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RESEARCH REPORT

MoES Model Forecast Verification during JJAS2019: Systematic Errors in Winds Temperature and Humidity

S. Karunasagar, Kuldeep Sharma, Abhishek Lodh and Raghavendra Ashrit

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10	Abstract	This report provides a compilation of the NWP model forecast verification for the MoES models during monsoon season (JJAS) 2019. The verification results are focused on upper air fields from the two high resolution deterministic models namely (i) IMD's GFS and (ii) NCMRWF's NCUM generating real time NWP forecasts in the medium range time scale (up to 10 days) over Indian land regions during South West Monsoon (June-September) 2019. The mean (JJAS 2019) analysis winds at all levels examined (850,700, 500 and 200 hPa) are very similar in both GFS and NCUM, except for a general stronger winds in NCUM 850 and 200 hPa levels suggesting stronger circulation in NCUM. The systematic errors in the Day-3 forecasts are also very similar in both NCUM and GFS suggesting very similar westerly bias over peninsula at 850, 700 and 500 hPa levels. Over the neighbouring seas (e.g., over eastern and western equatorial Indian Ocean), the nature of wind biases in NCUM and GFS are completely opposite at all levels. The mean analysis Temperatures at 850, and 700 hPa in GFS and NCUM are very similar with no prominent difference. However at 500 hPa (over eastern equatorial Indian Ocean) and 200 hPa level (over land and Sea) the mean temperature is higher (by 1-2C) in NCUM. The mean analysis RH at 850hPa indicate higher RH in NCUM over entire monsoon region. At 700 and 500 hPa, the RH in both model analysis seem comparable, although GFS features marginally higher RH over Bay of Bengal at 500 hPa. At 200 hPa mean RH in NCUM is just over 50% over large area compared to the same in GFS where the RH values exceed 80% over large area. GFS analysis and forecasts feature relatively dry characteristics compared to NCUM. This is reflected in the near surface humidity and also consistently at different levels in the lower troposphere. As a result, the mean (JJAS 2019) vertically integrated moisture transport (VIMT) in GFS is significantly lower in GFS compared to VIMT in NCUM.
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ABSTRACT

This report provides a compilation of the NWP model forecast verification for the MoES models during monsoon season (JJAS) 2019. The verification results are focused on upper air fields from the two high resolution deterministic models namely (i) IMD's GFS and (ii) NCMRWF's NCUM generating real time NWP forecasts in the medium range time scale (up to 10 days) over Indian land regions during South West Monsoon (June-September) 2019.

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GFS analysis and forecasts feature relatively dry characteristics compared to NCUM. This is reflected in the near surface humidity and also consistently at different levels in the lower troposphere. As a result, the mean (JJAS 2019) vertically integrated moisture transport (VIMT) in GFS is significantly lower in GFS compared to VIMT in NCUM.

Contents

1. Introduction

This report provides a compilation of the NWP model forecast verification for the MoES models during monsoon season (JJAS) 2019. The verification results are focused on upper air fields from the two high resolution deterministic models namely (i) IMD's GFS and (ii) NCMRWF's NCUM generating real time NWP forecasts in the medium range time scale (up to 10 days) over Indian land regions during South West Monsoon (June-September) 2019.

1.1 MoES Global Forecast Models

(a) IMD GFS (T1534)

Global Forecasting System (GFS T1534L64 SL) model run operationally at India Meteorological Department (IMD) twice in a day (00 & 12 UTC) to give deterministic forecast in the short to medium range upto10 days. The forecast model has a resolution of approximately 12 km in horizontal and has 64 levels in the vertical. The initial conditions for this GFS model is generated from the four-dimensional (4D) ensemble–variational data assimilation (DA) system (4DEnsVar) building upon the grid point statistical interpolation (GSI)-based hybrid Global Data Assimilation System (GDAS) run on High Performance Computing Systems (HPCS) at National Center for Medium Range Weather Forecasting (NCMRWF). The real-time GFS T1534L64 model outputs are generated daily at IMD. This 4DEnsVar data assimilation system has capabilities to assimilate various conventional as well as satellite observations including radiances from different polar orbiting and geo-stationary satellites.

(b) NCUM (NCMRWF Unified Model)

The NCMRWF Unified model (NCUM) is a global model and has a horizontal grid resolution of ~12 km with 70 levels in the vertical reaching 80 km height. It uses "ENDGame" dynamical core, which provides improved the accuracy of the solution of primitive model equations and reduced damping. This helps in producing finer details in the simulations of synoptic features such as cyclones, fronts, troughs and jet stream winds. ENDGame also increases variability in the tropics, which leads to an improved representation of tropical cyclones and other tropical phenomena (Walters et al., 2017). An advanced data assimilation method of Hybrid 4D-Var is used for the creation of NCUM global analysis. The advantage of the Hybrid 4D-Var is that it uses a blended background error, blend of "climatological" background error and day-to-day varying flow dependent background error (derived from the 22–member ensemble forecasts). The hybrid approach is scientifically attractive because it elegantly combines the benefits of ensemble data assimilation (flow-dependent co-variances) with the known benefits of 4D-Var within a single data assimilation system (Barker, 2011). A brief description on the NCUM Hybrid 4D-Var system is given in Kumar et al. (2018).

2. Mean Analysis and Systematic Errors

This section provides an intercomparison of the GFS and NCUM analysis fields and systematic errors in the Day-3 forecasts during JJAS 2019. This intercomparison is presented for Winds, Temperature and Relative Humidity for 850, 700, 500 and 200 hPa levels (Figure 1-12) to identify the similarities and differences among the two models in the initial analysis and forecast errors.

2.1 Mean Analysis Winds and Systematic Errors in Day-3 Forecasts

The 850 hPa mean winds in GFS and NCUM analysis (Figure 1a,b) are by and large very similar. However, NCUM analysis has slightly stronger winds over Arabian Sea and Bay of Bengal. The systematic errors in the 850 hPa Day-3 forecasts (Figure 1c,d) suggest that both models have very comparable westerly & northwesterly bias extending from NW part of India to over Bay of Bengal. NCUM Day-3 forecasts have stronger westerly bias over parts of peninsula and Bay of Bengal. Additionally, over the eastern equatorial Indian Ocean and adjoining parts of Indonesia, NCUM forecasts have prominent easterly bias which is missing in GFS forecasts. (These biases are prominent in each of the months and stronger during June and Aug in GFS and during June-Aug in NCUM. The mean analysis winds at 700 and 500 hPa (Figures in Annexure FigureA1 and A2) also indicate marginally stronger winds in NCUM. The systematic errors in the Day-3 forecasts of 700 hPa winds (Figure A1 in annexure) show westerly bias over peninsula and NW India in both models (stronger in NCUM). The biases over eastern and western Indian Ocean south of the equator in the two model forecasts are opposite.

