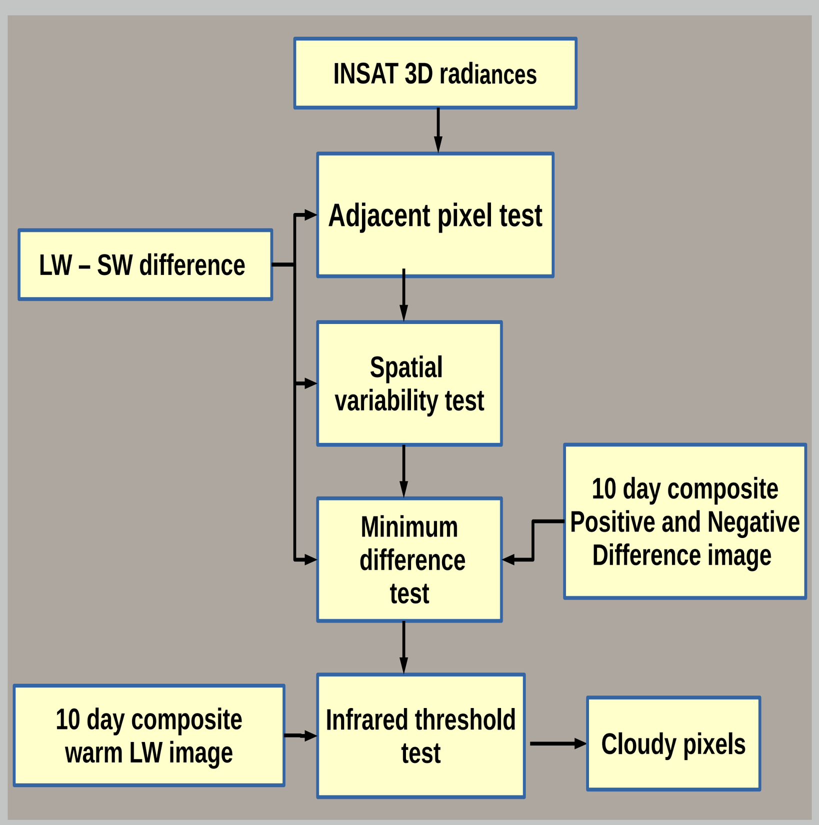

Figure 1 : Cloud screening methodology

Table 2 : Comparison of cloud screening methodology

Time	12 UTC	06 UTC	00 UTC
PP	0.89	0.87	0.82
HR	0.94	0.78	0.73
FAR	0.13	0.06	0.14
TSS	0.80	0.72	0.60

PP - Proportion of perfect classification
HR - Hit Rate
FAR - False Alarm Rate
TSS - True Skill Score

The observations were corrected for bias prior to the assimilation. The variation of bias with zenith angle is shown in figure 2. Figure 3 shows the frequency distribution of the Brightness Temperature difference for channel 18 before and after bias correction.

