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VERIFICATION REPORT

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

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9	Abstract	This report presents the verification summary of the NCMRWF Global Unified Model (NCUM hereafter) forecasts for March 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 March 2021, there were 7 westerns disturbances, seasons first low pressure area formed over BOB, seasons first heat wave condition prevailed over northern parts of India. These events have been verified and presented.
10	References	
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12	Distribution	General

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I. Introduction

This report presents the verification summary of the NCMRWF Global Unified Model (NCUM hereafter) forecasts for March 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 Hersbach et al., (2020) climatology (1979-2018). This section is followed by systematic errors in the forecast winds, temperature, and relative humidity at 850, 700, 500, and 200hPa levels. Additionally, systematic errors are presented for Temperature & Specific Humidity at 2m height, Winds at 10m height and column integrated precipitable water (PWAT). The systematic errors in model forecasts are computed against its own analysis.

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 (Mitra et al. 2009, 2013). 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 (Srivastava et al 2009). Categorical verification scores are presented for both temperature and rainfall for April 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), which are described in standard text books (Wilks, 2011, Jolliffe and Stephenson, 2012), and new Symmetric Extremal Dependency Index (SEDI) (Stephenson et al 2008, Ashrit et al 2015, Sharma et al 2021) suitable for rare and extreme events.

Further, the verification is carried out against the radiosonde observations over India. The 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.

Special attention is given to verify significant weather events of the month. During March 2021, the WD's activity is much higher than normal. In addition, the 1st season's low pressure area formed over BOB and first heat wave condition also formed over Rajasthan. Verification is presented for active WD's, the low pressure system and heat wave condition.

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

1. Highlights

- The wind anomaly at 850hPa shows an anomalous flow from east to west over southern parts of India whereas west to east flow over south of equator. At 700 hPa, northwesterly anomalous flow ($>2\text{m/s}$) is noticed over IG Plains to northeast India. In addition, a strong negative anomaly ($<-4\text{m/s}$) with easterly flow is noticed at 20°N belt. In the upper levels at 500hPa and 200 hPa an intense anomalous easterlies (less than -4m/s) around 20°N are an evident (**Figures 1-2**).
- At 850 hPa and 700 hPa, the bias in wind indicating a south-easterly flow over the BOB and strengthening with lead times. The northwesterly bias ($>2\text{ms/}$) at 850 hPa is noticed along the south-west coast of India. While at 700hPa a strong south westerly negative bias (approx. $2\text{-}3\text{m/s}$) is noted over Arabian Sea. At 500hPa, enhanced westerly bias in the equatorial Indian Ocean and south easterly bias over eastern Indian Ocean is noted (**Figures 3-5**).
- The warm bias in temperature over the Indian subcontinent is noticed from surface to mid-troposphere while cold bias in noticed in the upper troposphere (200hPa). The bias is prominent with forecast lead times (**Figures 7-10 and Figure 15**).
- A wet (*dry*) bias in humidity over the Arabian Sea (*Indian landmass*) is noticed near the surface. However, at higher levels wet bias over Indian landmass is prominent. (**Figures 11-13 and Figure 17**)
- Model forecasts indicate the rainfall patterns and intensities are in agreement with observations over the core monsoon region, north-eastern parts of India, along the foot hills of Himalayas and southern peninsular India. However, the model forecasts are over predicting the intensity of rainfall over these regions and the wide spread of rainfall is also noticed over central parts of India (**Figure 18**).
- Various statistical scores are computed to assess the NCUM mode skill in predicting the rainfall. The forecast skill is reasonable in predicting rainfall events of low intensity ($<9\text{mm/day}$) where the PSS values are > 0.3 . For rainfall events of higher intensities ($>9\text{mm/day}$ etc.,) the PSS values are lower than 0.3. (**Figure 19**).
- Tmax forecast verification during March 2021 is relatively poor, with PSS values lower than 0.3 at all lead times. However, the model skills are good for $36\text{-}38^{\circ}\text{C}$ (**Figure 20**).

2. Mean and anomaly of winds:

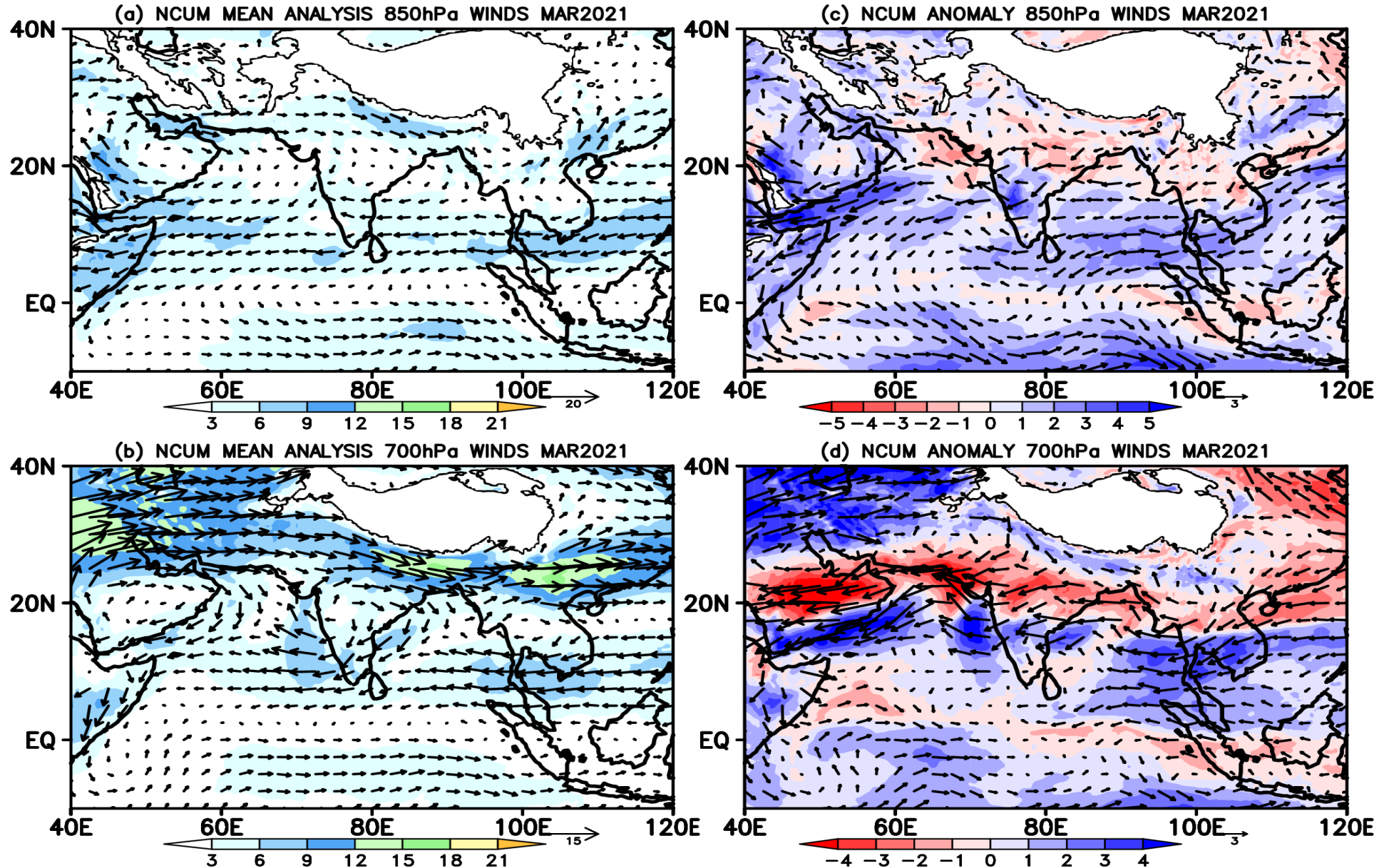


Figure 1. Mean winds at (a) 850 hPa and (b) 700 hPa in the NCUM Analysis during March 2021. Right panels show the anomaly circulation at (c) 850 hPa and (d) 700 hPa.

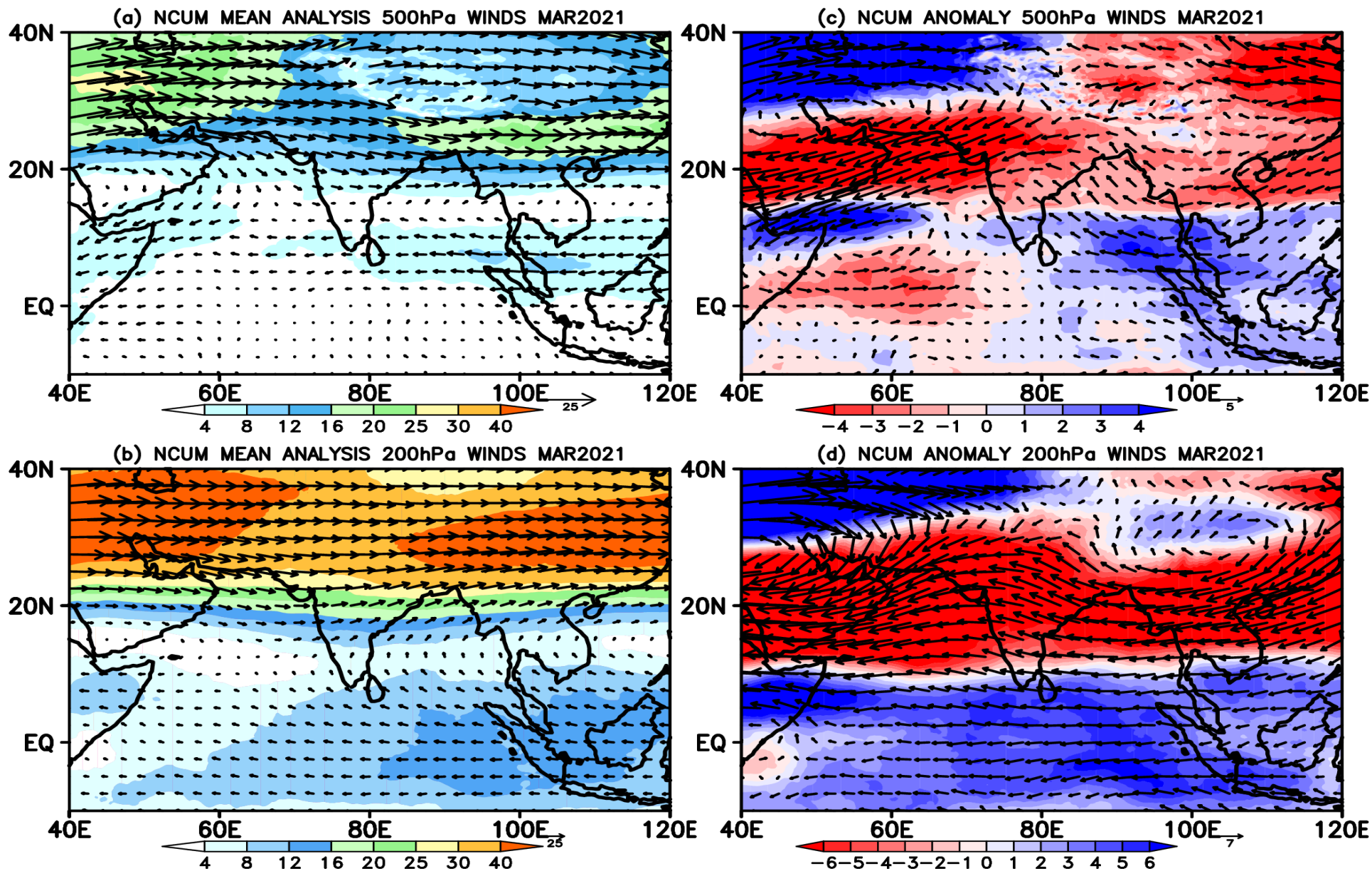


Figure 2. Mean winds at (a) 500 hPa and (b) 200 hPa in the NCUM Analysis during March 2021. Right panels show the anomaly circulation at (c) 500 hPa and (d) 200 hPa.