The analysis mean winds at 200 hPa are shown in Figure 2a,b. The prominent features of strong mid-latitude westerlies, tropical easterlies and Tibetan anticyclone are seen in both GFS and NCUM. However, relatively stronger winds in NCUM is evident over large part of Arabian Sea. Thus, the mean circulation pattern at different levels in the GFS and NCUM analysis show very similar patterns. However the intensity of winds is stronger in NCUM, particularly at 850, 700 and 200 hPa levels. The difference in the 850 hPa winds in GFS and NCUM analysis is mainly attributed to difference in the strength of zonal winds (U) and 850 hPa as can be inferred from Figure 3a,b. The mean intensity of the south-westerly monsoon flow excess of 15 m/s is widespread over western Arabian Sea in NCUM, which is confined to a small area in GFS analysis. The systematic errors in the Day-3 forecasts (Figure 3c,d) of GFS and NCUM also show comparable pattern. However, NCUM Day-3 forecasts errors have higher magnitude, particularly over eastern coast of peninsula. Unlike the 850 hPa zonal wind, the mean analysis 850 hPa meridional wind (V) (Figure 4a,b) show very comparable pattern and intensity (Figure 4a,b)

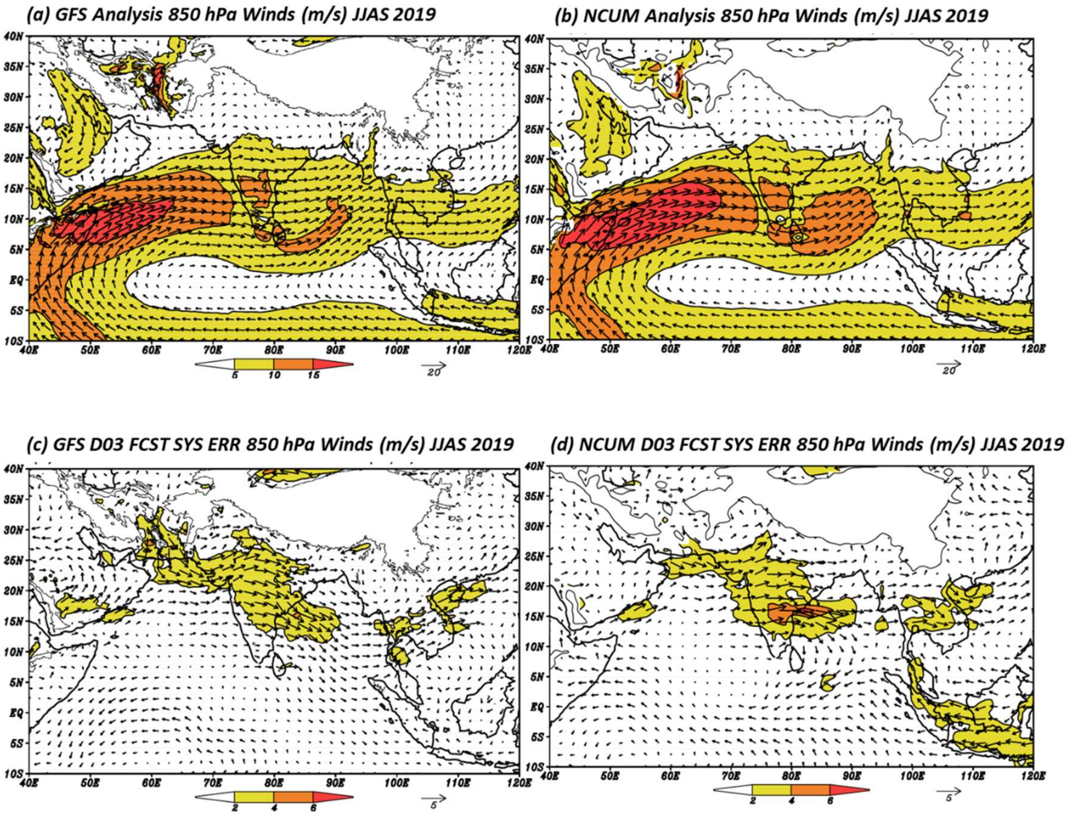

Figure 1. Mean (JJAS 2019) 850 hPa winds (*top*) and systematic errors in the Day-3 forecasts (*bottom*) in the GFS (*left*) and NCUM (*right*) model.