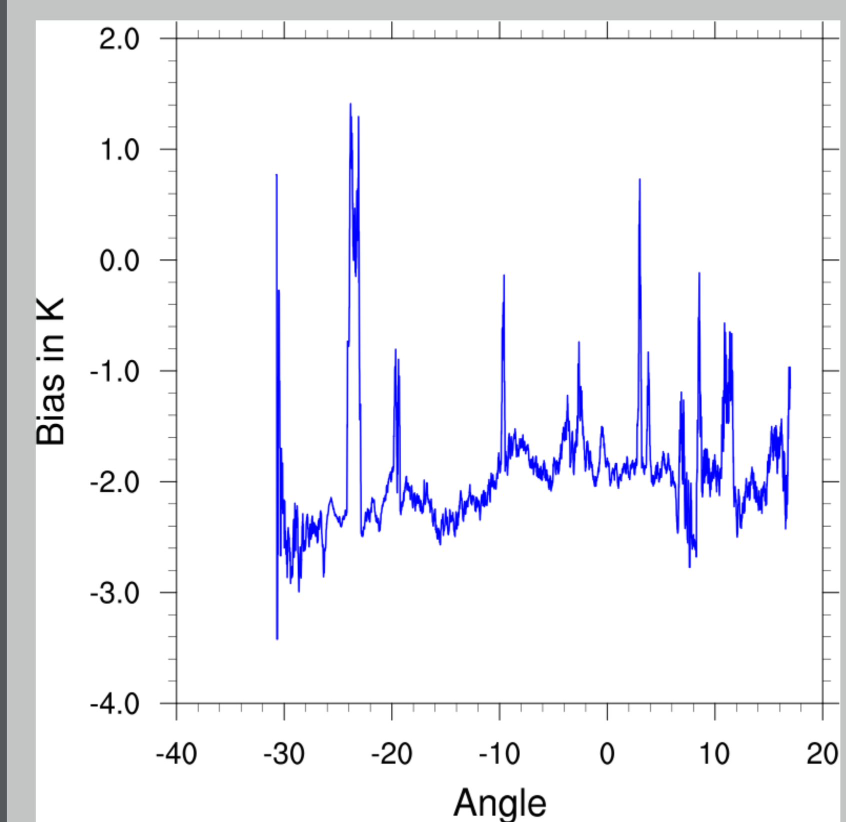

Figure 2 : Variation of bias with zenith angle

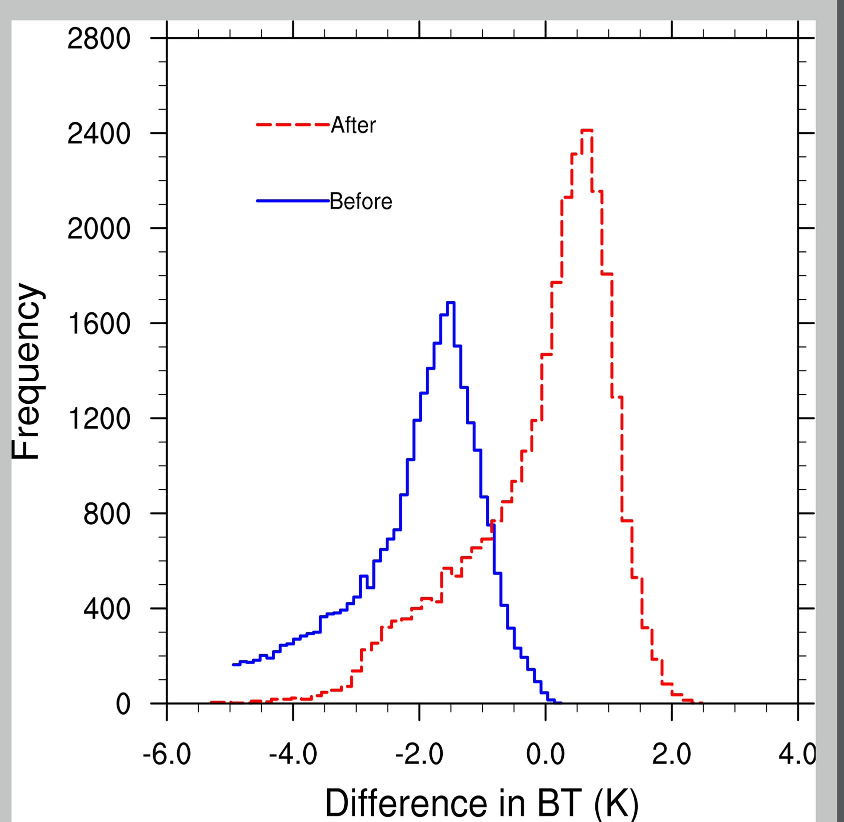

Figure 3 : Distribution of bias before and after correction

Weather Research and Forecasting (WRF) model and LETKF

Weather Research and Forecasting (WRF) [2] model was used to simulate the mesoscale dynamics involved in the present study. The model set up used for the simulations are listed in table 2. A domain spanning from **60°E** to **95°E** on longitude and **2°N** to **25°N** on latitude is used.

