NMRF/RR/GFS-1/2013

RESEARCH REPORT

Impact of Surface Cold Bias Correction in Global Forecast System

T.S. Mohan, Saji Mohandas and E. N. Rajagopal

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National Centre for Medium Range Weather Forecasting
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Control Data Sheet

1	Name of the Institute	National Centre for Medium Range Weather Forecasting (NCMRWF)
2	Document Number	NMRF/RR/GFS-1/2013
3	Date of publication	September 2013
4	Title of the document	Impact of Surface Cold Bias Correction in Global Forecast System
5	Type of Document	Research Report
6	No. of pages & figures, tables	19 pages, 14 figures, 4 tables
7	Number of References	11
8	Author (S)	T. S. Mohan, Saji Mohandas and E. N. Rajagopal
9	Originating Unit	National Centre for Medium Range Weather Forecasting (NCMRWF), A-50, Sector-62, NOIDA-201 309, India
10	Abstract (100 words)	An attempt has been made to study the impact of surface cold bias correction in Global forecast system (GFS) model. Various meteorological variables are utilised to study the surface and vertical thermodynamic characteristics. A substantial difference in the 2-m temperature and humidity in cold bias experiment and control run is observed. Warm and dry pockets spatially distributed over several parts of the Indian land mass and adjoining oceans. Comparison of AIRS derived PW vapor content present suggests that there is slight improvement in the correlation n cold bias corrected experiment (CBEX) compared to control (CTL) run over Northern latitudes above 25 N. Vertical profiles of temperature and humidity along with vertical velocities over Indian domain depicts considerable amount of change between CBEX and CTL. Also, observed prominent change in the vertical profiles of vertical velocities over oceanic region of Bay of Bengal.
11	Security classification	Unrestricted
12	Distribution	General

Contents

Abstract

An attempt has been made to study the impact of surface cold bias correction in Global Forecast System (GFS) model operational at NCMRWF. Various meteorological field variables, like 2-m temperature, 2-m specific humidity, Convective Available Potential Energy (CAPE) and Precipitable water content (PW) along with vertical profiles of temperature, humidity and vertical velocity are utilised to study the near surface and vertical thermodynamic characteristics of the atmosphere. Present analysis has depicted a substantial difference in the 2-m temperature and humidity in cold bias experiment and control run. It is observed that the warm and dry pockets spatially distributed over several parts of the Indian land mass and adjoining oceans. The significant changes in the surface temperature and humidity are also reflected in CAPE. Comparison of AIRS derived PW vapor content present in the atmosphere suggests that there is slight improvement in the correlation of PW in cold bias corrected experiment (CBEX) compared to control (CTL) run especially over northern latitudes above 25 N. Vertical profiles of temperature and humidity along with vertical velocities averaged over five homogenous regions over Indian domain depicts considerable amount of change between CBEX and CTL. Prominent changes in the vertical profiles of vertical velocities over oceanic region of Bay of Bengal are also noticed.

1. Introduction

Global weather forecast models, observational data streams, observation retrieval algorithms, and data assimilation techniques change with time. Therefore, weather forecasting centres periodically rerun their numerical forecast system with consistent atmospheric and coupled models, observational data, and data assimilation strategies producing a reanalysis data fields. Although observations are assimilated into the reanalyses, model output should be treated with disbelief because many of the meteorological fields forecasted are only weakly constrained to model input [Kalnay et al., 1996]. Operational global models have systematic errors based on the physics and parameterization schemes and also based on large scale weather patterns. Thus, global models might have a cold bias in a region, where as a warm bias in another region. Some regions may exhibit too cold or too warm. In contrast other regions may depict too dry or too wet, resulting in systematic errors in quantitative precipitation forecast (QPF).

Much research has been devoted to model initialization and data assimilation issues. An outstanding problem in atmospheric modeling is the existence of large model biases. As long as model biases are intact, a forecast system will not be able to accurately predict the state of the atmosphere. Bias in forecast products has been the subject of much research [Betts et al., 1996, 1998a, 1998b, 1998c; Maurer et al. 2001a, 2001b; Roads and Betts, 2000], and hence using reanalysis forcing to drive offline land surface models (LSMs) can result in unrealistic estimates of energy, mass, and momentum exchanges between the land and atmosphere [Lenters et al., 2000; Maurer et al., 2001a]. For instance with 850 hPa temperatures, if bias is positive (negative) it is known as warm (cold) bias. Bias correction in the models can improve the range of predictability and increase the accuracy of the forecasts. By applying the bias correction in the models systematic errors can be removed. Bias correction has most impact at lower levels and at longer forecast periods.

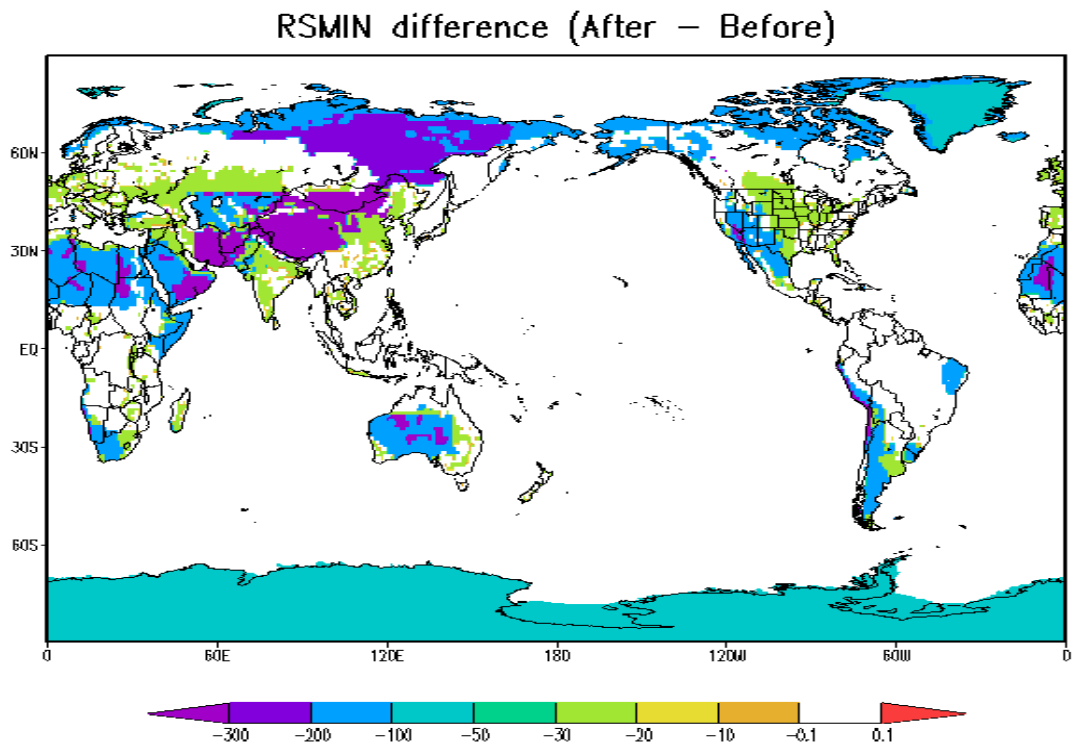

Figure 1: RSMIN difference before and after the cold bias correction (courtesy, NCEP)