3. Systematic errors in Upper air variables:

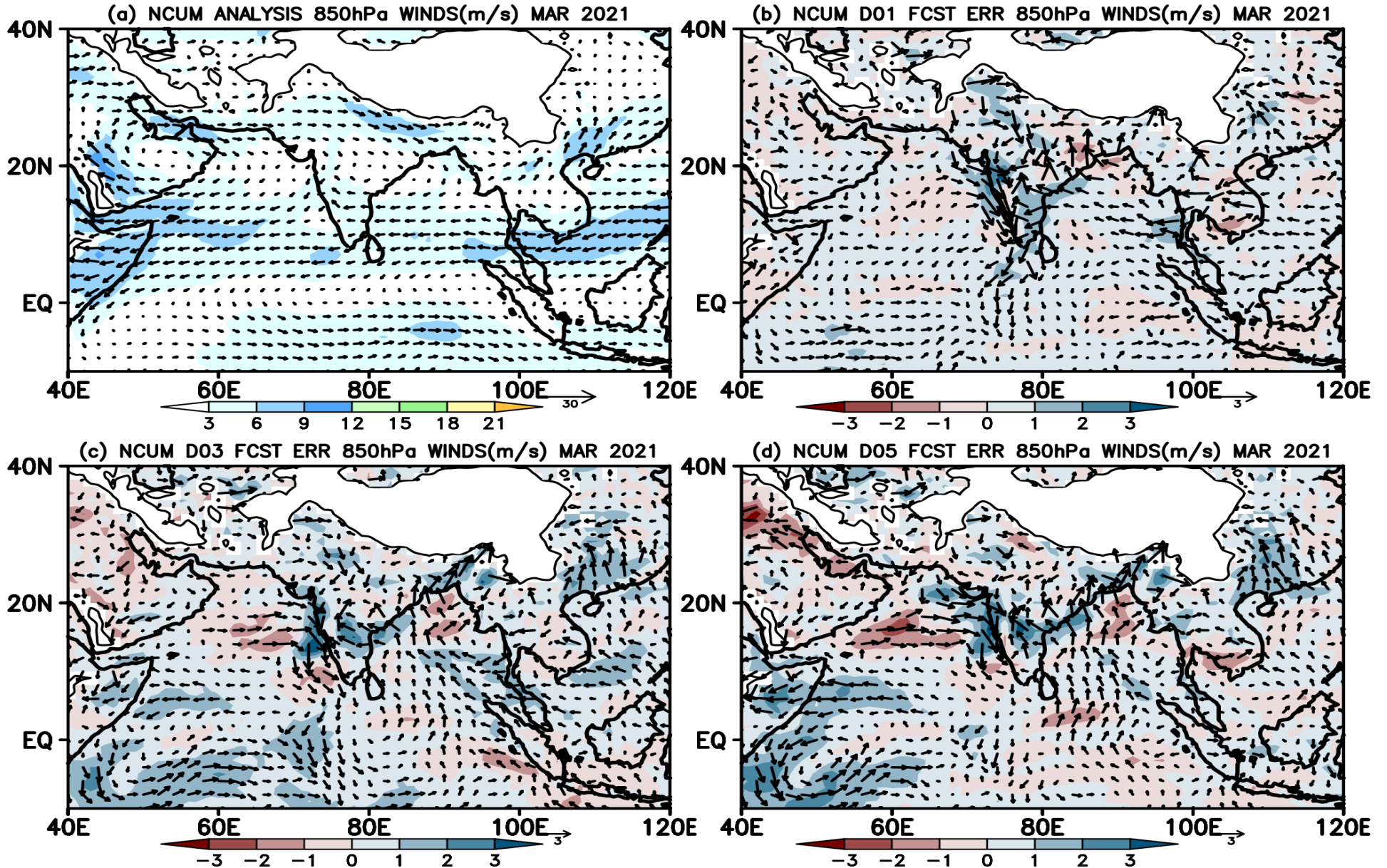


Figure 3. (a) Mean winds at 850 hPa and systematic errors in (b) Day-1 (c) Day-3 and (d) Day-5 forecasts during March 2021

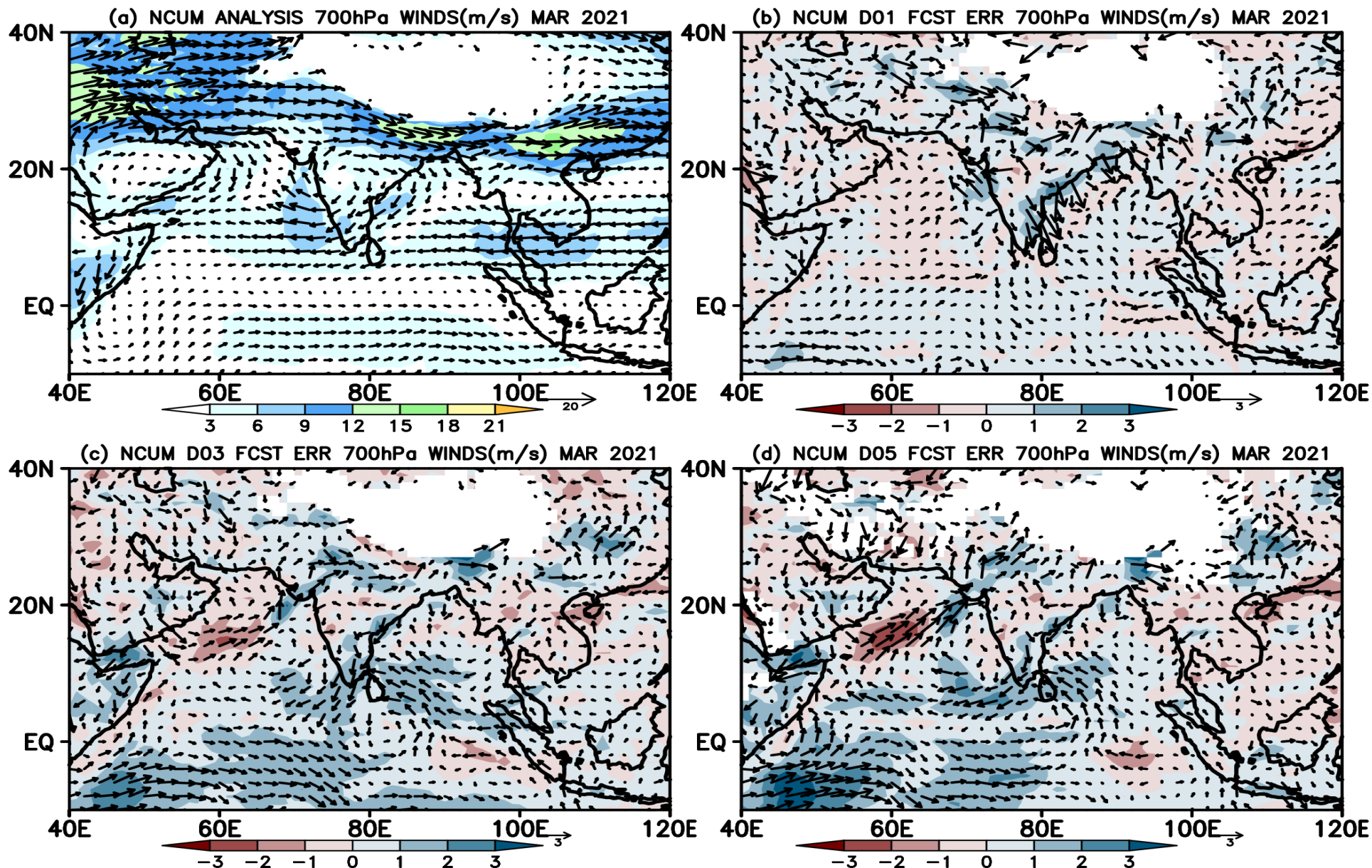


Figure 4. (a) Mean winds at 700 hPa and systematic errors in (b) Day-1 (c) Day-3 and (d) Day-5 forecasts during March 2021

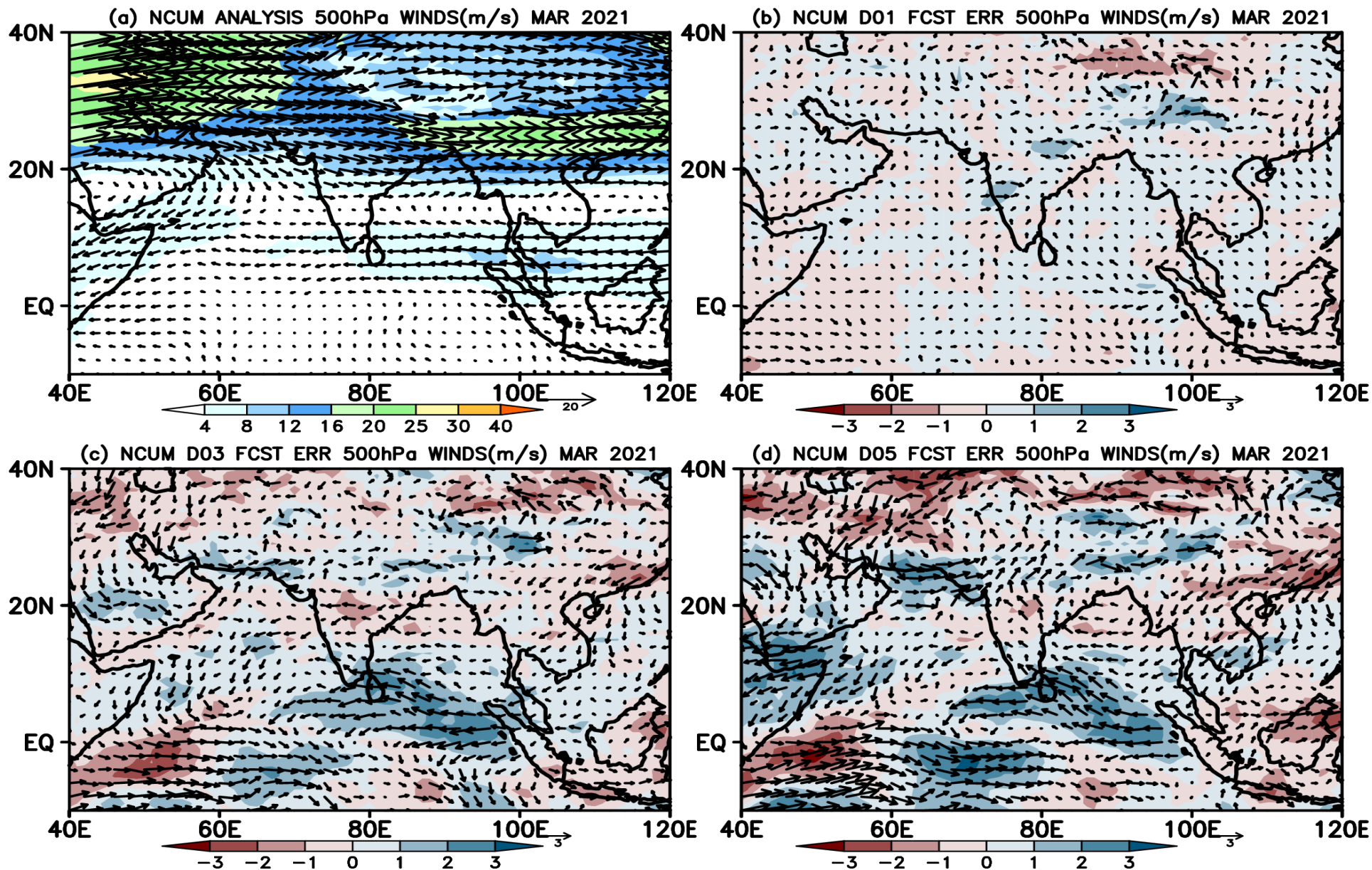


Figure 5. (a) Mean winds at 500 hPa and systematic errors in (b) Day-1 (c) Day-3 and (d) Day-5 forecasts during March 2021