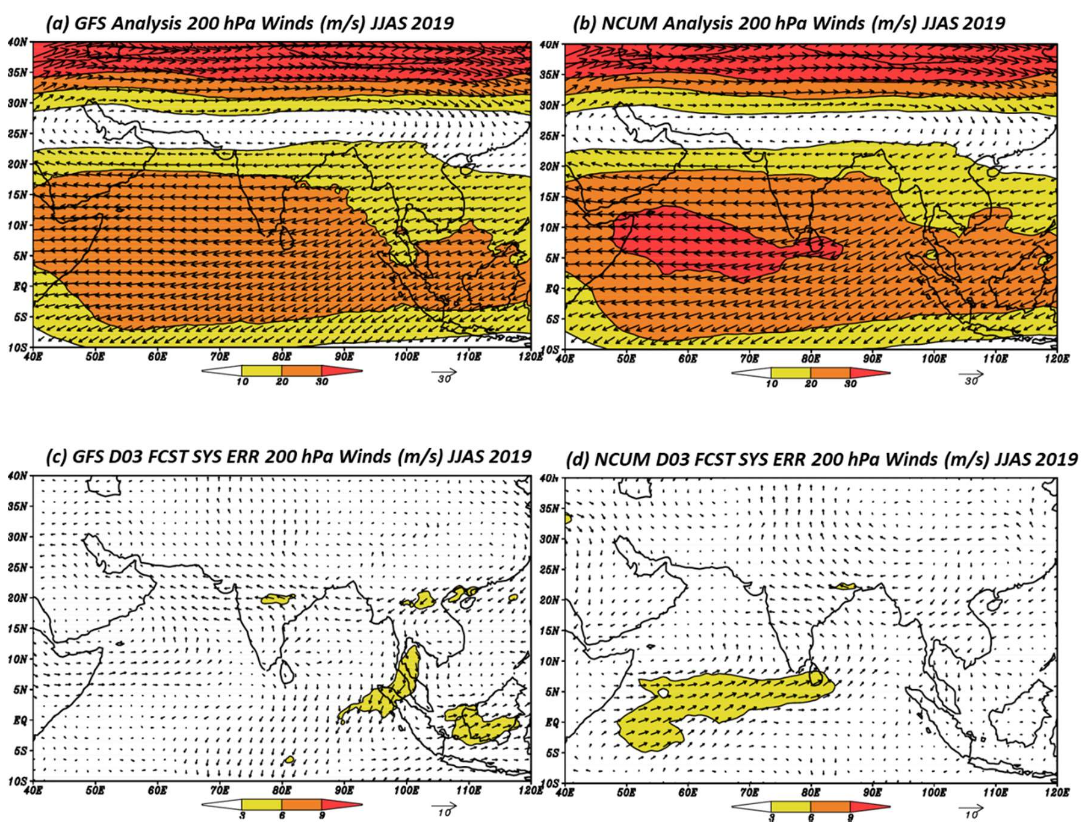

Figure 2. As in Figure 1 for 200 hPa winds

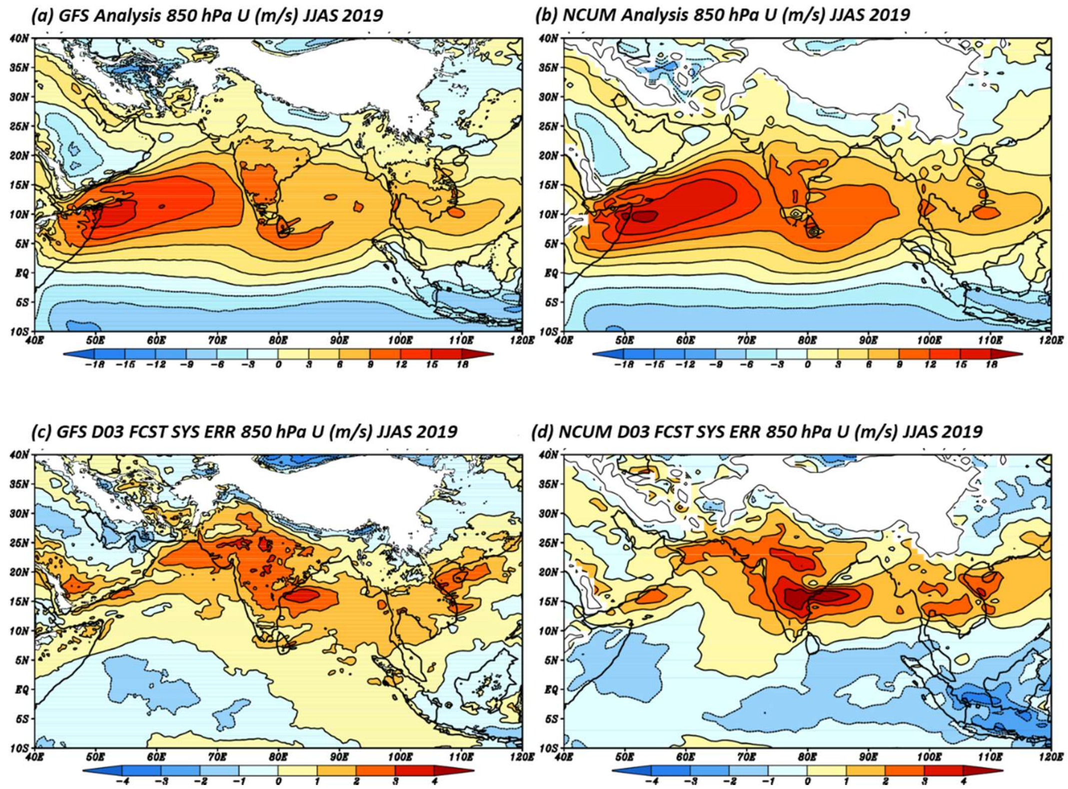

Figure 3. As in Figure 1 for 850 hPa zonal wind (U)

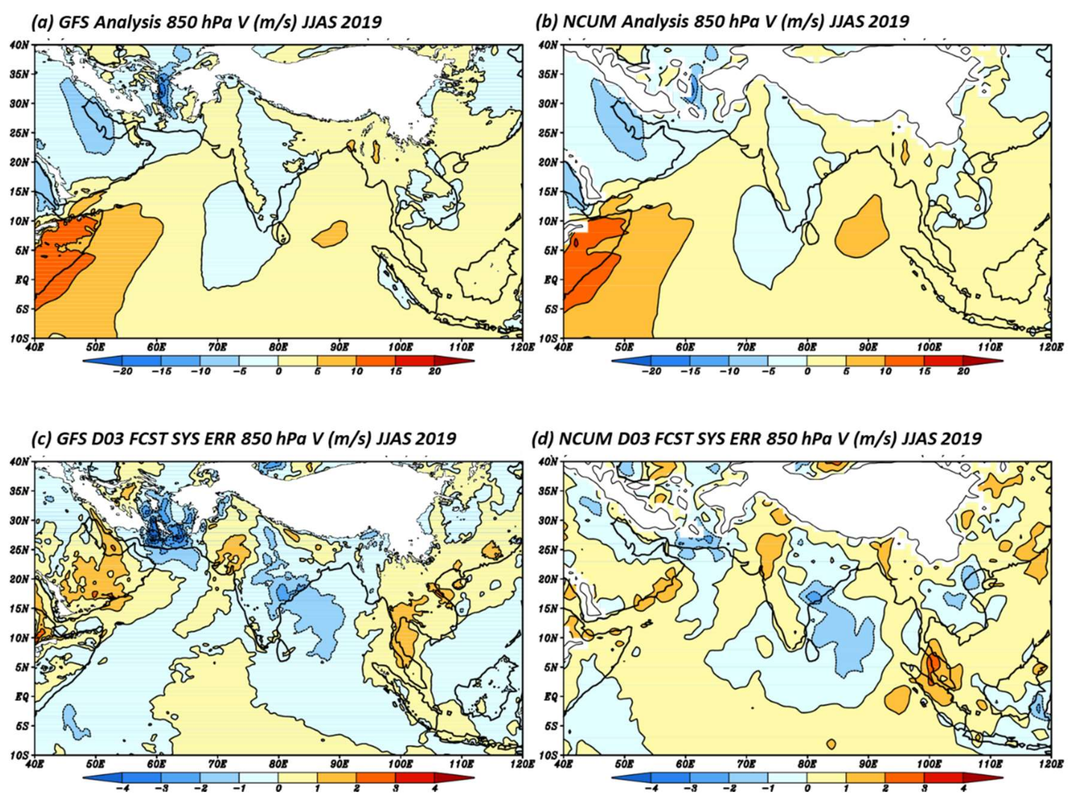

Figure 4. As in Figure 1 for 850 hPa meridional wind (V)

2.2 Mean Analysis and Systematic Errors in Day-3 Forecast Temperatures

Similar intercomparison of mean analysis Temperatures and systematic errors in Day-3 forecasts is presented for 850 and 200 hPa levels in Figures 5-6. The mean analysis Temperatures at 850 (*top* panels in Figure 5) in GFS and NCUM are very similar with no prominent difference.

The systematic errors in the Day-3 forecasts 850 hPa Temperature indicate –

- Warm bias (>1°C) over Indo-Gangetic plains in both models (higher warm bias in GFS forecasts)
- Cold bias (-0.5°C) over entire Indian land regions in both models.
- Over the neighboring Arabian Sea and Bay of Bengal, NCUM has warm bias (+0.5°C) and GFS has cols bias(-0.5°C)

At 200 hPa level (over land and Sea) the mean temperature is higher (by 1-2°C) in NCUM. The Day-3 forecast in NCUM has cold bias (-1°C) over large area and GFS has cold bias (-0.5°C) mostly over land and warm bias (+0.5°C) over Sea and India.

It is also found that at 700 hPa level (Figure A3 in Annexure) both models feature warm bias (+0.5°C) over Indian land region. Over entire domain of interest, NCUM by and large has warm bias (+0.5°C) and GFS has cold bias (-0.5°C). At 500 hPa level (Figure A3 in Annexure), both models generally indicate very similar warm bias (+0.5°C) over land and cold bias (-0.5°C) over Sea.

