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VERIFICATION REPORT

**NCUM Global Model Monthly Verification for
January 2021**

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Data control sheet

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9	Abstract	This report presents the verification summary of the NCMRWF Global Unified Model (NCUM hereafter) forecasts for January 2021 over India. Firstly, the monthly mean analysis and anomalies in the winds at four levels (850, 700, 500, and 200 hPa) are presented. The anomalies are computed against the ERA-5 climatology (1979-2018). This section is followed by systematic errors in the forecast winds, temperature, relative humidity at 850, 700, 500, and 200 hPa levels. Additionally, systematic errors are presented for Temperature & Specific Humidity at 2m height and Winds at 10m height along with column integrated precipitable water (PWAT). Special attention is given to verify significant weather events of the month. During January 2021, there were unusual rainfall spells over southern Indianas well as over northern India. These events have been verified in detail using the spatial verification approach to quantify the spatial biases. Verification is also presented for the visibility forecasts over IGI-T3 in Delhi, based on the Delhi Model (DM 330m).
10	References	--
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I. Introduction

This report presents the verification summary of the NCMRWF Global Unified Model (NCUM hereafter) forecasts for January 2021 over India. The operational unified global model NCUM runs twice a day at NCMRWF with a horizontal grid resolution of 12km and 70 vertical levels reaching up to 80 km height and provides weather forecast for the next ten days. However, the forecasts based on 00UTC initial conditions up to Day-5 are considered in this report. The verification is carried out at daily intervals (Day-1, Day-2, etc., up to Day-5) against the model analysis for the near-surface, lower, and upper tropospheric variables.

Firstly, the monthly mean analysis and anomalies in the winds at four levels (850, 700, 500, and 200 hPa) are presented. The anomalies are computed against the ERA-5 climatology (1979-2018). This section is followed by systematic errors in the forecast winds, temperature, relative humidity at 850, 700, 500, and 200 hPa levels. Additionally, systematic errors are presented for Temperature & Specific Humidity at 2m height and Winds at 10m height along with column integrated precipitable water (PWAT).

Verification of daily rainfall forecasts (24hr accumulated rainfall valid at 03UTC) is based on the 0.25 x0.25 grid merged (Satellite+Gauge) IMD-NCMRWF rainfall analysis. Verification of daily Temperature forecasts (Tmax and Tmin) is carried out against the IMDs daily observed gridded (0.5 x 0.5) Tmax and Tmin data. Categorical verification scores are presented for both temperature and rainfall for January 2021. The scores include Frequency Bias (BIAS Score), Probability of Detection (POD), False Alarm Ratio (FAR), Critical Success Index (CSI), Peirce's Skill Score (PSS), and Symmetric Extremal Dependency Index (SEDI).

Special attention is given to verify significant weather events of the month. During January 2021, there were unusual rainfall spells over southern Indianas well as over northern India. These events have been verified in detail using the spatial verification approach to quantify the spatial biases. Verification is also presented for the visibility forecasts over IGI-T3 in Delhi, based on the Delhi Model (DM 330m). These forecasts have been communicated to IMD as part of FDP-Winter Fog and Visibility activity.

At the end of the document, in the Appendix, statistics are tabulated for verification carried out against the radiosonde observations over India. The Mean error, RMSE, and Correlation are presented for Geopotential height, Temperature, and winds at two levels (850 and 500 hPa) for all lead times from day-1 to Day-10.

Some important highlights of the entire evaluation of NCUM forecasts during January 2021 and related biases are given below. These highlights are compiled from the Figures given below

1. Highlights:

1. Mean Analysis & anomaly winds (850, 700, 500 and 200 hPa):

- The mean 850 hPa winds feature (a) northwesterlies over Indo-Gangetic Plains (IGP) and (b) easterlies over Bay of Bengal and Arabian Sea. The wind anomaly circulation indicates stronger westerlies over equatorial Indian Ocean, weaker winds over IGP at 850 hPa and stronger westerlies at 700 hPa. (**Figures 1**).
- The mean 700 hPa wind features northwesterlies over IGP extending from 850 hPa level. The wind anomaly shows stronger than normal flow associated with (a). Stronger than normal westerly flow is seen to the north of 20°N extending over from west to east. The anomalous westerlies over southern peninsula and neighbouring seas suggests weakened flow in January 2021. (**Figures 1**).
- The mean 500 and 200 hPa winds show strong westerly flow over northern parts of the domain. The anomaly flow over Horn of Africa and northern Arabian Sea suggests weaker than circulation. Easterly anomalies over peninsula and Bay of Bengal indicate stronger than normal circulation. (**Figure 2**).

2. Systematic errors in winds, temperature & moisture fields:

- Systematic errors in the 850 hPa forecast winds show southeasterly bias of 2-3ms-1 over eastern Indian Ocean in Day-3 and Day-5 forecasts (**Figure 3**). Similar biases are evident near the surface (**10m winds; Figure 14**). Westerly bias is prominent over northern Arabian Sea and adjoining land regions.
- At 700 hPa notable features include westerly bias over IGP extending from Iran and Persian Gulf, western Indian Ocean just south of the equator southeasterly bias over eastern Indian Ocean. (**Figure 4**)
- At 500hPa, westerly bias over IGP, easterly bias over peninsular, Arabian Sea and Bay of Bengal and westerly bias over western Indian Ocean south of the equator are prominent. (**Figure 5**).
- At 200 hPa widespread southwesterly bias is prominent over Arabian Sea and adjoining Africa in Day-3 and Day-5. Over the northern parts of India, westerly bias is seen in Day-3 and Day-5 extending from Iran up to IGP. Northeasterly (*northwesterly*) bias over entire India (*Bay of Bengal*) is seen in Day-5(**Figure 6**).
- The systematic errors in temperatures at 850, levels feature strong warm bias (>0.5 to 2°C) over the Indian subcontinent. However the warm bias is reduced at 700& 500 hPa with cold bias in Day-5. At 200 hPa cold bias is seen in Day-1 over land and wide spread warm bias is prominent over Indian Ocean in Day-3 and Day-5 (**Figures7-10 and Figure 15**).
- Relative humidity at 850 hPa (& near surface) show strong dry bias over India and wet bias over neighboring seas. Wet bias over Indian landmass is prominent at 700 & 500 hPa levels. Dry bias over Indian land region is also reflected in PWAT and specific humidity at 2m height (**Figures 11-13, 16-17**).

3. Verification Scores for Rainfall and minimum Temperature:

- The rainfall activity (>50mm/day) is mainly observed over (i) south peninsula and neighbouring Arabian Sea and Bay of Bengal (ii) hilly regions of J & K and Himachal region. Over the land regions, the mean error (me) shows overestimated rainfall over J & K and parts of NW India (**Figure 18**).
- The forecast skill is impressive in predicting rainfall events of low intensity (<3mm/day) where the PSS values are > 0.5 in Day-1. For rainfall events of higher intensities (>12mm/day etc.) the PSS values are lower than 0.3.(**Figure 19**).

Tmin forecast verification during January 2021 is relatively poor, with PSS values lower than 0.3 at all lead times.(**Figure 20**).

2. Mean and anomaly of winds:

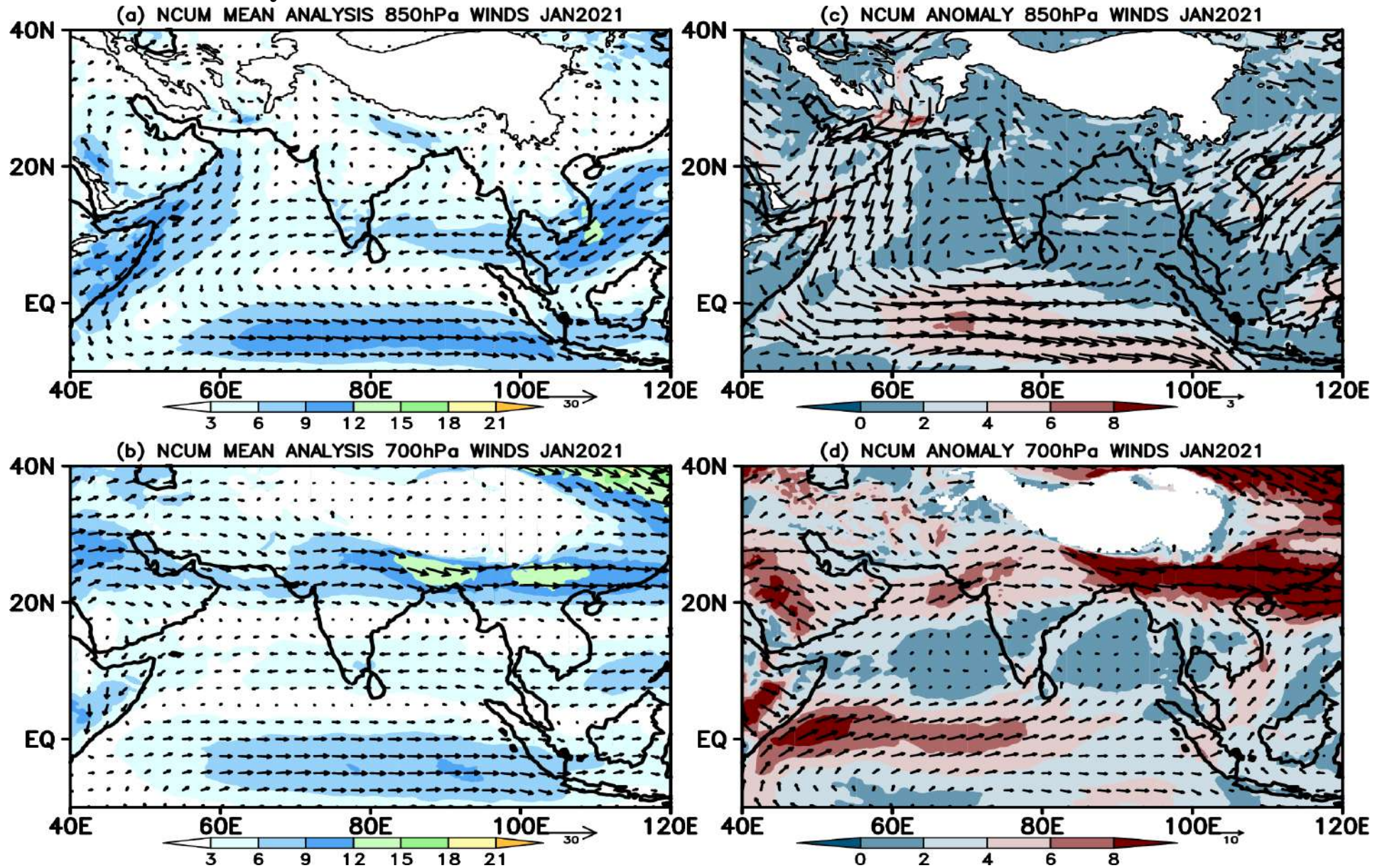


Figure 1. Mean winds at (a) 850 hPa and (b) 700 hPa in the NCUM Analysis during January 2021. Right panels show the anomaly circulation at (c) 850 hPa and (d) 700 hPa.

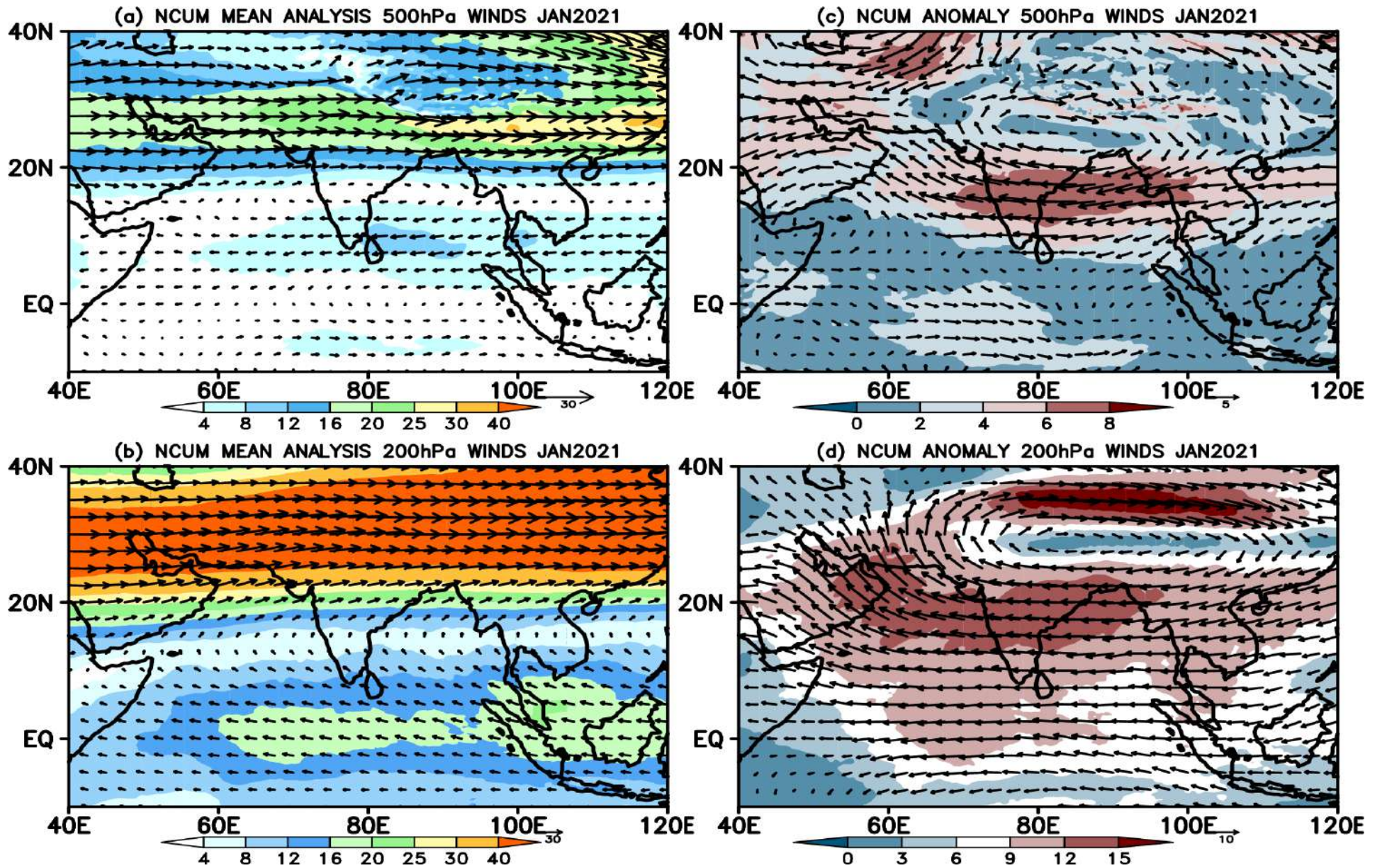


Figure 2. Mean winds at (a) 500 hPa and (b) 200 hPa in the NCUM Analysis during January 2021. Right panels show the anomaly circulation at (c) 500 hPa and (d) 200 hPa.