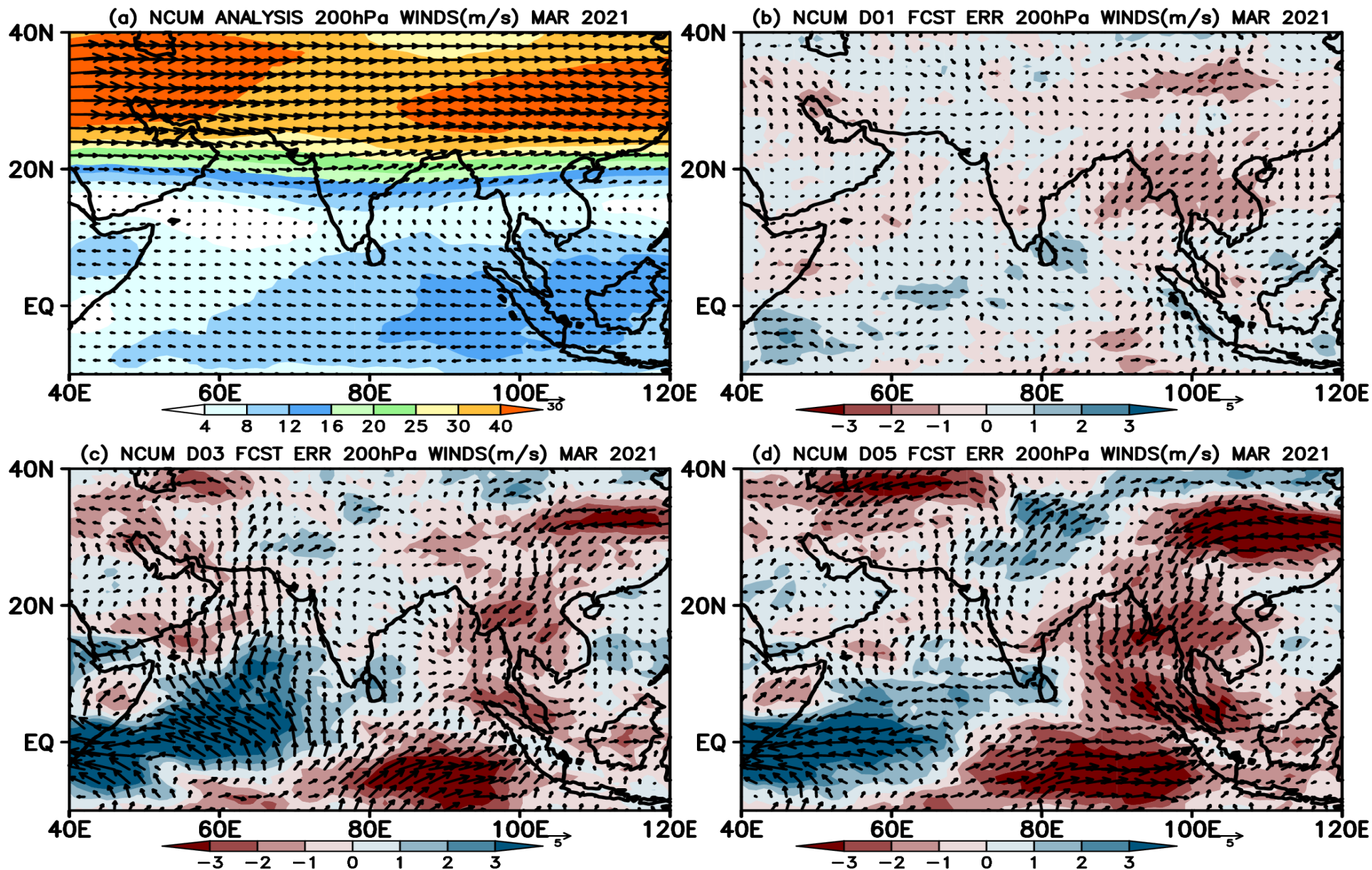


Figure 6. (a) Mean winds at 200 hPa and systematic errors in (b) Day-1 (c) Day-3 and (d) Day-5 forecasts during March 2021

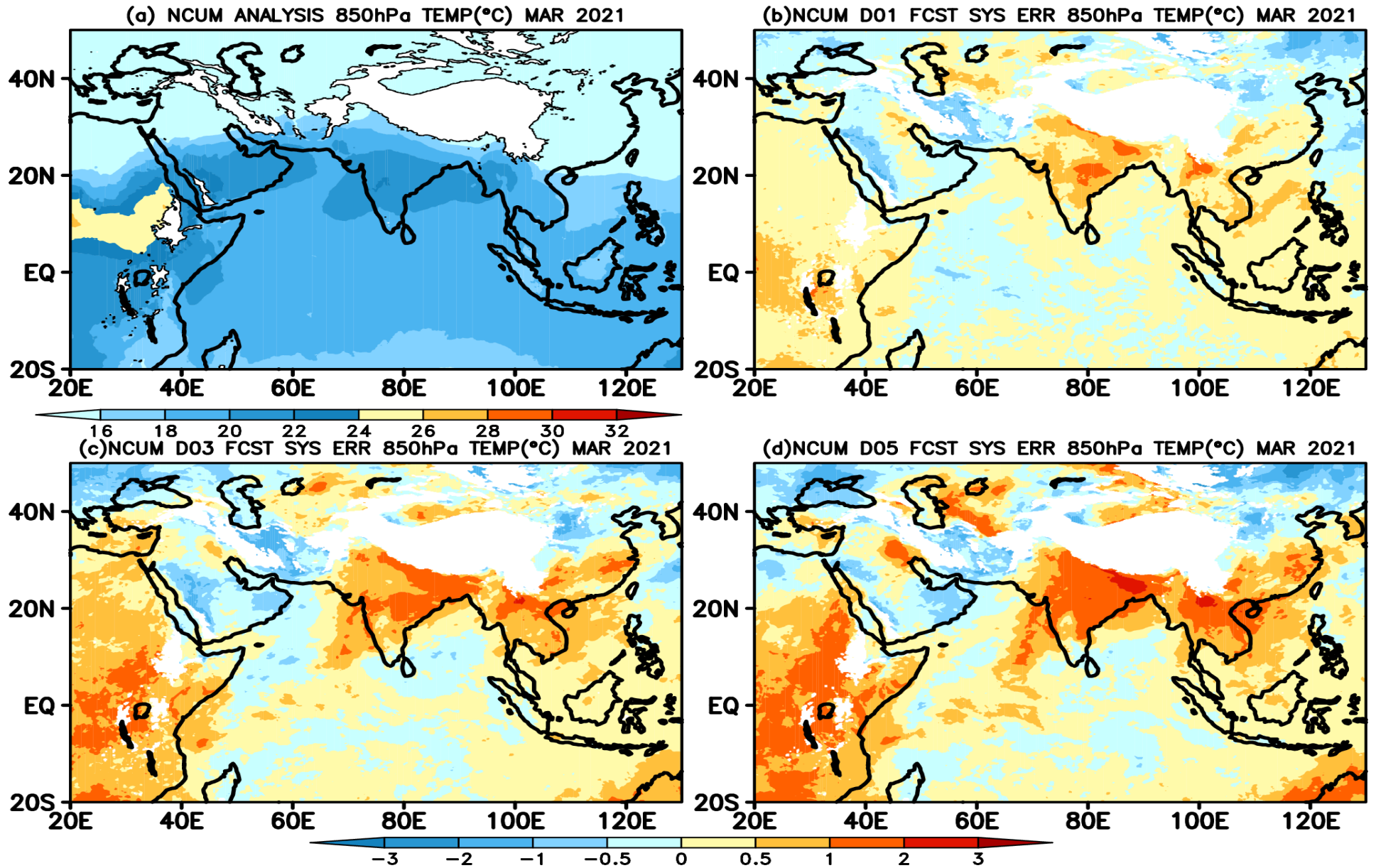


Figure 7. (a) Mean Temperature at 850 hPa and systematic errors in (b) Day-1 (c) Day-3 and (d) Day-5 forecasts during March 2021

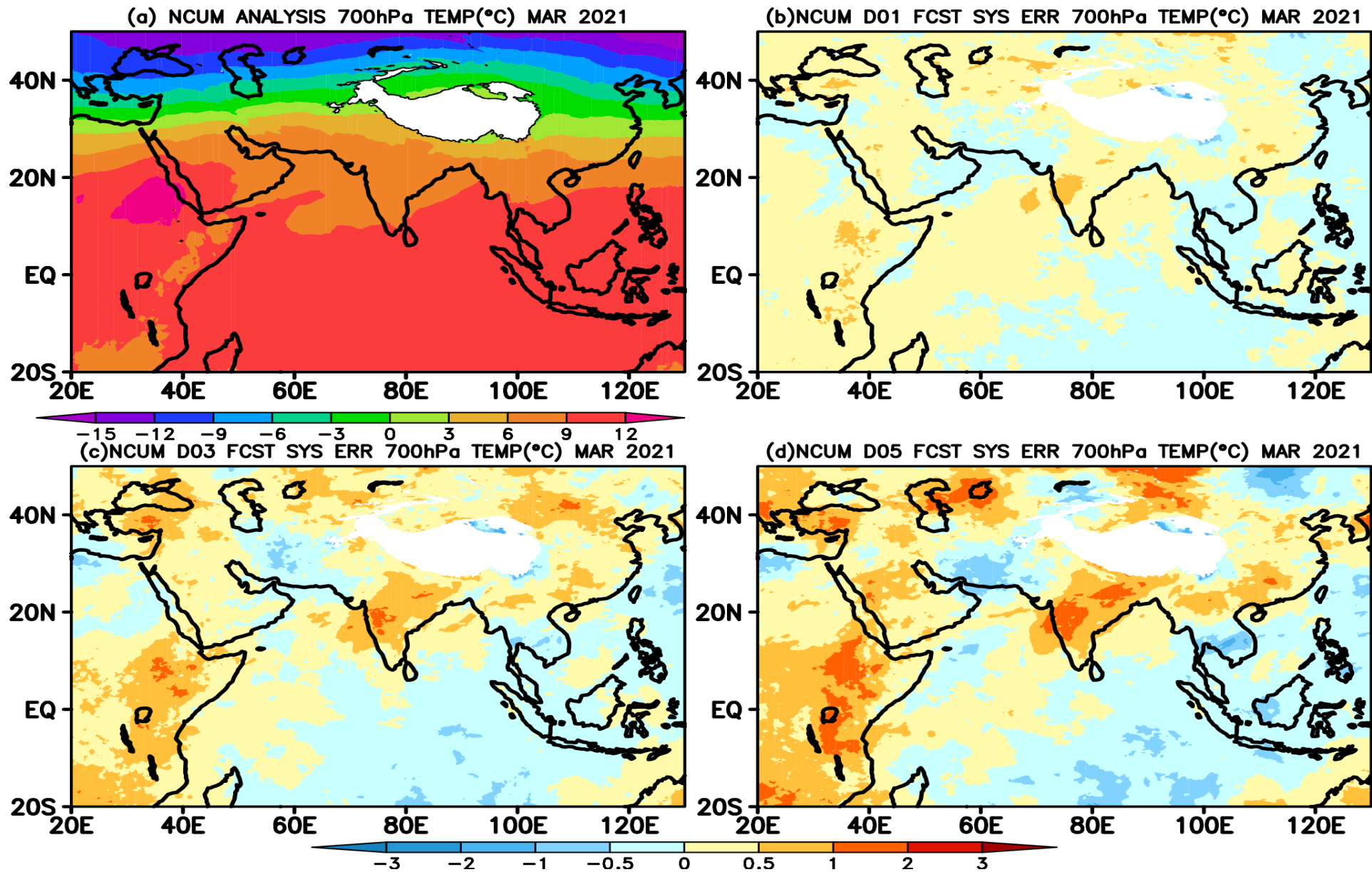


Figure 8. (a) Mean Temperature at 700 hPa and systematic errors in (b) Day-1 (c) Day-3 and (d) Day-5 forecasts during March 2021