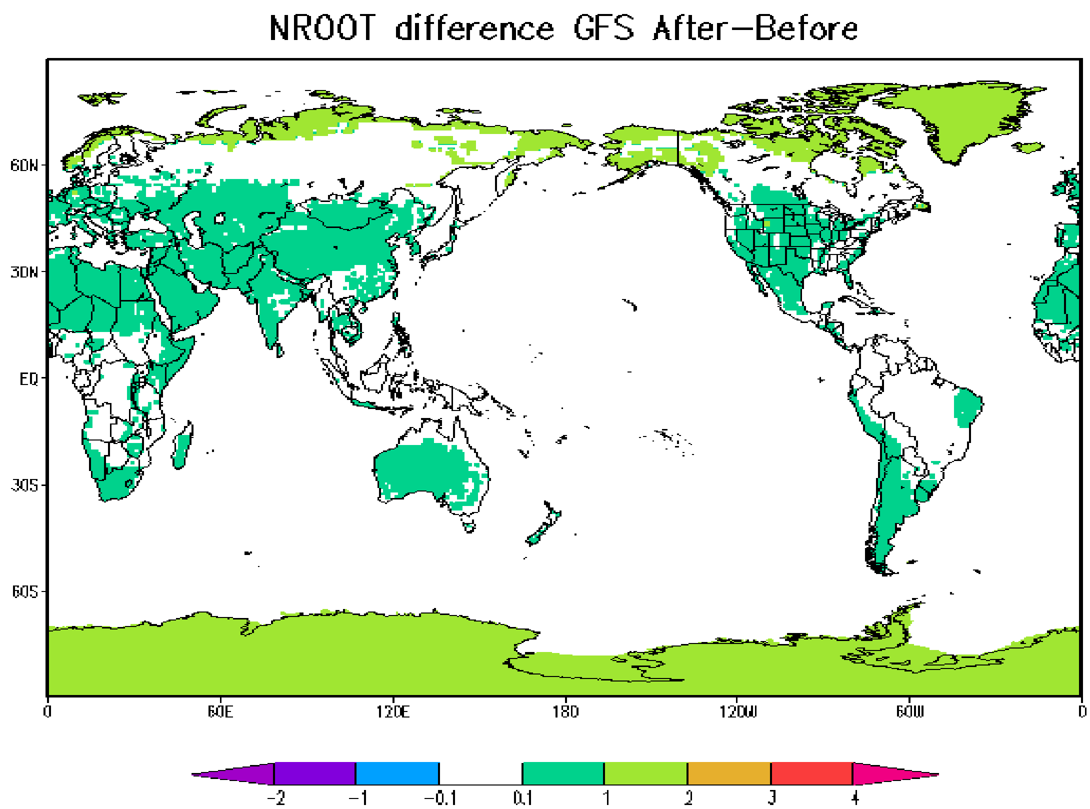

Figure 2: NROOT difference before and after the cold bias correction (courtesy, NCEP)

In the present report, cold bias correction of the GFS model and its impact on forecast has been discussed. GFS (T574L64) model is an atmospheric spectral model which is an upgraded version of NCEP GFS (Kanamitsu, 1989; Kalnay et al., 1990; Kanamitsu, et al., 1991; Moorthi et al., 2001; EMC, 2003), with all latest developments in the data decoding, assimilation, model and pre/post processing. The model was upgraded at NCMRWF and made operational in May 2011 (Prasad et al., 2011). Operational changes in NCMRWF GFS model including land surface parameterisation have been carried out. Minimum canopy resistance (RSMIN) and root depth number (NROOT) were changed in May 2011. This implementation was leading to increased evapotranspiration over some regions depending on the vegetation type. NCEP has reported this and found reduced late-afternoon surface cold bias and moisture bias over the northern and Southern Great Plains and slightly worsened mid-day warm bias over the southern United States during warm seasons due to the above mentioned changes. The problem was indentified and the corrective measures were devised to reduce this bias. Figure 1 and 2, depicts the RSMIN and NROOT difference before and after the cold bias correction. It shows significant changes over some parts of globe. For instance mixed forest over Siberia RSMIN reduced from 300 to 70, and over China bare soil was reduced from 400 to 70, and over crop land, RSMIN was reduced more than half from 45 to 20. However, over Indian subcontinent, the changes are very minimal. NCEP has comprehensively tested the same for warm and cold seasons for any unwanted consequences on the global model forecasts and performances. The correction is expected to improve the cold and moist bias in the near surface air temperature and moisture during the cold seasons and accordingly light precipitation skill scores over some regions. The primary objective of the report is to check the sensitivity of the cold bias removed and quantification of impact over warm season for Indian region

2-m temperatures and humidity changes are one of the most important sources of uncertainty in the NWP models. Variations in global and regional temperature and humidity patterns have profound effect on the precipitation and circulation patterns across the globe. Given the importance of the temperature and humidity in the global climate and their role in rainfall, it is necessary to have accurate forecasts in the global models. However, the current global models exhibit substantial regional biases in the surface meteorological field variables, and these biases are often larger than the simulated ones. Operational changes in NCMRWF GFS model were tested with initial conditions during 00 UTC 29 August 2012 and 00 UTC 28 May 2012. In a positive note, very minor impacts of the test on the forecasts are inferred. It was observed that the correction had a slight positive impact on the spurious cyclonic circulation generated in the Day-10 forecast from the analysis of 28 May 2012. Hence, the correction has been implemented in the NCMRWF's GFS model with effect from 1 October, 2012. In this report the necessity of the cold bias correction is examined by comparisons with control run results.

2. Data used and Methodology

We have used cold bias corrected and control model run output from NCEP GFS for few selected cases on 28-29 May, 28-31 July, 29th August and 19-26th October for the present analysis. Model runs which are mentioned above represents various seasons, i.e., pre monsoon, monsoon and Post monsoon respectively. 2-m temperature, Precipitable water (PW), Convective Available Potential Energy (CAPE) and specific humidity forecast data of GFS model output are utilised in the present study. Vertical profiles of temperature and humidity along with vertical velocity in both the control runs and cold bias corrected runs are also used to study the impact of cold bias correction in upper levels. Atmospheric Infra Red Sounder (AIRS), PW is also used to compare with the observations.

3.1 Sensitivity on important forecast parameters

The composite map of spatial distribution of temperature at 2-m over Indian domain is depicted in Figure 3(a)-(h). The composites are prepared by using the model runs for case studies described in section 2. Difference between experiment and control is increasing as the forecast time increases. Spatial map of difference between cold bias experiment (CBEX) and GFS control (CTL) is showing warm pockets over North western and Eastern parts of the Indian domain and also over Bay of Bengal. Significant changes in Day-3 through Day-7 in 2-m temperature are observed. Figure 4(a)-(h) shows the spatial distribution of specific humidity at 2-m height. Specific humidity values over

Indian domain are ranging from 0-30 g/kg. The composite maps of differences between control run and cold bias corrected humidity values are showing dry pockets over Northwestern Indian regions and at a few places over Bay of Bengal. Since the surface temperature and humidity values are showing a considerable change in cold bias corrected runs, the convection over Indian land mass and adjoining oceanic regions also change accordingly.