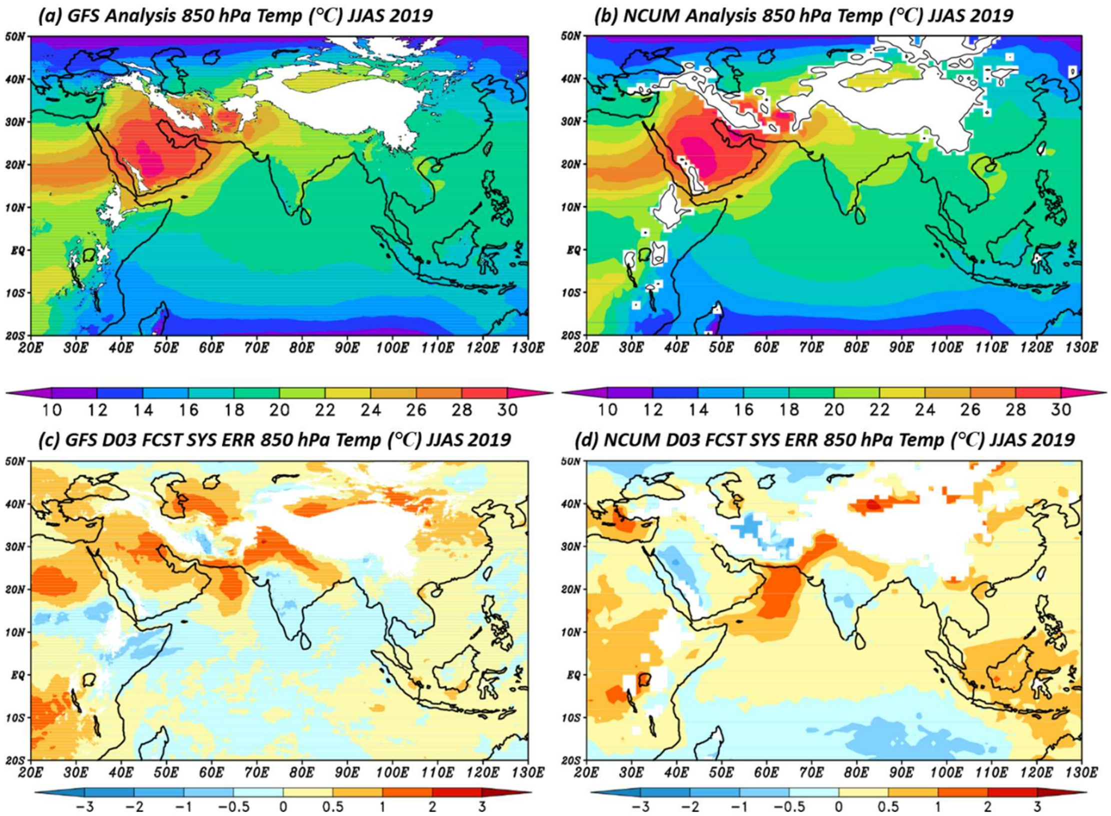

Figure 5. As in Figure 1 for 850 hPa Temperature

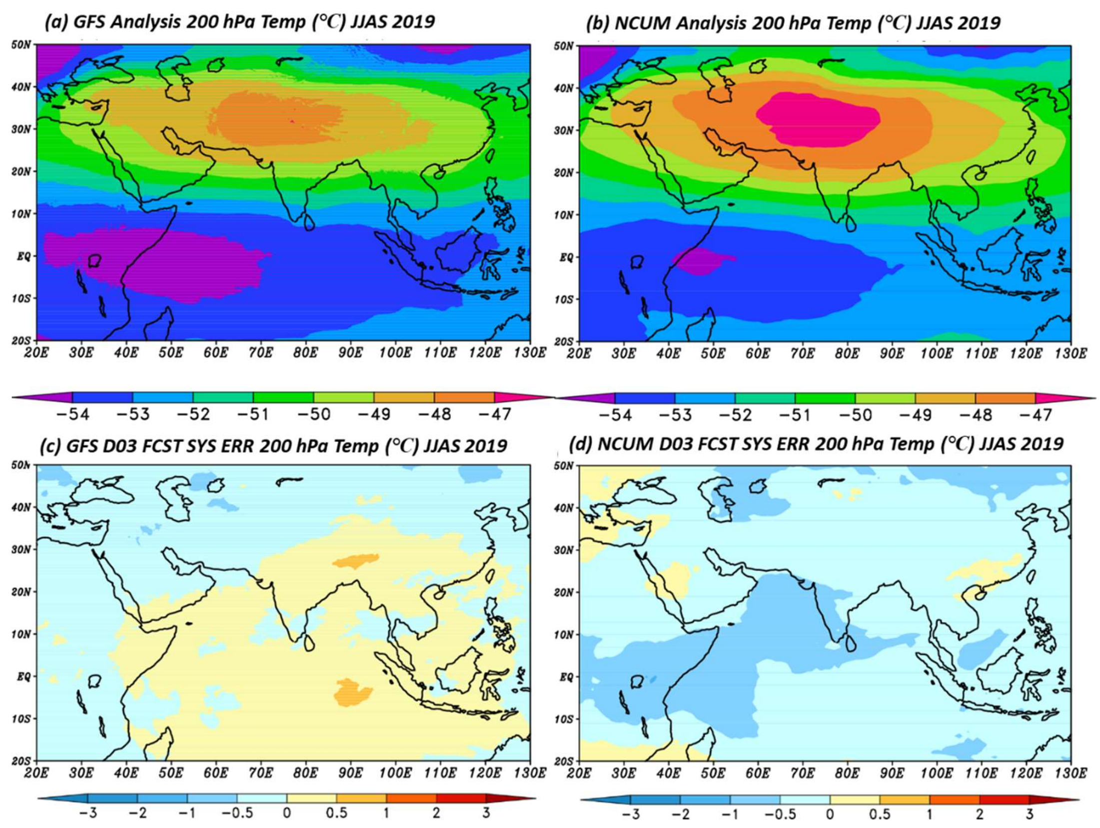

Figure 6. As in Figure 1 for 200 hPa Temperature

2.3 Mean Analysis and Systematic Errors in Day-3 Forecast Relative Humidity

Similarly, an intercomparison of mean analysis Relative Humidity (RH) and systematic errors in Day-3 forecasts (RH) is presented for 850 and 200 hPa levels in Figures 7-8. The mean analysis RH at 850hPa (Figure 7a,b) indicate higher RH in NCUM over entire monsoon region. The systematic errors in Day-3 forecast RH at 850 hPa level show dry bias over Indo-Gangetic plains and wet bias over Peninsula in both models (Figure 7c,d). On the whole NCUM features relatively higher dry bias over large area compared to GFS. At 200 hPa (Figure 8a,b) mean RH in NCUM is just over 50% over large area compared to the same in GFS where the RH values exceed 80% over large area. At 200 hPa level (Figure 8c,d) the biases in NCUM and GFS are quite different.

At 700 and 500 hPa (Figure A5 and A6 in annexure), the RH in both model analysis seem comparable. At 700 hPa level (FigureA5cd) also both models feature widespread dry bias over most part of India, Arabian Sea and Bay of Bengal (and wet bias over south Bay of Bengal region). At 500 hPa (FigureA6cd) both models have wet bias over neighboring Seas with dry bias over some Indian and regions.