Table 3 : WRF model configuration

Equation	Non-hydrostatic
Time integration scheme	Third order Runge-Kutta
Time step	90 s
Horizontal grid type	Arakawa-C grid
Map projection	Mercator
Radiation parametrization	RRTM (long-wave radiation),Dudhia (short-wave radiation)
Surface parametrization	Monin-Obukhov Scheme
Horizontal resolution	15 km

The initial and boundary conditions required for the model was fed from Global Forecast System data. The generation of ensembles were accomplished using an iterative Empirical Orthogonal Function based perturbations, wherein the initial fields were perturbed and allowed to run for 24 hours as a spin-up time. These ensembles were then used for assimilation. A Local Ensemble Kalman Filter assimilation framework developed by Hunt et al. [3] was adopted to perform the assimilation. The forward radiative transfer calculations were carried out using the RTTOV solver [4]. The horizontal localization was carried out using the physical distance based Gaspari-Cohn function whereas in the vertical direction normalized weighting functions were used.

Analysis and forecast verification

The analysis from the LETKF assimilation at 00 UTC of 30 November 2015 was compared with the GDAS FNL data obtained from CISL RDA. Figure 4 and 5 shows the domain averaged temperature and humidity profiles from the analysis and background.

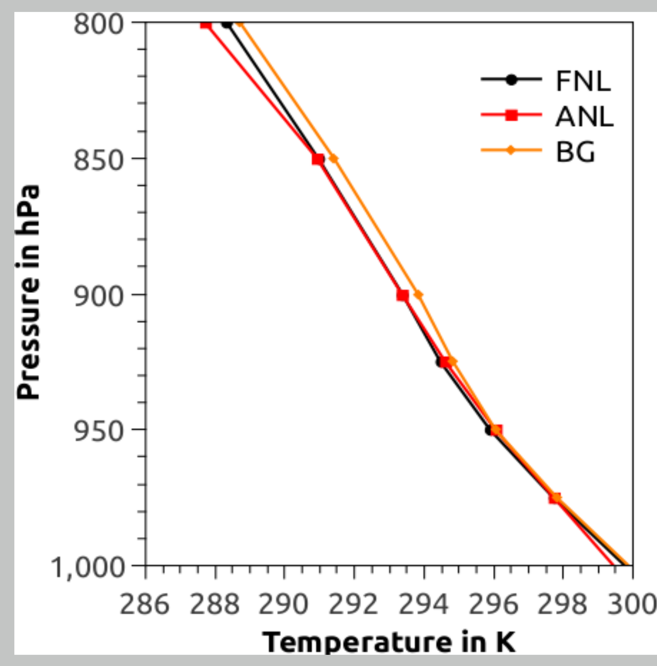

Figure 4 : Domain averaged temperature profile

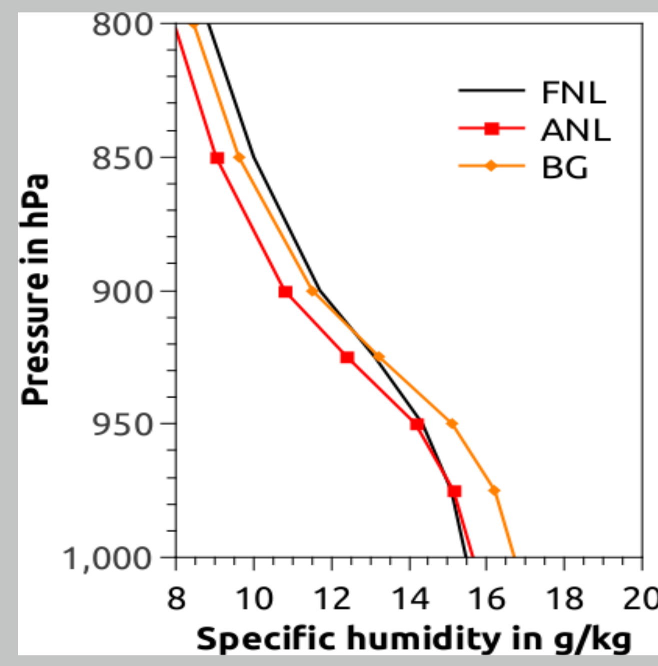

Figure 5 : Domain averaged humidity profile

The domain averaged values of RMSE in temperature and humidity is shown in figure 6 and 7