3. Systematic errors in Upper air variables:

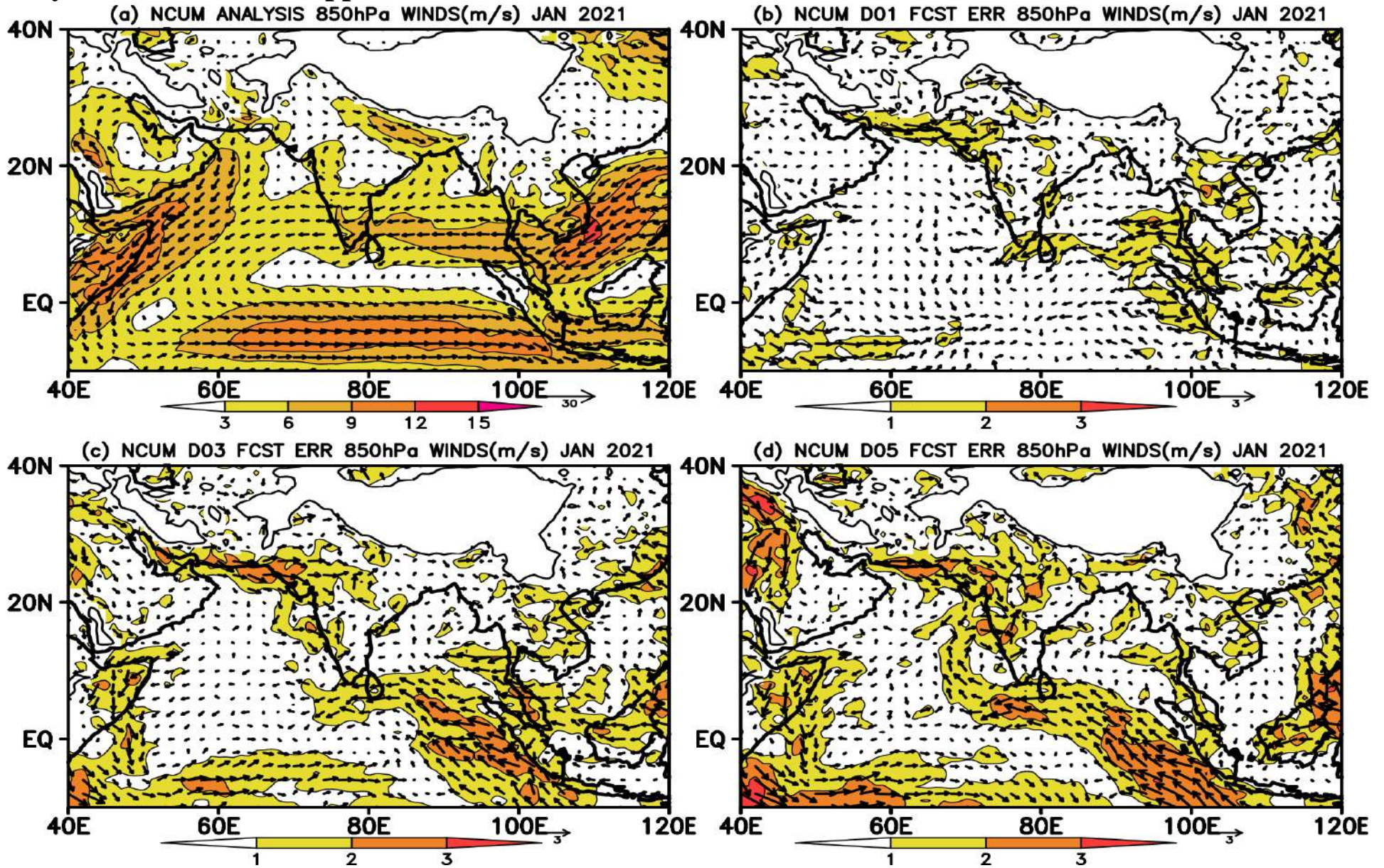


Figure 3. (a) Mean winds at 850 hPa and systematic errors in (b) Day-1 (c) Day-3 and (d) Day-5 forecasts during January 2021

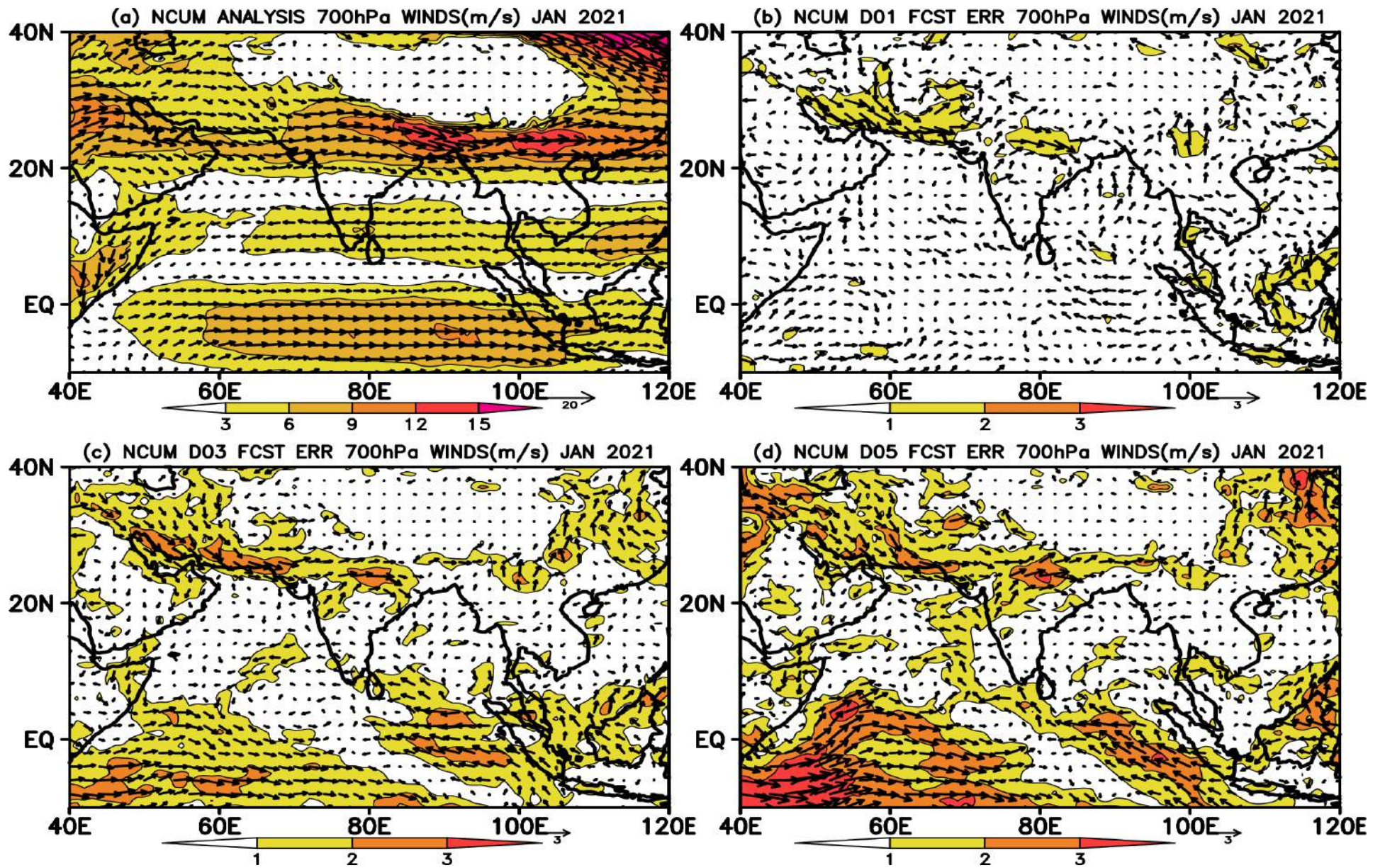


Figure 4. (a) Mean winds at 700 hPa and systematic errors in (b) Day-1 (c) Day-3 and (d) Day-5 forecasts during January 2021

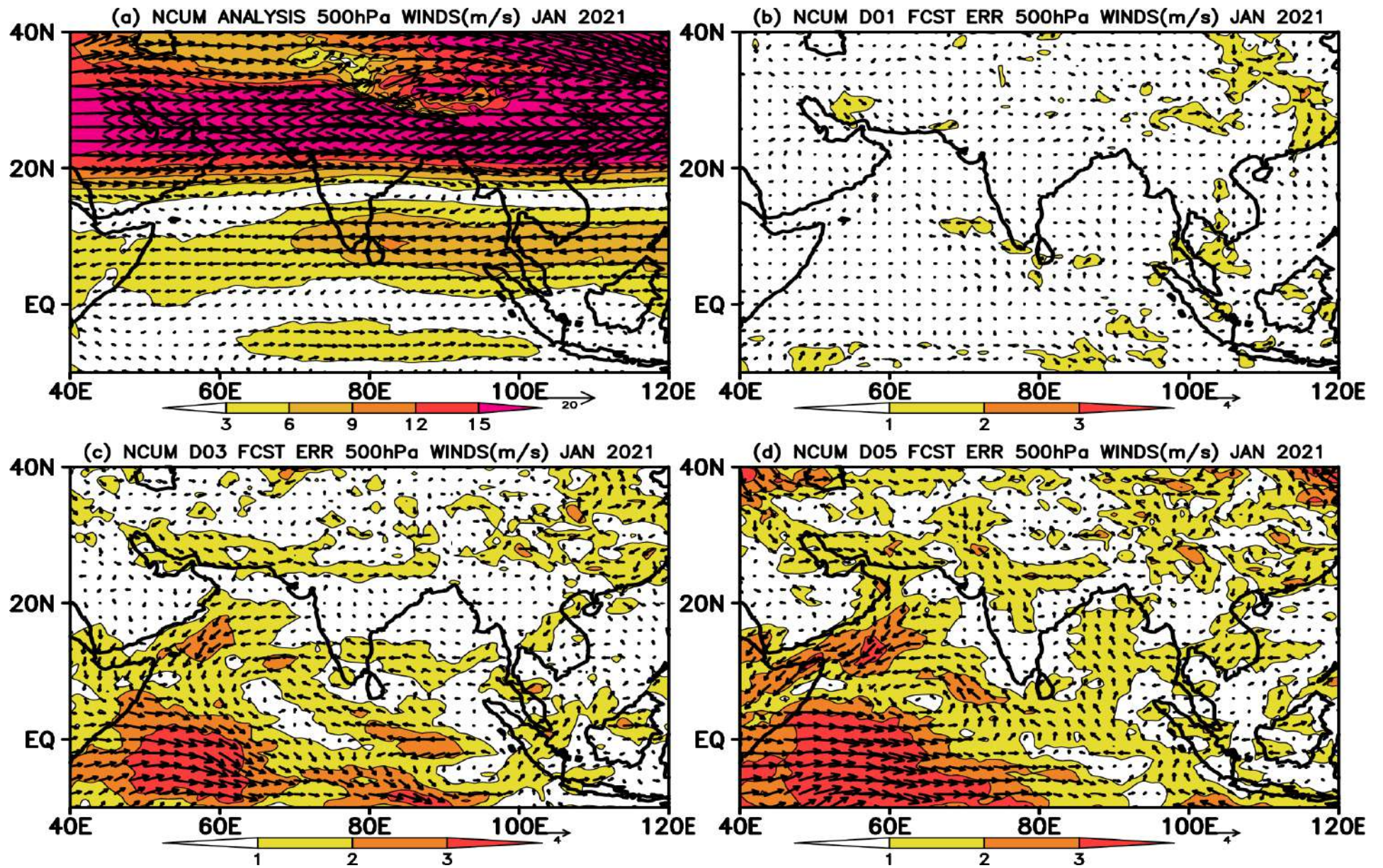


Figure 5. (a) Mean winds at 500 hPa and systematic errors in (b) Day-1 (c) Day-3 and (d) Day-5 forecasts during January 2021

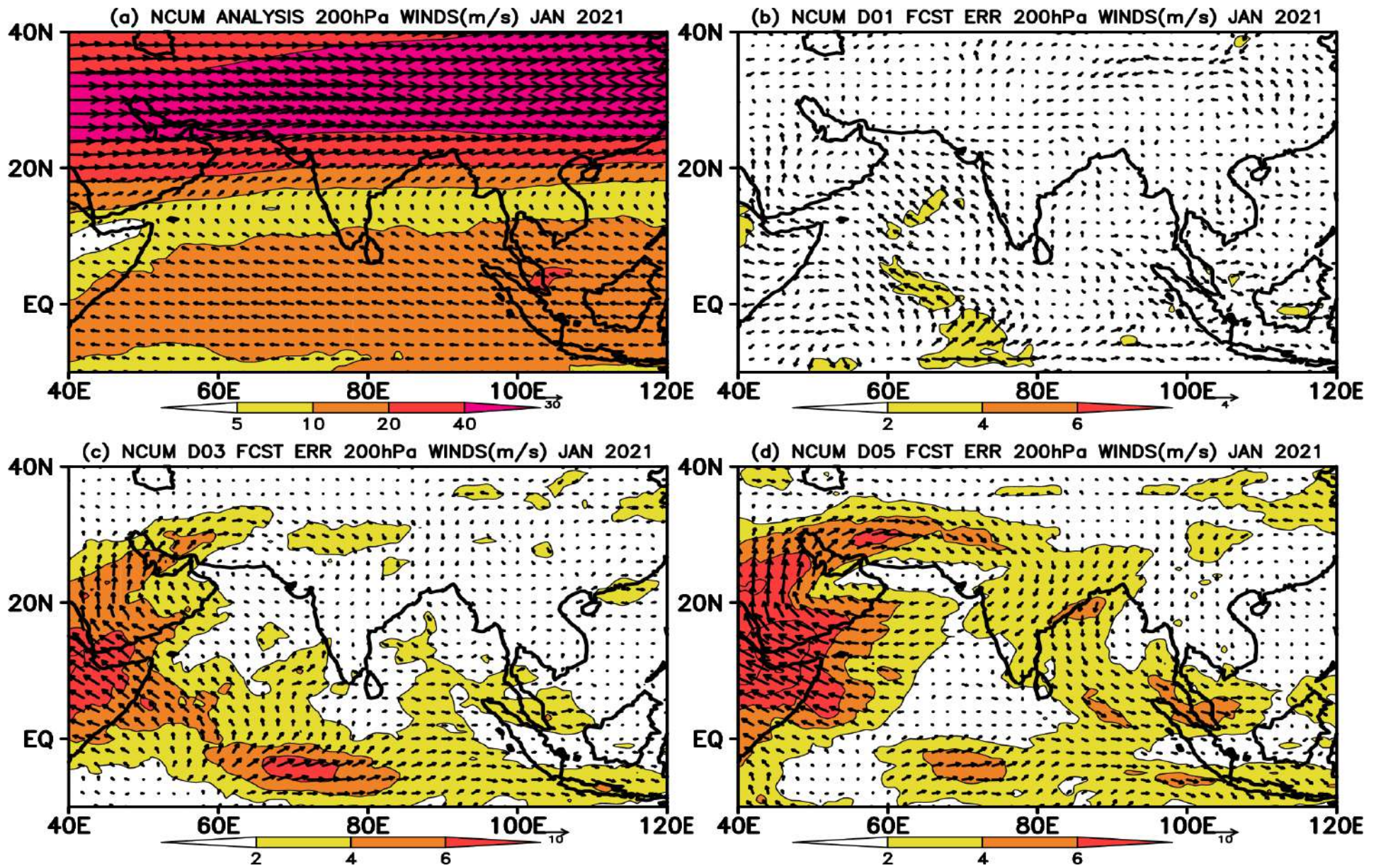


Figure 6. (a) Mean winds at 200 hPa and systematic errors in (b) Day-1 (c) Day-3 and (d) Day-5 forecasts during January 2021

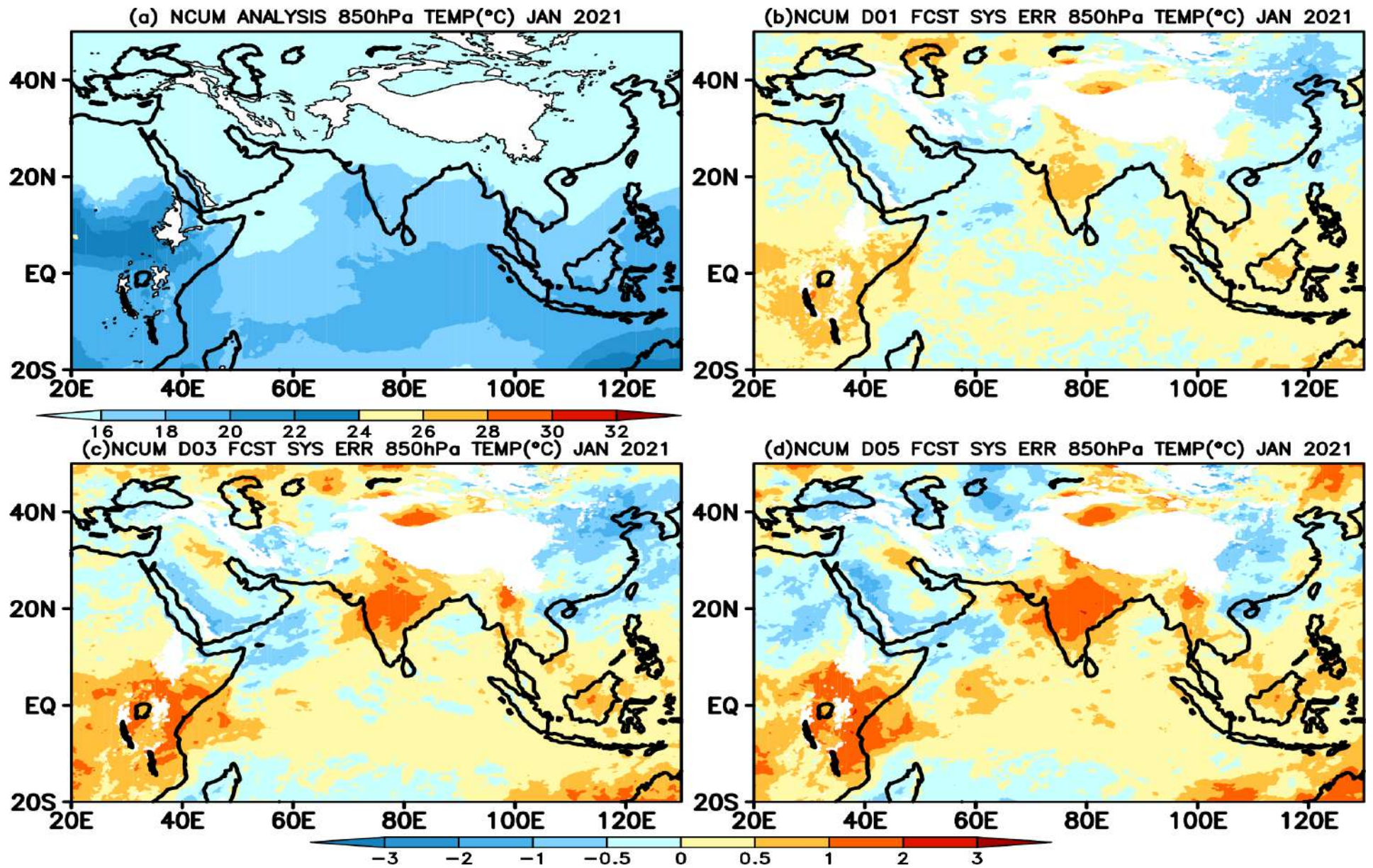


Figure 7. (a) Mean temperature at 850 hPa and systematic errors in (b) Day-1 (c) Day-3 and (d) Day-5 forecasts during January 2021