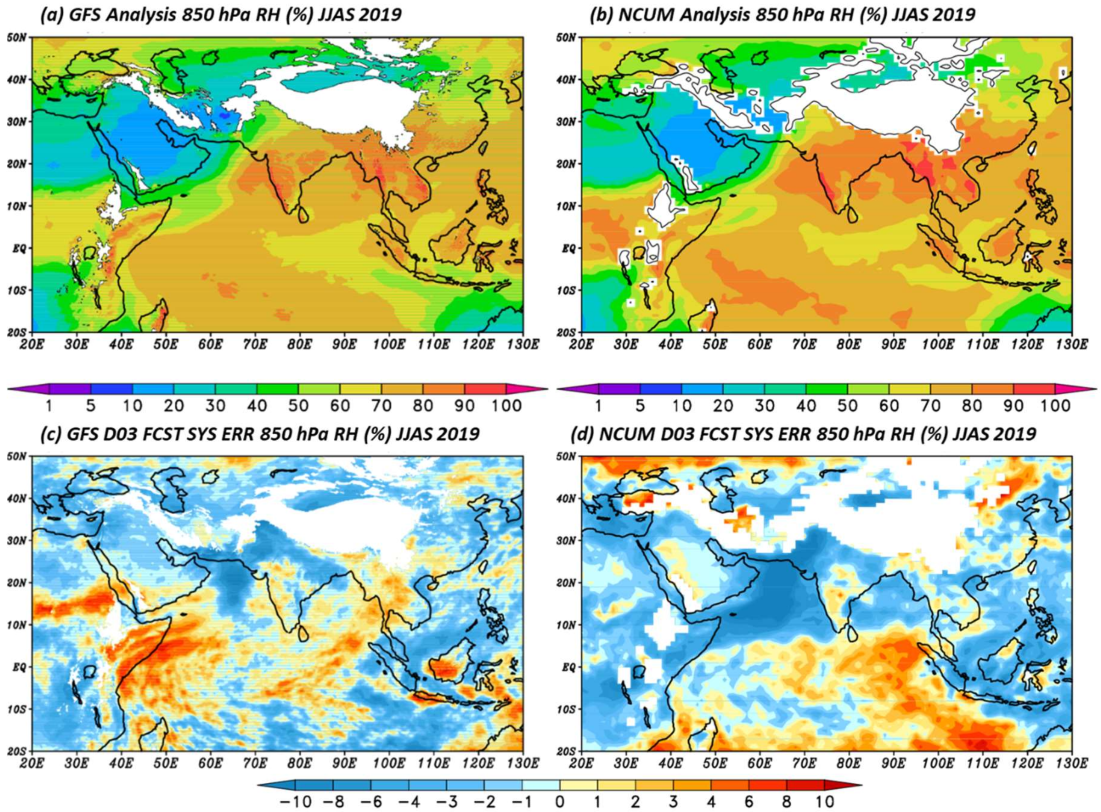

Figure 7. As in Figure 1 for 850 hPa Relative Humidity

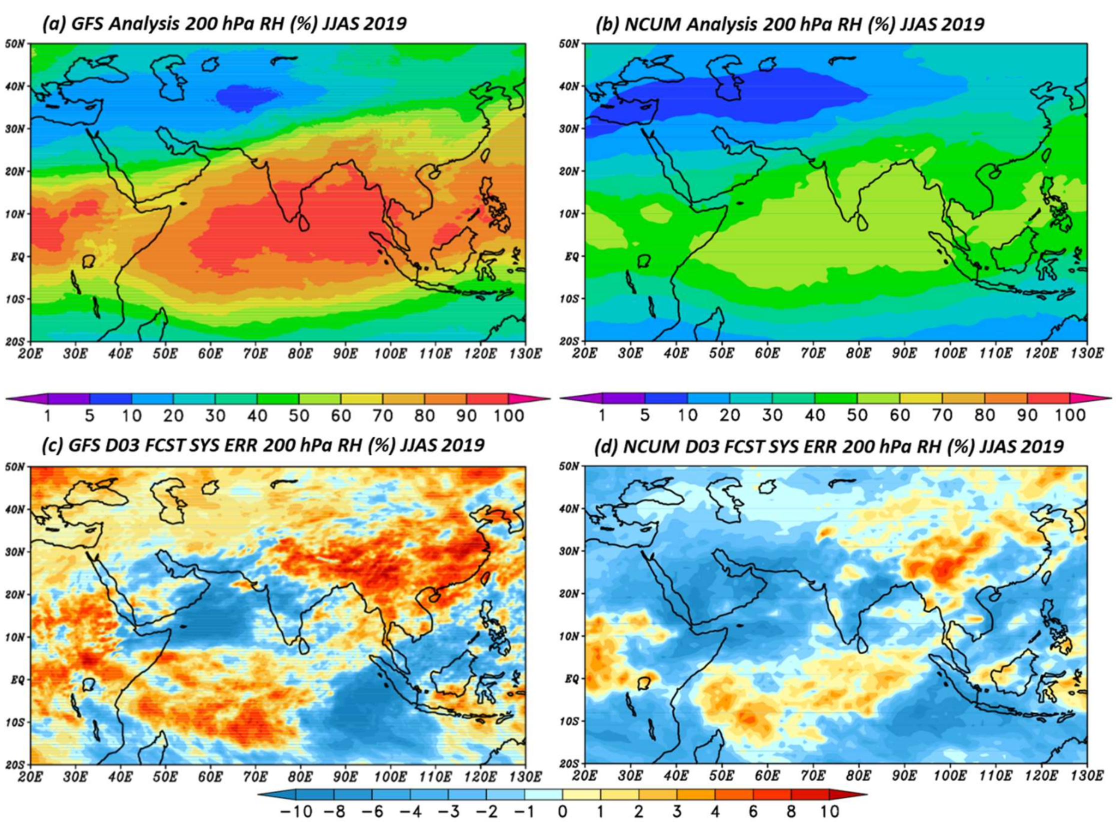

Figure 8. As in Figure 1 for 200 hPa Relative Humidity

2.4 Mean Analysis VIMT

The GFS and NCUM models are able to predict the mean climate state (precipitation, wind pattern etc.) on regional scale with some useful level of skill. However, in this section, an intercomparison of mean analysis vertically integrated moisture transport (VIMT) (upto 300hPa) and systematic errors in Day-3 forecasts is discussed for the summer monsoon season of 2019.

The vertical integral of mean field as a mass-weighted sum corresponding to $\int_0^{\bar{P}_s} (\,)dp/g$ where *( )* in the vertical integral is the monthly mean operator, and $\bar{P}_s$ the monthly mean surface pressure. The total horizontal mean flux components (zonal and meridional) of specific humidity (q) and q.**U** are calculated by vertical integration. The precipitable water is defined as total amount of water vapor in a column of the atmosphere, measured as if it all fell to the ground as precipitation (mm/inches). The precipitable water (PW) is the integral of water vapor in a vertical column through the atmosphere, and is usually in mm (or kg/m^2). It is defined as :

$$\mathbf{PW} = \int_0^{\bar{P}_s} (q\,)dp/g$$

Vertically integrated moisture transport (upto 300hPa) is the integral of scaler product of specific humidity and wind vector (**U**) in the vertical column of the atmosphere upto 300hPa. It is defined as :

$$\mathbf{VIMT} = \int_0^{\bar{P}_s} (q.\mathbf{U})dp/g$$

The mean (JJAS 2019) VIMT in the GFS and NCUM analysis is shown in Figure 9a,b. The magnitude of mean VIMT in GFS analysis is remarkably low compared to that in NCUM, indicating rather weak moisture transport in GFS analysis. This difference between GFS and NCUM is also reflected in the Day-3 forecasts mean (JJAS 2019) VIMT shown in Figure 9c,d. Thus the mean analysis and Day-3 forecasts clearly show that GFS analysis and forecasts feature relatively dry lower troposphere. This is further corroborated in Figure 10 a,b which show vertical profile of RH averaged over (a) Arabian Sea (50-70°E/5-15°N) and (b) central India (70-90°E/15-25°N) for GFS and NCUM. RH values in GFS analysis are lower than in NCUM at all levels in most part of lower troposphere which explains relatively lower magnitude of VIMT compared to NCUM as seen in Figure 9.