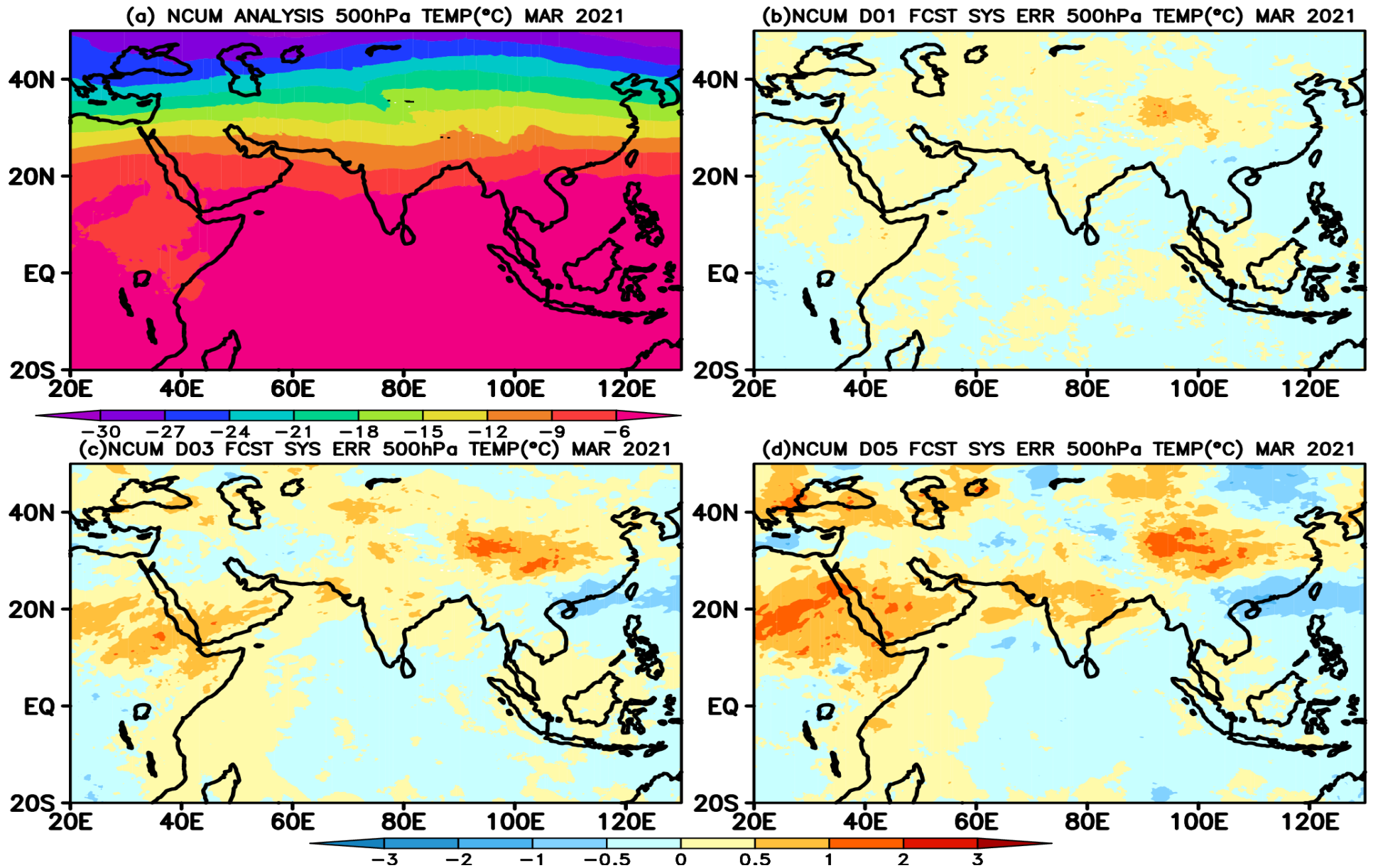


Figure 9. (a) Mean Temperature at 500 hPa and systematic errors in (b) Day-1 (c) Day-3 and (d) Day-5 forecasts during March 2021

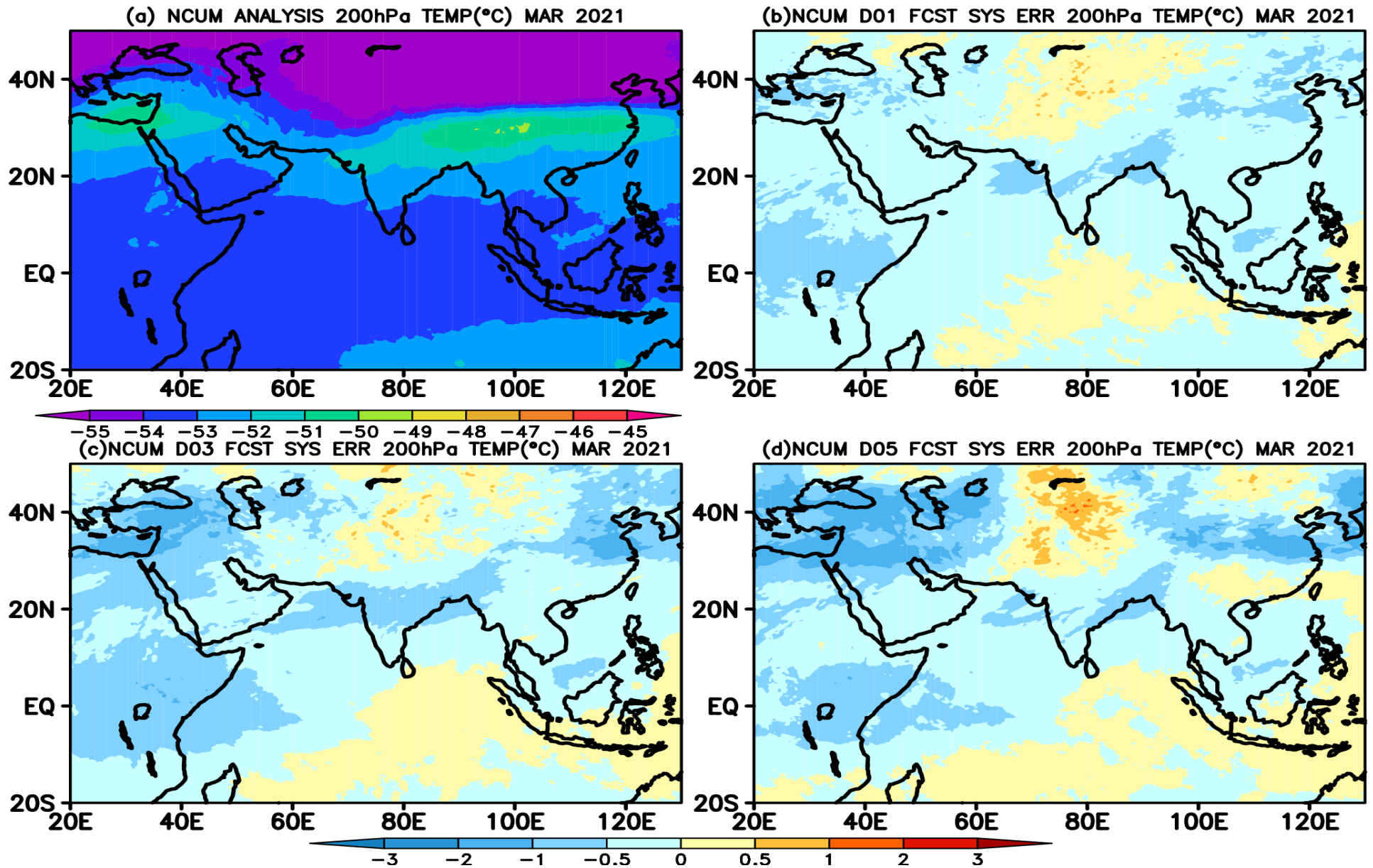


Figure 10. (a) Mean Temperature at 200 hPa and systematic errors in (b) Day-1 (c) Day-3 and (d) Day-5 forecasts during March 2021

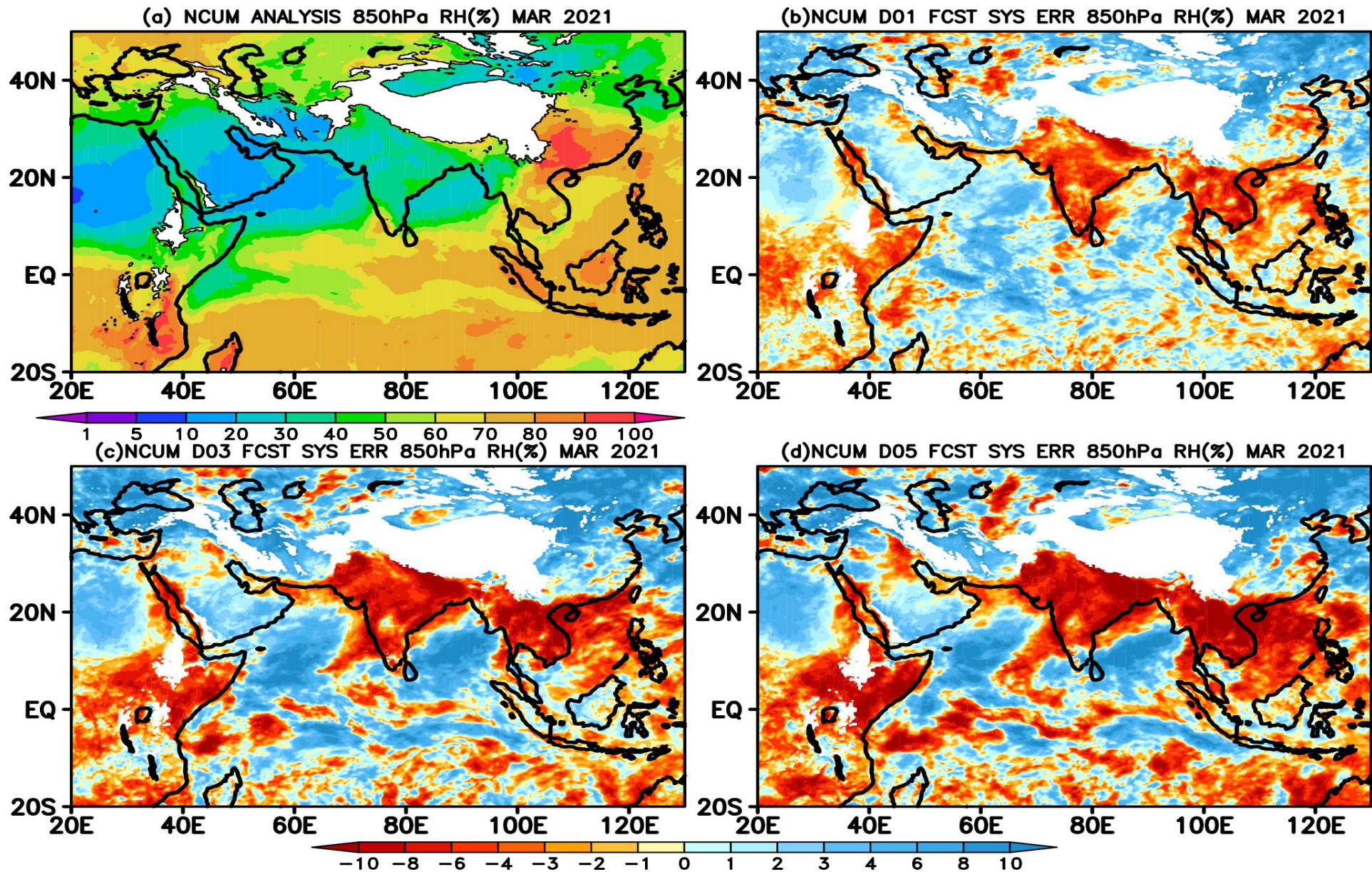


Figure 11. (a) Mean Relative Humidity at 850 hPa and systematic errors in (b) Day-1 (c) Day-3 and (d) Day-5 forecasts during March 2021