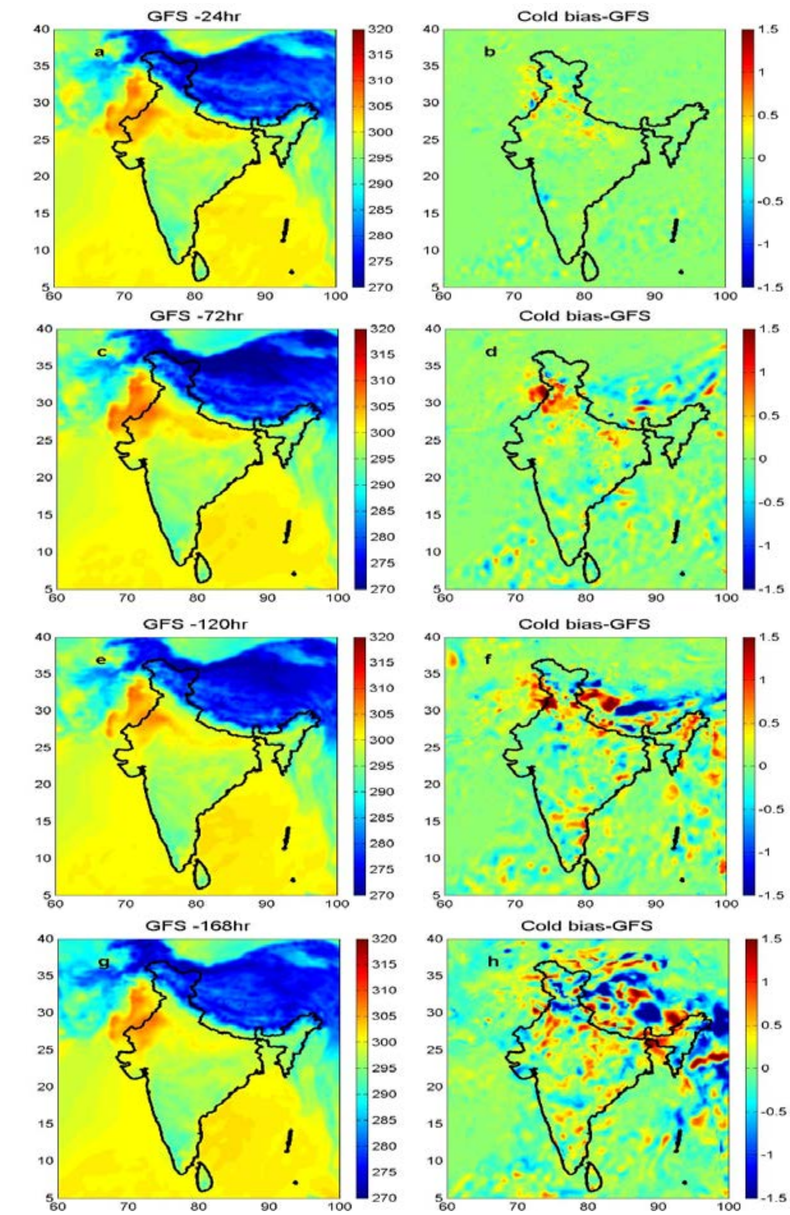

Figure 3: Spatial distribution of temperature at 2m level. Left panel represents the GFS temperature and the right panel shows the difference between CBEX and CTL.

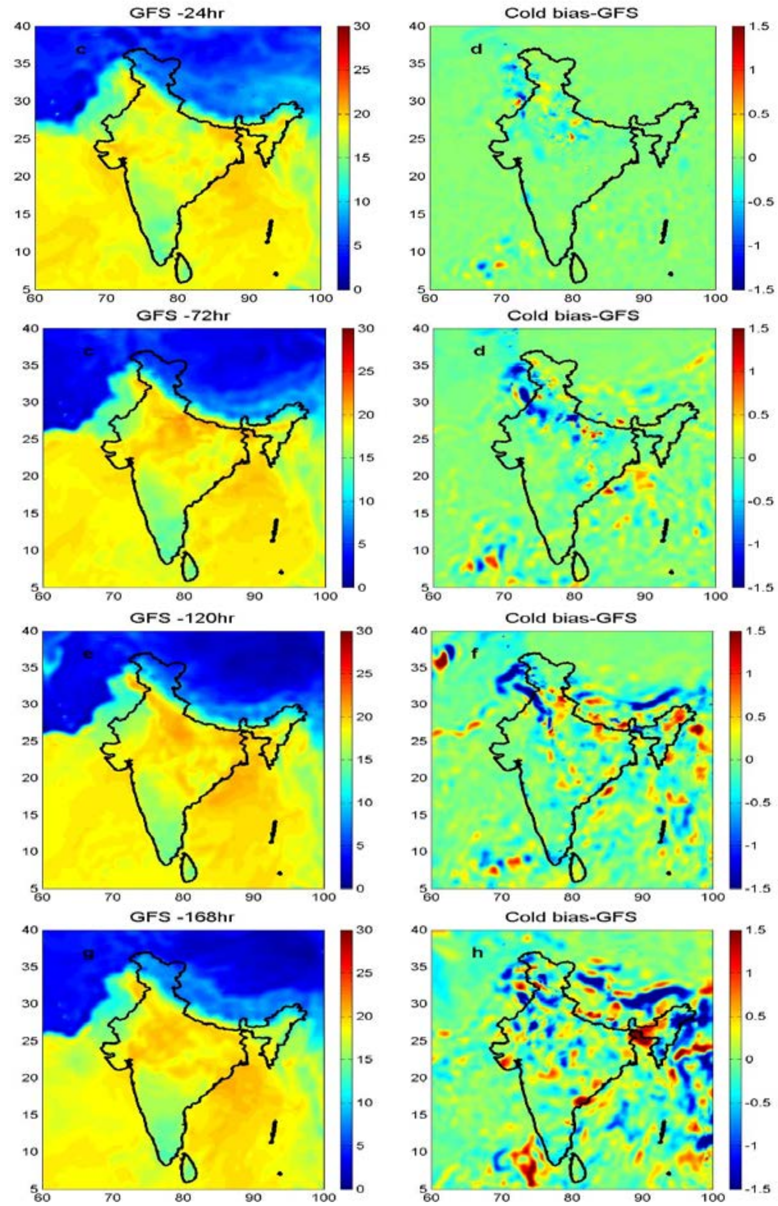

Figure 4: Same as Figure 3, but for specific humidity.

