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TECNICAL REPORT

Verification of Analysis of GDAS and NCUM-DA with Radiosonde Observations using MET

Sujata Pattanayak, V. S. Prasad and E.N. Rajagopal

August 2020

National Centre for Medium Range Weather Forecasting
Ministry of Earth Sciences, Government of India
A-50, Sector-62, Noida-201 309, INDIA

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Document Control Data Sheet

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10	Abstract	The National Centre for Medium Range Weather Forecasting (NCMRWF) generates daily analysis based on Global Data Assimilation System (GDAS) and also based on NCMRWF Unified Model (NCUM) Data Assimilation (NCUM-DA). This technical report presents a comprehensive statistics on the performance of the GDAS and NCUM-DA analysis as per the Commission for Basic Systems (CBS) guidelines using Model Evaluation Tool (MET). The performances of the two analyses are evaluated over 12 different regions covering the entire globe. The verification of analysis is carried out against the radiosonde (RS/RW) observations available over the specific regions at 12 hourly intervals (00 & 12 UTC). The daily, weekly and monthly statistics in terms of mean error, RMSE, Pearson Correlation Coefficient, and Anomaly Correlation etc. are computed for temperature, geopotential height, zonal (u) and meridional (v) wind components at standard pressure levels. This verification methodology will also be helpful in inter-comparison of the two analyses with the other operational centres worldwide.
11	Security classification	Non-Secure
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13	Key Words	GDAS Analysis, NCUM-DA Analysis, radiosonde observation, CBS score

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Abstract

The National Centre for Medium Range Weather Forecasting (NCMRWF) generates daily analysis based on Global Data Assimilation System (GDAS) and also based on NCMRWF Unified Model (NCUM) Data Assimilation (NCUM-DA). This technical report presents a comprehensive statistics on the performance of the GDAS and NCUM-DA analysis as per the Commission for Basic Systems (CBS) guidelines using Model Evaluation Tool (MET). The performances of the two analyses are evaluated over 12 different regions covering the entire globe. The verification of analysis is carried out against the radiosonde (RS/RW) observations available over the specific regions at 12 hourly interval (00 & 12 UTC). The daily, weekly and monthly statistics in terms of mean error, RMSE, Pearson Correlation Coefficient, and Anomaly Correlation etc. are computed for temperature, geopotential height, zonal (u) and meridional (v) wind components at standard pressure levels. This verification strategy will also be helpful in inter-comparison of the two analyses with the other operational centres worldwide.

1. Introduction

The National Centre for Medium Range Weather Forecasting (NCMRWF) has the mandate to provide observational data analysis to the leading operational centres in India. For this purpose, the Global Data Assimilation and Forecasting system (GDAS), based on National Centers for Environmental Prediction (NCEP) Global Forecasting System (GFS) is operated in real-time at NCMRWF since 1994. Since 2012, NCMRWF Unified Model (NCUM) Data Assimilation (NCUM-DA) is also operated in real-time to generate global analysis for NCUM. Both the systems have been upgraded many times since 1994 and 2012 respectively. With the advancement of observational network for both conventional and non-conventional observations, the performances of DA systems have improved. Hence, the verification of the analysis is crucial to validate and to improve the performance of the Numerical Weather Prediction (NWP) systems. This verification strategy will also be helpful in inter-comparison of the two analyses with the other operational centers worldwide.

The radiosonde sounding (RS/RW) remains a significant contributor to upper-air observations and also has a significant impact on the Numerical Weather Prediction (NWP) systems. This technical report brings out the daily, weekly and monthly statistics on the verification of GDAS and NCUM-DA analysis over 12different regions covering the whole globe. Among these regions, 9 regions are World Meteorological Organisation (WMO) approved regions for deterministic NWP verification and along with that 3 more regions like global, Regional Specialized Meteorological Centre (RSMC), New Delhi, and Indian regions are considered. The detail about the regions is provided in subsequent section. Brief descriptions of the two DA systems are presented in section 2. The description of the verification strategy is presented in section 3, followed by the verification statistics in section 4. A few verification statistics showcasing the performance of the 2 analysis are presented in section 5, followed by the conclusions in section 6.

2. Data Assimilation Systems

Brief details of the two data assimilation systems, namely GDAS and NCUM-DA are in the two sub-sections below.

2.1 Global Data Assimilation System (GDAS)

The GDAS analysis at NCMRWF was started more than two decades ago. The initial system was implemented at a horizontal resolution of T80 with 18 vertical layers (T80L18) on CRAY supercomputer. Many applications such as location specific forecast for agriculture, wind energy, special event forecasts, and forecast for adventure sports etc. were developed based on T80L18 system. From 1st January 2007, T80L18 GDAS was replaced with newer updated version with horizontal resolution of T254 at par with operational version of NCEP GFS. This new T254L64 system included all the changes that NCEP implemented in its GFS during the period 1995-2006 (Rajagopal et al., 2007). The newer version was further updated subsequently as and when NCEP upgraded their operational suite (Prasad et al., 2011). Table 1 summarises the major upgradations of the GDAS at NCMRWF. The improved features of this analysis system includes; observation selection, quality control, minimization algorithm, dynamic balance constraint, and assimilation of new observation types.

Table 1: Major up-gradations of the GDAS at NCMRWF

Sl. No.	Year	Model Resolution	Assimilation System
1	1994	T80L18	SSI
2	2007	T254L64	SSI
3	2008	T254L64	GSI
4	2009	T382L64	GSI
5	2011	T574L64	GSI
6	2016	T574L64	Hybrid GSI
7	2018	T1534L64	4D EnVAR

The GDAS analysis cycles are carried out in six hourly intermittent time period. In each assimilation cycle, a new estimate of the atmospheric state (analysis) is required every 6 hr to initialise a global model forecast. Although the background used for each analysis is the previous 6-hr forecast, a 9-hr forecast is necessary to allow for time interpolation of synoptic observations that fall within the 6-hr analysis time window (i.e., time interpolation of the background is done among 3-, 6-, and 9-hr forecasts that covers the 6-hr data window centered on the analysis time). The analyses so obtained are then used as the initial condition for subsequent forecasts and the cycle continues. The details of the analysis system can be found in Kleist et al. (2009) and the results of pre-implementation test carried out at NCMRWF can be found in Rajagopal et al. (2007). The subsequent upgradations of the GDAS are elaborated in Prasad et al. (2011) and Prasad et al. (2014). The GDAS analysis has wide range of applications in India, namely, to initialise the daily the IMD-GFS for medium range prediction, INCOIS GODAS for ocean analysis, weekly extended range (4 weeks) prediction using IMD-GFS & MM-CFS and MM-CFS for seasonal prediction on a monthly basis. In addition, the GDAS has been used in the generation of a 20 year (1999-2018) global retrospective reanalysis (Prasad et al., 2017), generation of high resolution hindcasts (Johny and Prasad, 2020) and used in satellite data assimilation studies (Johny et al., 2020).

2.2 NCUM Data Assimilation System (NCUM-DA)

NCMRWF Unified Model (NCUM) Data Assimilation system (NCUM-DA) is adapted from the UM Partnership. The NCUM data assimilation system has been upgraded periodically to incorporate new developments in observations, science and technology for improving the analysis. More details of the NCUM-DA system and its upgradations can be found in John et al. (2016), Sumit Kumar et al. (2018) and Sumit Kumar et al. (2020). The current NCUM-DA system is an end-to-end system from observation processing system, hybrid 4D-Var data assimilation system and surface data assimilation/preparation system at a high spatial resolution of 12 km. The in-house development of the observation pre-Processing system is a major component of the NCUM system (Jangid et al., 2019).

3. Verification Strategy

A comprehensive description about the data used, methodology adopted and evaluation domains and validation are presented in this section.

3.1 Verification Domains

The two analyses are verified for the global domain (GL) and also for different regions like, Northern Hemisphere (NH), Southern Hemisphere (SH), Tropics (TR), Asia (AS), North America (NA), Europe/N. Africa (EU), Australia/New Zealand (AN), North Pole (NP), South Pole (SP), RSMC (RS), and India (IN). The details of the verification domain is presented in Table 2.

3.2 Observational Data

Radiosondes are the primary source of upper-air observations. With the advent of GPS radiosonde, the upper-air sounding measurements for various types of meteorological data such as wind speed, wind direction, pressure, temperature and humidity are improved. The radiosonde observation stations as per WMO/CBS standard verification are used in this study. The maximum number of radiosonde observations over different parts of the globe recommended by WMO is presented in Table 3. Additionally, the maximum number of RS/RW observations over RSMC and IN regions are 124 and 52, respectively. The list of observations over RSMC and IN regions is extracted from the global distribution of WMO.