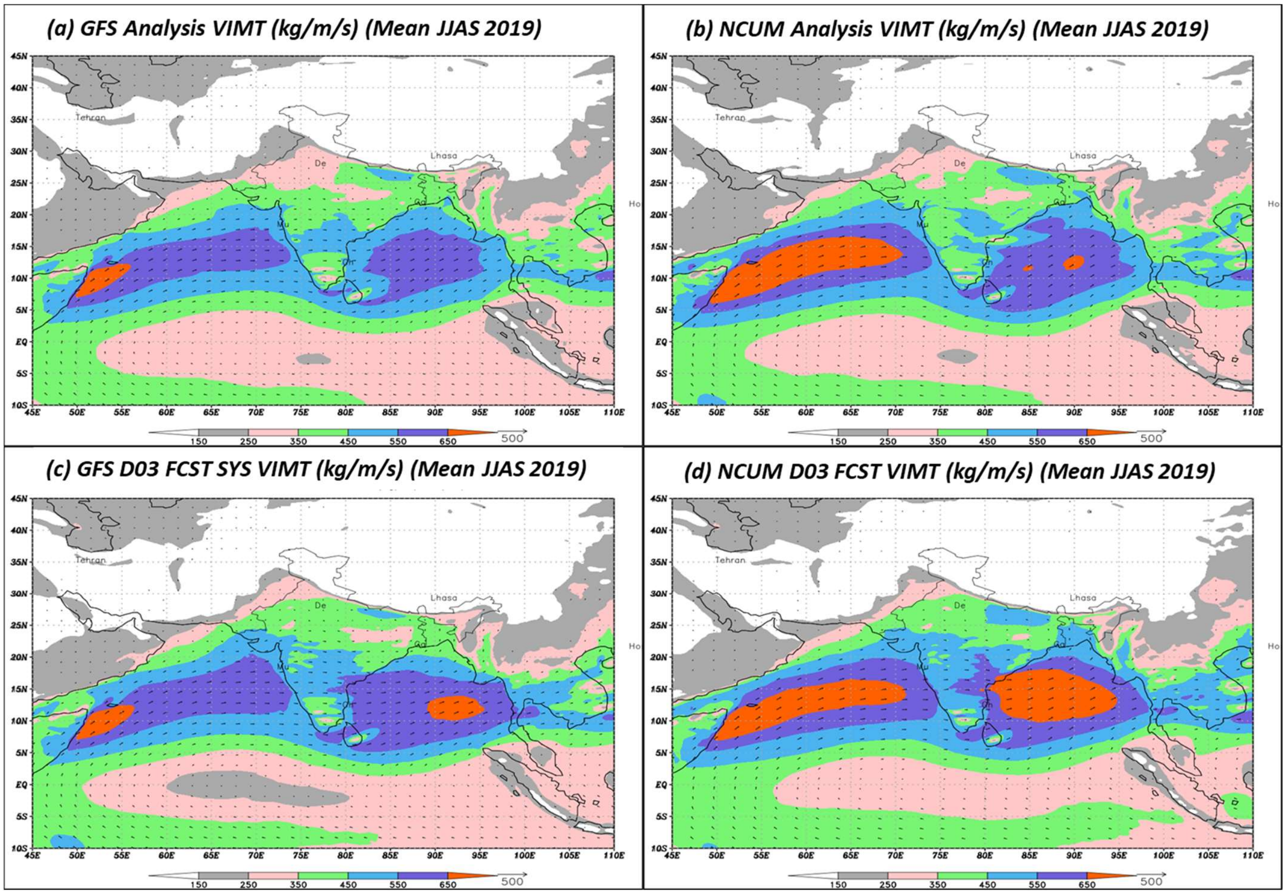

Figure 9. Vertically Integrated Moisture Transport (VIMT) in (a) GFS and (b) NCUM mean (JJAS 2019) analysis. Panels (c) and (d) correspond to Day-3 forecast VIMT from GFS and NCUM models respectively.

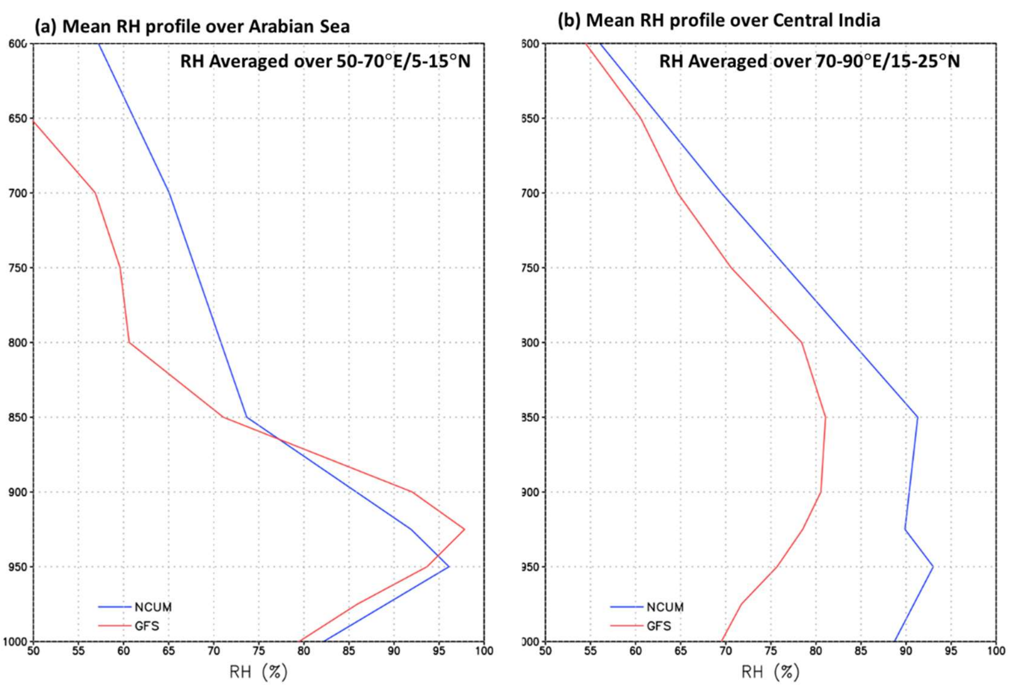

Figure 10. Mean (JJAS 2019) vertical profile of RH averaged over (a) Arabian Sea and (b) central India for GFS and NCUM

Summary

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- The systematic errors in the Day-3 forecasts are also very similar in both NCUM and GFS suggesting very similar types of biases over Indian land regions (e.g., westerly bias over peninsula at 850, 700 and 500 hPa). However over the neighboring seas (e.g., over eastern and western equatorial Indian Ocean), the nature of wind biases in NCUM and GFS are completely opposite at all levels.