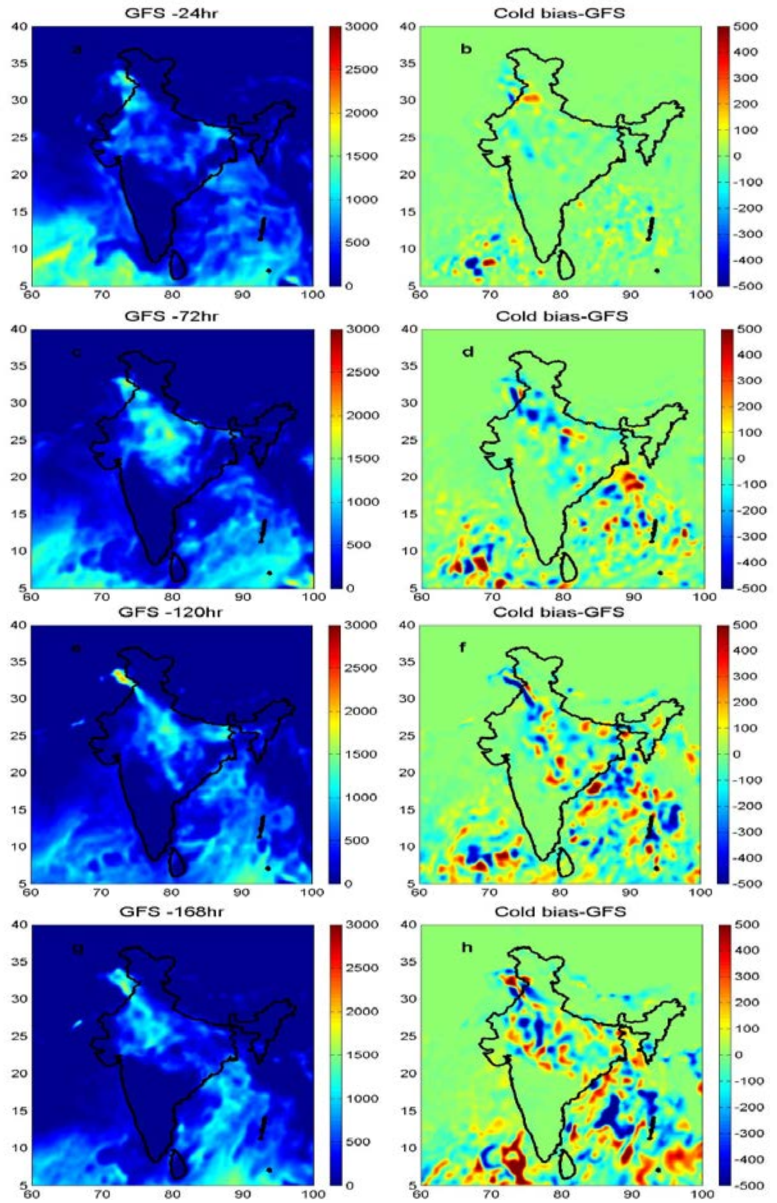

Figure 5: (a)-(h): Figure shows the spatial distribution of CAPE, left panel shows the CAPE derived from CTL run, and right panel shows the difference between CBEX and CTL.

Spatial distribution of convective available potential energy (CAPE) with cold bias correction and control runs is shown in Figure 5(a) – (h). It is clear from the Figure 5 that, CAPE is more over oceanic regions of Bay of Bengal and Arabian Sea during Day-7. Higher values in CAPE are observed over monsoon trough region in cold bias corrected run. However, the magnitude of CAPE is reducing as the model forecast time is increasing (for instance Day-7).

To study the regional impact, variability in the area averaged vertical profiles of temperature, humidity and vertical velocities for five regions selected over Indian land mass are elaborately studied. The regions which are selected for the present study are represented with red boxes (see, Figure 6). Vertical profile anomalies of temperature, specific humidity and vertical velocity are depicted in Figures 7-12. Forecast hour are indicated with different color in the plots.

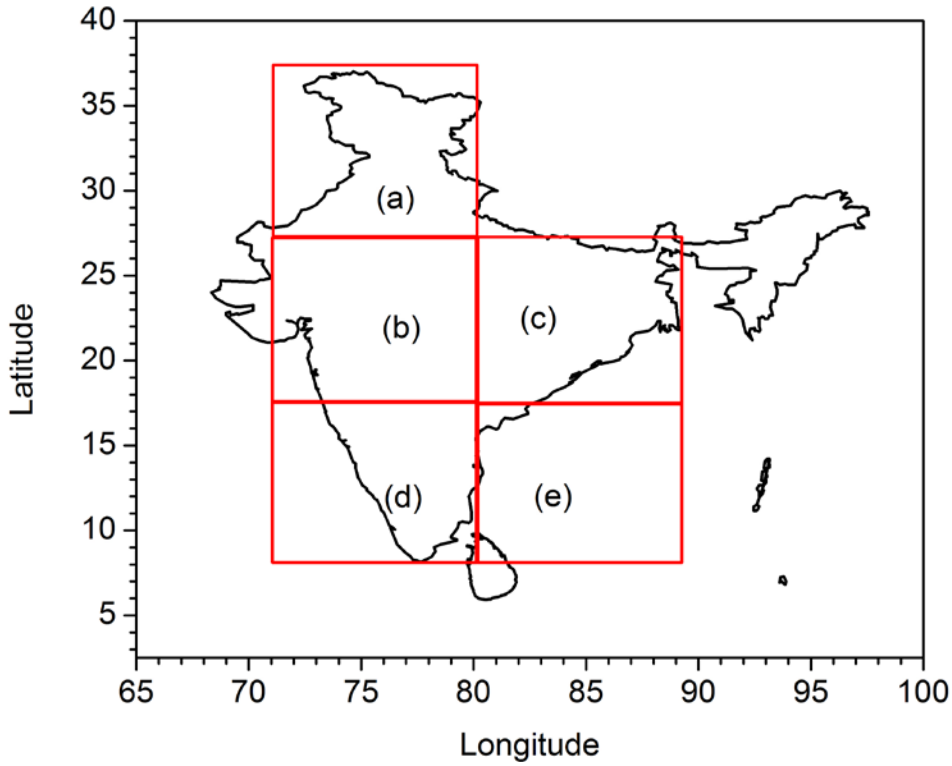

Figure 6: Five regions selected over Indian region to study the impact of Cold bias correction.

It is clear from Figures 3-5, that the spatial distribution of temperature and specific humidity at 2m and CAPE are exhibiting more and more significant variability between CBEX and CTL runs as the forecast hour increases. In order to see the impact of cold bias correction, we have quantified the meteorological parameters in Tables 1-3 by averaging them in their respective regions distributed over Indian landmass. It is clear from Tables 1-3 that the magnitude of impact is more in Day-5 and Day-7 over the regions under consideration. It is interesting to note that the CAPE values over regions (d) and (e), which are adjacent to each other, are exhibiting positive and negative values in Day-5 and Day-7 respectively, which reconfirms the point that the strength of the convection over land is more than the ocean due to large surface temperatures.

Table 1: Area average of Temperature at 2-m over different regions considered in the study.

T2m	Region (a)	Region (b)	Region (c)	Region (d)	Region (e)
Day -1	0.12	0.0033	0.026	0.0079	-0.004
Day-3	0.22	0.005	0.02	0.01	-0.004
Day-5	0.12	0.009	0.023	-0.018	0.028
Day-7	0.09	0.031	0.066	0.014	0.048

Table 2: Same for Table 1, but for specific humidity

Sp2m	Region (a)	Region (b)	Region (c)	Region (d)	Region (e)
Day -1	-0.093	-0.017	-0.018	0.0041	0.0063
Day-3	-0.043	-0.028	-0.0026	-0.0075	-0.0018
Day-5	-0.25	-0.032	-0.06	-0.0603	-0.0221
Day-7	-0.183.	-0.057	0.093	0.12	-0.057

Table 3: Same for Table 1, but for CAPE.