Table 2: Verification Domains

Domain	**Definition**
Global (GL)	90°S - 90°N; inclusive all longitudes
Northern Hemisphere (NH)	20°N - 90°N; inclusive all longitudes
Southern Hemisphere (SH)	20°S - 90°S; inclusive all longitudes
Tropics (TR)	20°S - 20°N; inclusive all longitudes
Asia (AS)	25°N - 65°N & 60°E - 145°E
North America (NA)	25°N - 60°N & 145°W - 50°W
Europe &North Africa (EA)	25°N - 70°N & 10°W - 28°E
Australia & New Zealand (AN)	10°S - 55°S & 90°E - 180°E
North Pole (NP)	60°N - 90°N; inclusive all longitudes
South Pole (SP)	60°S - 90°S; inclusive all longitudes
RSMC, New Delhi(RS)	10°S - 50°N & 40°E -110°E
India (IN)	5°S - 40°N & 50°E - 100°E

Table 3: The maximum number of radiosonde observations as per WMO

Domains	**Max. No. Radiosonde Observations**
GL	718
NH	508
SH	76
TR	135
AS	162
NA	96
EA	89
AN	37
NP	70
SP	12

3.3 Model Evaluation Tool (MET)

The verification of both the analyses is carried out using the Model Verification Tool (MET) with the radiosonde (RS/RW) observations available over the specific regions at every 12 hourly intervals, received at NCMRWF. MET is a state-of-the-art verification tools developed by the Developmental Testbed Center (DTC), National Oceanic and Atmospheric Administration (NOAA) for its use to verify the NWP analysis and forecasts, especially for the WRF user community. However, this verification package can be used for other models with certain format changes. The desired input format for the MET verification is the gridded model output on a standard de-staggered grid on pressure levels in the vertical. For this purpose, the unified post-processor, available in the WRF source code is used. Additionally, the "copygb" utility is recommended for re-gridding analysis and observation datasets in GRIB version 1 format to a common verification grid. Hence, both the GDAS and NCUM-DA analyses are de-staggered using "copygb" utility before its validation. The verification statistics are generated using the "Point-stat Evaluation Package" of MET. More details on the MET package can be found at https://dtcenter.org/community-code/model-evaluation-tools-met.

4. Verification Statistics

The set of verification statistics (Wilks, 2011) used by the WMO lead centres for the deterministic verification of the NWP products, and used in this verification report are described briefly below.

The Mean Error (ME) is a measure of overall bias for continuous variables. It is the bias in the model analysis/forecast and a perfect analysis/forecast has the ME of 0. It is defined as,

$$ME = \frac{1}{n}\sum_{i=1}^{n}(f_i - o_i)$$

The variance in the model analysis/forecast is defined as,

$$SD_f = \sqrt{\frac{1}{T+1}\sum_{i=1}^{T}\left(f - \bar{f}\right)^2}, \quad \bar{f} = \frac{1}{n}\sum_{i=1}^{n} f_i$$

The variance in the observation is defined as,

$$SD_o = \sqrt{\frac{1}{T+1}\sum_{i=1}^{T}(o - \bar{o})^2}, \quad \bar{o} = \frac{1}{n}\sum_{i=1}^{n} o_i$$

The root mean square error (RMSE) can be defined as,

$$RMSE = \sqrt{\frac{1}{n}\sum (f_i - o_i)^2}$$

The Pearson correlation coefficient (PR_{CORR}) measures the strength of linear association between the model analysis/forecast and observations. It is defined as,

$$PR_{CORR} = \frac{\sum_{i=1}^{T}\left(f - \bar{f}\right)(o - \bar{o})}{\sqrt{\sum\left(f_i - \bar{f}\right)^2}\sqrt{\sum(o_i - \bar{o})^2}}$$

The value of the PR_{CORR} ranges between -1 and 1. A value of 1 indicates perfect correlation and a value of -1 indicates perfect negative correlation. A value of 0 indicates that the forecasts and observations are not correlated.

Additionally, the anomaly correlation coefficient is estimated which is the equivalent to the Pearson correlation coefficient, but both the observation and forecast are first adjusted to the climatological value. It measures the strength of linear association between forecast anomalies and observed anomalies. It is defined as,

$$ANOM_{CORR} = \frac{\sum(f_i - c)(o_i - c)}{\sqrt{\sum(f_i - c)^2}\sqrt{(o_i - c)^2}}$$

The skill of the analysis evaluated through Gilbert Skill Score (GSS). It is defined as follows.

$$GSS = \frac{a - \frac{(a+b)(a+c)}{a+b+c+d}}{a + b + c - \frac{(a+b)(a+c)}{a+b+c+d}}$$

$$K = \frac{(a + b)(a + c) + (c + d)(b + d)}{a + b + c + d}$$

The value of a, b, c, d are measures as in Table 4.

Table 4: Observation and Forecast measures to evaluate skill

Forecast	Observation		Total
	o = 1 (Yes)	o = 0 (No)	
f = 1 (Yes)	a	B	a + b
f = 0 (No)	c	d	c + d
Total	**a + c**	**b + d**	**T = a + b + c + d**

The basic error statistics are generated at standard pressure levels i.e., 1000, 925, 850, 700, 500, 400, 300, 250, 200, 150, 100 hPa. However, anomaly correlation coefficient ($ANOM_{CORR}$) and Gilbert Skill Score (GSS) are generated at 850, 500 and 250 hPa.

5. Results and Discussion

The performances of both the analyses are evaluated on daily, weekly and monthly basis. The mean error, standard deviation, correlation coefficient, anomaly correlation, and skill etc. are evaluated basic meteorological parameters such as temperature, geopotential height, zonal (u) and meridional (v) wind components at standard pressure levels.

The model performance is evaluated over the 12 different regions as described above as per the CBS guidelines. Figure 1 shows the bias in the analyses from both GDAS and NCUM-DA for wind, temperature and geopotential height for 00 UTC 15th July 2020. It is seen that both the analyses have similar performance in most of the regions. Both the models show comparatively less bias over GL, NH, AS, NA, EA, NP regions, whereas SP, AN, and IN regions shows slightly higher biases. This may be due to the less sample size as comparable to the other regions. The temperature bias is also little higher over SP, AN, and IN regions. The SP region has also higher geopotential height bias. Figure 2 represents the RMSE of wind, temperature and geopotential height for 00 UTC 15th July 2020. The RMSE in the wind components clearly depicts the lower levels up to 850 hPa have higher errors than the middle and upper levels, however the GL, NH and NA regions shows higher RMSE at 200 hPa. In case of meridional wind components, the low level RMSE over TR, RS, and IN regions is higher than other regions. The temperature RMSE shows higher value in lower and upper level than the middle level. Similarly, the geopotential wind height has higher RMSE in the lower levels over SH and SP regions than the other regions. Figure 3 represents the vertical distribution of Pearson correlation coefficient for wind, temperature and geopotential height for 00 UTC 15th July 2020. Both the analysis presents similar type of results in terms of correlation.

The performance of the analysis is also evaluated in terms of weekly and monthly at 850, 500 and 250 hPa levels. For the weekly charts, last 7 days statistics are generated on each day. This will be helpful in estimating the performance of analysis for a weekly basis. Apart from this, weekly statistics will illustrate the behaviour of the analysis for recent couple of days which will be helpful in modifying the analysis system. Figure 4 shows the weekly statistics of Mean Error, RMSE, Pearson correlation and anomaly correlation for zonal (u) and meridional (v) wind components at 850 hPa and temperature and geopotential height at 500 hPa over the Global region for 24-30 July 2020. Both the analyses are performing in a similar way except for few exceptions. Figure 5 represents the weekly statistics of Mean Error, RMSE, Pearson correlation and anomaly correlation for zonal (u) and meridional (v) wind components at 850 hPa and temperature and geopotential height at 500 hPa over Indian region for 24-30 July 2020. Over Indian region, the GDAS analysis is found to be slightly better than NCUM-DA analysis during this verification week.