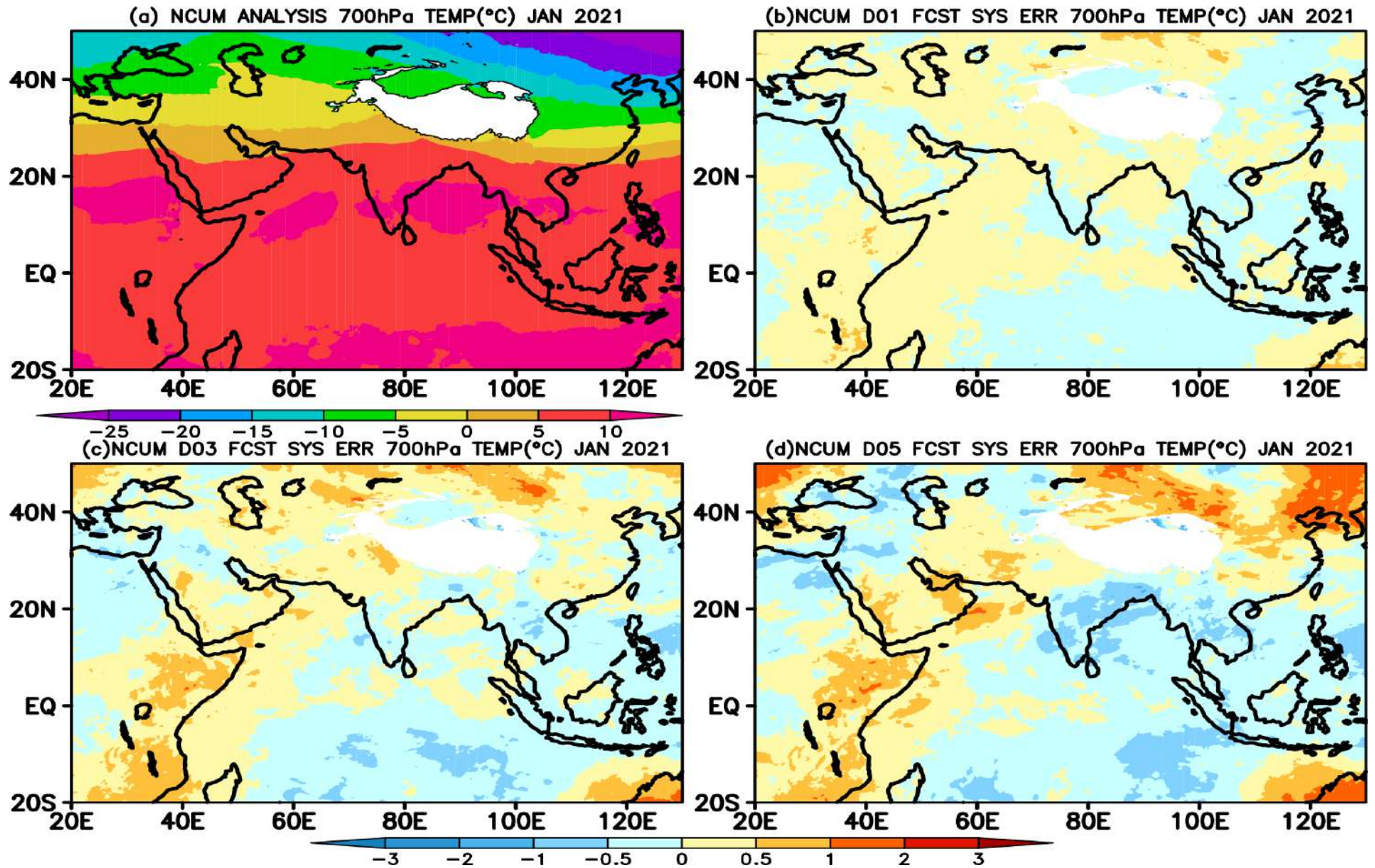


Figure 8. (a) Mean temperature at 700 hPa and systematic errors in (b) Day-1 (c) Day-3 and (d) Day-5 forecasts during January 2021

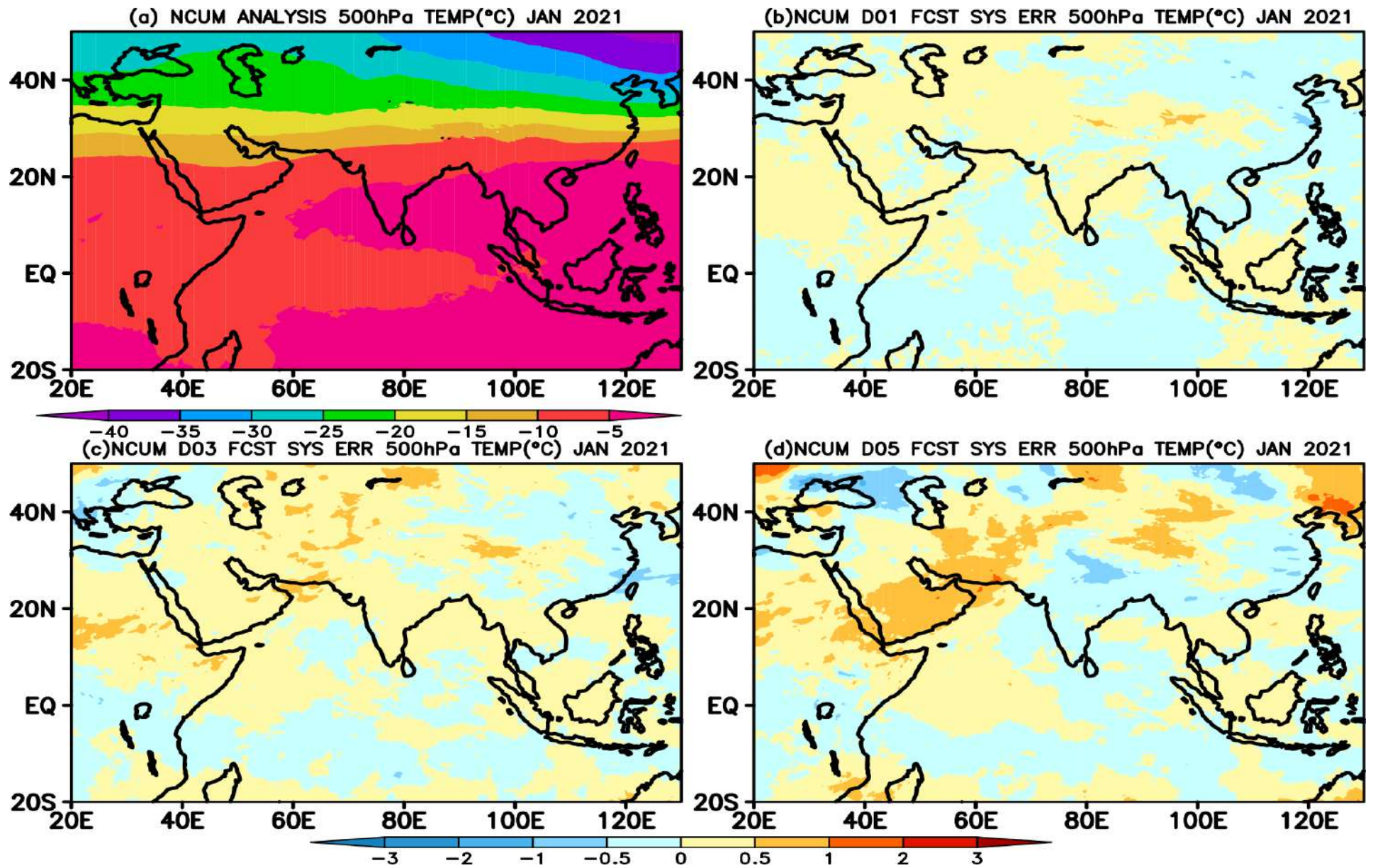


Figure 9. (a) Mean temperature at 500 hPa and systematic errors in (b) Day-1 (c) Day-3 and (d) Day-5 forecasts during January 2021

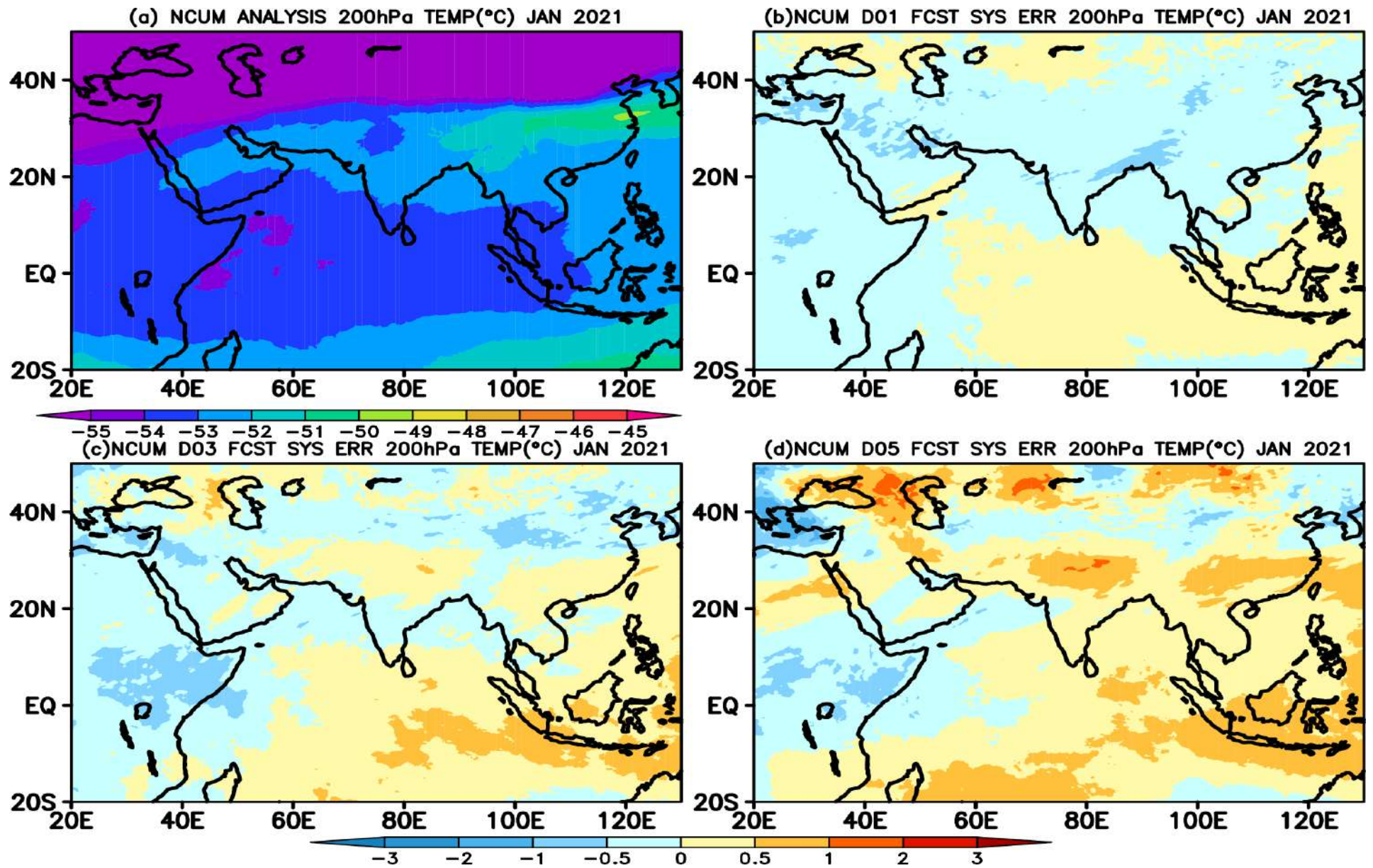


Figure 10. (a) Mean Temperature at 200 hPa and systematic errors in (b) Day-1 (c) Day-3 and (d) Day-5 forecasts during January 2021

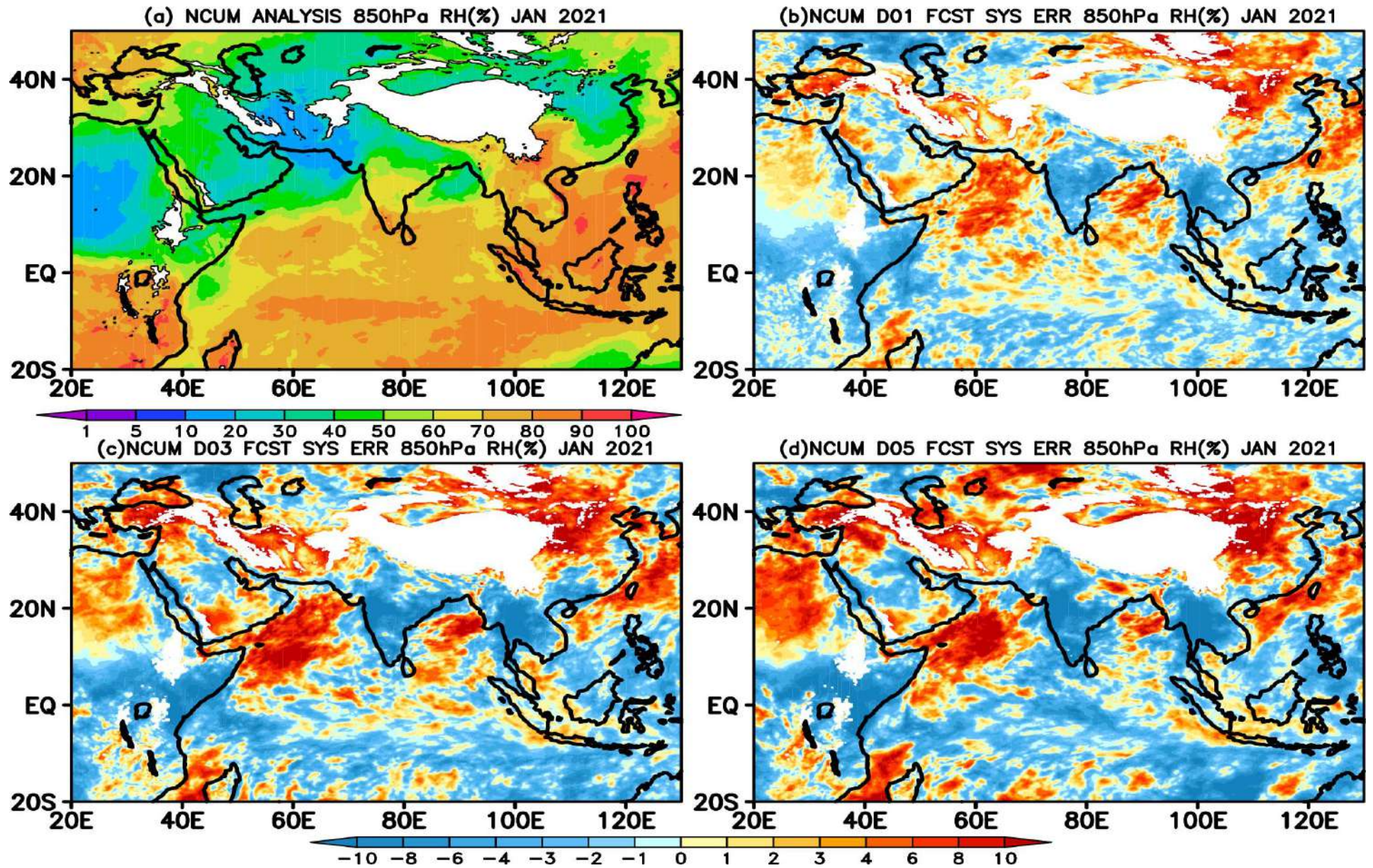


Figure 11. (a) Mean Relative Humidity at 850 hPa and systematic errors in (b) Day-1 (c) Day-3 and (d) Day-5 forecasts during January 2021