CAPE	Region (a)	Region (b)	Region (c)	Region (d)	Region (e)
Day -1	-0.07	-6.4	-4.9	-1.2	-0.9
Day-3	-31.6	-14.6	-2.9	-6.5	-6.9
Day-5	-61.3	1.44	-47.9	8.1	-9.4
Day-7	-75.8	6.26	11.36	92.3	-37.9

From the Figure 7(a)-(c), it is observed that warm and moist regions exist below 600 hPa with suppressed vertical motions over region (a). It is interesting to see that the magnitude of difference in the vertical profiles of temperature, specific humidity and vertical velocity increases as the forecast hour increases. Moist layers are observed above 600 hPa level in CBEX. On the other hand, it is clear from the Figure 8, the dry environment with descending motion over region (b). Bimodal distributions of the temperature profiles are observed, one peak corresponds to the middle troposphere and the other peak in the upper troposphere. Not many changes are seen in the forecast humidity profiles. Large ascending motion is strong over region (b) in Day-3 and Day-7 forecasts.

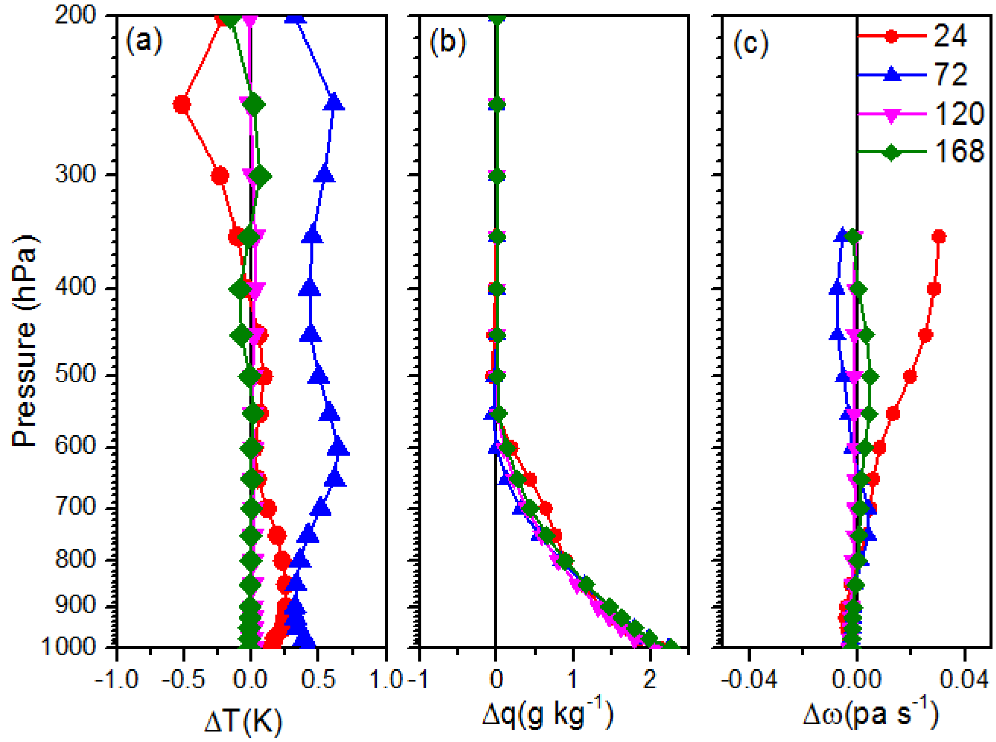

Figure 7: Vertical profiles of difference in (a) temperature, (b) specific humidity and (c) vertical velocity over region (a) of Indian land mass between cold bias correct experiment and GFS.