The monthly statistics shown in Figure 6 represents the Mean Error, RMSE, Pearson correlation coefficient and anomaly correlation for zonal (u) and meridional (v) wind components at 850 hPa and temperature and geopotential height at 500 hPa over Global region for June 2020. Both the analysis represents more or less in a similar way for all the meteorological parameters except geopotential height, which exhibit a very sharp increase in bias, RMSE and with less correlation coefficient on 26th June 2020. Figure 7 shows the monthly statistics of Mean Error, RMSE, Pearson correlation coefficient and anomaly correlation for zonal (u) and meridional (v) wind components at 850 hPa and temperature and geopotential height at 500 hPa over the Indian region. The results indicate that GDAS analysis has slightly less Mean Error, RMSE and higher correlation compared to NCUM-DA analysis during June 2020. More results of the verification of the two analyses (GDAS and NCUM-DA) are available in near real-time on NCMRWF's internal webpage at http://192.168.1.100/product_main_ncmrwf_analysis_verification.php

6. Conclusions

The performance of the GDAS and NCUM-DA analysis is evaluated over 12 different regions and the CBS score is computed on daily, weekly and monthly basis over those regions using Model Evaluation Tool (MET). In addition to the specified regions of ECMWF, WMO Lead Centre for Deterministic NWP Verification, the scores are computed over three more regions such as global, RSMC and India. The MET has the capability to validate the model analyses/forecasts with the gridded or point observations and using this tool some of the important meteorological parameters are verified. The daily statistics clearly shows similar type of performance for both the analysis. The weekly and monthly analysis over the global region also presents similar statistics for both GDAS and NCUM-DA analyses. The weekly and monthly verification over the Indian region shows a slightly better performance of GDAS analysis during the comparison period. This verification strategy will also be helpful in inter-comparison of the two analyses with the other operational centres worldwide. The real-time verification statistics of the two analyses against observations will be made available in NCMRWF's webpage (https://www.ncmrwf.gov.in) soon.

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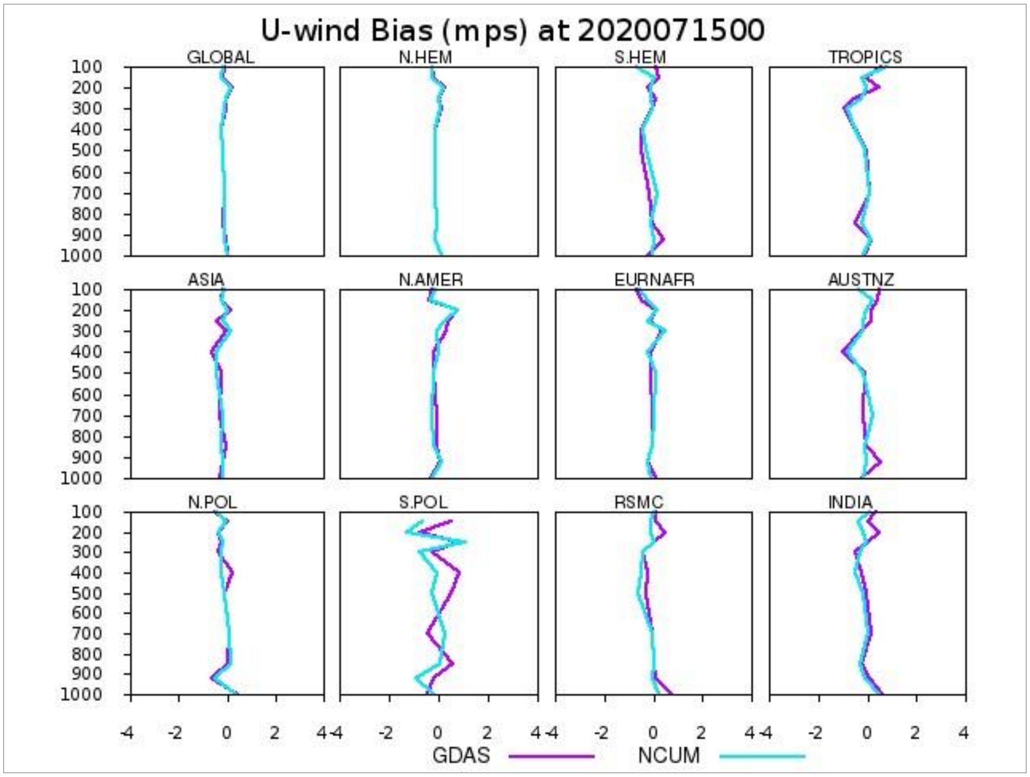
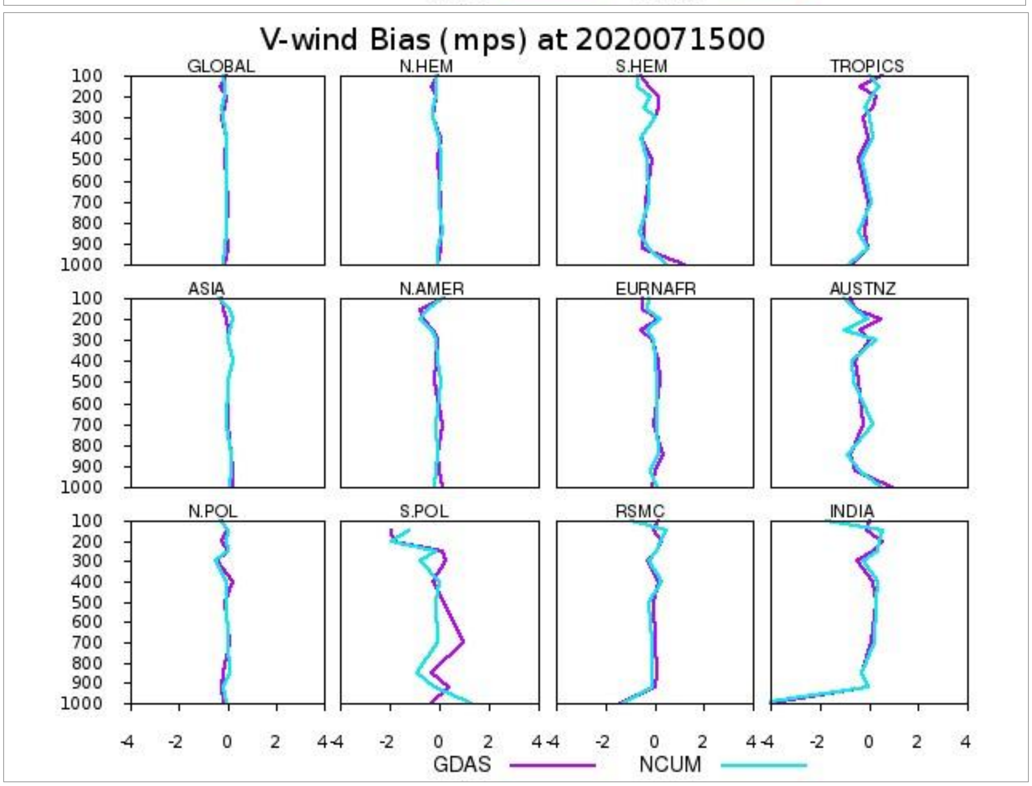


U-wind Bias (mps) at 2020071500
GLOBAL
N.HEM
S.HEM
TROPICS
ASIA
N.AMER
EURNAFR
AUSTNZ
N.POL
S.POL
RSMC
INDIA
100
200
300
400
500
600
700
800
900
1000
-4 -2 0 2 4
GDAS
NCUM



V-wind Bias (mps) at 2020071500
GLOBAL
N.HEM
S.HEM
TROPICS
ASIA
N.AMER
EURNAFR
AUSTNZ
N.POL
S.POL
RSMC
INDIA
100
200
300
400
500
600
700
800
900
1000
-4 -2 0 2 4
GDAS
NCUM