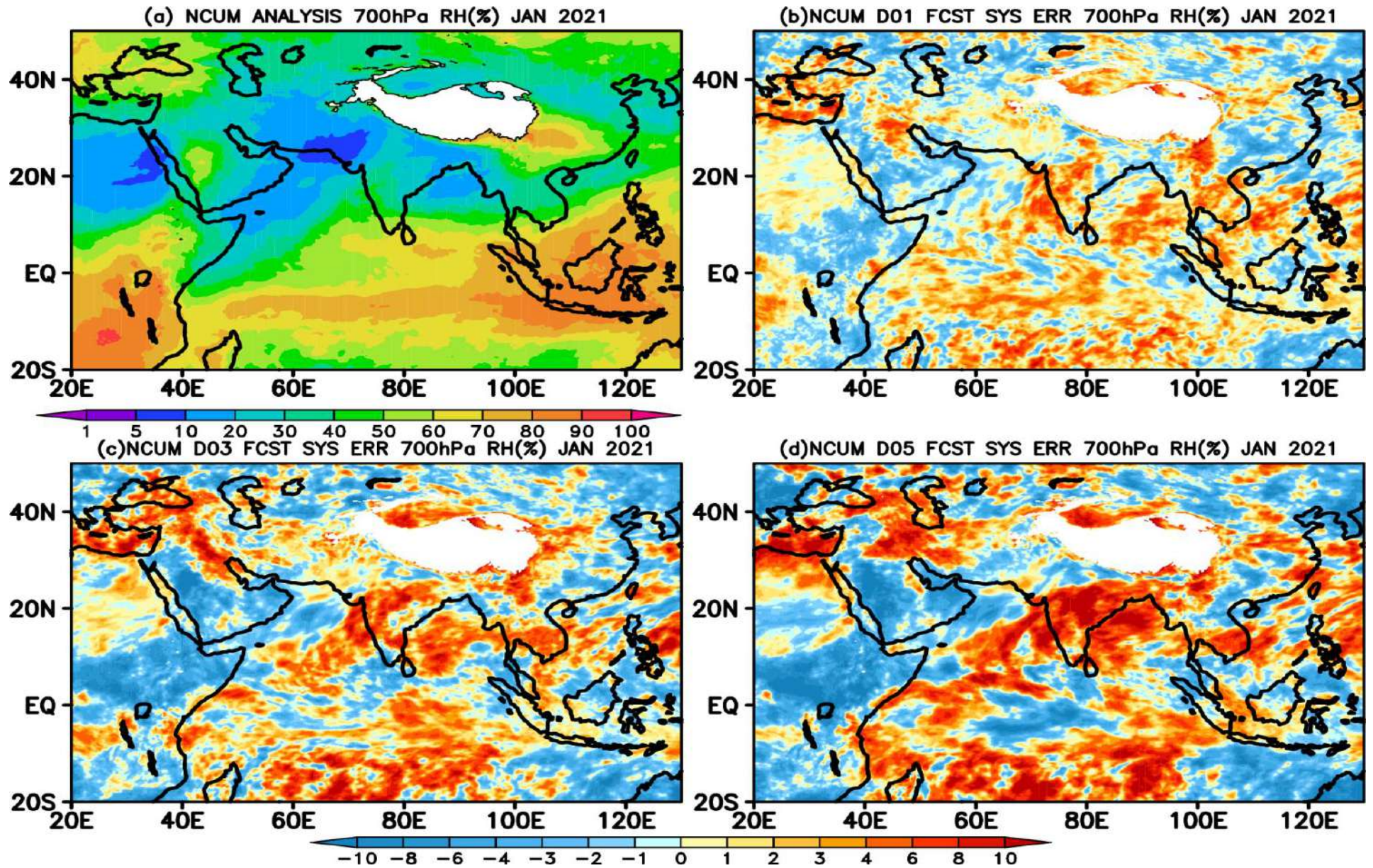


Figure 12. (a) Mean Relative Humidity at 700 hPa and systematic errors in (b) Day-1 (c) Day-3 and (d) Day-5 forecasts during January 2021

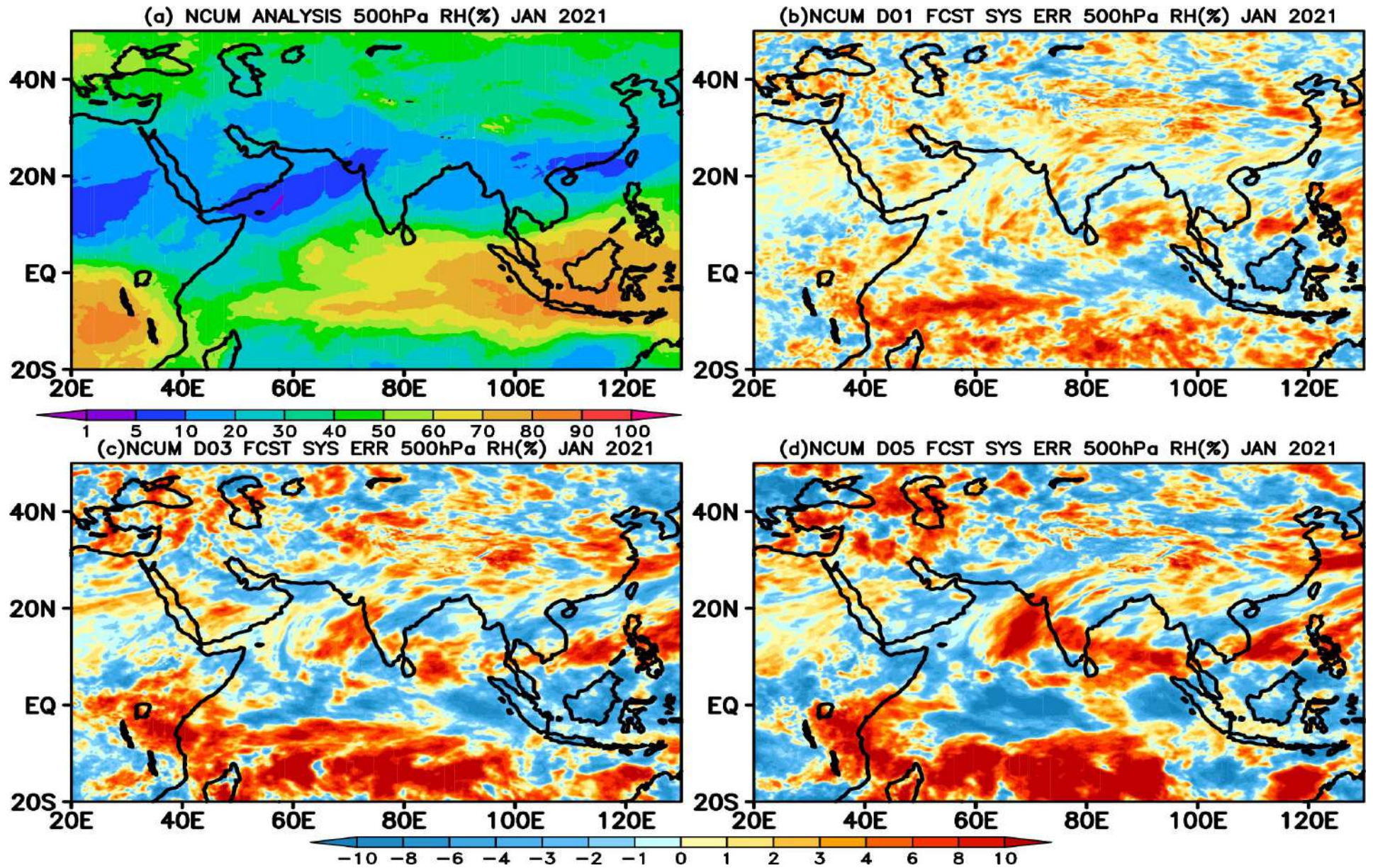


Figure 13. (a) Mean Relative Humidity at 500 hPa and systematic errors in (b) Day-1 (c) Day-3 and (d) Day-5 forecasts during January 2021

4. Systematic errors in surface variables

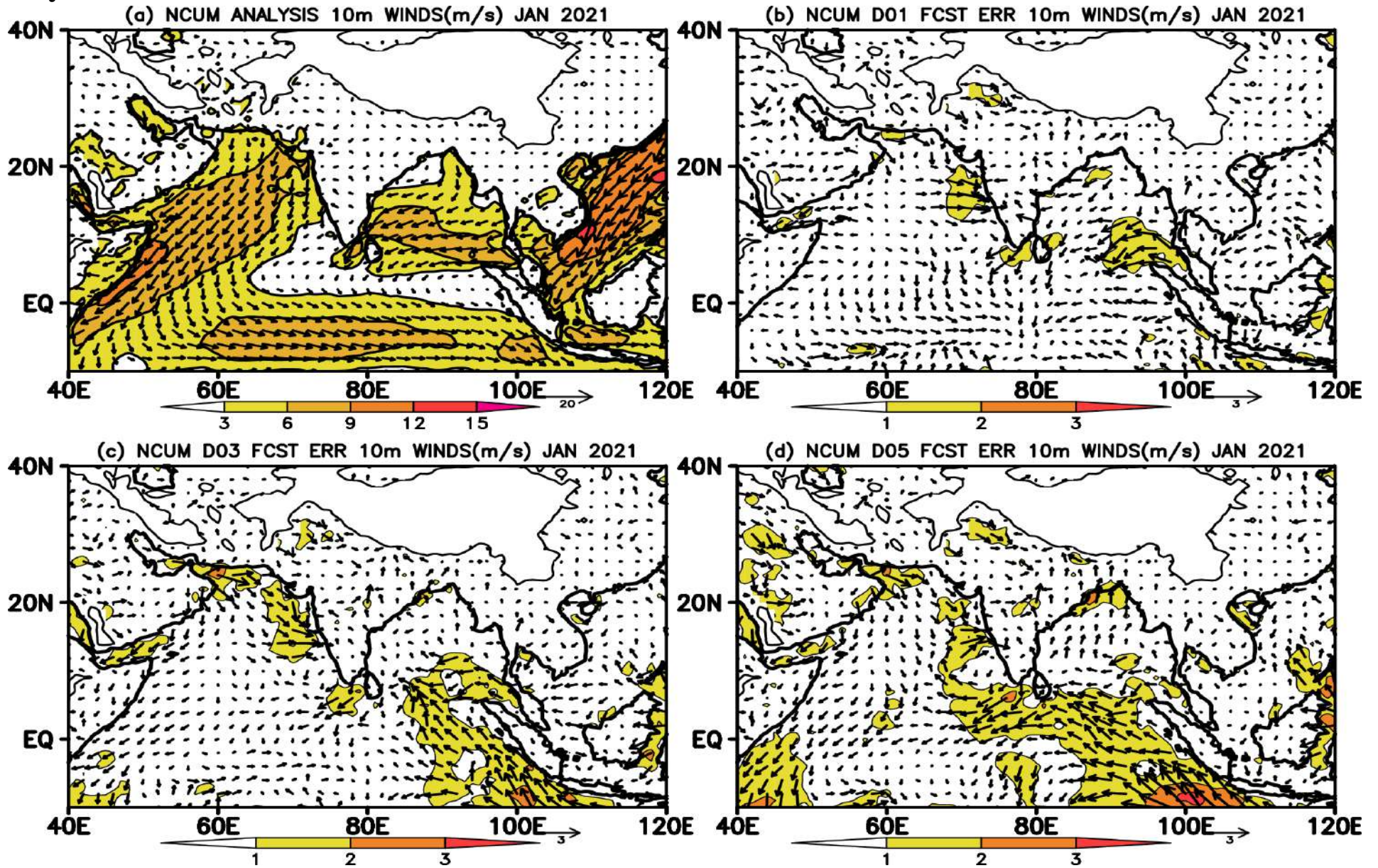


Figure 14. (a) Mean winds at 10m height and systematic errors in (b) Day-1 (c) Day-3 and (d) Day-5 forecasts during January 2021

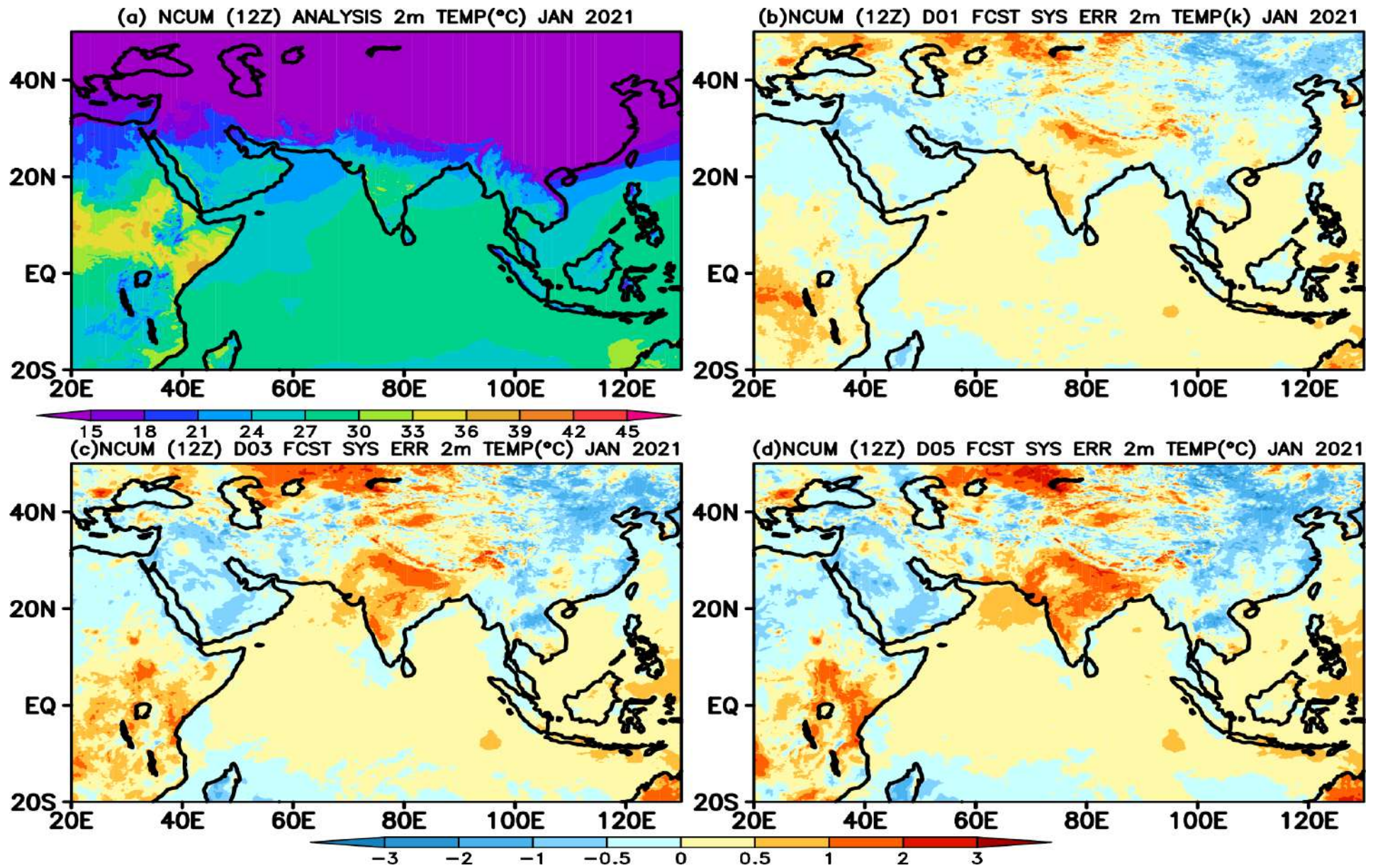


Figure 15. (a) Mean temperature at 2mt height and systematic errors in (b) Day-1 (c) Day-3 and (d) Day-5 forecasts during January 2021

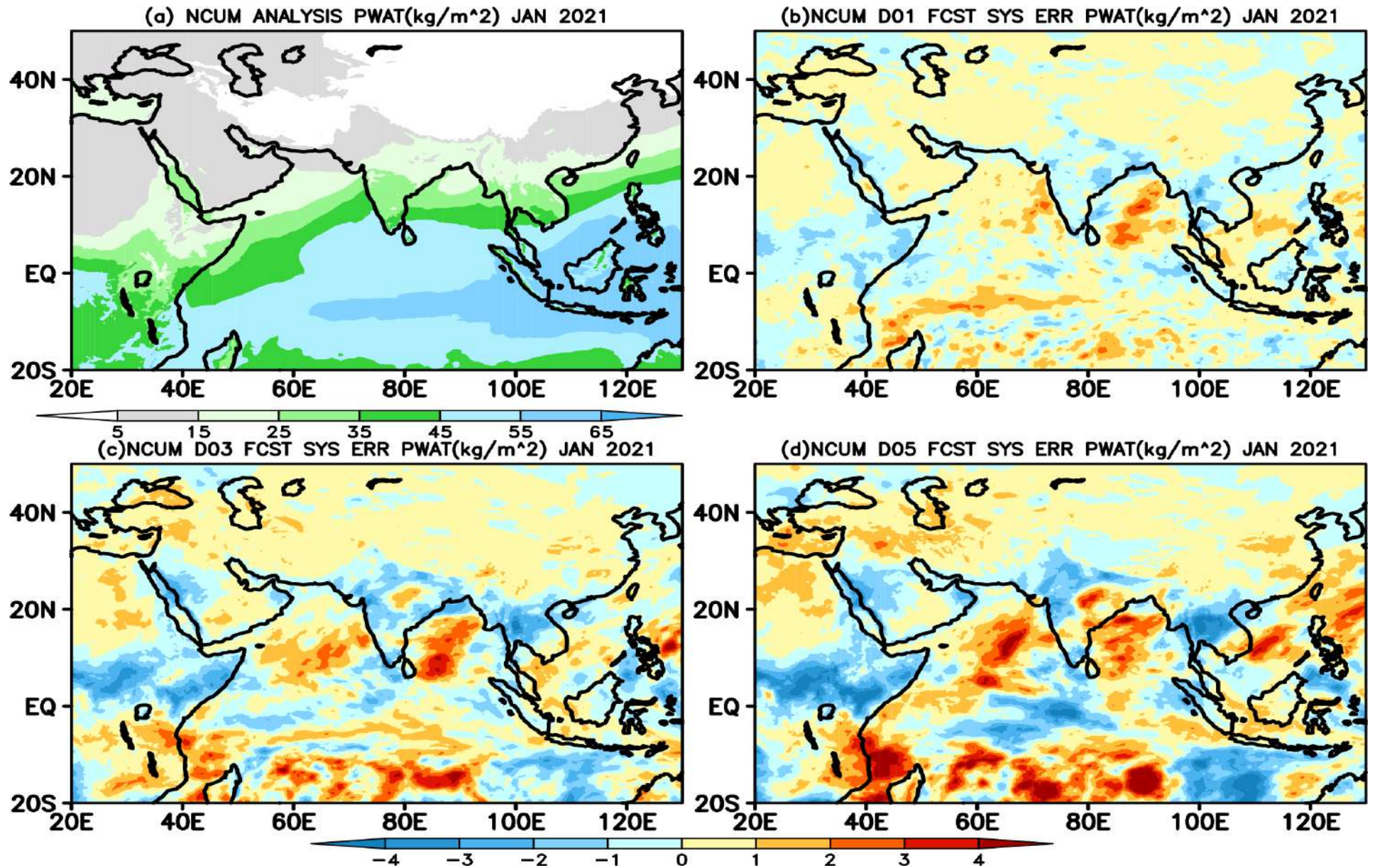


Figure 16. (a) Mean precipitable water content (PWAT) up to model levels and systematic errors in (b) Day-1 (c) Day-3 and (d) Day-5 forecasts during January 2021