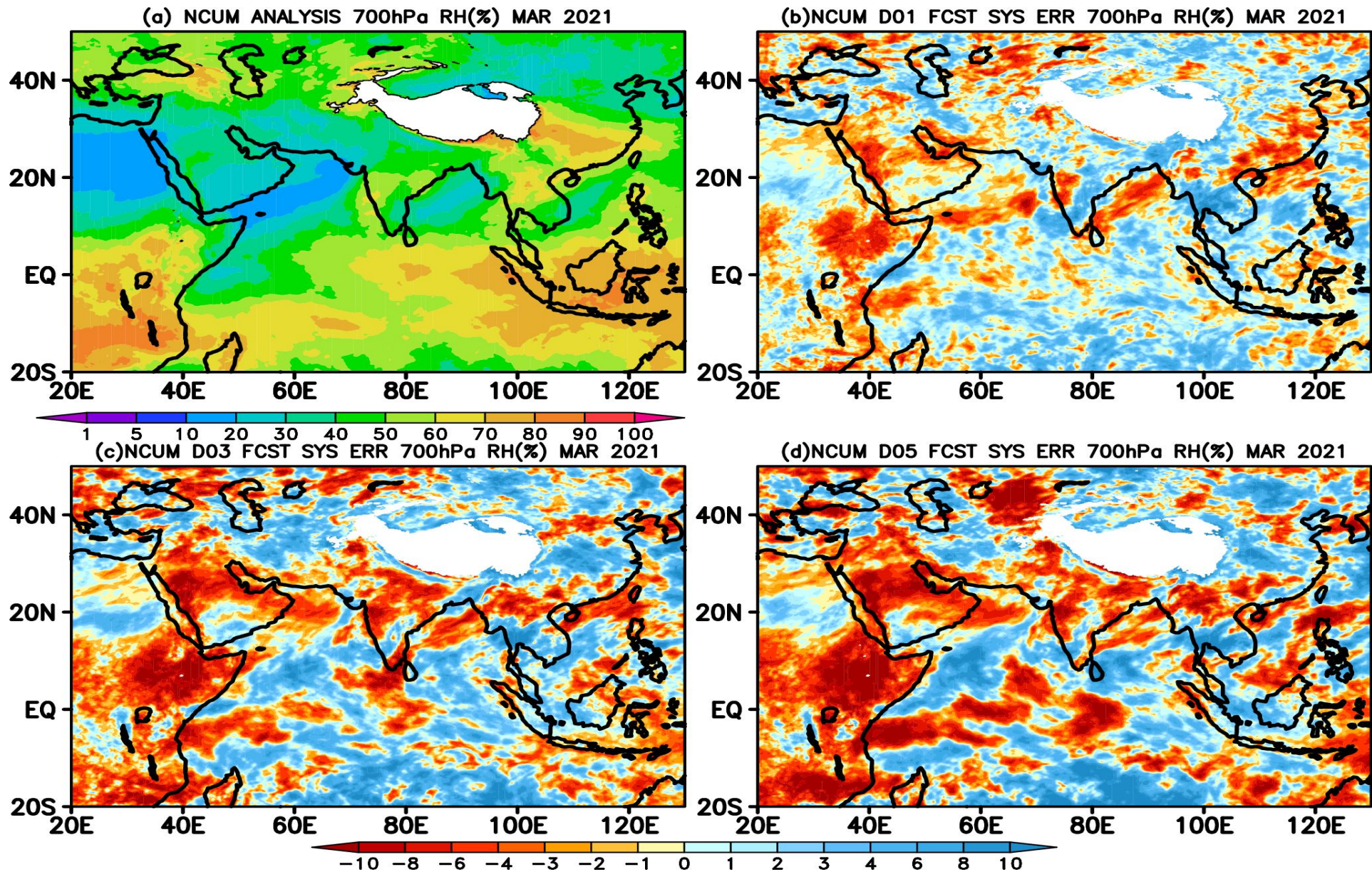


Figure 12. (a) Mean Relative Humidity at 700 hPa and systematic errors in (b) Day-1 (c) Day-3 and (d) Day-5 forecasts during March 2021

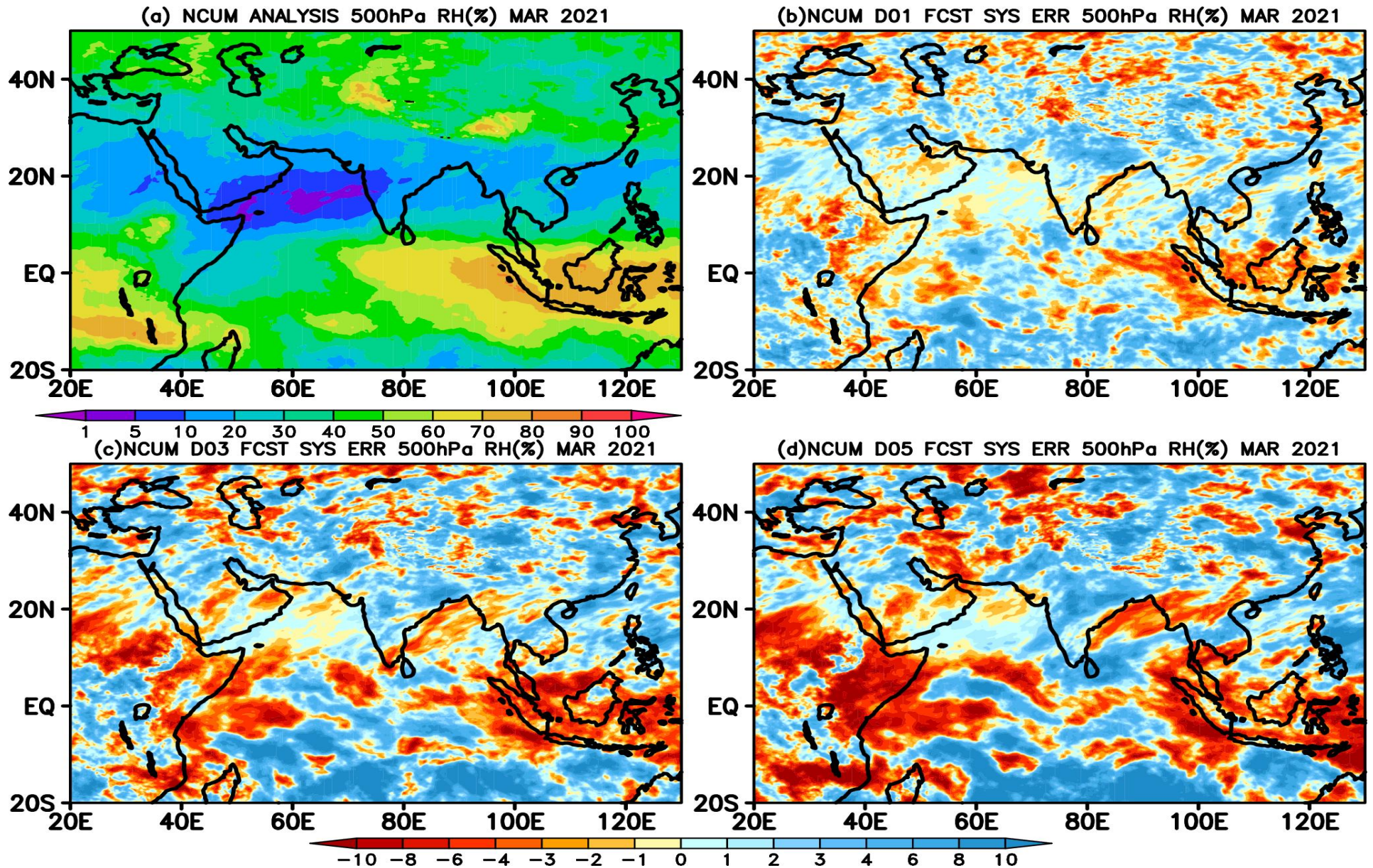


Figure 13. (a) Mean Relative Humidity at 500 hPa and systematic errors in (b) Day-1 (c) Day-3 and (d) Day-5 forecasts during March 2021

4. Systematic errors in surface variables

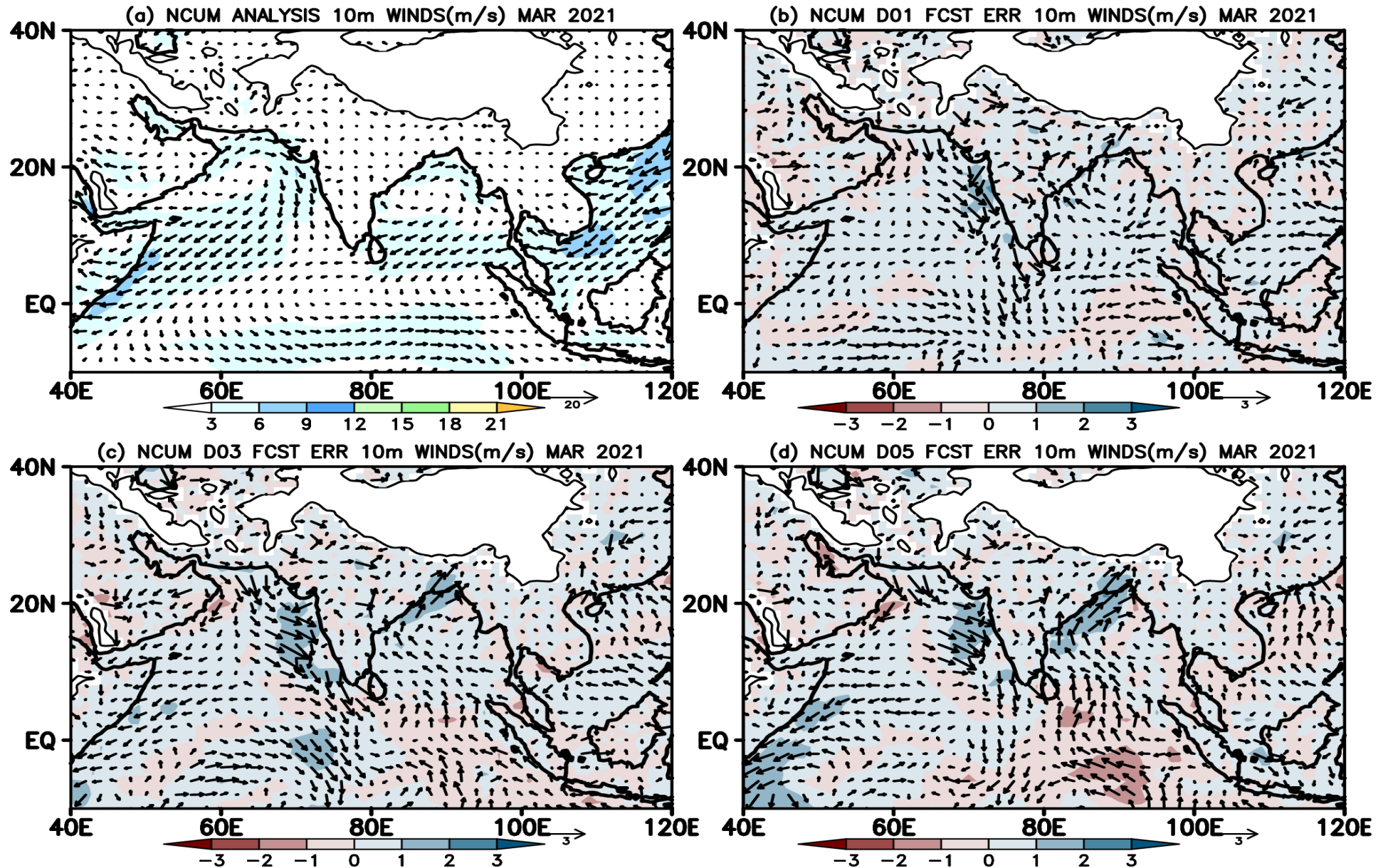


Figure 14. (a) Mean winds at 10m height and systematic errors in (b) Day-1 (c) Day-3 and (d) Day-5 forecasts during March 2021