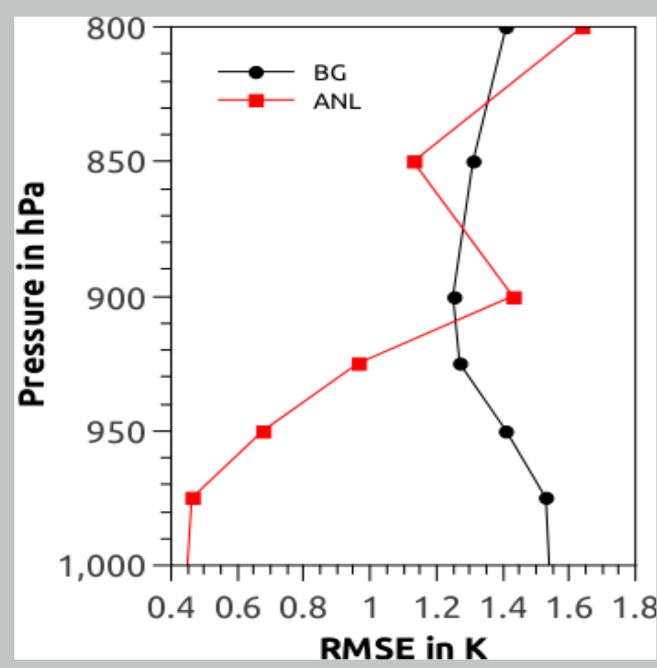

Figure 6 : Domain averaged RMSE in temperature

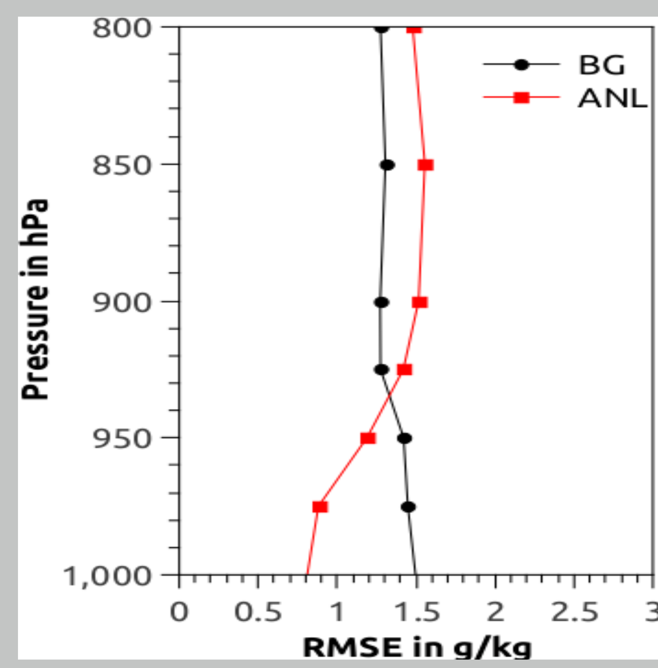

Figure 7 : Domain averaged RMSE in humidity

Accumulated precipitation forecast for 01 - 02 Dec 2015 and 02 - 03 Dec 2015 from control run and assimilated run is compared with TRMM gridded data and threat scores were computed.