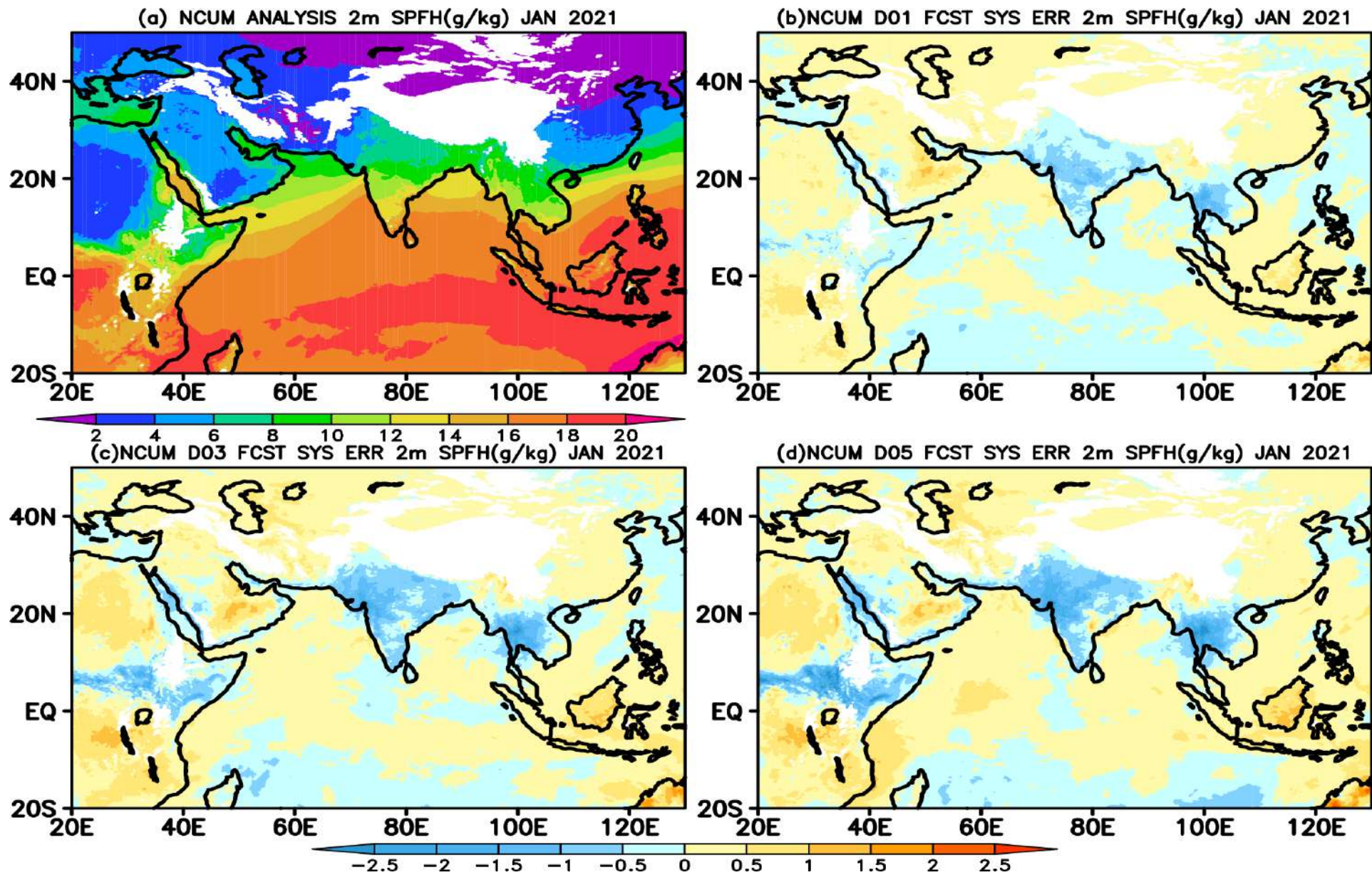


Figure 17. (a) Mean specific humidity and systematic errors in (b) Day-1 (c) Day-3 and (d) Day-5 forecasts during January 2021

5. Verification of Rainfall Forecasts

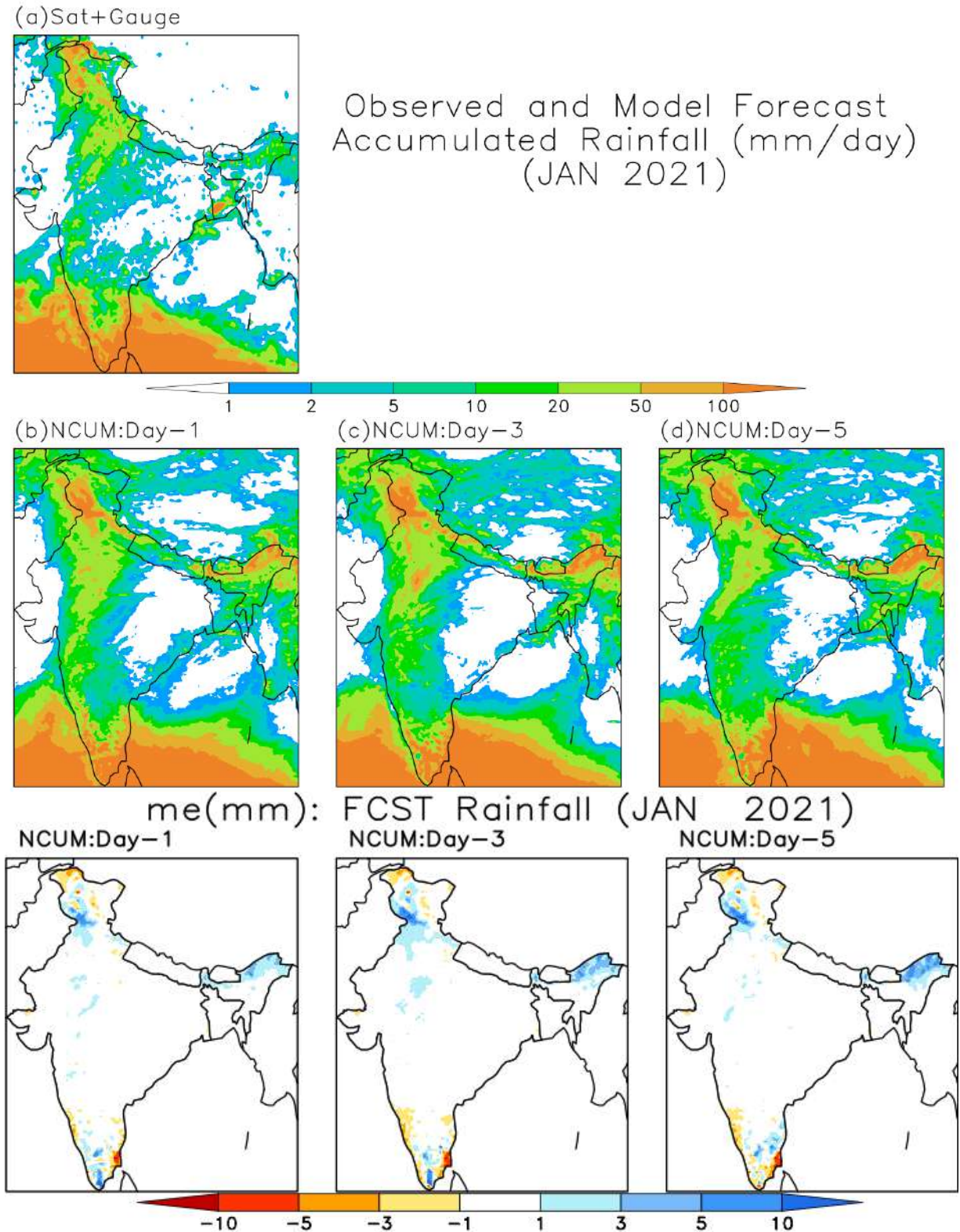


Figure 18. Accumulated January rainfall in (a) Observations and (b) Day-1 (c) Day-3 and (d) Day-5 forecasts. Bottom panels (e), (f) and (g) show Mean Error (ME) in Day-1, Day-3 and Day-5 forecasts respectively.

6. Rainfall Categorical scores for NCUM

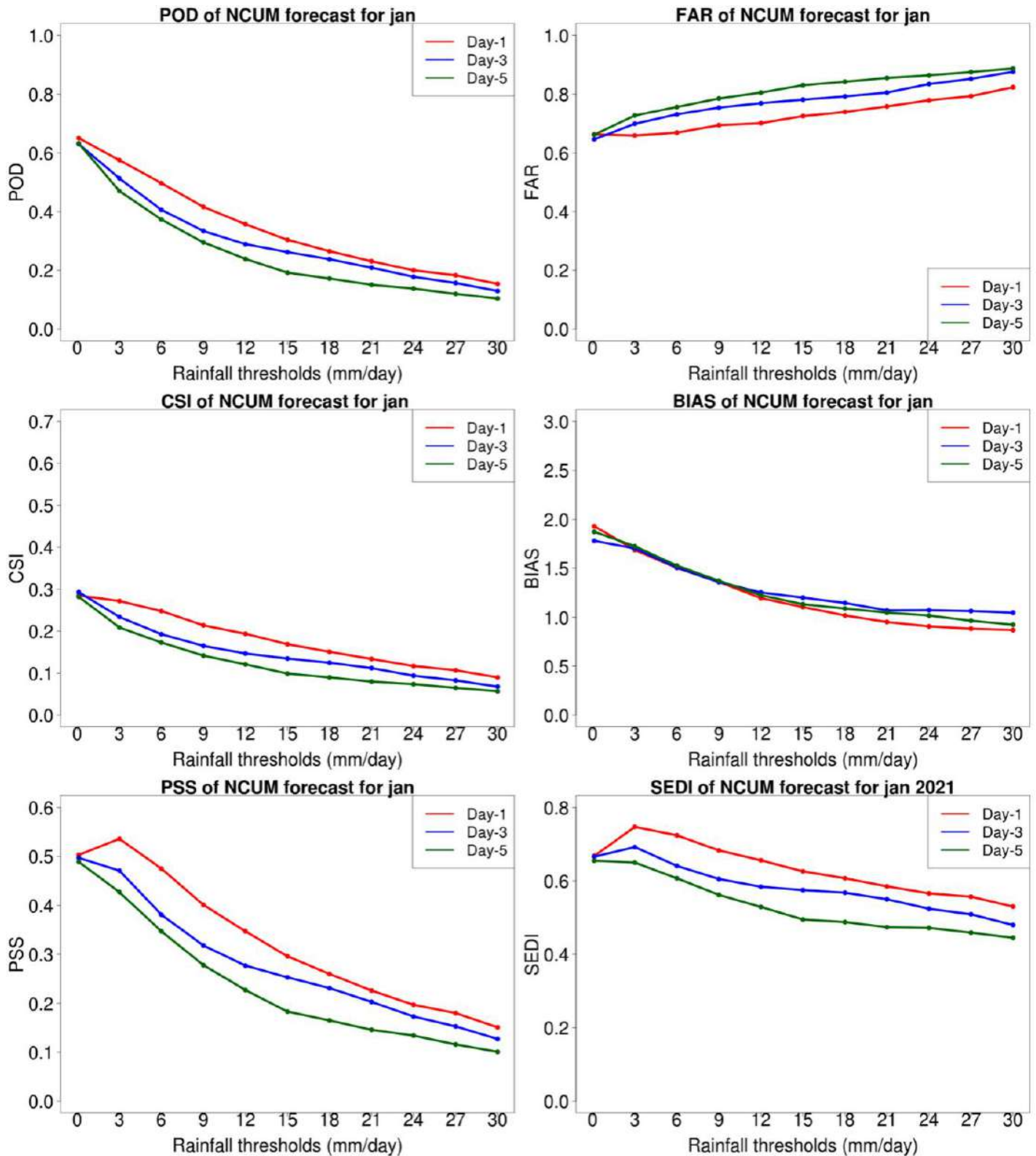


Figure 19. Categorical all India Rainfall scores POD (top left), FAR (top right), CSI(middle left), BIAS (middle right), PSS (bottom left) and SEDI (bottom right).

7. Tmin categorical Scores for NCUM:

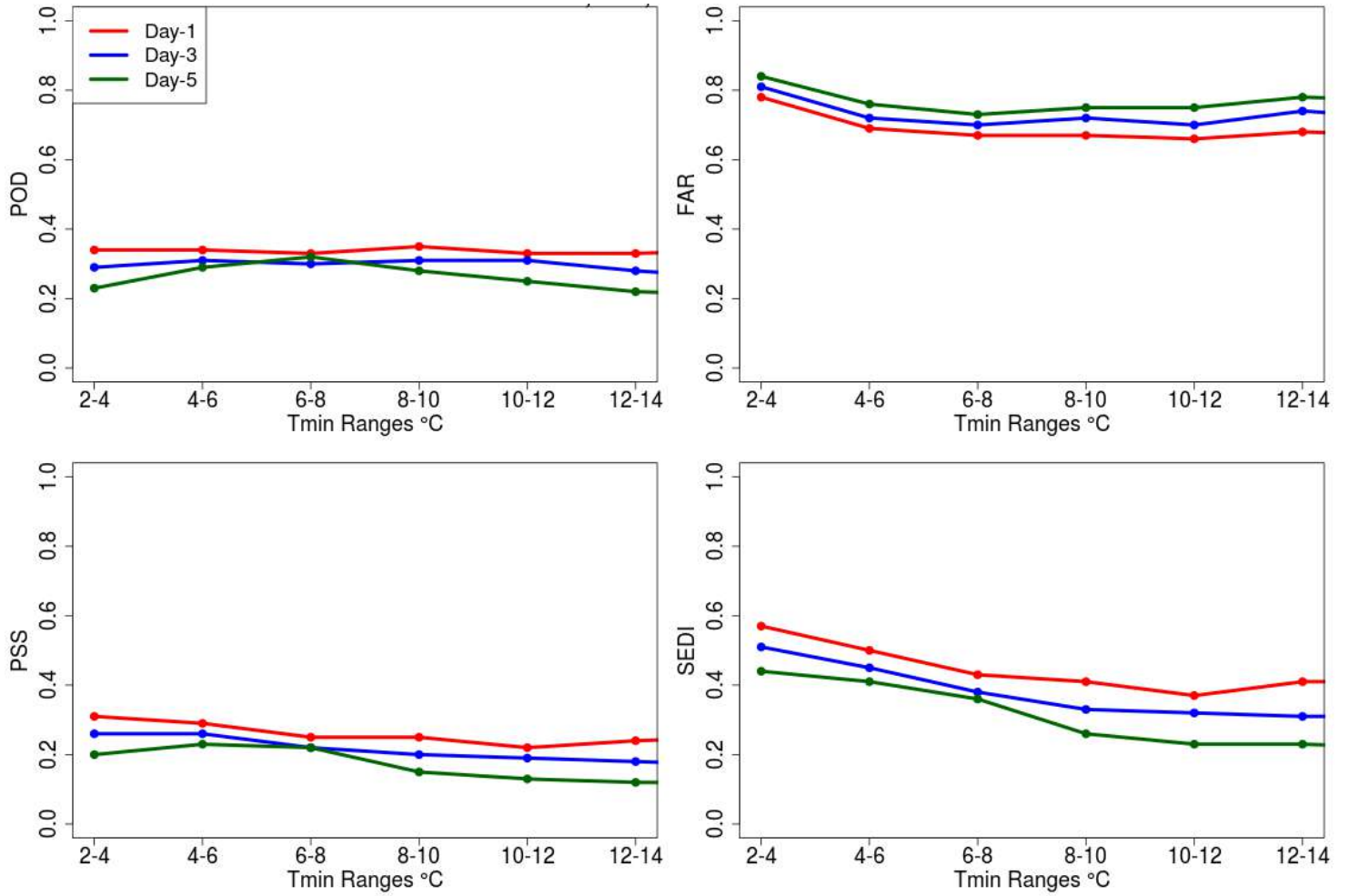


Figure 20. Categorical all India Tmin scores POD (*top left*), FAR (*top right*), PSS (*bottom left*) and SEDI (*bottom right*).

II. Special Weather Events of the Month

In this report, we have further evaluated model skill for some specific weather events during the month of January 2021.

Highlights:

There are three rainfall spells during 1-16 Jan 2021 one over northern parts of India and other two events over south peninsular regions.