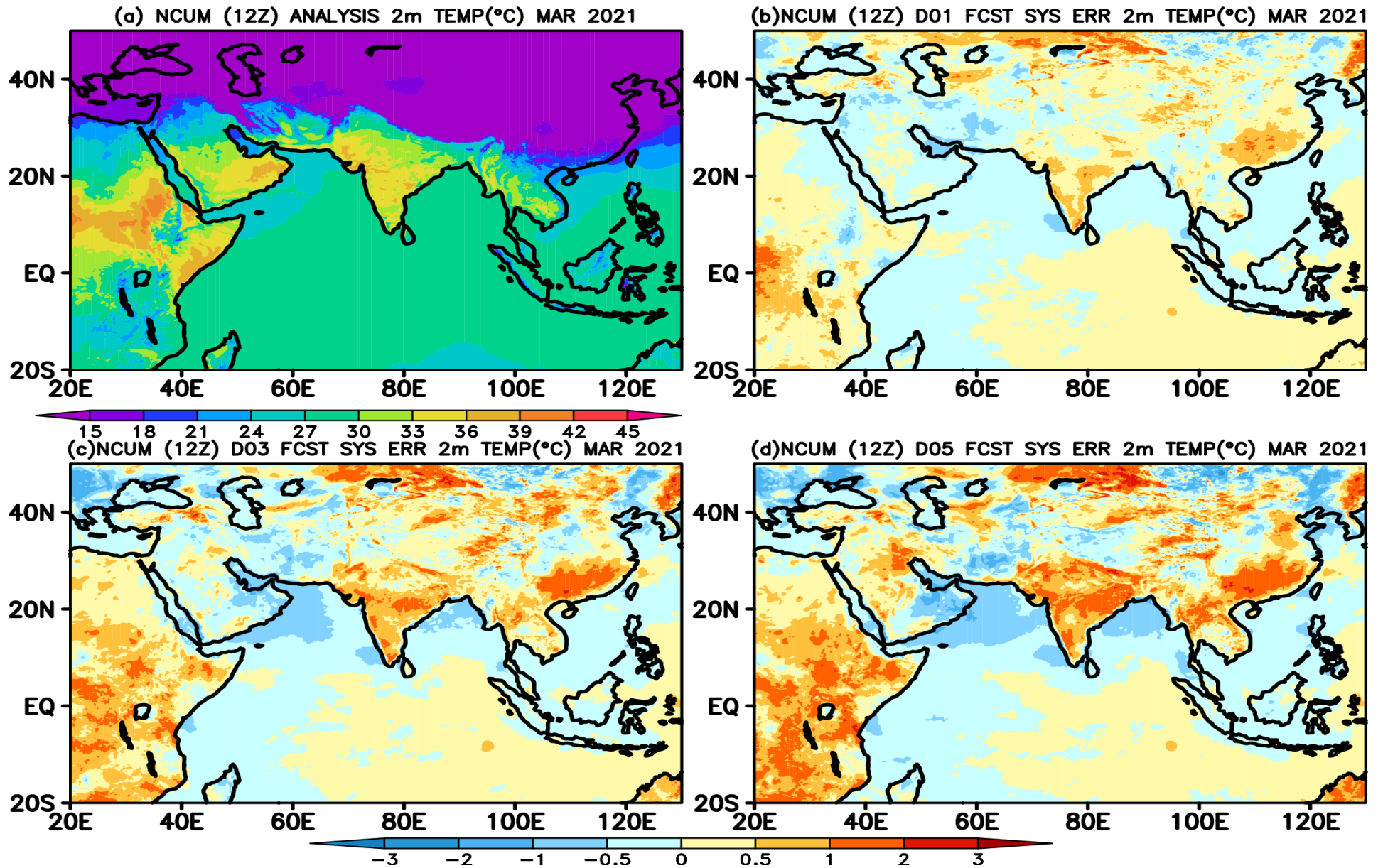


Figure 15. (a) Mean Temperature at 2mt height and systematic errors in (b) Day-1 (c) Day-3 and (d) Day-5 forecasts during March 2021

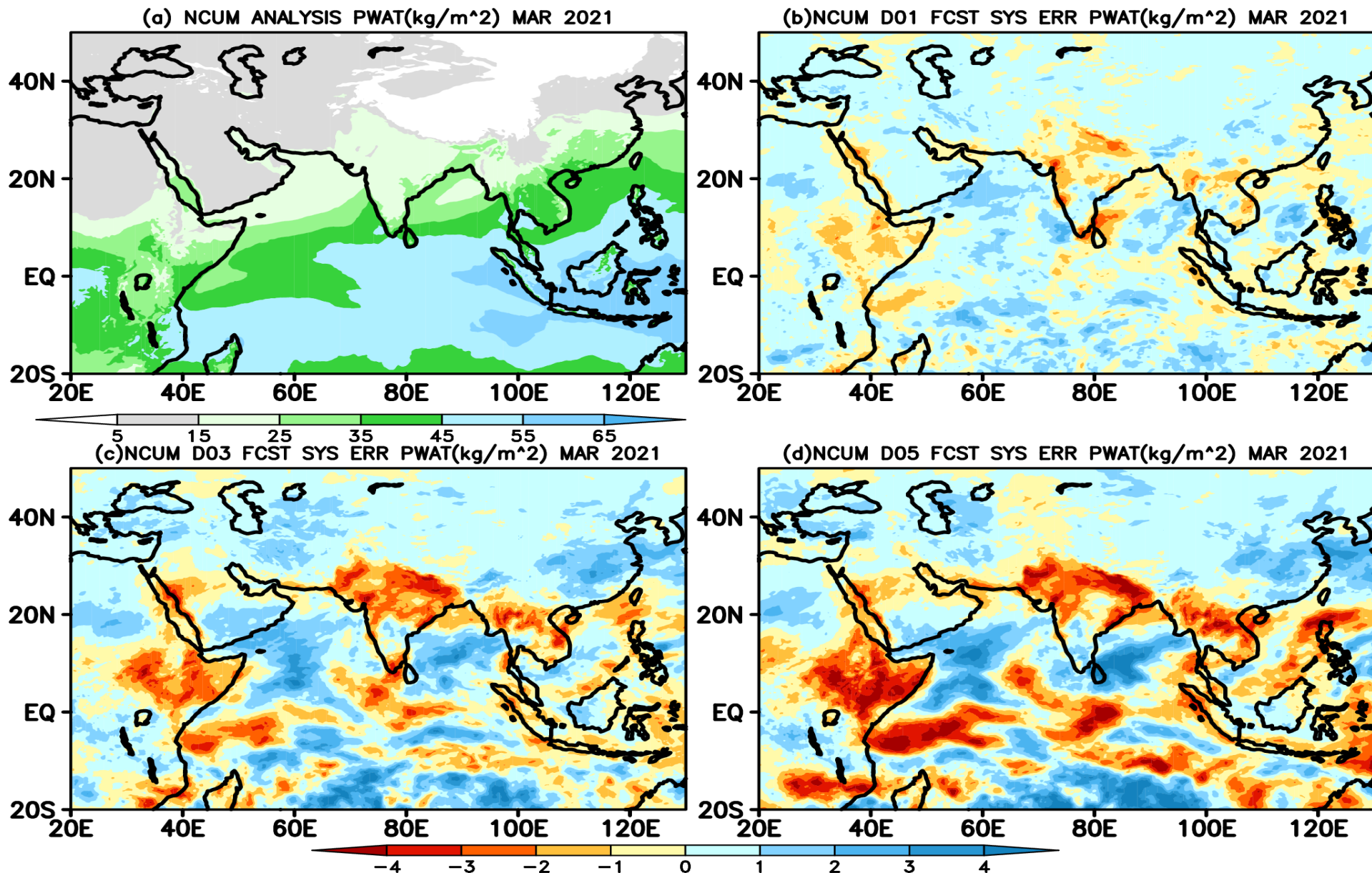


Figure 16. (a) Mean precipitable water content (PWAT) up to model levels and systematic errors in (b) Day-1 (c) Day-3 and (d) Day-5 forecasts during March 2021

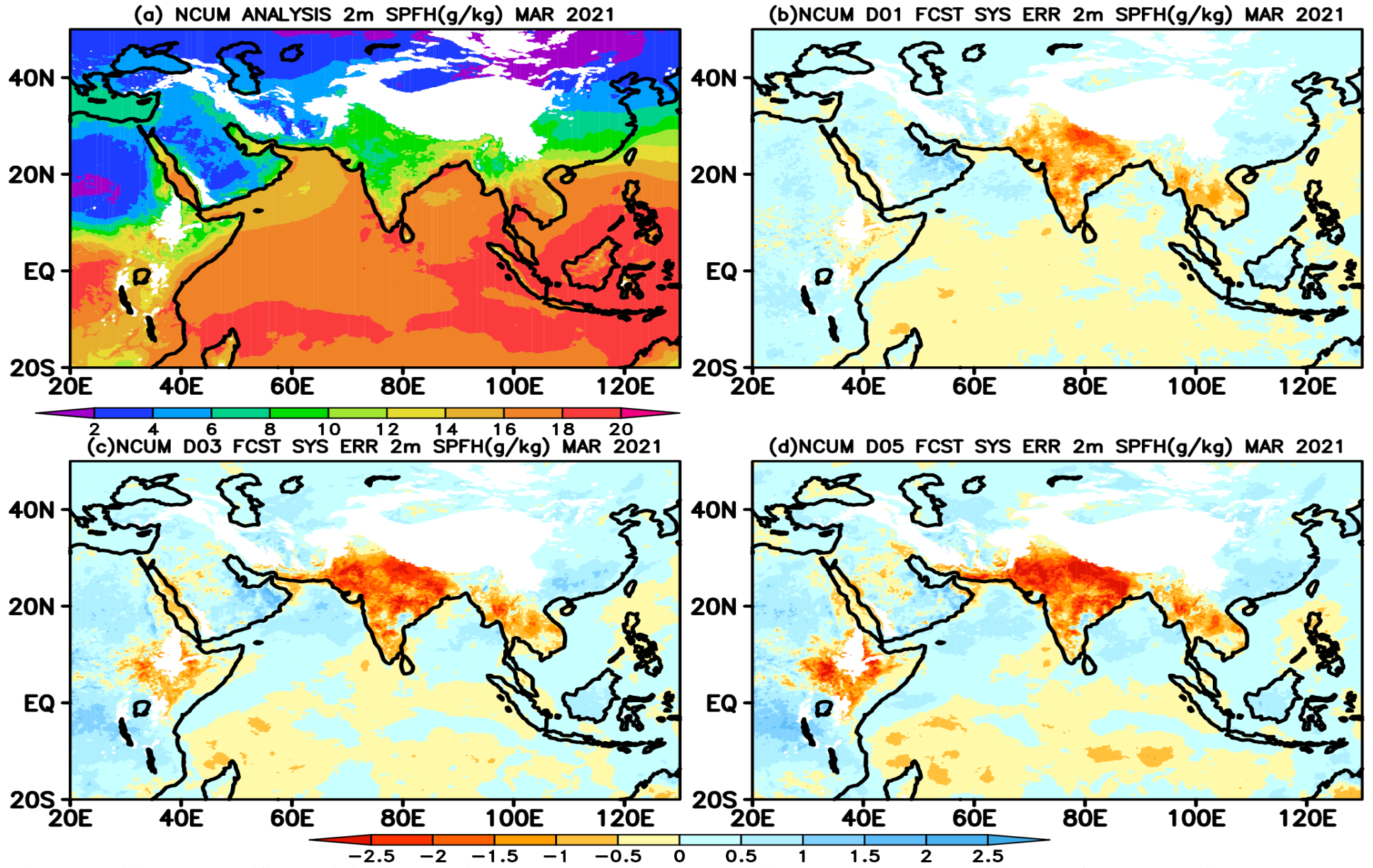


Figure 17. (a) Mean specific humidity at 2m height and systematic errors in (b) Day-1 (c) Day-3 and (d) Day-5 forecasts during March 2021