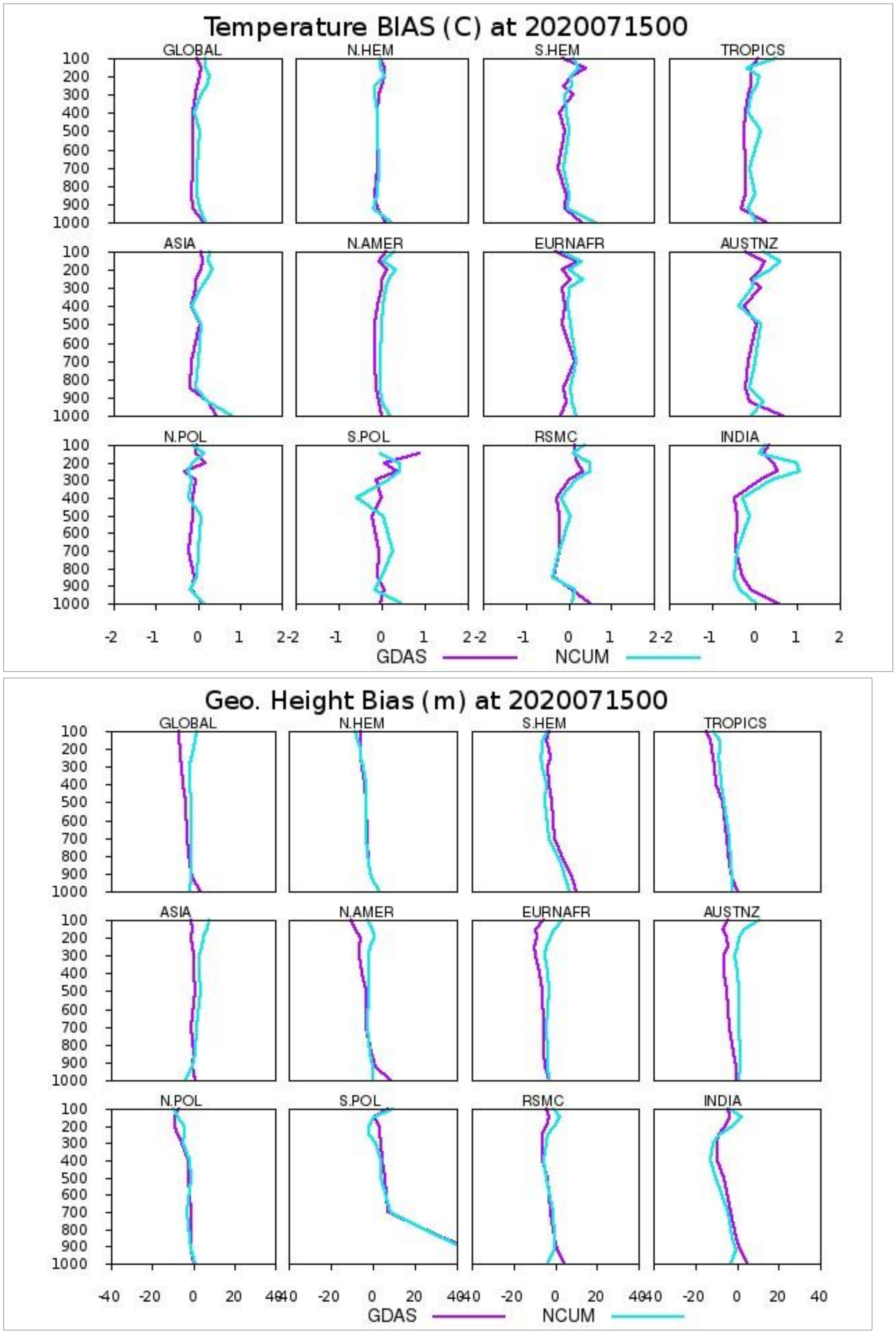
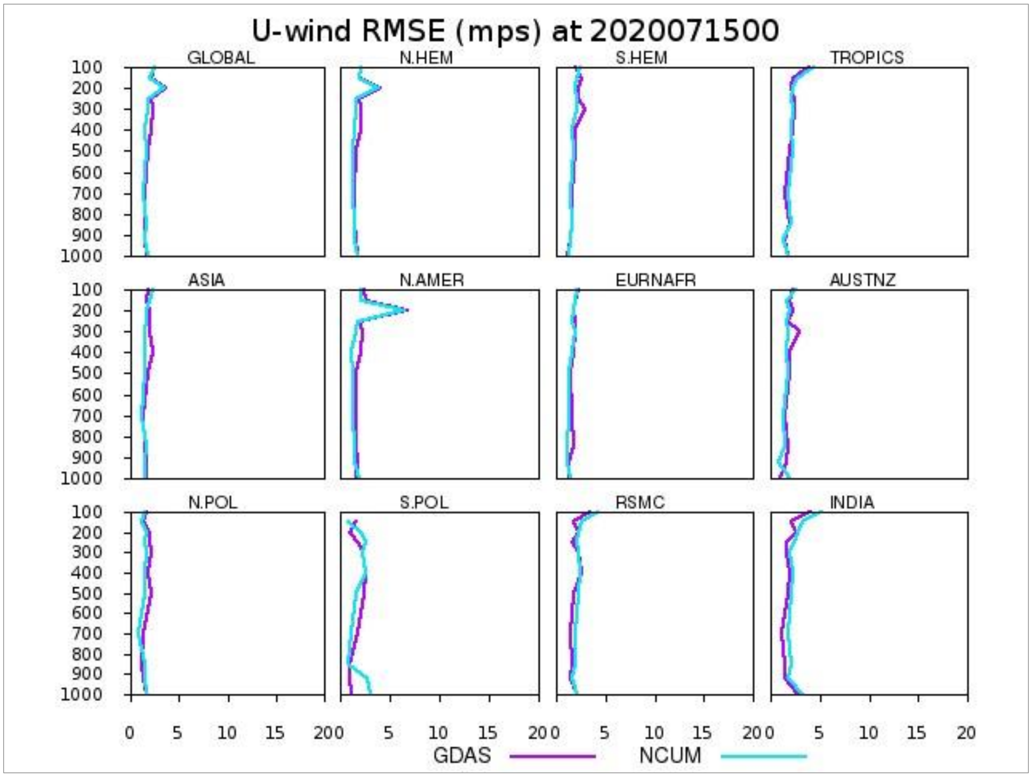
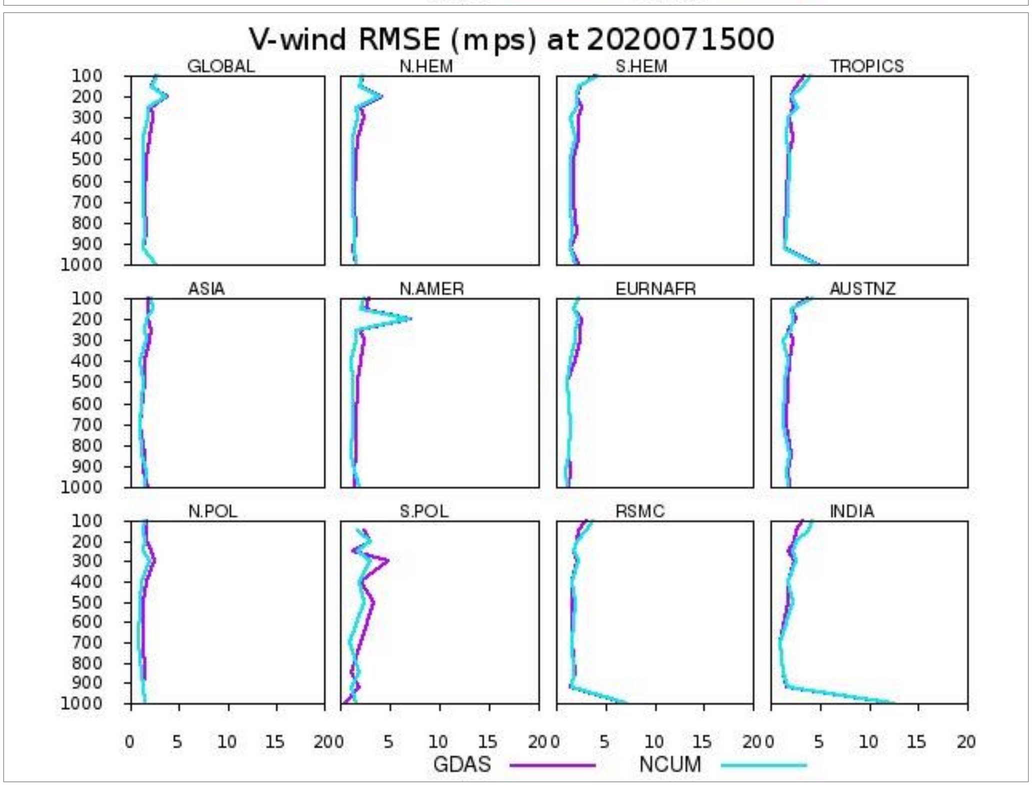


Figure 1: Vertical distribution of daily bias of GDAS and NCUM-DA analyses for 00 UTC 15th July 2020 over 12 specific domains of verification



U-wind RMSE (mps) at 2020071500
GLOBAL
N.HEM
S.HEM
TROPICS
ASIA
N.AMER
EURNAFR
AUSTNZ
N.POL
S.POL
RSMC
INDIA
GDAS
NCUM



V-wind RMSE (mps) at 2020071500
GLOBAL
N.HEM
S.HEM
TROPICS
ASIA
N.AMER
EURNAFR
AUSTNZ
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S.POL
RSMC
INDIA
GDAS
NCUM