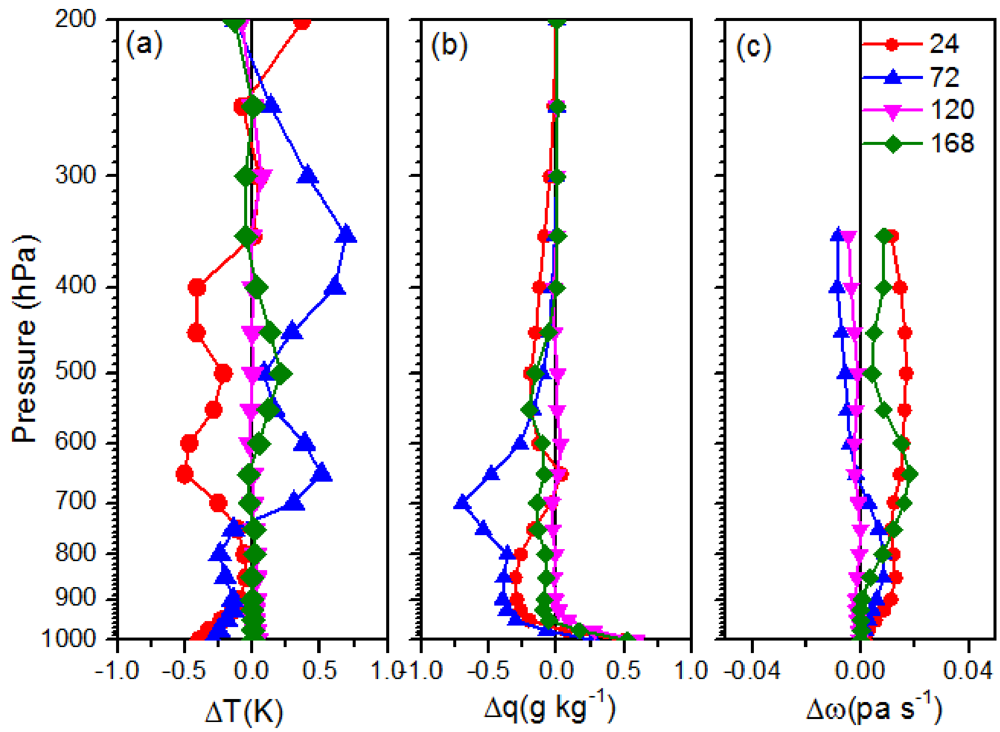

Figure 8: Same as Figure 7, but for region (b) over India

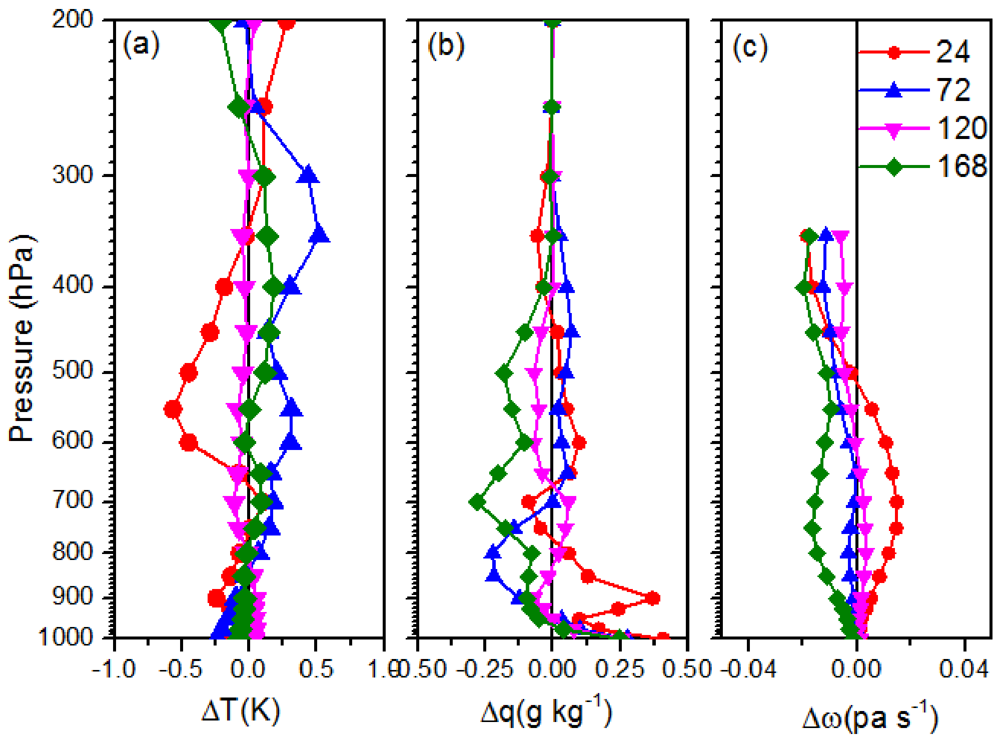

Figure 9: Same as Figure 7, but for region (c)

The ambient air temperature difference between CBEX and CTRL is showing cooling over region (c). Cooling of the environment is more prominent in the 400 hPa level on Day-7 forecast. The Vertical profiles of moisture anomalies over region (c) are depicting strong dry and shallow layers. These shallow layers are confined upto 800 hPa level. Larger scale ascending motion in Figure 9(c) is clearly apparent from both the Day-3 and Day-7 forecast. It is seen an ascending motion in Day-3 and Day-5 forecast at upper tropospheric levels ~500 hPa (see, Figure 9(c)). The ambient temperature profile from region (d) is exhibiting cooler atmosphere above 500 hPa level in Day-5 and Day-7. However, this cooling is confined to low level below 700 hPa in Day-3 forecast profile. It is interesting to note that the warmer temperature profile is seen in 24-hr forecast. Humidity profiles are showing larger drying below 600 hPa level in Day-1 and Day-3 forecasts. On the other hand humidity profiles during Day-5 and Day-7 are depicting relatively lesser drying. Vertical velocity profiles are showing large variations in Day-1 and Day-5 forecasts. It is seen that the strong descending motion is observed over region (d). In contrast ascending motion is apparent in Day-3 and Day-5 forecast profiles.

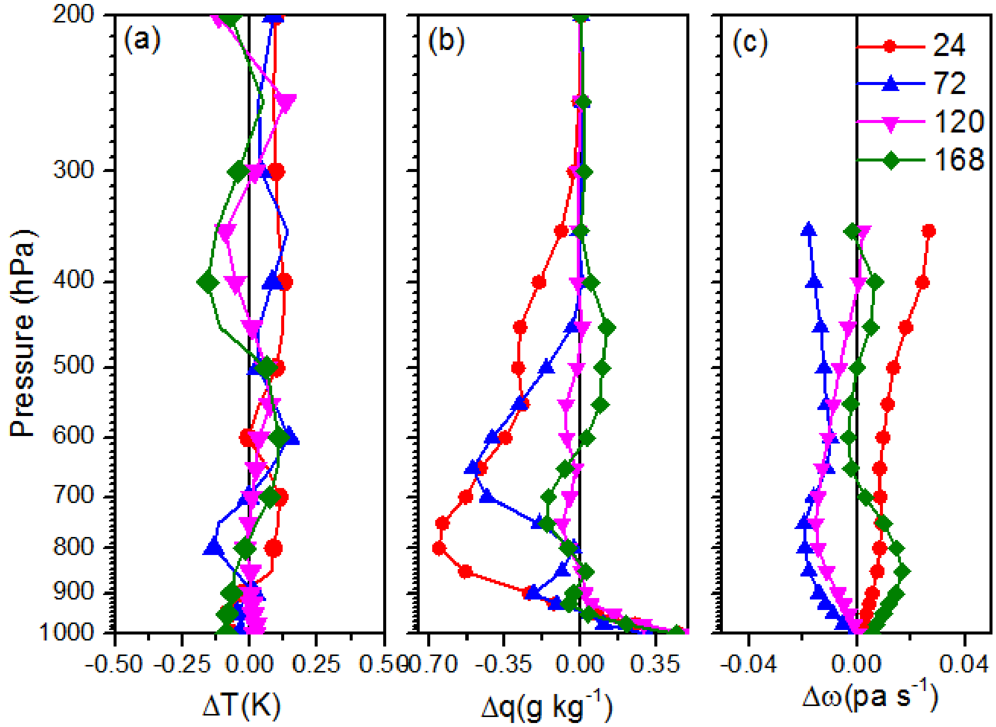

Figure 10: Same as Figure 7, but for region (d)

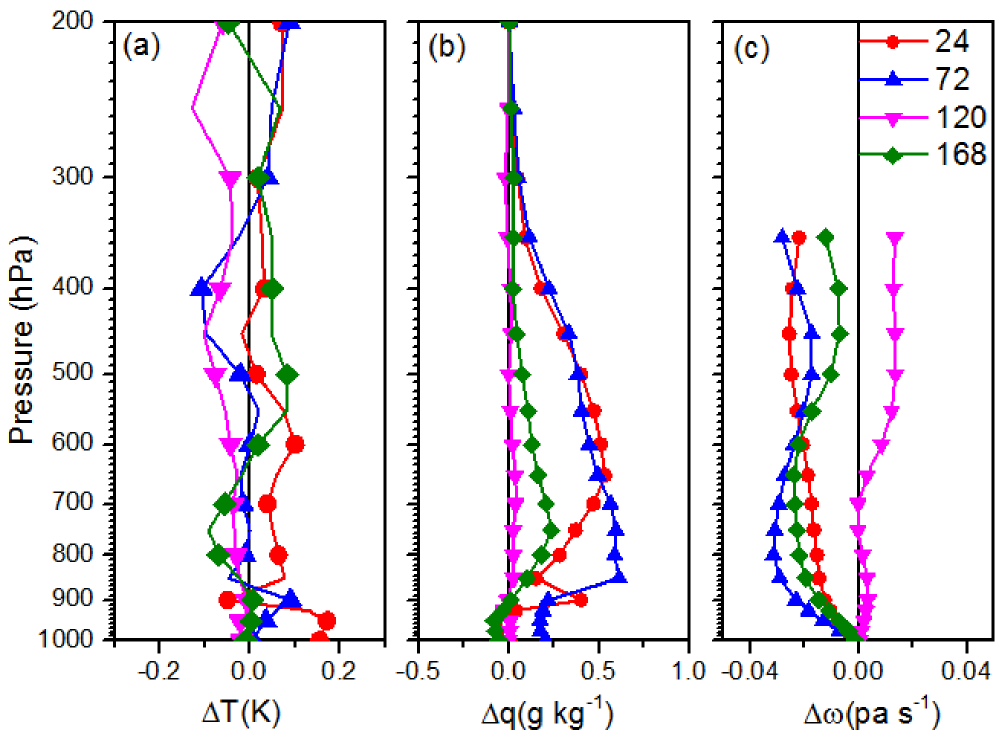

Figure 11: Same as Figure 7, but for region (e)

Over oceanic region, like region (e) i.e., Bay of Bengal, the vertical profiles are exhibiting considerable variations compared to land regions. Warm and moist layers are predominantly seen over region (e) (Figure 11(b)). However, these moist layers are confined to few pressure layers below 600 hPa. The main differences observed are in the vertical distribution of vertical velocity. Strong ascending and descending motions are observed in forecasts over region (e). The magnitude of vertical air motions over region (e) relatively large in the upper levels, which in turn affects the convective initiation and maintenance over oceanic regions. Spatial distribution of CAPE from Figure 5 is also in confirmation with the result obtained from the vertical profiles.