5. Verification of Rainfall Forecasts

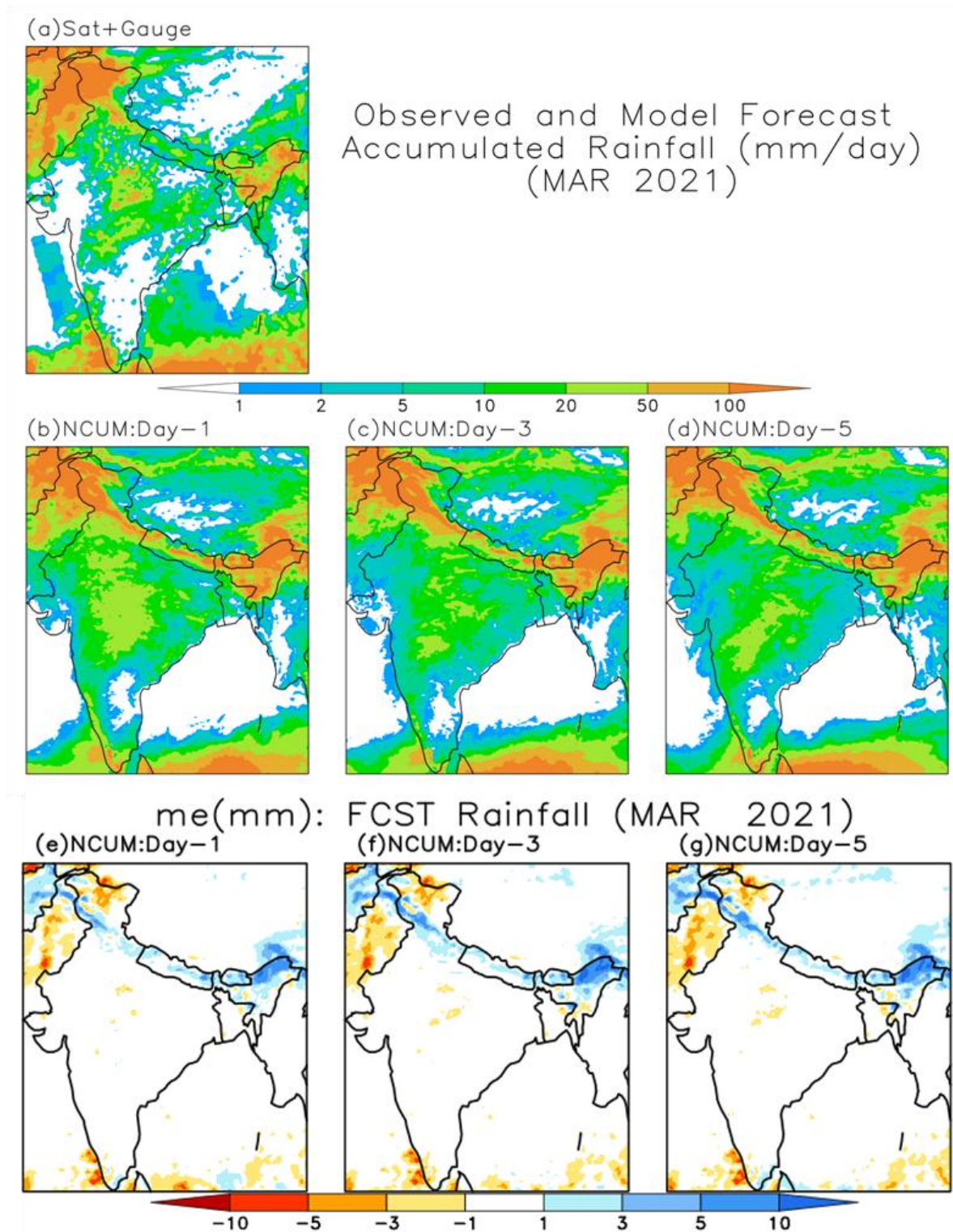


Figure 18. Accumulated March rainfall in (a) Observations and (b) Day-1 (c) Day-3 and (d) Day-5 forecasts. Bottom panels (e), (f) and (g) show Mean Error (ME) in Day-1, Day-3 and Day-5 forecasts respectively.

6. Rainfall Categorical scores for NCUM

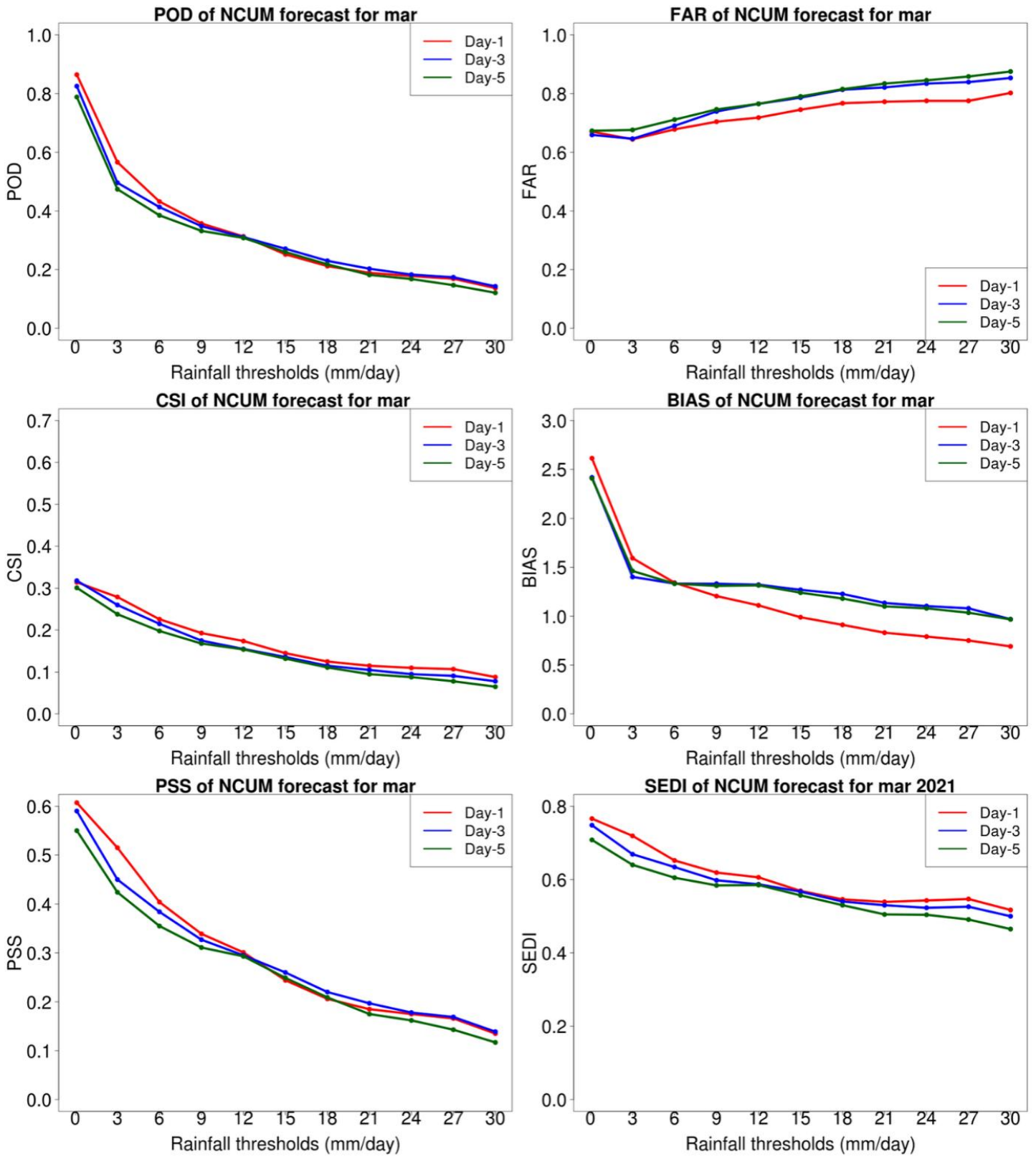


Figure 19. Categorical all India Rainfall scores POD (top left), FAR (top right), CSI(middle left), BIAS (middle right), PSS (bottom left) and SEDI (bottom right).

7. Tmax categorical Scores for NCUM:

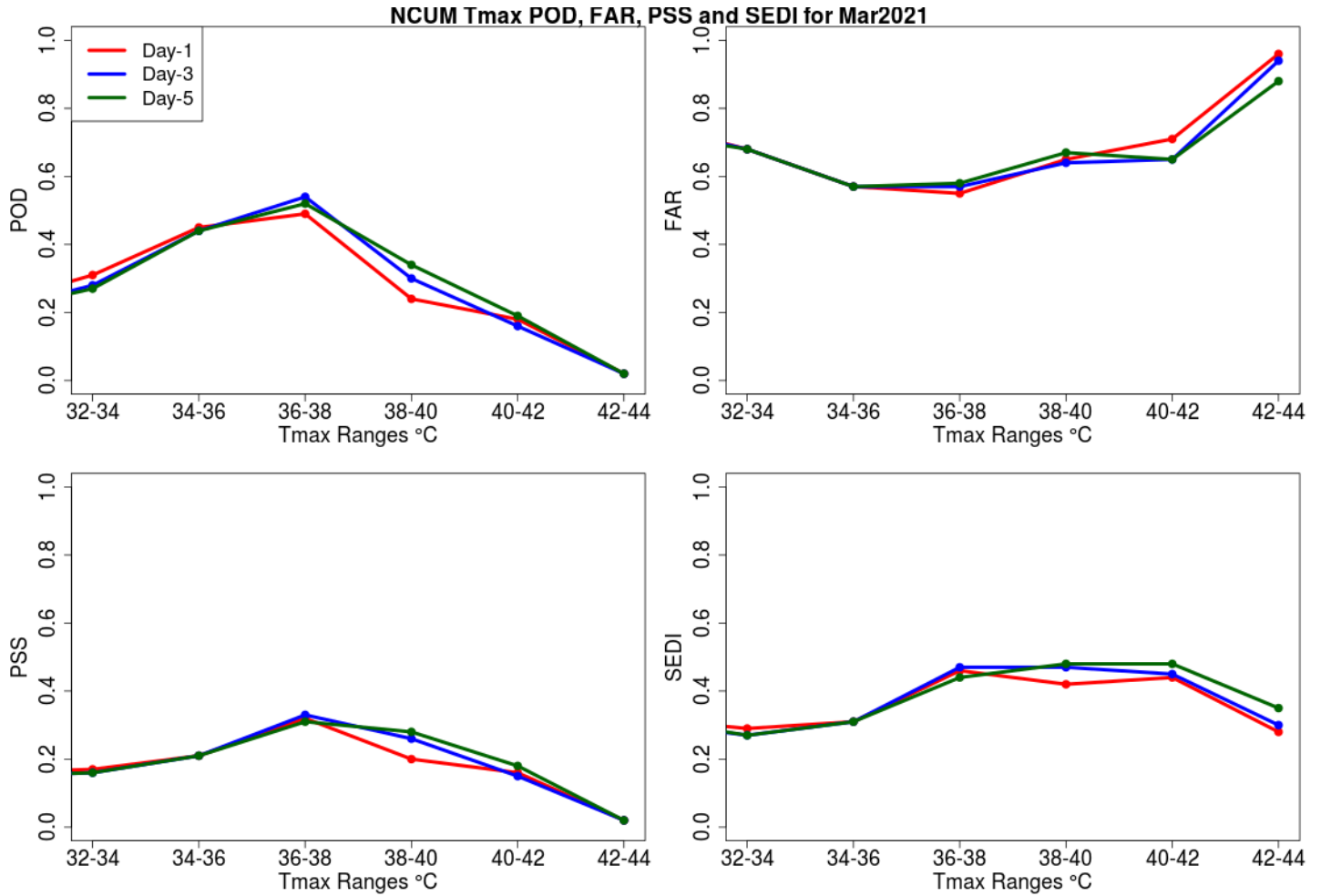


Figure 20. Categorical all India Tmax scores POD (top left), FAR (top right), PSS (bottom left) and SEDI (bottom right).