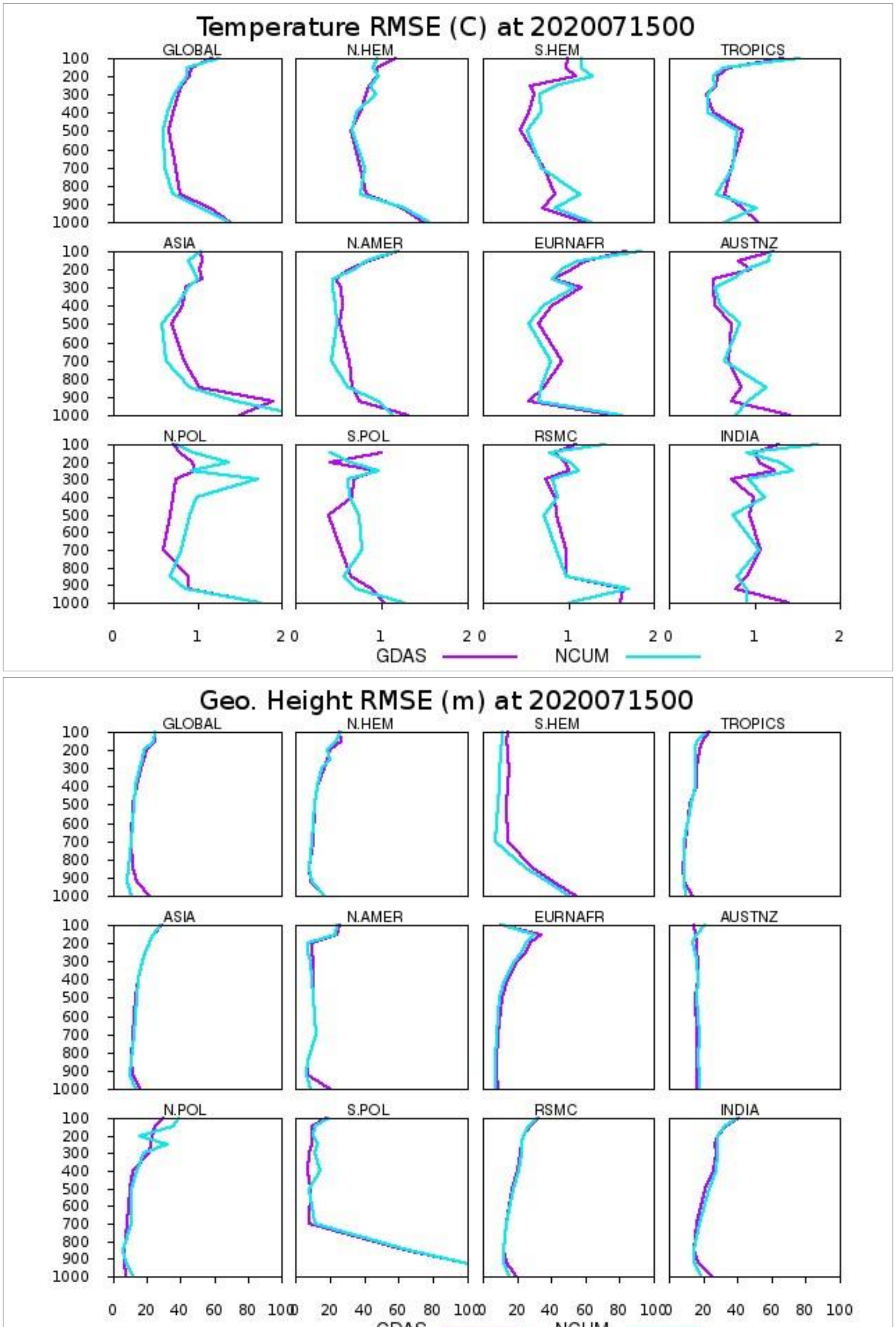
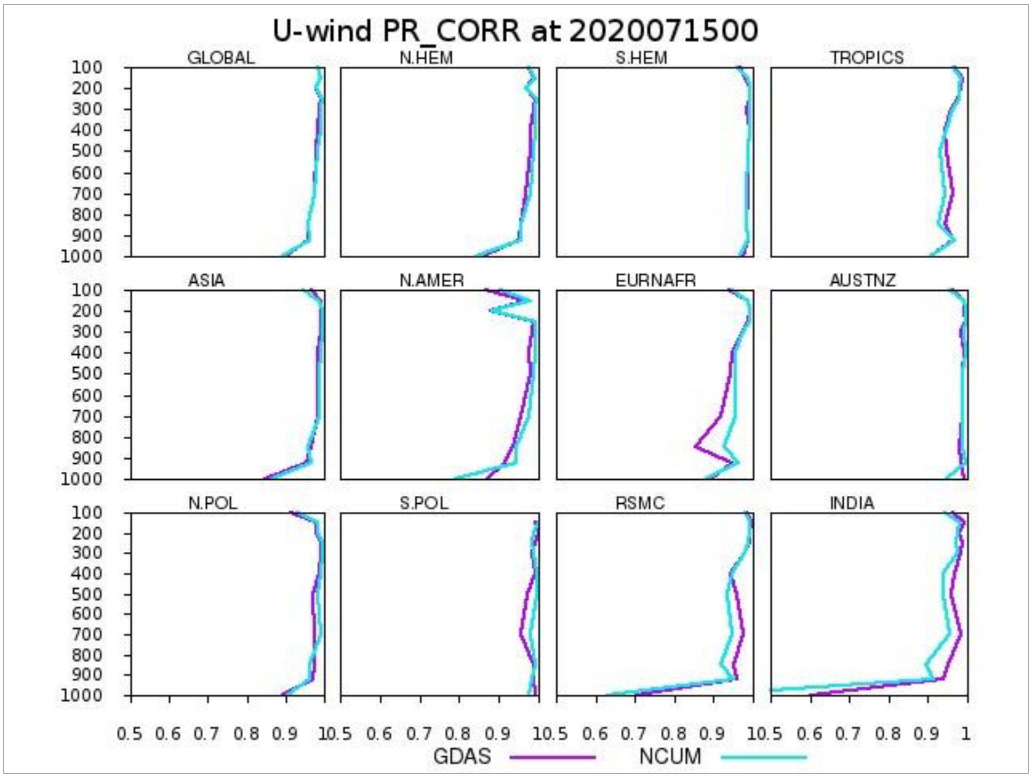


Figure 2: Vertical distribution of daily RMSE of GDAS and NCUM-DA analyses for 00 UTC 15th July 2020 over 12 specific domains of verification


U-wind PR_CORR at 2020071500
GLOBAL
N.HEM
S.HEM
TROPICS
ASIA
N.AMER
EURNAFR
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S.POL
RSMC
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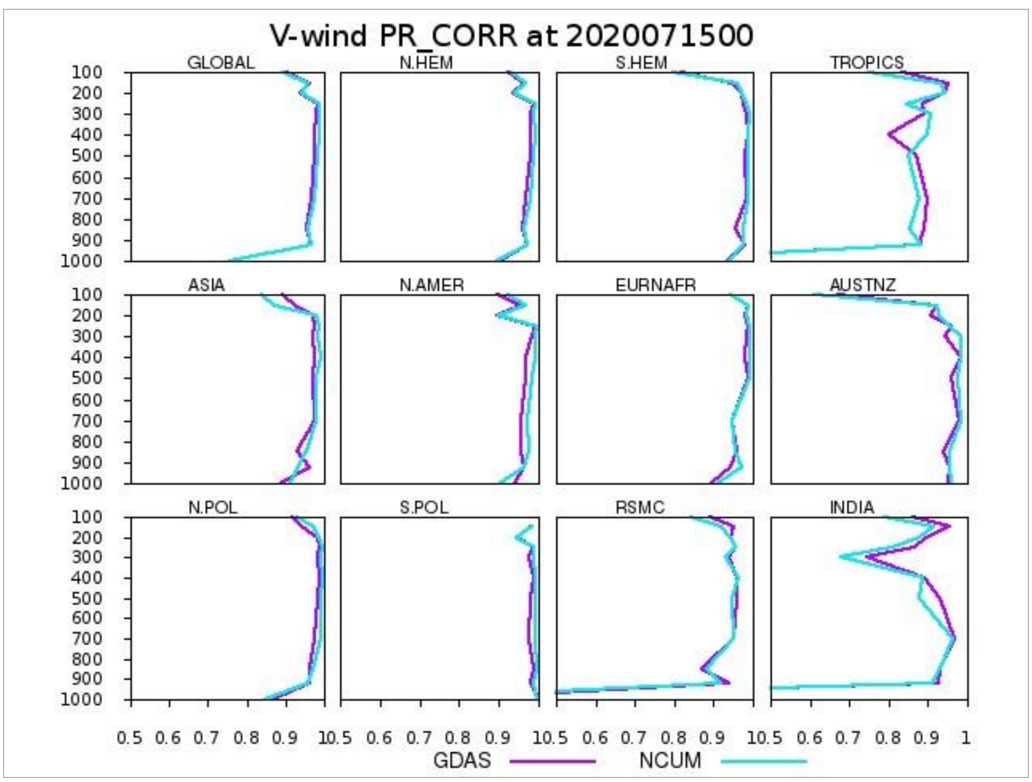
0.5 0.6 0.7 0.8 0.9 1
GDAS
NCUM