- **The rainfall spell over the northern parts of India (26°N-36°N and 72°E-82°E) on 6 January 2021:**
The spell is associated with a Western Disturbance (WD). The model is able to predict the WD(**Figure. 21**) and its associated rainfall distribution up to 3 days ahead, however, the area-averaged rainfall intensities are higher (~5 mm/day) relative to the observations. Detailed quantitative assessment using the Contiguous Rain Area (CRA) technique depicts the higher contribution of errors are from displacement followed by pattern errors(**Figures 22-24**). The Day-1 forecast rainfall has a displacement of about 1° east wards and 1.25° southwards.
- **Rainfall spells over Southern Peninsula (7 & 13 January 2021):**
The area-averaged (8°N-16°N and 74°E-82°E) rainfall from the model forecast upto 3 lead days is very well predicted, however, the contribution of pattern errors are higher for the two events (70% for 7 January and 43% for 13 January cases) based on CRA verification (**Figures 26-28 & Figures 30-32**). The Day-1 predicted rainfall object in the 7th January 2021 case is displaced to the east by 1° and north 0.5°. Similarly in the 13th January event, the Day-1 predicted rainfall object is shifted 1.5° westwards and 2.25° southwards

Verification of Visibility:

Fog is one of the major weather hazards during winter over Delhi. Dense (<500m visibility) to very dense fog (<200m visibility) conditions are observed at isolated places during February over Delhi. The visibility verification has been carried out over Indira Gandhi International (IGI) Airport using NCMRWF Delhi models with 1.5 km and 330mtrs horizontal resolutions. Here we also showed diurnal variability of temperature and humidity during some special fog event days.

- The model forecasts are able to predict the low visibility conditions during late hours and early hours of the day.
- Forecasts are in good agreement with Metar observations on 07, 16, 25 and 28 Jan 2021 (**Figure 33**). However, poor predictability is noticed on 11 and 31 January 2021.

Verification of rainfall spells over northern and southern parts of India during 1-16 JAN 2021:

1. Rainfall Spell over northern India: 6JAN2021

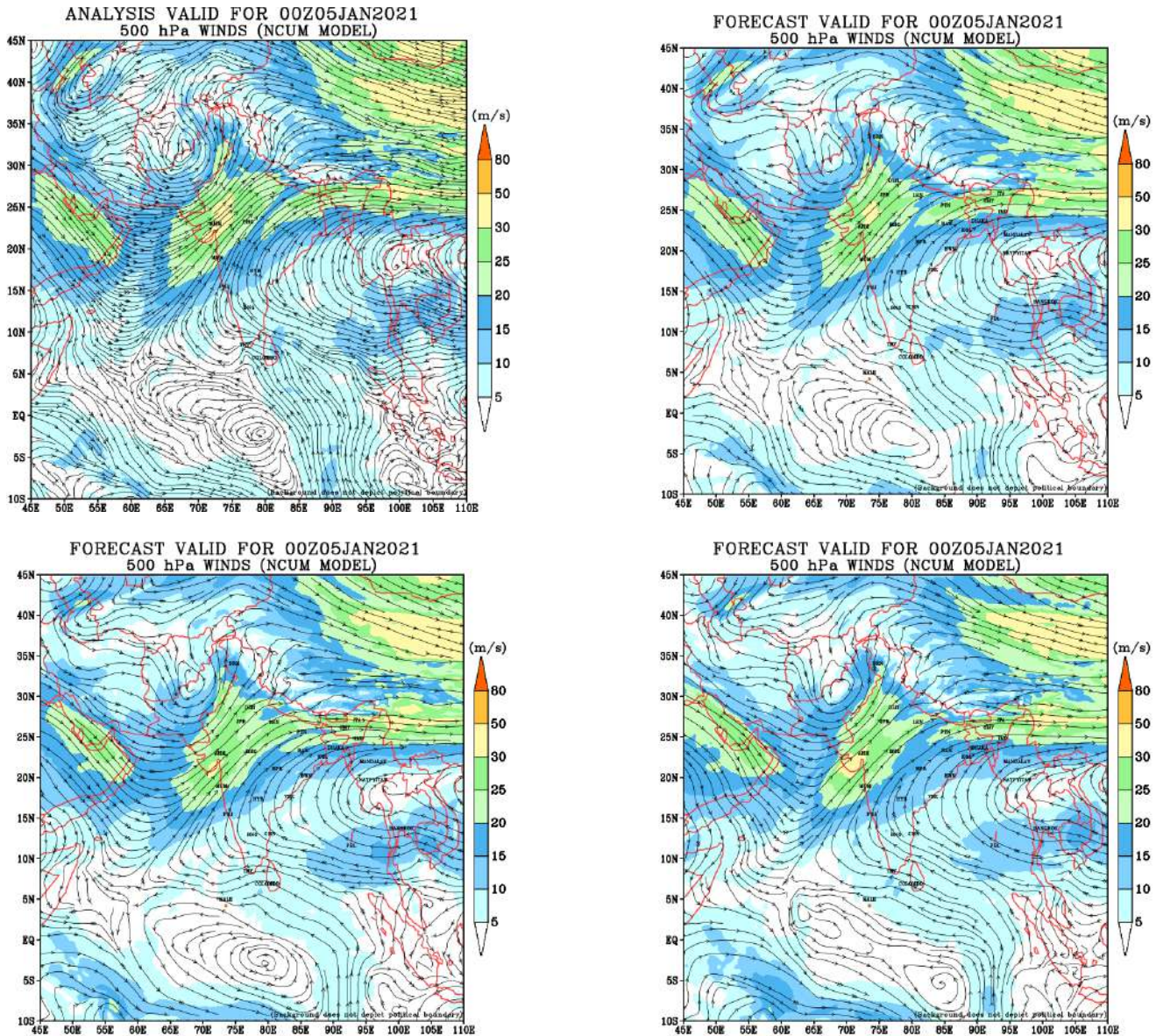


Figure 21. Analysis winds at 500 in Analysis(upper left), Day-1 (Upper right), Day-2 (lower left) and Day-3 (lower right) forecasts on 05January2021

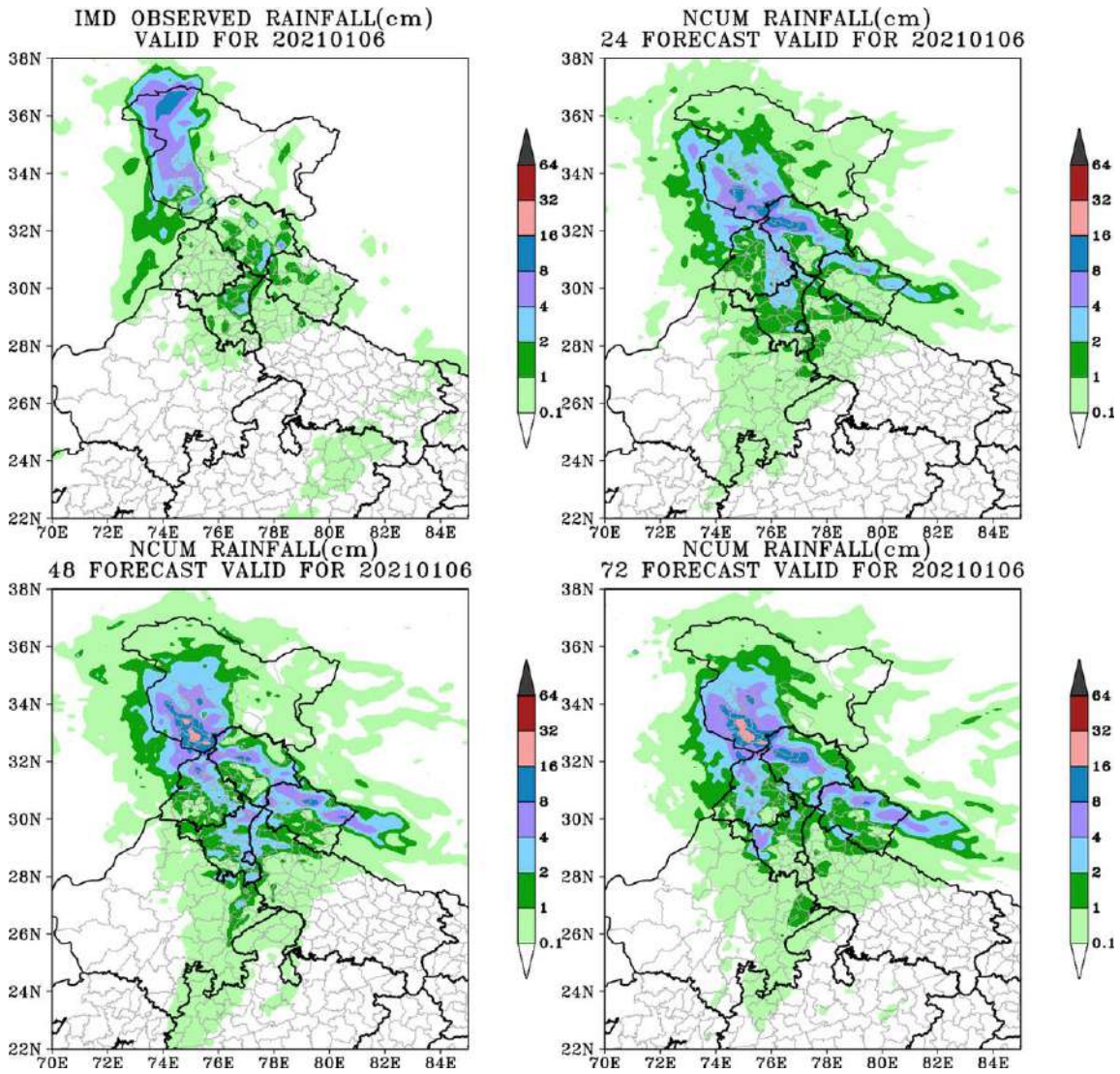


Figure 22. Observed Rainfall (IMD) (upper left), Day-1 (upper right), Day-2 (lower left) and Day-3 (lower right) forecasts on 6 January 2021

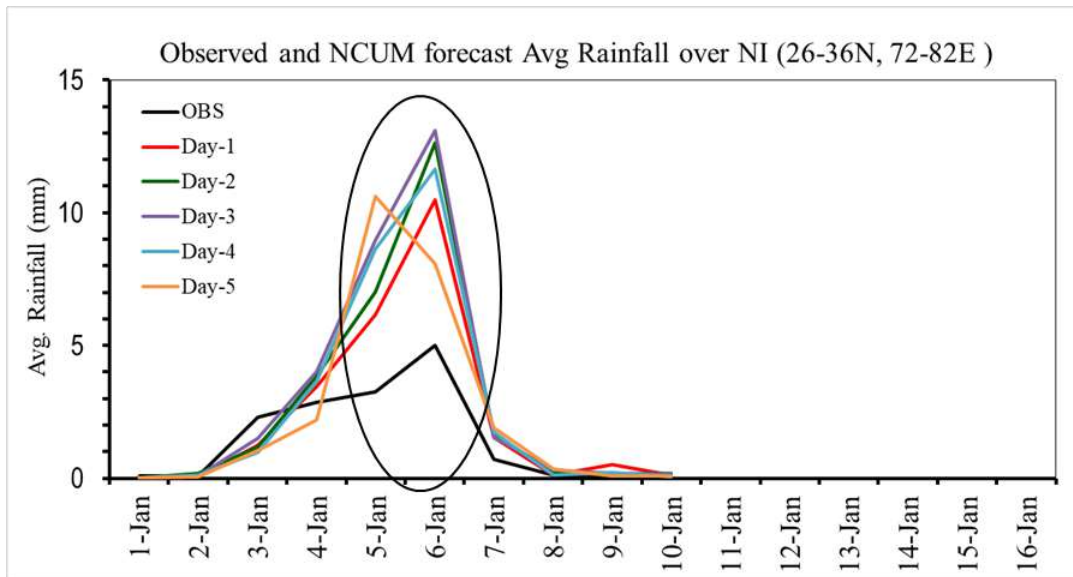


Figure 23. Time series of averaged observed and forecasted rainfall during 1-16Jan2021

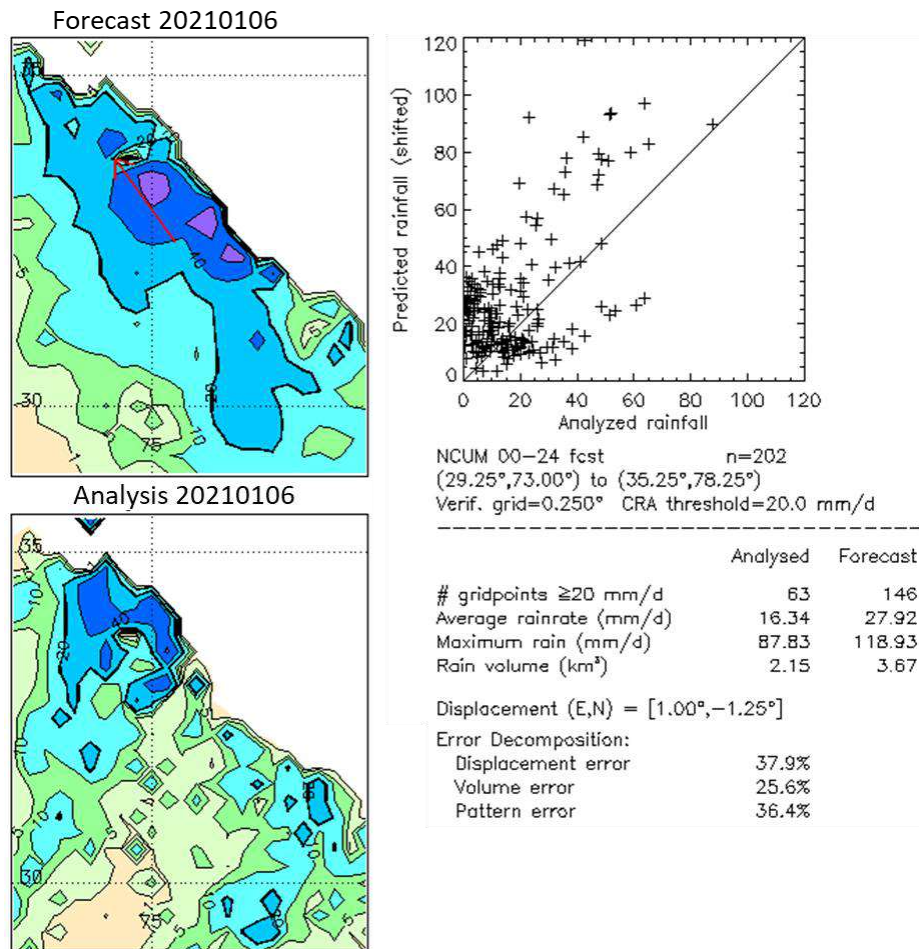


Figure.24 Spatial verification of rainfall for Day-1 forecast on 06Jan2021

2. Rainfall Spell over southern India: 07JAN2021

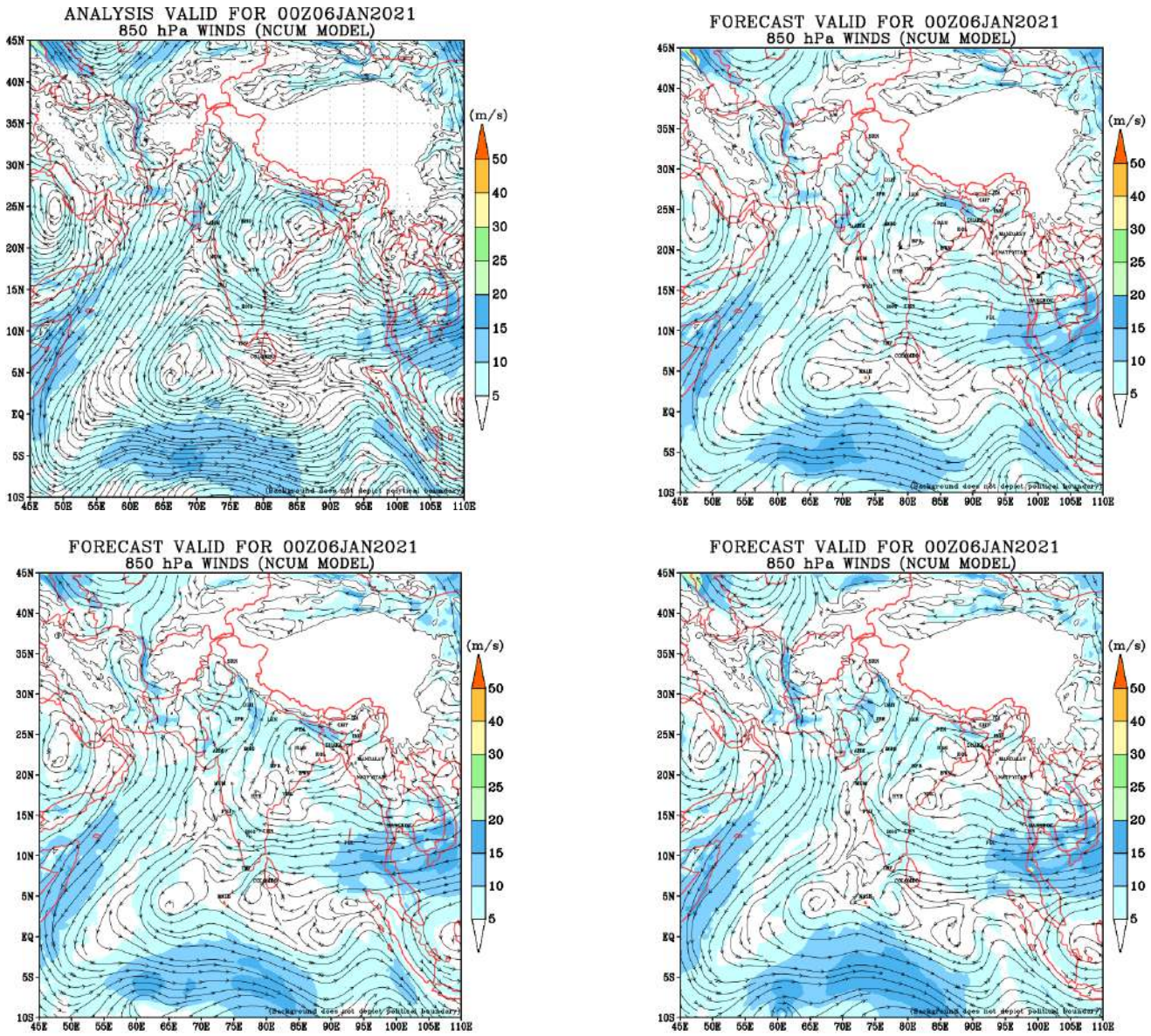


Figure 25. Analysis winds at 850 in Analysis(upper left), Day-1 (Upper right), Day-2 (lower left) and Day-3 (lower right) forecasts on 06January2021.