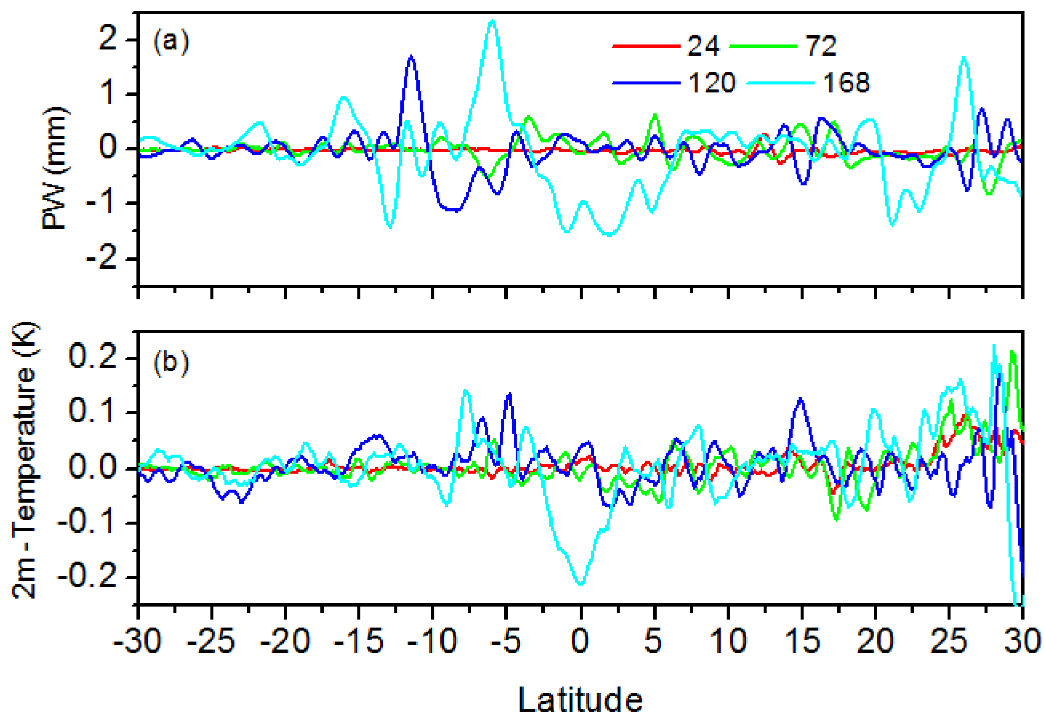

Figure 12: Composite plot of (a) difference of precipitable water (mm) and (b) 2m Temperature (K) over tropical latitude, averaged over Indian longitudes (70-90 E). The colour legend indicates the forecast hours.

Composite map of bias in total precipitable water content which directly accounts for surface rainfall is shown in Figure 12 (a). Precipitable water over Indian longitudes (70-90 E) are averaged over tropical latitudes is depicting a strong bias around 15 S. It is clear from the figure that the difference between CTL and CBEX mid-latitude belt is relatively low even in Day-7 forecast. Regions above North of 25 N are showing drier (negative values in PW content) upto Day-3 forecast. On the other hand, Day-5 and Day-7 forecasts exhibit relatively moist regions. Interestingly the bias is positive (more moist) around 10 S.

In the earlier sections significance variability in the spatial structure of 2m temperature is discussed. Composite map of 2m temperature averaged over the Indian longitudes are shown in Figure 12(b). It is seen from figure that there is a substantial warming over North of 25 N in all the forecast days. Even though the magnitude of warming (positive anomalies in 2m temperature) is less, it occurs upto Day-5 forecast. However, from Figure 12 (b), it is clear that the Day-7 forecast data is showing a cooling over North of 25 N. Also it is fascinating to note that the equatorial regions are showing cool and drier atmosphere. A noticeable feature is observed that on an average the latitudinal variability over Northern hemisphere (NH) is relatively higher in both PW and 2-m temperature compared to Southern hemisphere (SH).

3.2 Comparison of Precipitable water - AIRS and model data

In the present section a comparison study has been carried out for precipitable water (PW) from the CTL and CBEX with AIRS satellite derived PW. Figure 13 (a)-(c) depicts the typical example of AIRS swath gridded (1 x 1) precipitable water along with the spatial distribution of PW from CTL and CBEX over the domain between -10 S - 40 N and 40-120 E in Day-3 respectively. It is clear from Figure 13 that the PW distribution is more in the tropics with values larger than 60 mm, in both the satellite and model derived precipitable values. Magnitude of satellite derived PW values are relatively less compared to model derived. Larger PW values are clearly apparent over tropical oceanic regions near Equator. However, large discrepancy between AIRS and CTL is seen over few regions over Indian domain. It is to be noted that the spatial resolution between satellite and model data are different. This may be one of the reasons for observed variability in PW between AIRS and CTL. Even though there is large variability exists between model and satellite derived values, there is close agreement over few regions in terms of PW distribution and magnitude.