V-wind PR_CORR at 2020071500
GLOBAL
N.HEM
S.HEM
TROPICS
ASIA
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EURNAFR
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0.5 0.6 0.7 0.8 0.9 1
GDAS
NCUM

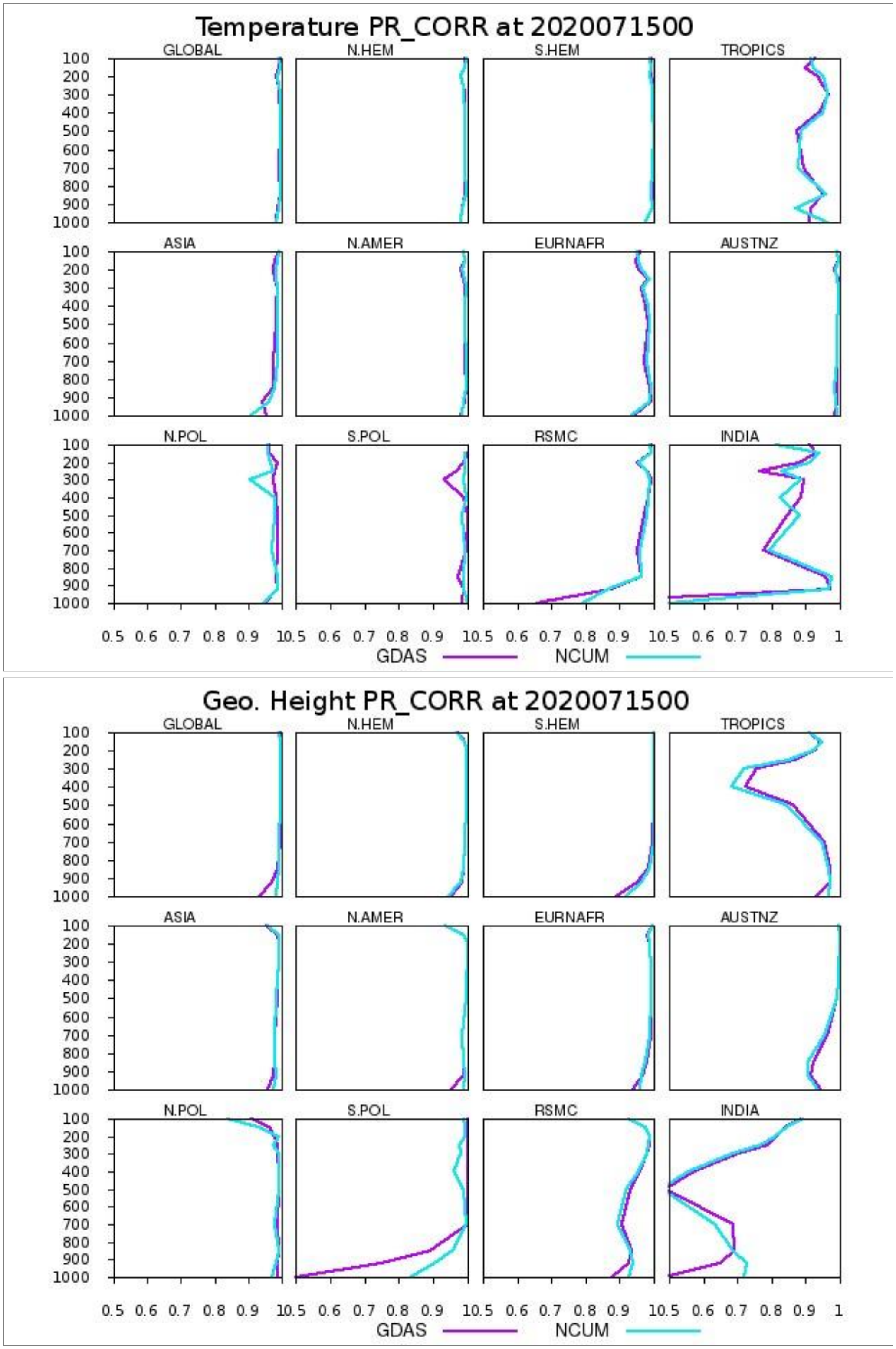

Figure 3: Pearson correlation coefficient of GDAS and NCUM-DA analyses for 00 UTC 15th July 2020 for 12 specific domains of verification

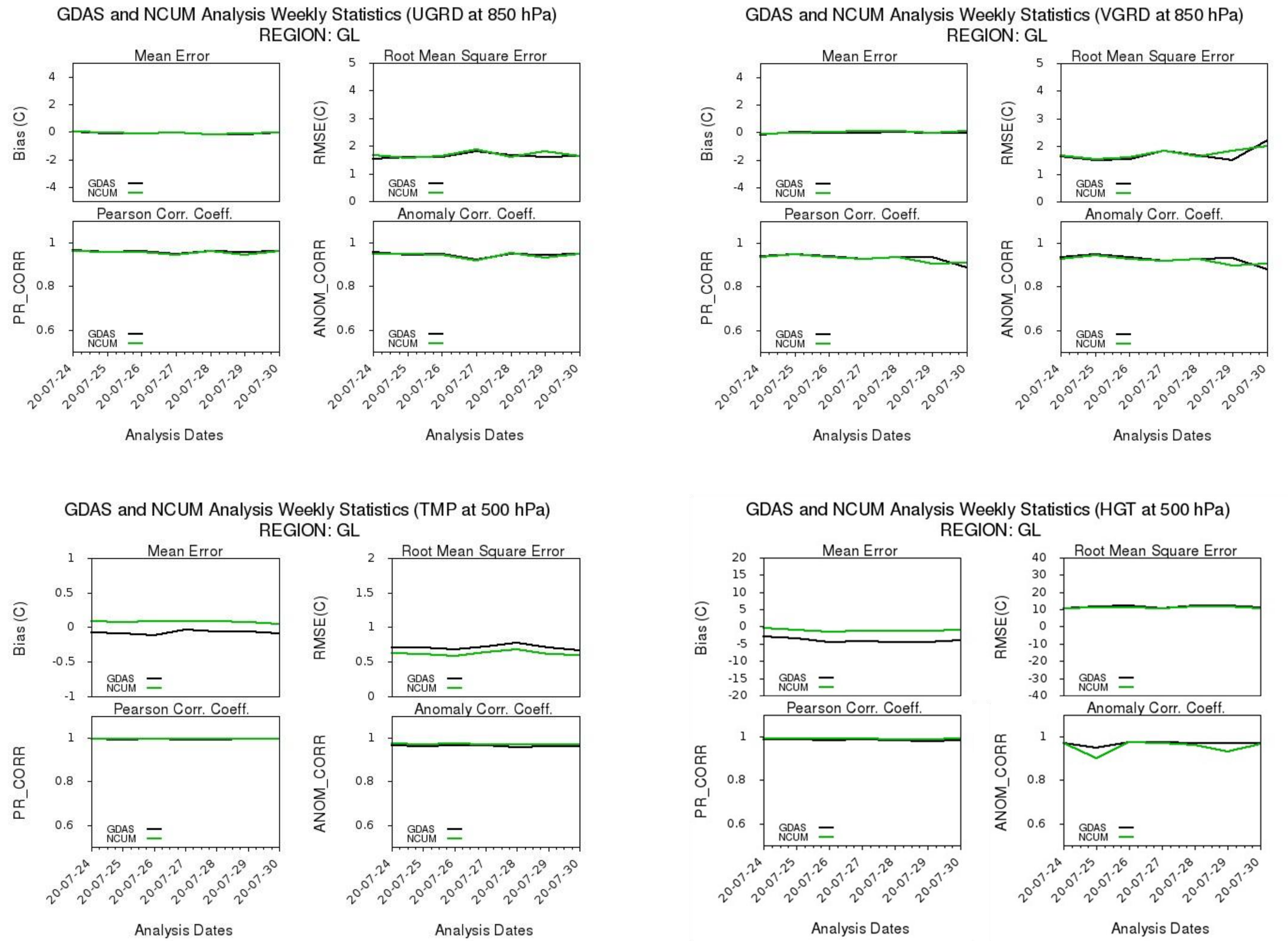

Figure 4: Weekly Mean Error, RMSE, Pearson correlation and anomaly correlation of GDAS and NCUM-DA analysis for zonal (u) and meridional (v) wind components at 850 hPa and temperature and geopotential height at 500 hPa over Global region for 24-30 July 2020