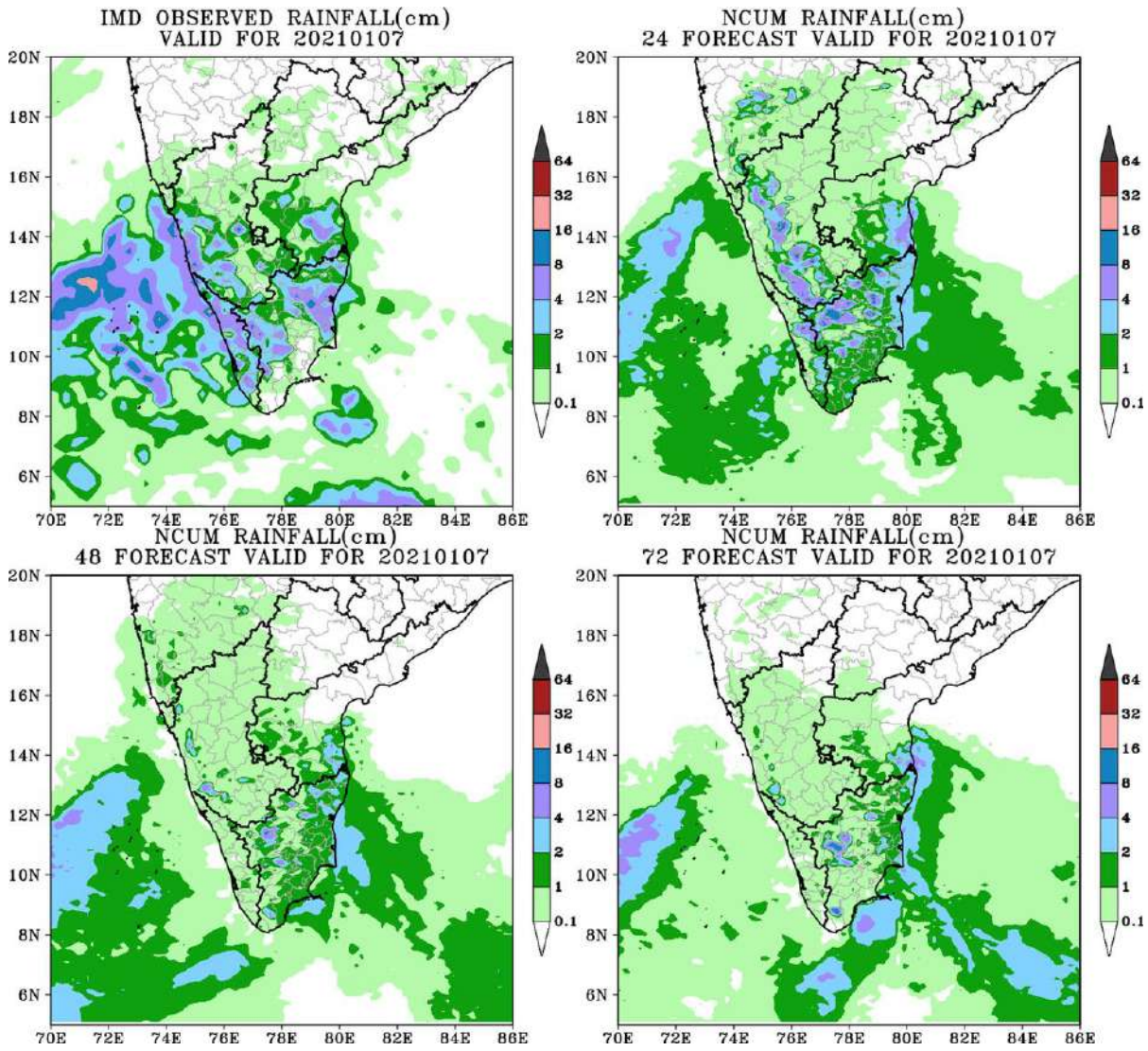


Figure 26. Observed Rainfall (IMD) (upper left), Day-1 (Upper right), Day-2 (lower left) and Day-3 (lower right) forecasts on 07January2021.

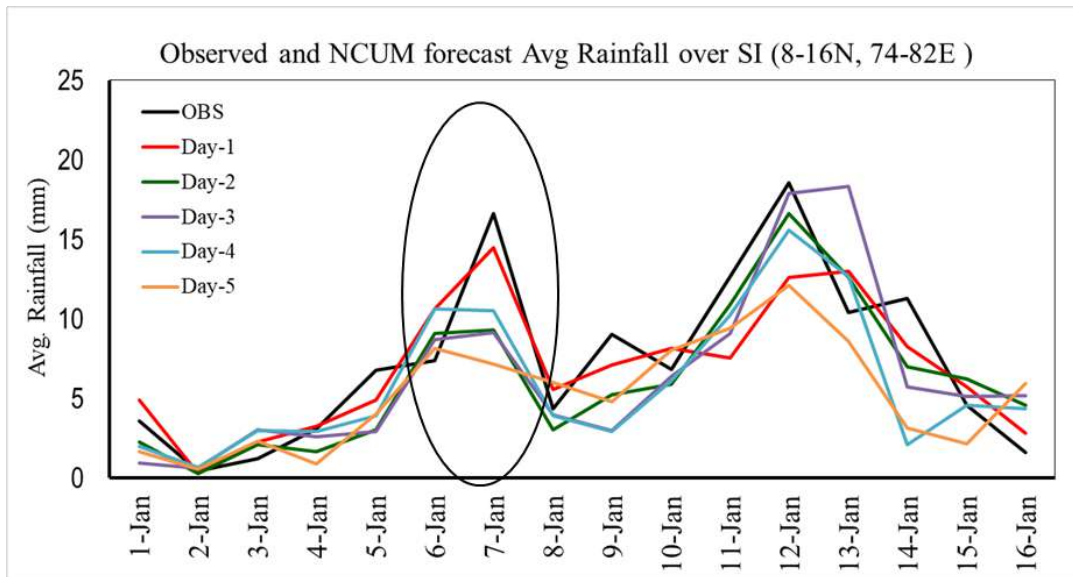


Figure 27. Time series of averaged observed and forecasted rainfall during 1-16Jan2021

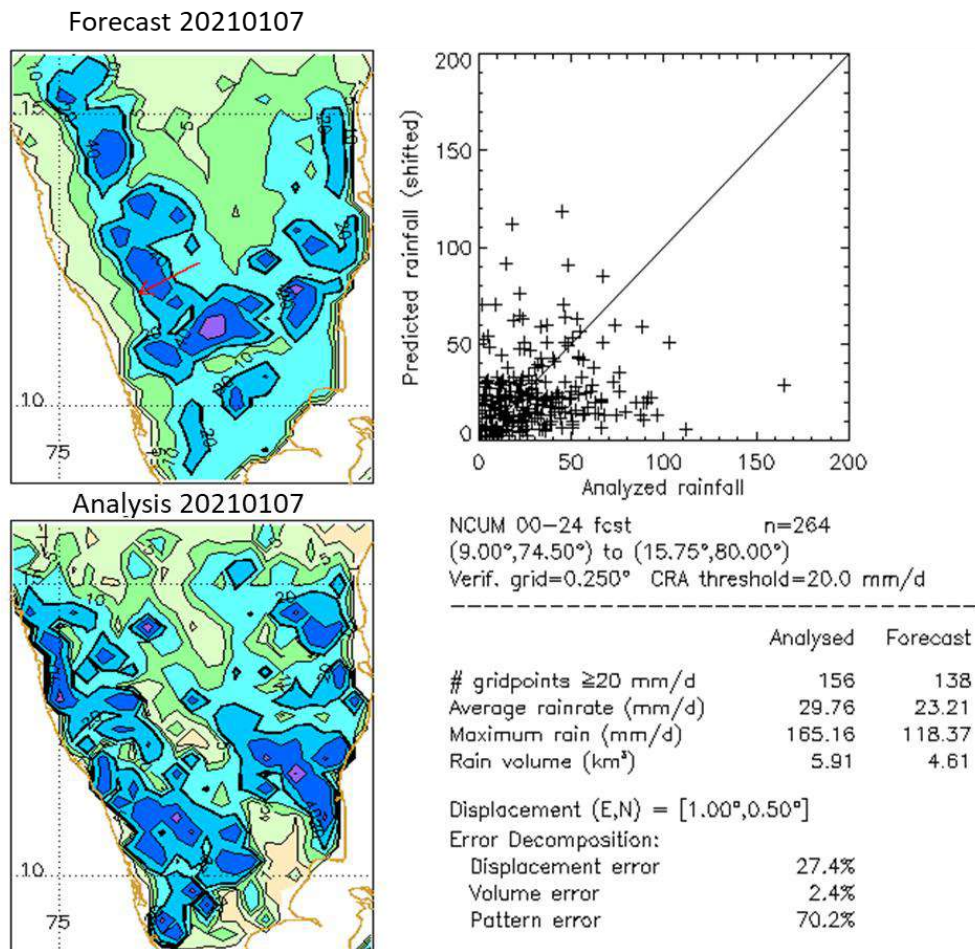


Figure.28 Spatial verification of rainfall for Day-1 forecast on 07Jan2021

3. Rainfall Spellover southern India: 12JAN2021

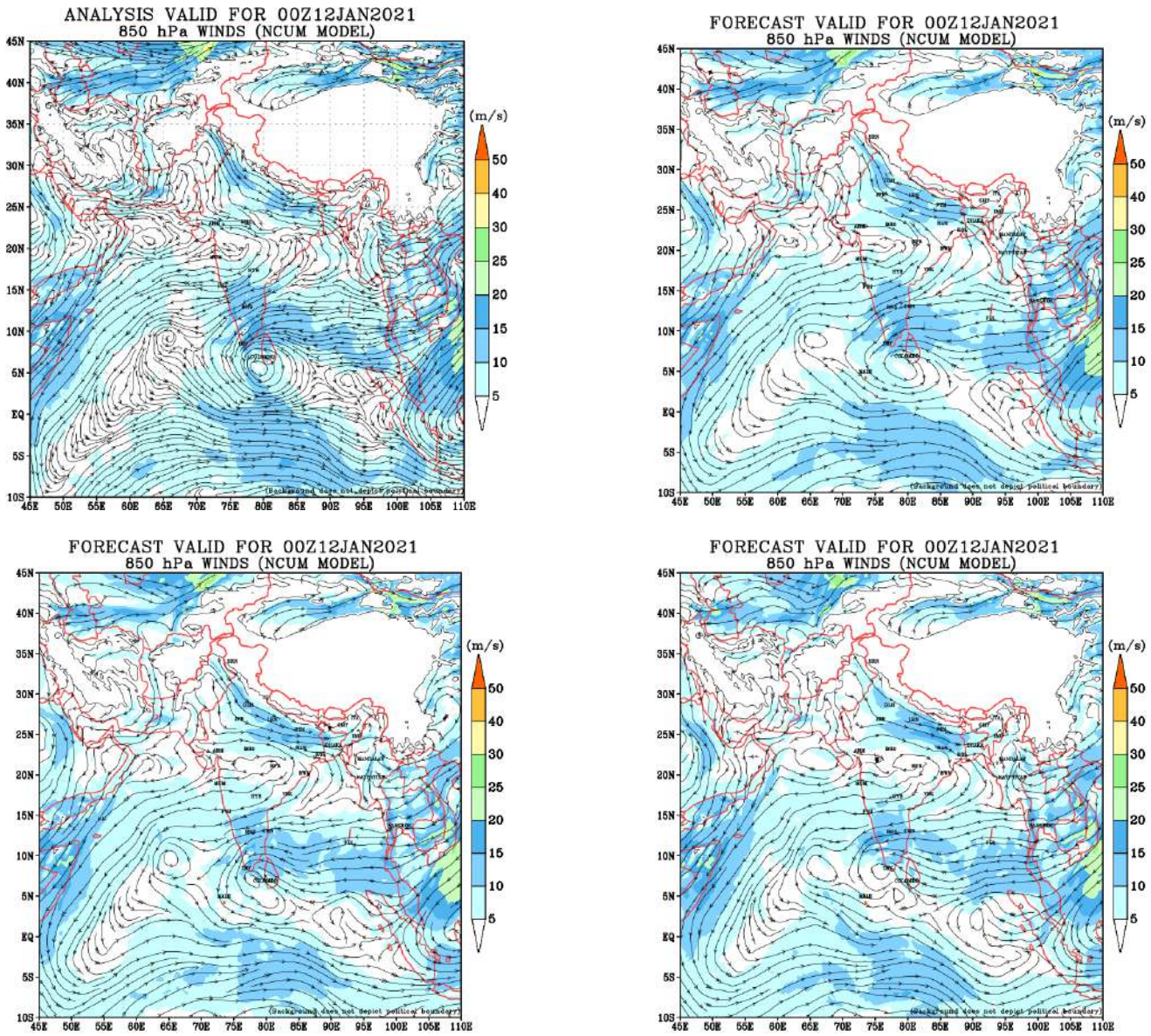


Figure 29. Analysis winds at 850 in Analysis(upper left), Day-1 (Upper right), Day-2 (lower left) and Day-3 (lower right) forecasts on 12January2021.

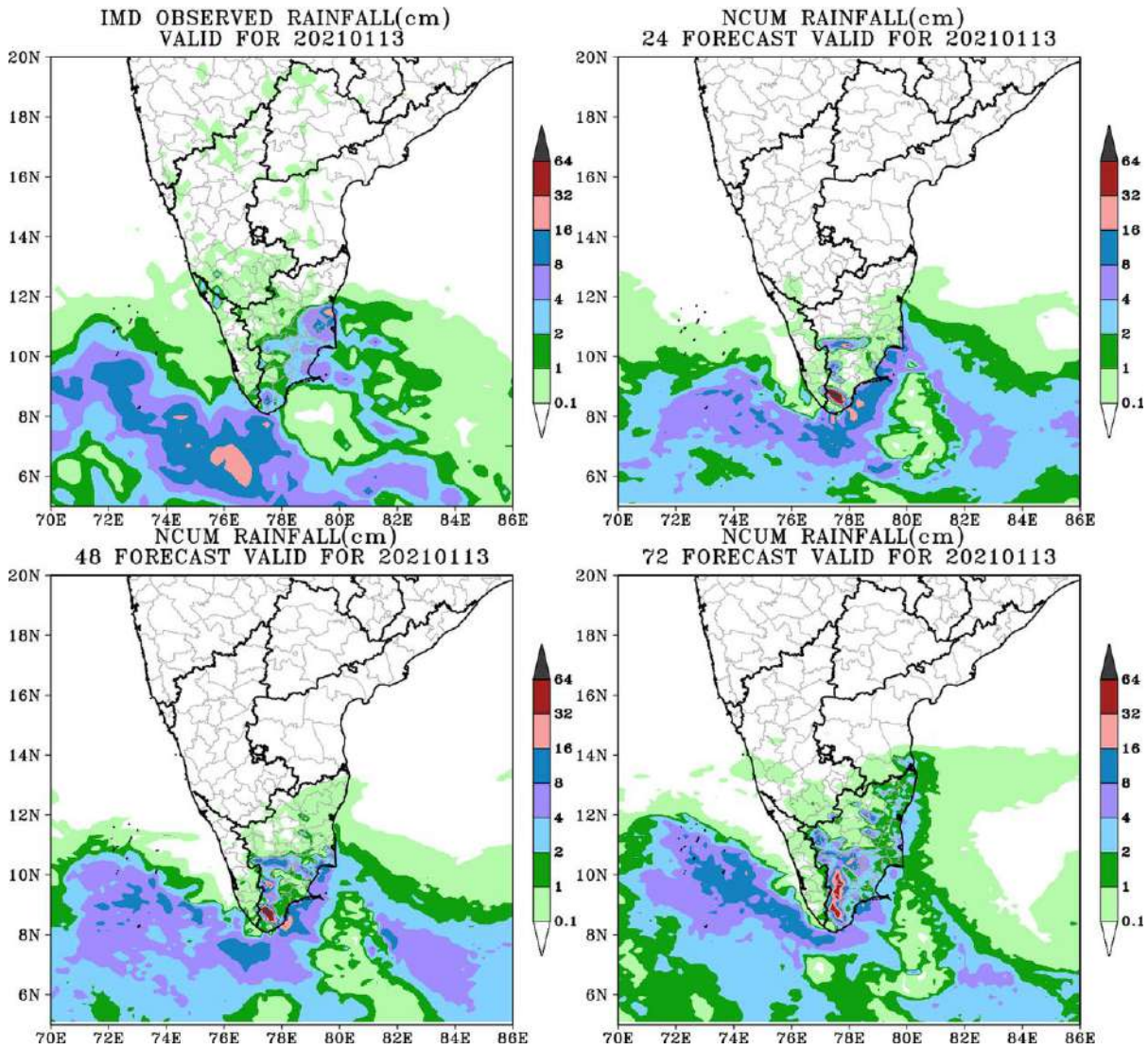


Figure 30. Observed Rainfall (IMD) (upper left), Day-1 (Upper right), Day-2 (lower left) and Day-5 (lower right) forecasts on 13 January2021