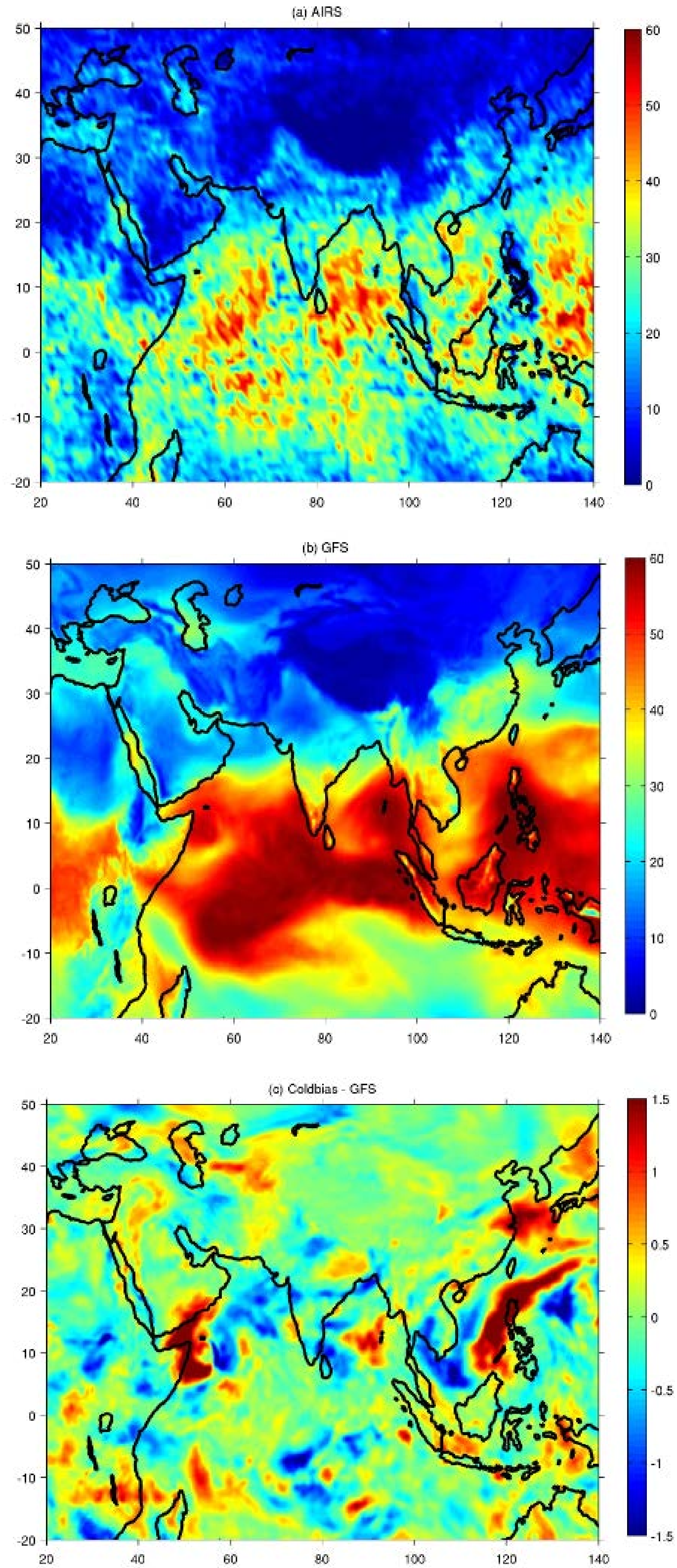

Figure 13: (a) Spatial distribution of swath gridded (1 x 1) AIRS precipitable water vapor. (b) GFS (c) depicts the difference between CBEX and CTL.

A strong spatial gradient of PW is clearly visible in both the AIRS and GFS composite map. Magnitude of PW in convectively prone regions like west pacific, Indian Ocean and Bay of Bengal are larger than 60 mm. A typical spatial map of difference between CBEX and CTL values in Day-3 is shown in Figure 13 (c), it is clear from fig 13 (c) that PW values are ranging from -2 to 6 over the latitude domain between 30 S – 30 N. Maximum changes in PW are observed between 10-20 N which are apparent from Figure 13(c). It is clear from Figure 13(c) that the cold bias removal experiment is exhibiting significant differences over some regions compared to CTL over Bay of Bengal and Central India and West pacific regions.

Latitudinal distribution of PW averaged over Indian longitudes (i.e., 70-90 E) is shown in Figure 14. It is clear from the figure that the maximum peak in the distribution is observed over equatorial regions. However, there is a secondary peak in the PW seen around North of 10 N. The distribution of CTL and CBEX PW values over 30 S – 30 N are in agreement with each other. Mean PW values over tropics for CBEX and CTL are 37.95 and 36.89 mm respectively and for AIRS 36.57 mm. However, a small difference can be seen at few latitudes, especially around 0 - 20 N and also around 20 S. The difference between CBEX and CTL is shown in Figure 14b. It is noted that there is a slight improvement in PW observed in CBEX compared to CTL. Statistical correlation between AIRS and model derived PW for forecast hours are given in Table 4. It is clear from the table that the CBEX is in close agreement with the observations in Day-3. In all the forecast days it is clear that the correlations of CBEX with AIRS are relatively larger than CTL. Correlation values are significant at 95% confidence level.

Table 4: Correlation coefficients between AIRS, CBEX and CTL, during different forecast hours. These correlations are significant at 95 % confidence level.

S No	**Forecast hour**	**AIRS vs. CBEX**	**AIRS vs. GFS**
1	**24**	**0.89**	**0.85**
2	**72**	**0.92**	**0.91**
3	**120**	**0.9**	**0.89**
4	**168**	**0.85**	**0.83**

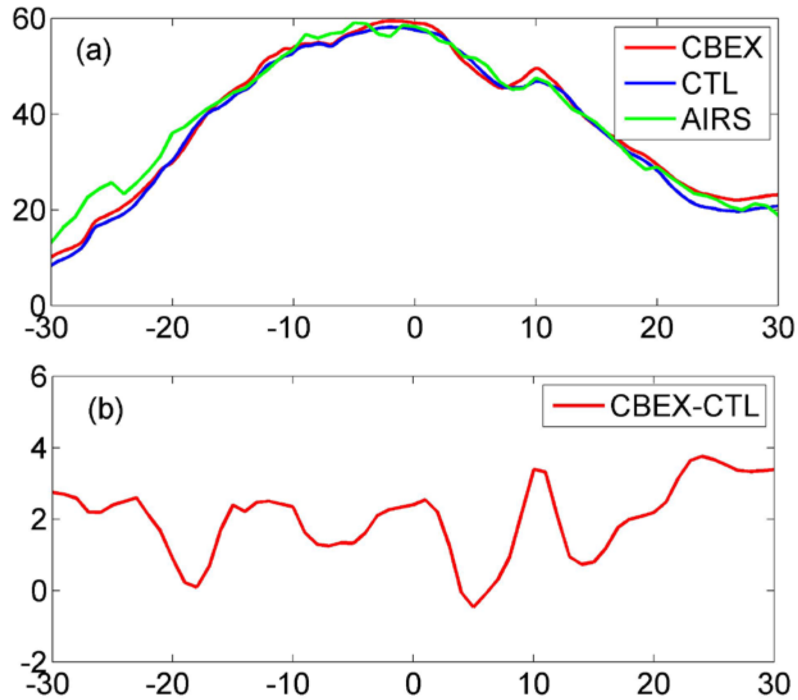

Figure 14: (a) The latitudinal distribution of PW over 30 S - 30 N from CBEX (red curve), CTL (blue curve) and AIRS (green curve). (b) Difference between CBEX and CTL (red curve).

4. Conclusions

A sensitivity study has been carried out to study the impact of surface cold bias correction on the performance of GFS model. For this study, GFS model and cold bias runs for a few selected days during May, July, August and October 2012 are utilised. These days correspond to different seasons over Indian domain. It is observed form the preliminary analysis that the difference between 2-m temperature and specific humidity from cold bias experiment and operational GFS is showing warm and dry regions over North western and Eastern parts of the Indian domain and also over Bay of Bengal. Increase of surface based CAPE is also observed from the difference between cold bias experiment and GFS control model run. Vertical profiles of differences vertical velocity, temperature and specific humidity anomalies over five Indian regions are exhibiting considerable changes. Increase in the moist layers and ascending motion over Oceanic regions are apparent. Increment in the large scale updrafts are clearly seen in all the regions except south peninsular India. A slight improvement in the latitudinal distribution of PW form CBEX is observed compared to CTL. A noticeable feature observed from the present analysis is that on an average the latitudinal variability over NH is relatively higher in both PW and 2-m temperature compared to SH. Since the data considered in the present work is relatively small, in order to obtain much more robust results the same exercise should be repeated for different seasons and spatial regions.

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