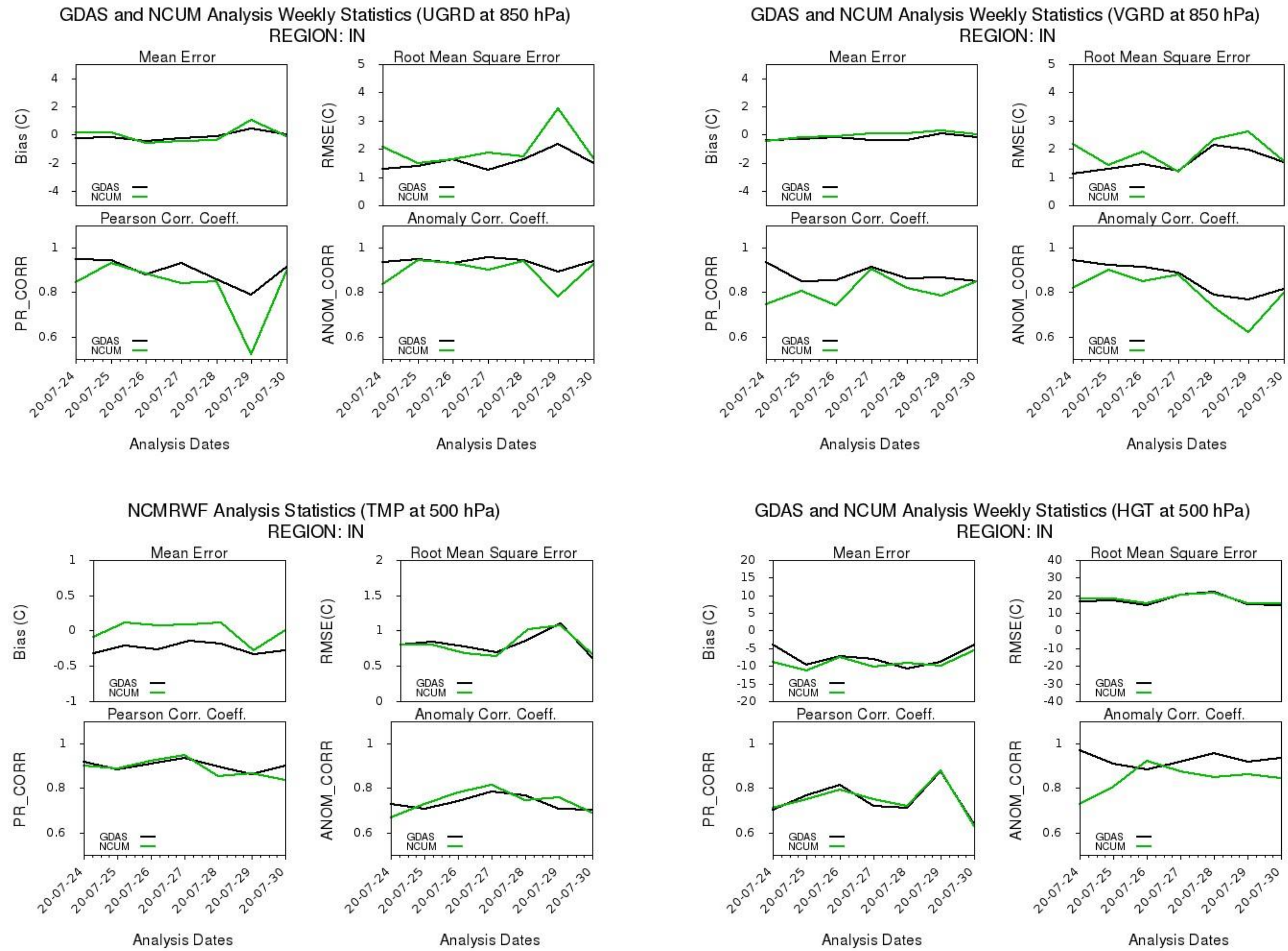

Figure 5: Weekly Mean Error, RMSE, Pearson correlation and anomaly correlation of GDAS and NCUM-DA analysis for zonal (u) and meridional (v) wind components at 850 hPa and temperature and geopotential height at 500 hPa over Indian region for 24-30 July 2020

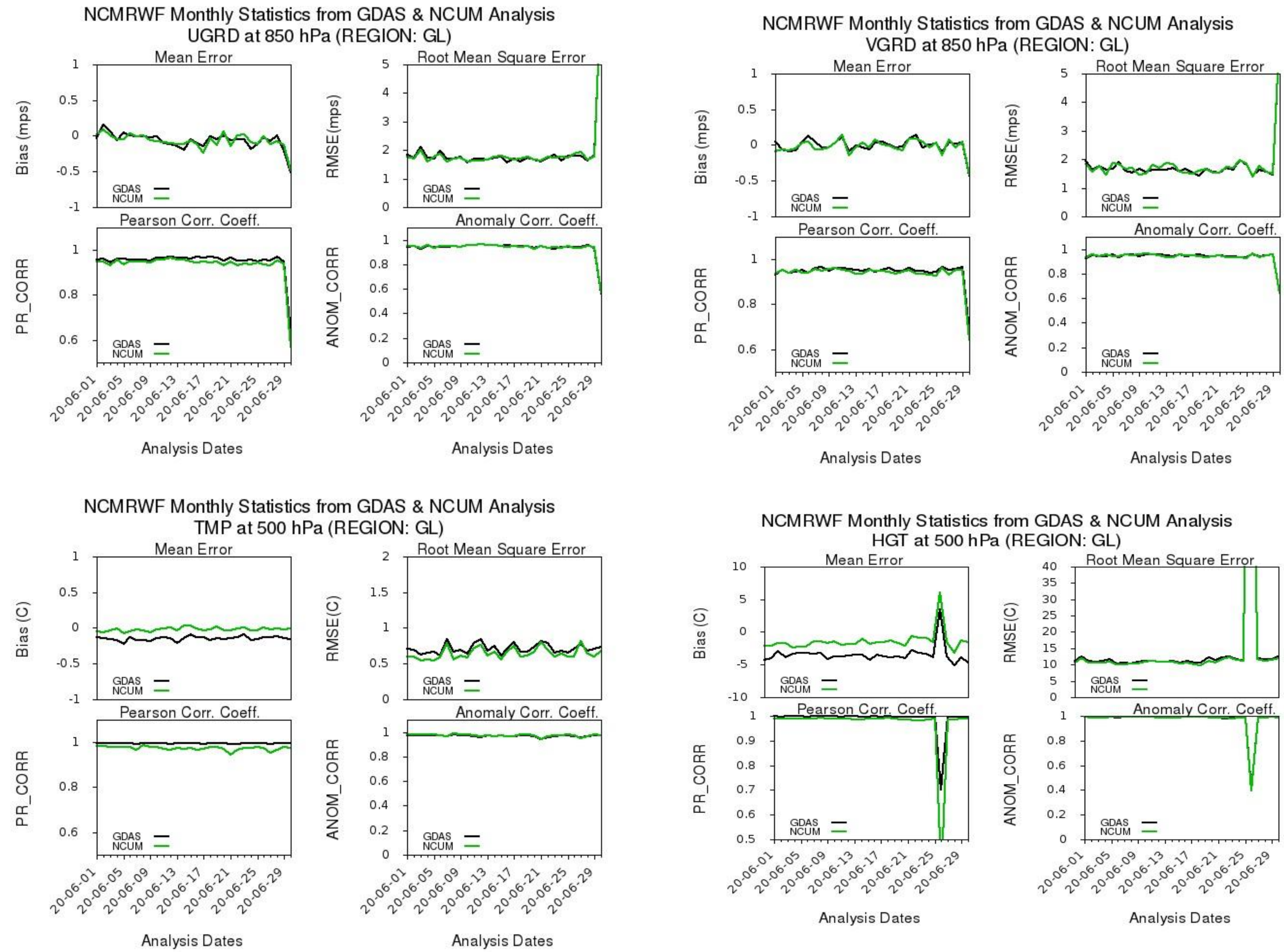

Figure 6: Monthly Mean Error, RMSE, Pearson correlation and anomaly correlation of GDAS and NCUM-DA analysis for zonal (u) and meridional (v) wind components at 850 hPa and temperature and geopotential height at 500 hPa over Global region for June 2020