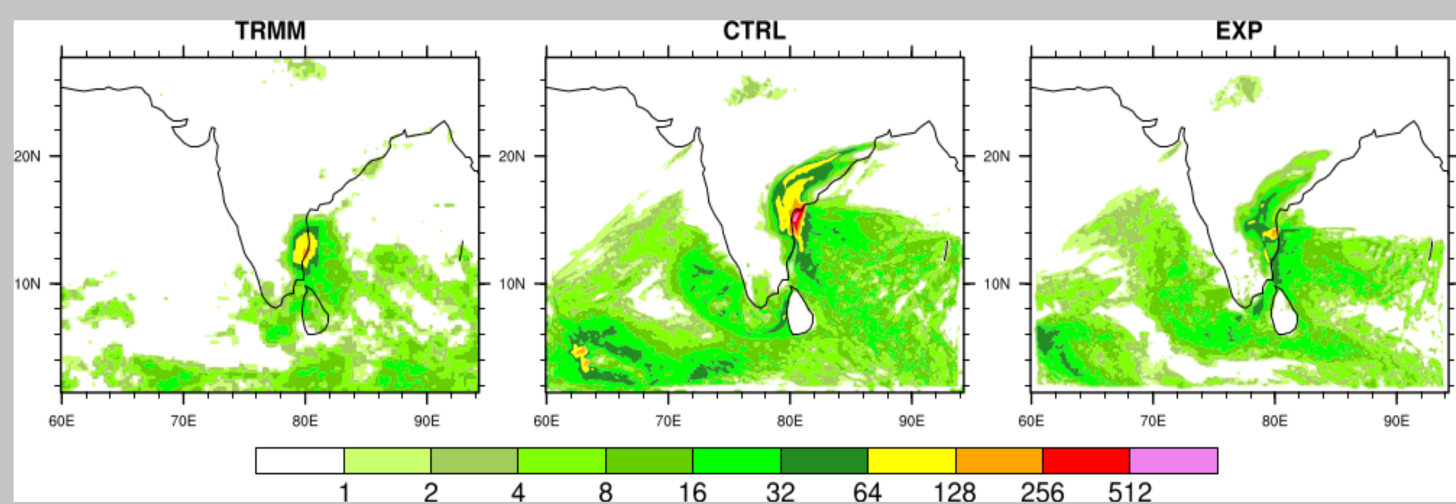

Figure 8 : Precipitation forecast from 00 UTC 01 Dec to 00 UTC 02 Dec 2015

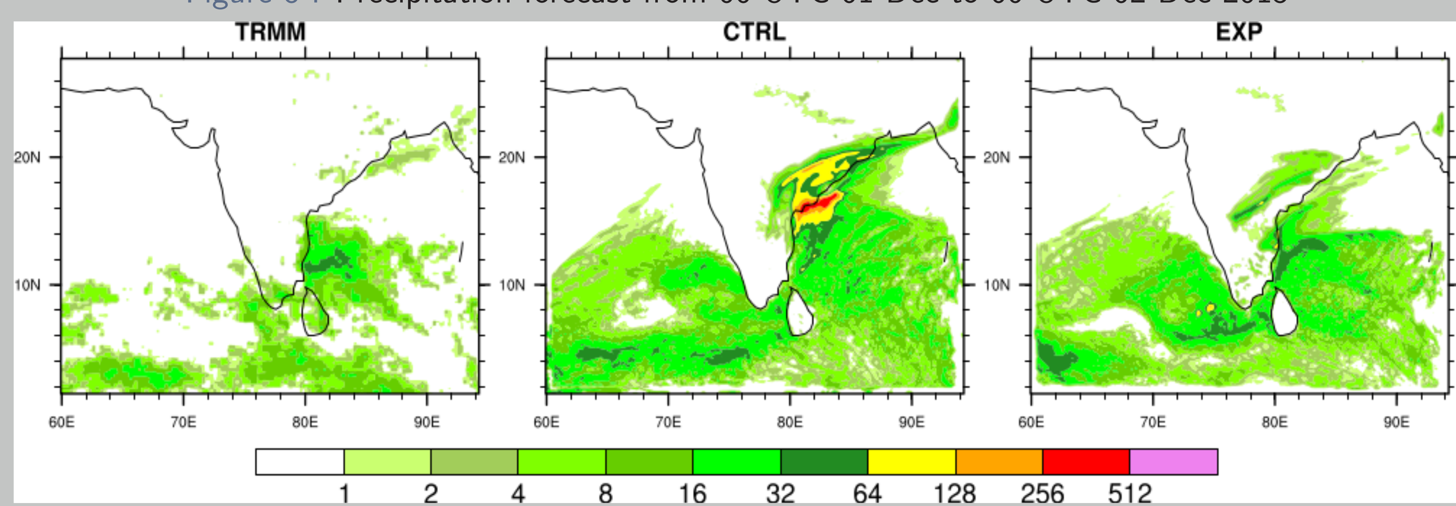

Figure 9 : Precipitation forecast from 00 UTC 02 Dec to 00 UTC 03 Dec 2015

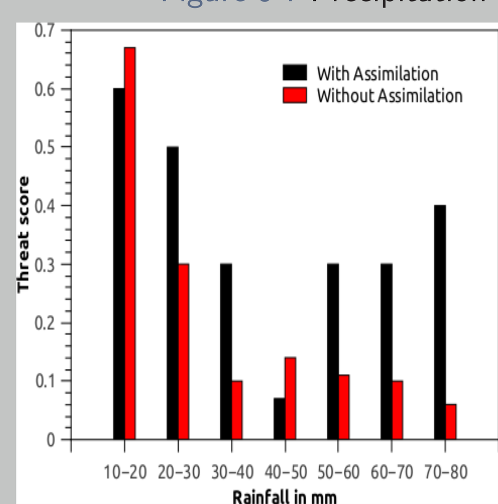

Figure 10 : Threat score for day 1

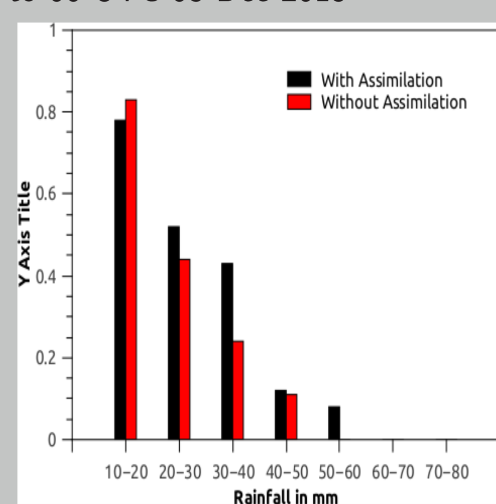

Figure 11 : Threat score for day 2

Conclusions

- Assimilation of clear sky window channel radiances tend to improve the atmospheric specific humidity and temperature between 850 - 1000 hPa layers compared to the control run. The improvement in humidity in terms of RMSE is superior to that of temperature.
- The forecast of heavy precipitation for 00 UTC 01 - 02 Dec 2015, the overall assimilation showed improvements in the moderate rainfall ranges. Both the control and assimilated runs failed to capture the heavy precipitation. Whereas for the precipitation forecast on 02 - 03 December 2015, the assimilated run shows very good agreement with the TRMM data.
- Above presented methodology will be tested on various heavy rainfall events over the Indian Ocean region to reinforce the proposed limitations in assimilating INSAT 3D radiances.
- The limitations posed in this study, demands a more robust assimilation framework and efforts are underway to assimilate all-sky radiances from INSAT 3D sounder into WRF.

References

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[2] William C Skamarock, Joseph B Klemp, Jimy Dudhia, David O Gill, Dale M Barker, Wei Wang, and Jordan G Powers. A description of the advanced research wrf version 2. Technical report, National Center For Atmospheric Research Boulder Co Mesoscale and Microscale Meteorology Div, 2005.

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