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Annexure

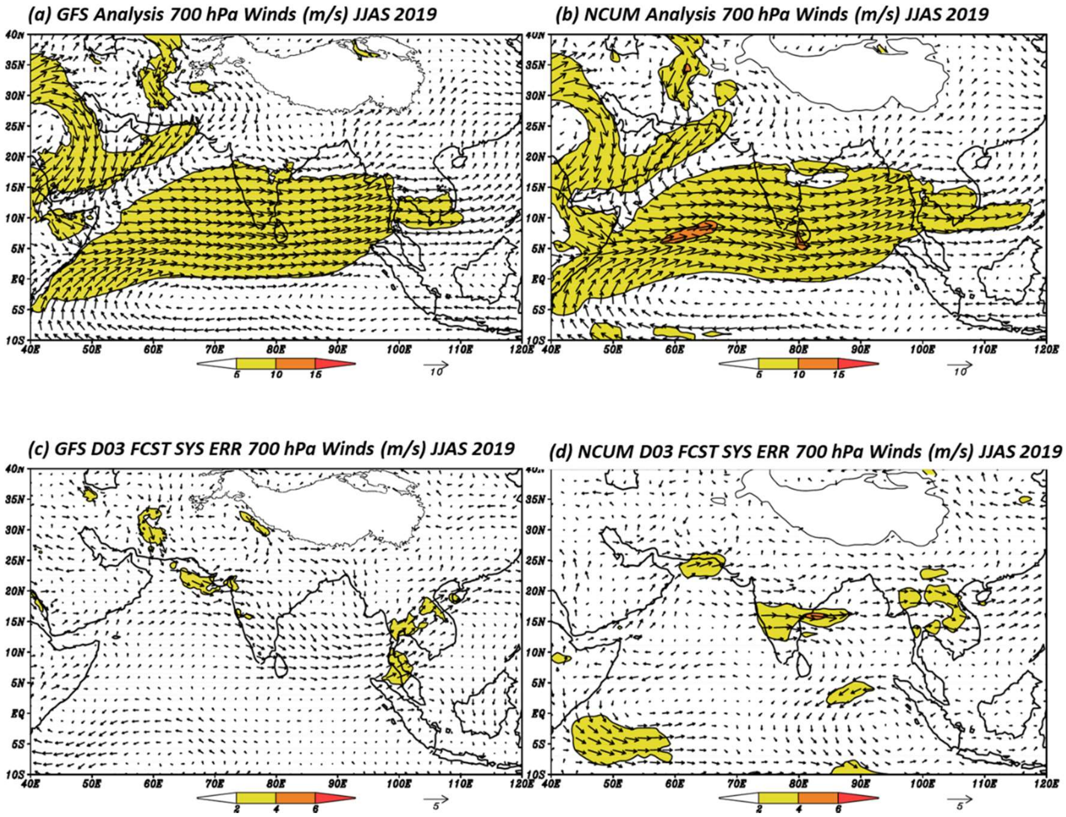

Figure A1. As in Figure 1 for 700 hPa winds

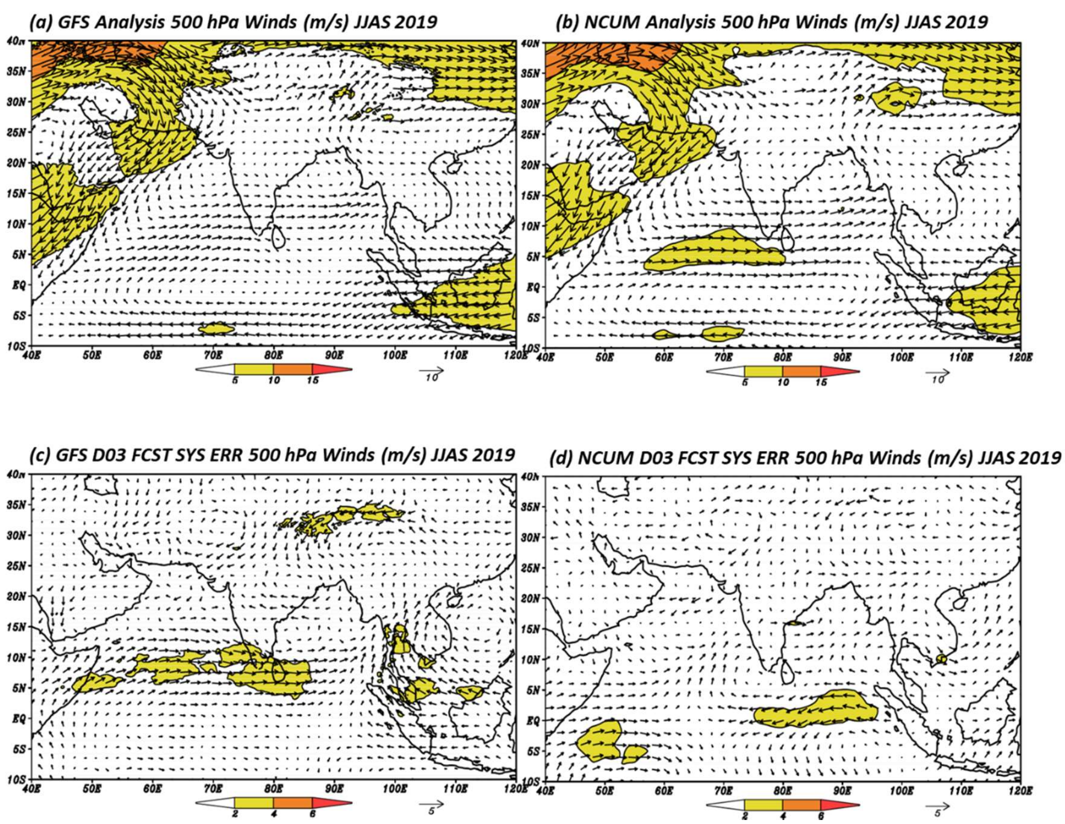

Figure A2. As in Figure 1 for 500 hPa winds

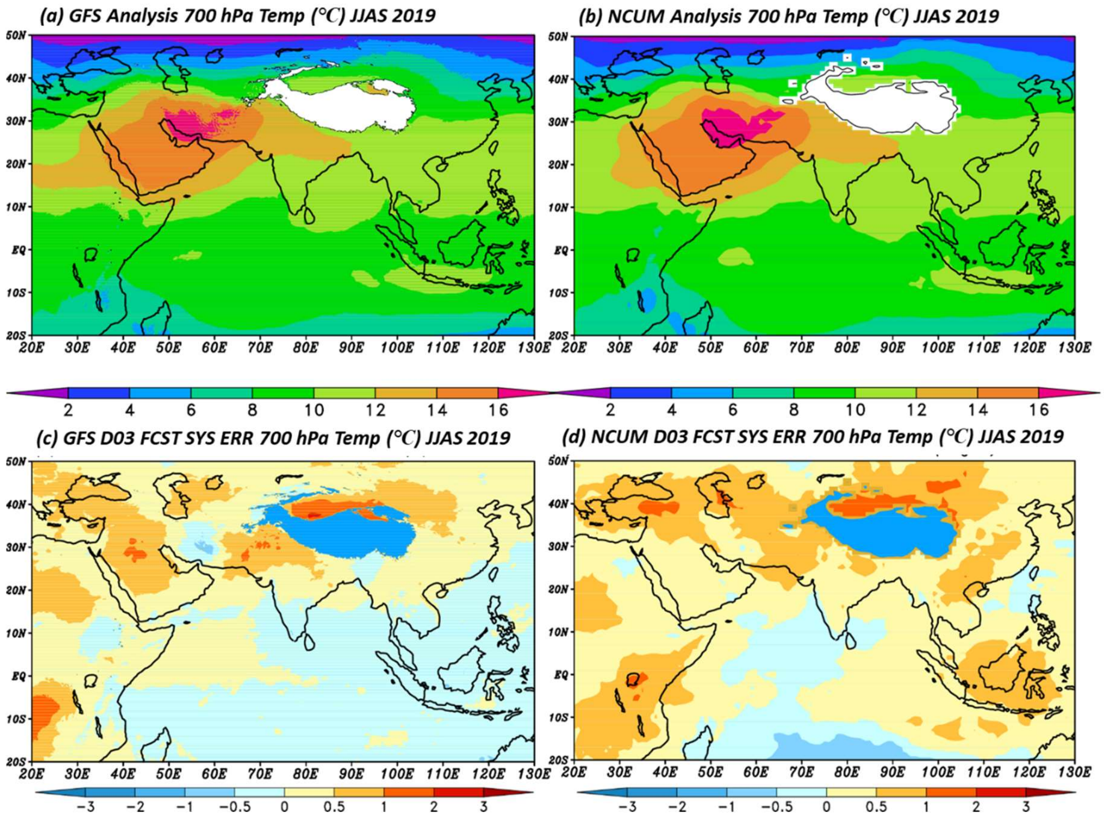

Figure A3. As in Figure 1 for 700 hPa Temperature