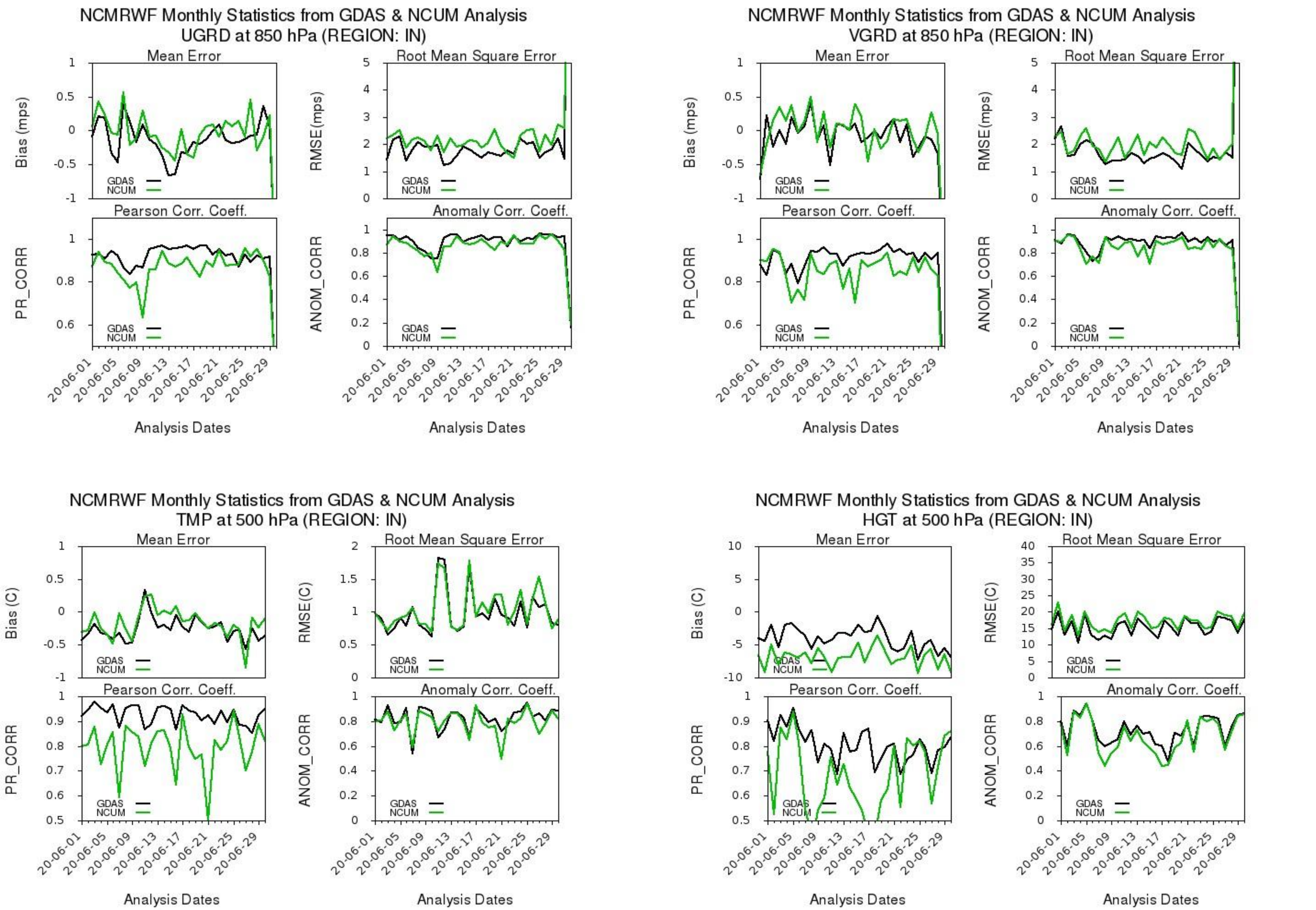

Figure 7: ***Monthly Mean Error, RMSE, Pearson correlation and anomaly correlation of GDAS and NCUM-DA analysis for zonal (u) and meridional (v) wind components at 850 hPa and temperature and geopotential height at 500 hPa over Indian region for June 2020***

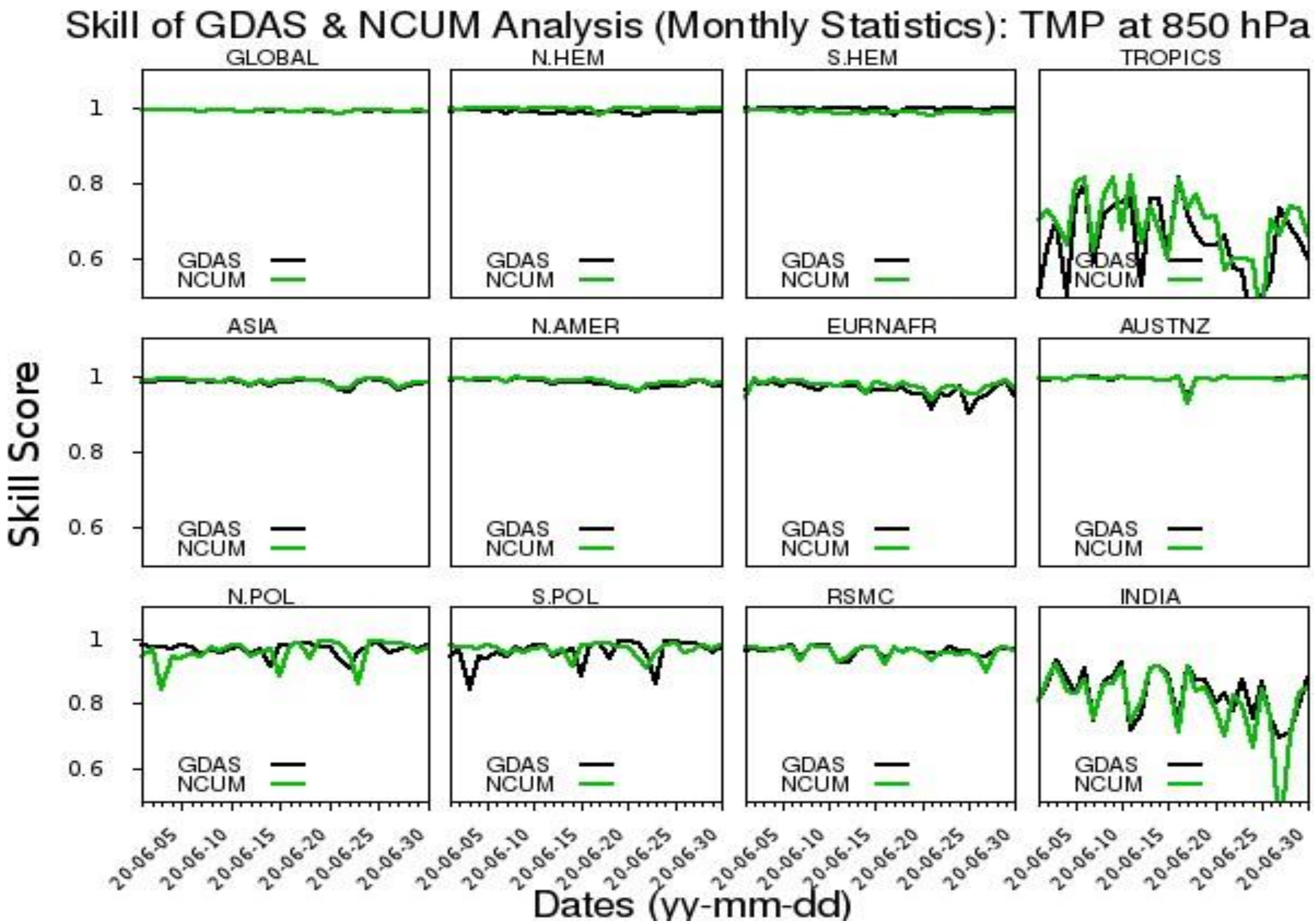

Figure 8: Gilbert Skill Score of GDAS and NCUM-DA analyses for temperature at 850 hPa over the specified regions for June 2020

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