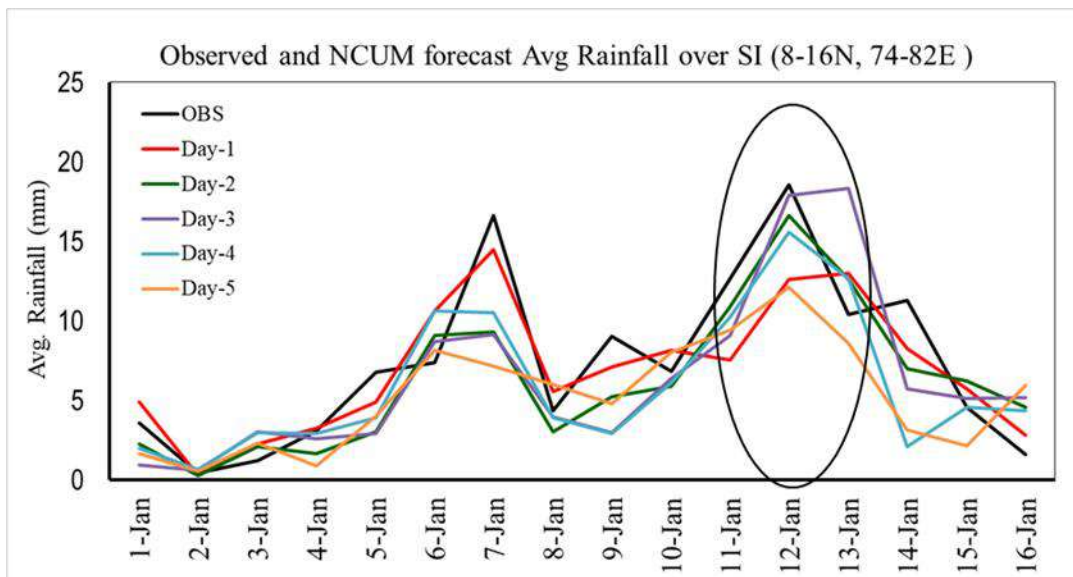


Figure 31. Time series of averaged observed and forecasted rainfall during 1-16Jan2021

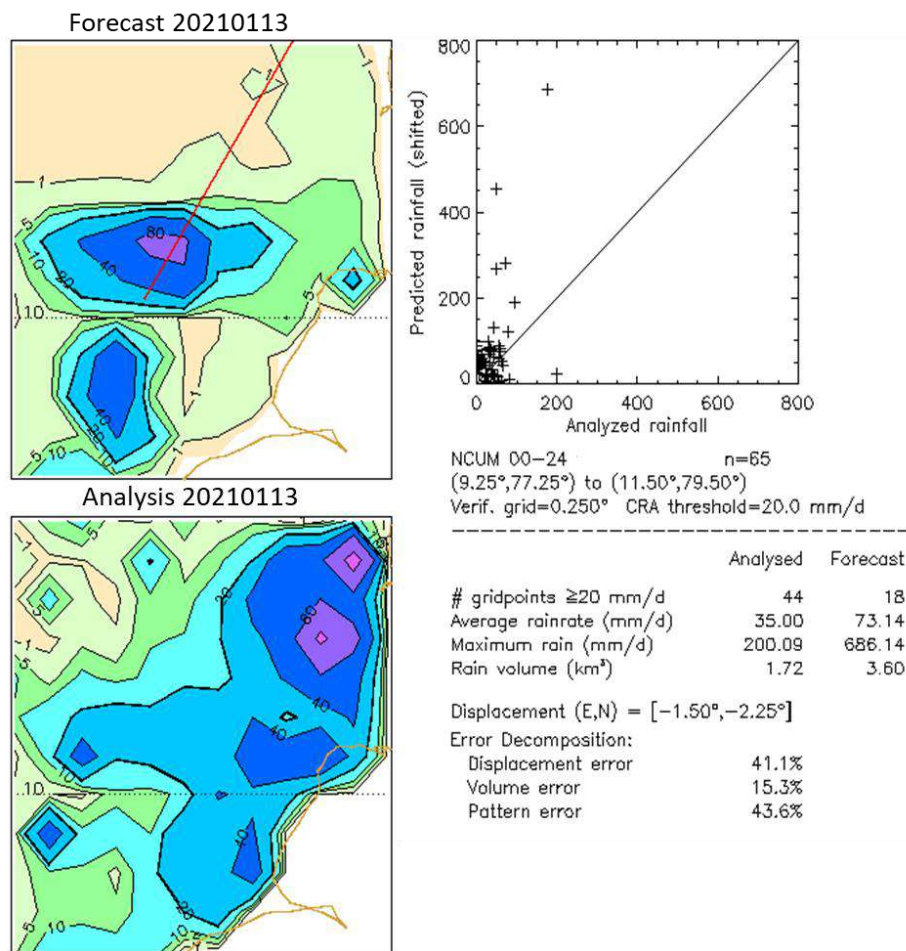


Figure.32 Spatial verification of rainfall for Day-1 forecast on 13Jan2021

Verification of Visibility:

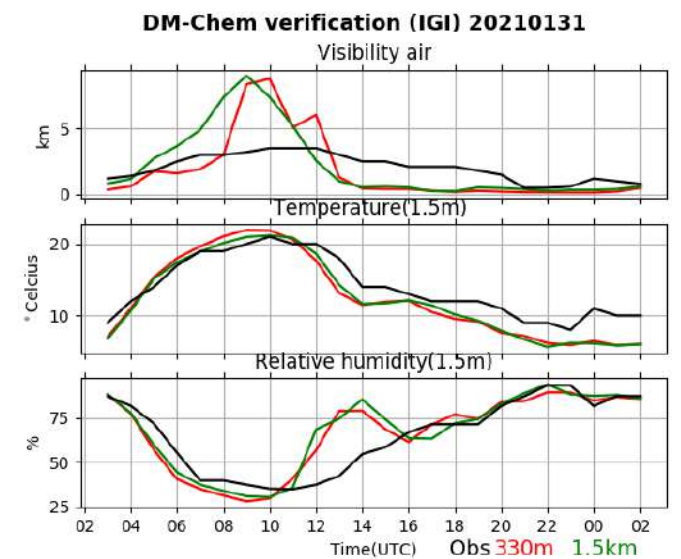
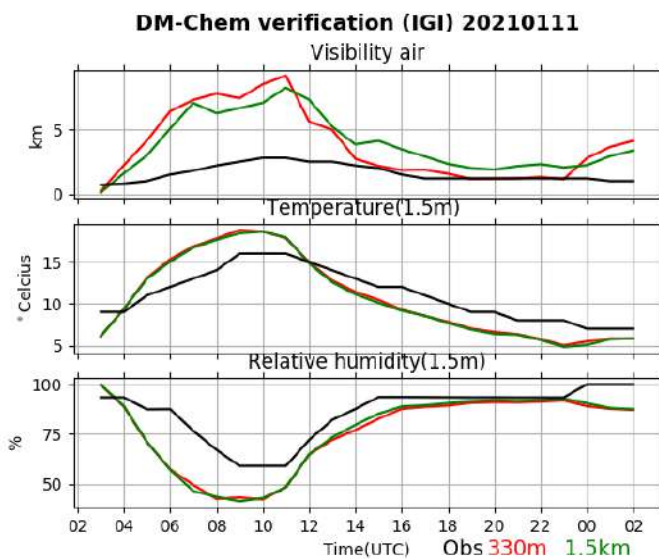
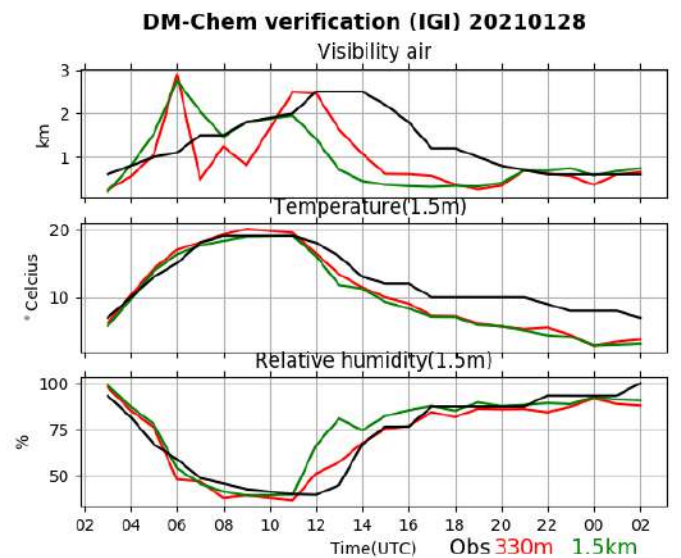
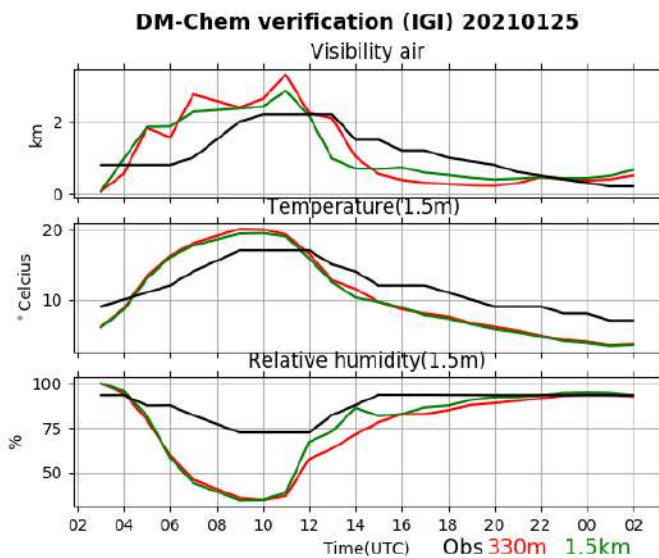
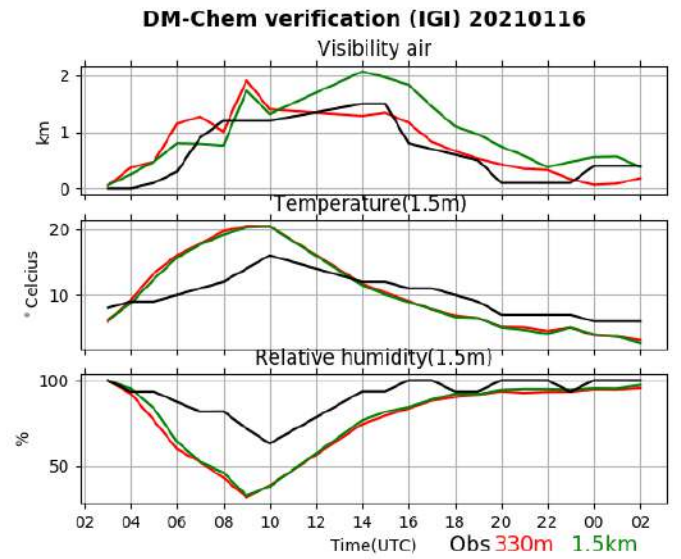
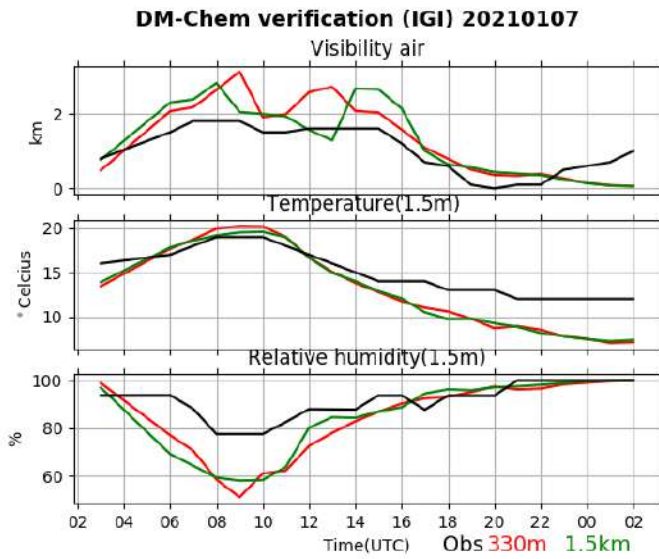


Figure 33. Observed and forecast Visibility, Temperature and Relative Humidity over IGI-T3 on 7th, 16th, 25th, 28th, 11th, and 31st January 2021

Annexure: Verification scores against Radiosonde

TABLE 1 INDIAN REGION VERIFICATION AGAINST RADIOSONDES

850 HPA GEOPOTENTIAL HEIGHT JANUARY 2021

FORECAST PERIOD	MEAN ERROR		RMSE	CORRELATION
(HOURS)	00GMT	00GMT00GMT		
24	0.9330	13.0504	0.4614	
48	2.0026	13.3712	0.6021	
72	0.3728	13.5950	0.5625	
96	0.3625	13.7892	0.5436	
120	-0.0658	14.0322	0.5858	
144	-0.5019	14.5605	0.6230	
168	-1.3185	15.4174	0.6532	
192	-0.3190	16.3352	0.6503	
216	-0.1559	18.7713	0.5797	
240	-1.2070	21.1788	0.5692	

TABLE 2 INDIAN REGION VERIFICATION AGAINST RADIOSONDES

500 HPA GEOPOTENTIAL HEIGHT JANUARY 2021

FORECAST PERIOD	MEAN ERROR		RMSE	CORRELATION
(HOURS)	00GMT	00GMT00GMT		
24	-12.2634	38.2340	0.5571	
48	-10.8788	37.8128	0.6928	
72	-12.3199	38.4043	0.6010	
96	-13.3931	39.2946	0.6686	
120	-16.2532	40.5711	0.6456	
144	-18.0468	42.8995	0.7222	
168	-19.1194	44.2945	0.7617	
192	-20.7922	46.5793	0.6464	
216	-22.5316	47.2644	0.6195	
240	-24.9500	52.6443	0.6604	

TABLE 3 INDIAN REGION VERIFICATION AGAINST RADIOSONDES

850 HPA TEMPERATURE				JANUARY 2021	
FORECAST PERIOD	MEAN ERROR	RMSE	CORRELATION		
(HOURS)	00GMT	00GMT	00GMT		
24	-0.1960	1.1750	0.6125		
48	-0.0051	1.2023	0.6719		
72	0.2341	1.2666	0.7629		
96	0.3720	1.4304	0.7461		
120	0.4541	1.5554	0.7511		
144	0.4892	1.6894	0.7124		
168	0.4679	1.7598	0.7187		
192	0.4831	1.7998	0.7144		
216	0.4736	1.8703	0.6683		
240	0.3935	2.0340	0.6760		

TABLE 4 INDIAN REGION VERIFICATION AGAINST RADIOSONDES

500 HPA TEMPERATURE				JANUARY 2021	
FORECAST PERIOD	MEAN ERROR	RMSE	CORRELATION		
(HOURS)	00GMT	00GMT	00GMT		
24	-0.2744	1.5688	0.6992		
48	-0.2236	1.5572	0.7861		
72	-0.2370	1.5466	0.8243		
96	-0.3242	1.6840	0.7938		
120	-0.5648	1.8696	0.7803		
144	-0.5902	2.0711	0.8368		
168	-0.5001	2.0132	0.8058		
192	-0.9138	2.3650	0.6859		
216	-0.9009	2.5609	0.6525		
240	-0.9816	2.8509	0.6711		

TABLE 5 INDIAN REGION VERIFICATION AGAINST RADIOSONDES

850 HPA WIND			JANUARY 2021		
FORECAST PERIOD		MEAN SPEED ERROR		RMSWVE	
(HOURS)	00GMT	00GMT			
24	-0.6496	3.9209			
48	-0.5393	4.1426			
72	-0.6025	4.3422			
96	-0.6893	4.5559			
120	-0.7678	4.7402			
144	-0.8356	4.9369			
168	-0.7095	5.3442			
192	-0.8738	5.3504			
216	-0.7936	5.5837			
240	-0.9710	6.0742			

TABLE 6 INDIAN REGION VERIFICATION AGAINST RADIOSONDES

500 HPA WIND			JANUARY 2021		
FORECAST PERIOD		MEAN SPEED ERROR		RMSWVE	
(HOURS)	00GMT	00GMT			
24	-0.6163	4.0394			
48	-0.4827	4.2059			
72	-0.4004	4.6692			
96	-0.4655	5.0092			
120	-0.6802	5.4168			
144	-0.4379	6.3240			
168	-0.3556	6.9784			
192	-0.4786	7.8127			
216	-0.6376	8.4264			
240	-0.7993	9.7554			