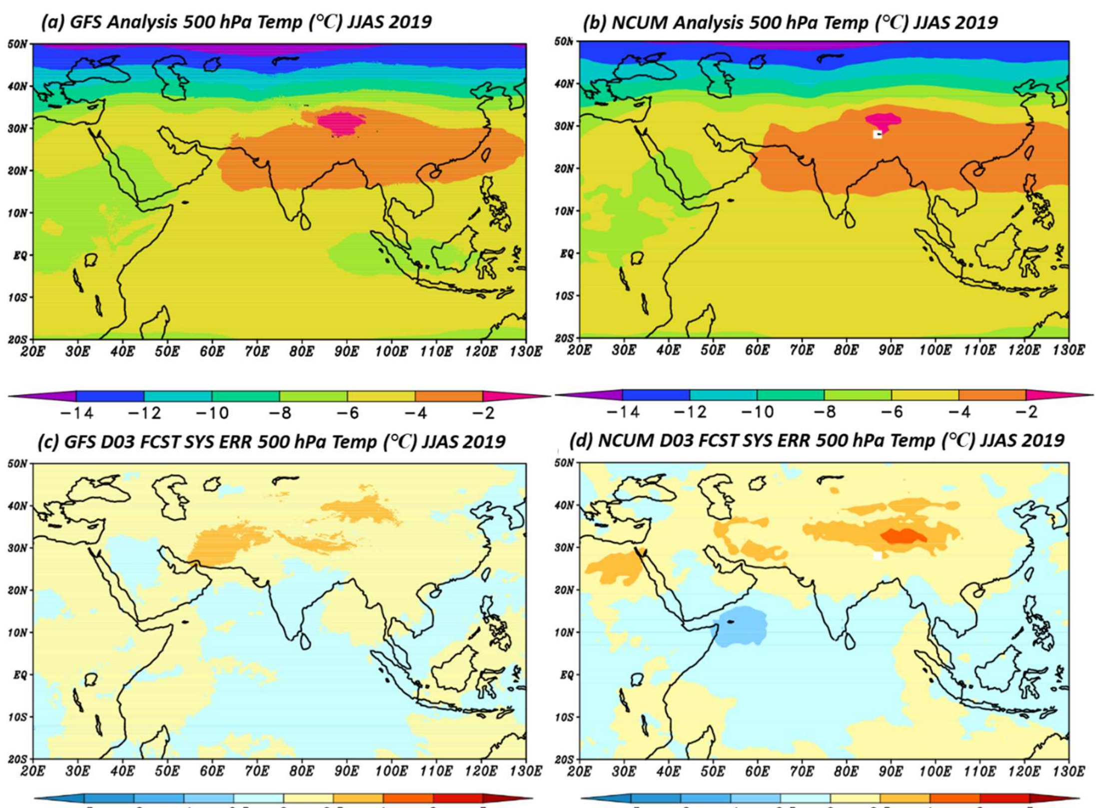

Figure A4. As in Figure 1 for 500 hPa Temperature

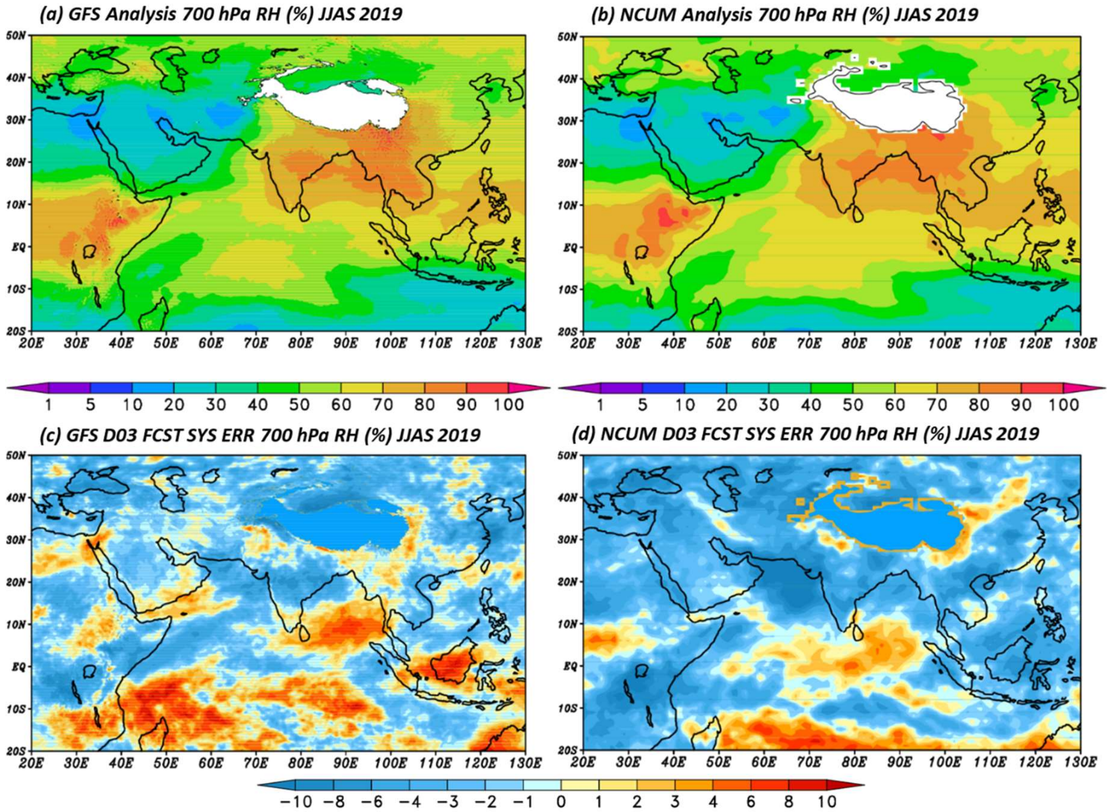

Figure A5. As in Figure 1 for 700 hPa Relative Humidity

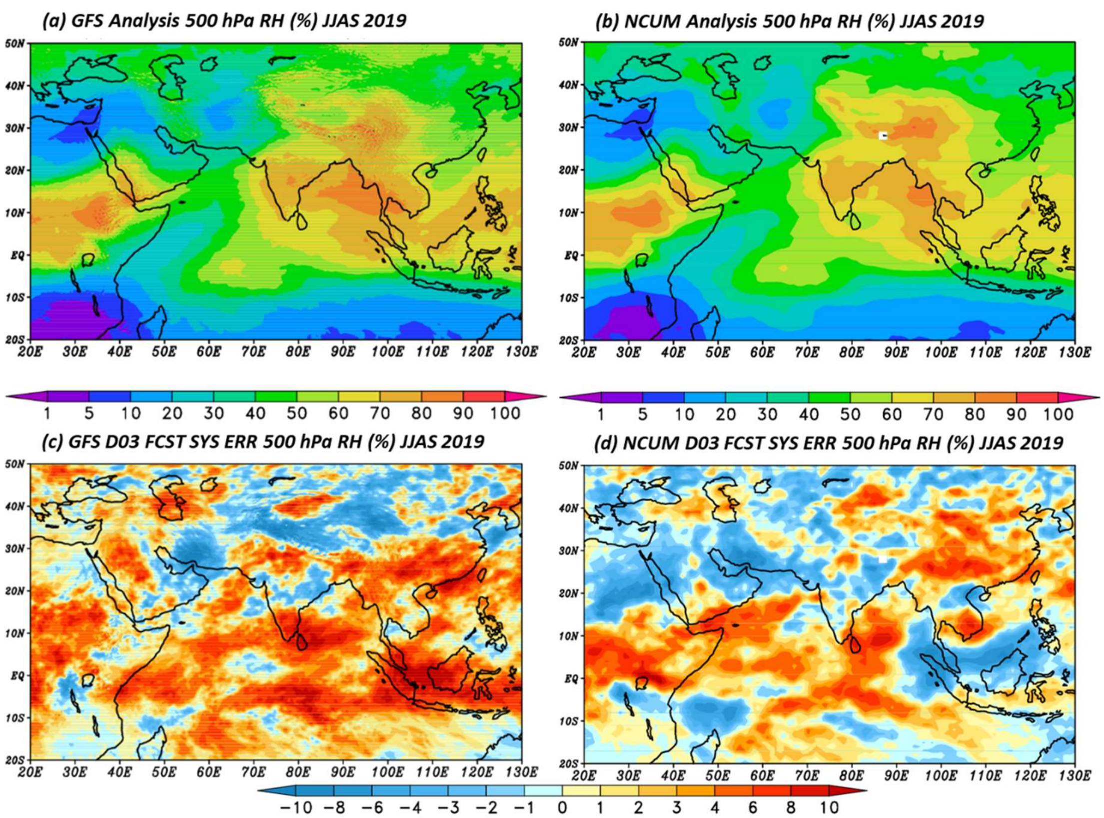

Figure A6. As in Figure 1 for 500 hPa Relative Humidity