8. Verification against Radiosonde

a. GEOPOTENTIAL HEIGHT VERIFICATION AGAINST RADIOSONDES OVER INDIAN REGION

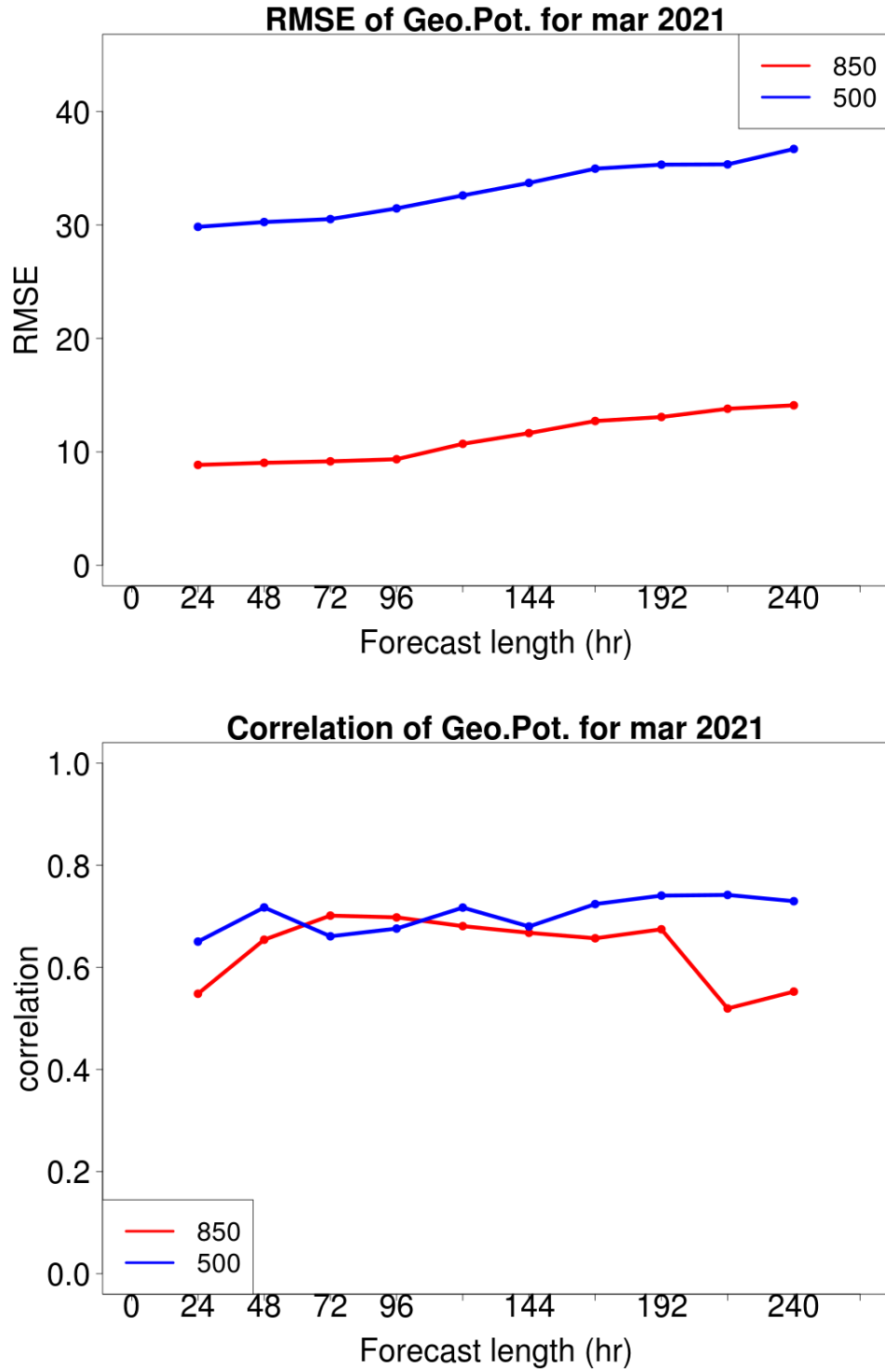


Figure.21. RMSE (upper panel) and Correlation (bottom panel) of geopotential height over Indian region during March 2021

b. TEMPERATURE VERIFICATION AGAINST RADIOSONDES OVER INDIAN REGION

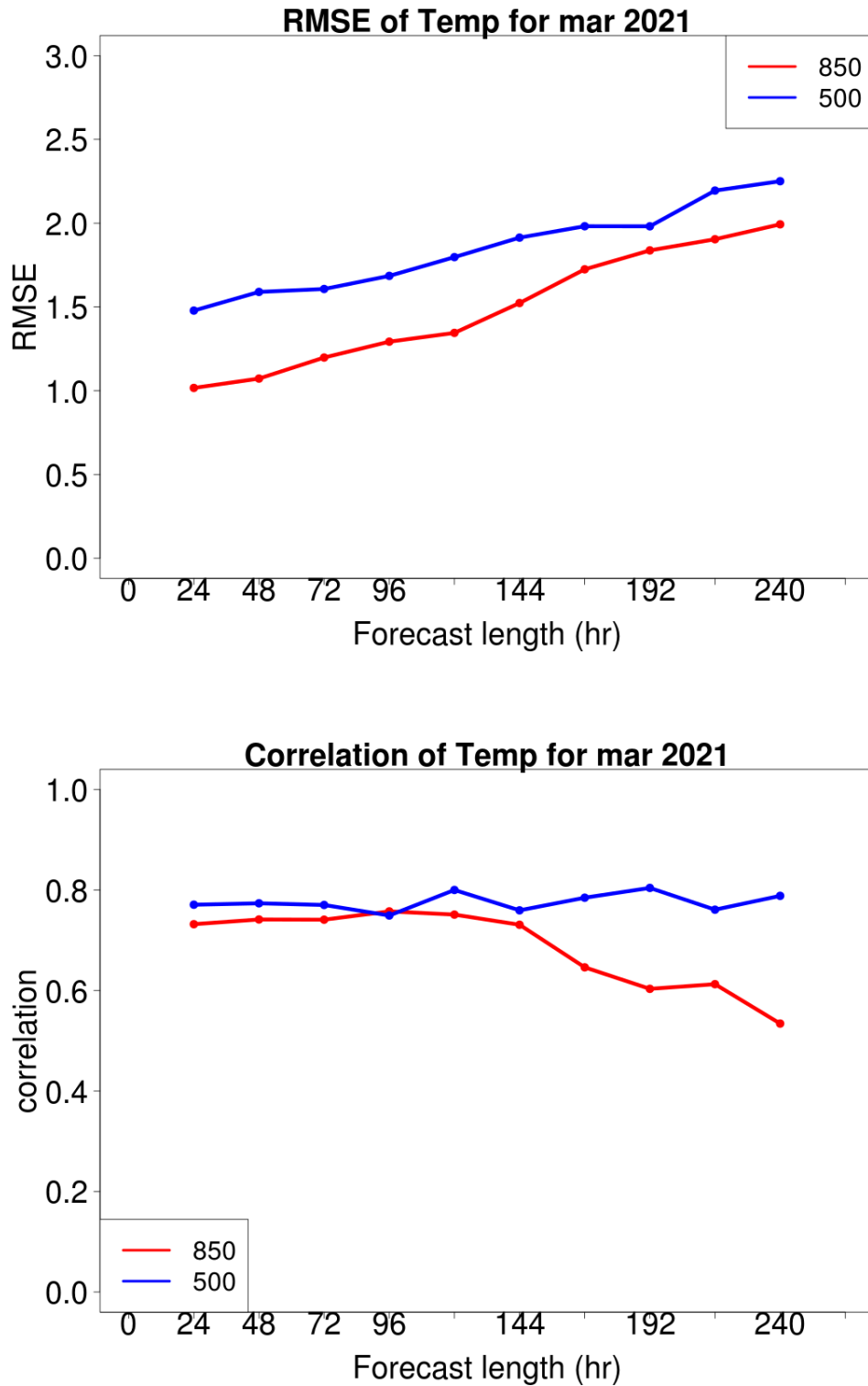


Figure.22. RMSE (upper panel) and Correlation (bottom panel) of Temperature over Indian region during March 2021

c. WIND VERIFICATION AGAINST RADIOSONDES OVER INDIAN REGION

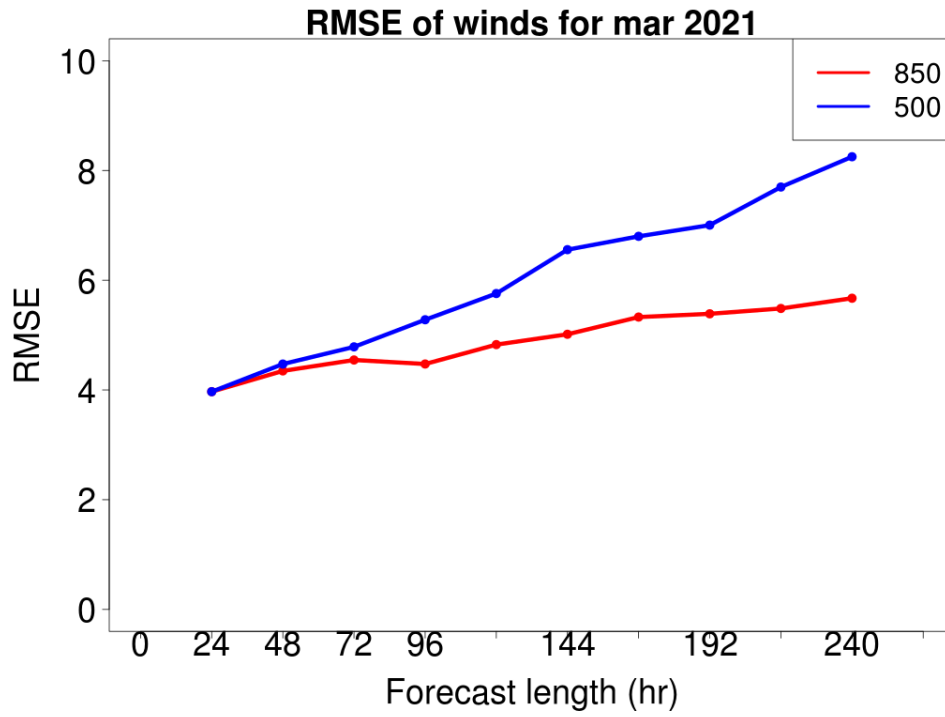


Figure.23. RMSE of wind over Indian region during March 2021.

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 March 2021

Western Disturbances:

The western disturbance activity in the month of March was higher than normal. There were 7 WD's formed against the normal of 4 WD's. Out of 7, two active WD's are presented in this report.

- The analysis on 12 March 2021 (**Figure. 24**) depicts the presence of WD activity over north-western parts of India. The model is able to predict the WD in all forecast lead times. However, the extending of trough and its intensity is weaker in Day-5 forecast. The rainfall associated with this WD (**Figure. 25**) reflects the same.
- The model is able to predict the WD on 23 March 2021 (**Figure. 26**) over north-western side of Punjab and adjoining area. The intensity of the trough is weaker in higher forecast lead times. The rainfall associated with this WD (**Figure. 27**) reflects the same.

Season's First low pressure area over Bay of Bengal:

- A low pressure area as a cyclonic circulation formed over southeast BOB on 31st March 2021. The model is able to predict (**Figure. 28**) the low pressure area accurately up to Day-3. However, the circulation over southern BOB is noticed with spatial shift in Day-3. But, Day-4 and Day-5 forecasts are not able to predict the low pressure area over southern BOB.

Season's First heat wave:

- Heat wave conditions ($>40^{\circ}\text{C}$) at most places over West Rajasthan and adjoining regions are occurred on 30 Mar 2021. Model forecasts (**Figure, 29**) are able to predict the heat wave condition very well over West Rajasthan and adjoining region up to 120 Hrs (Day-5) ahead.

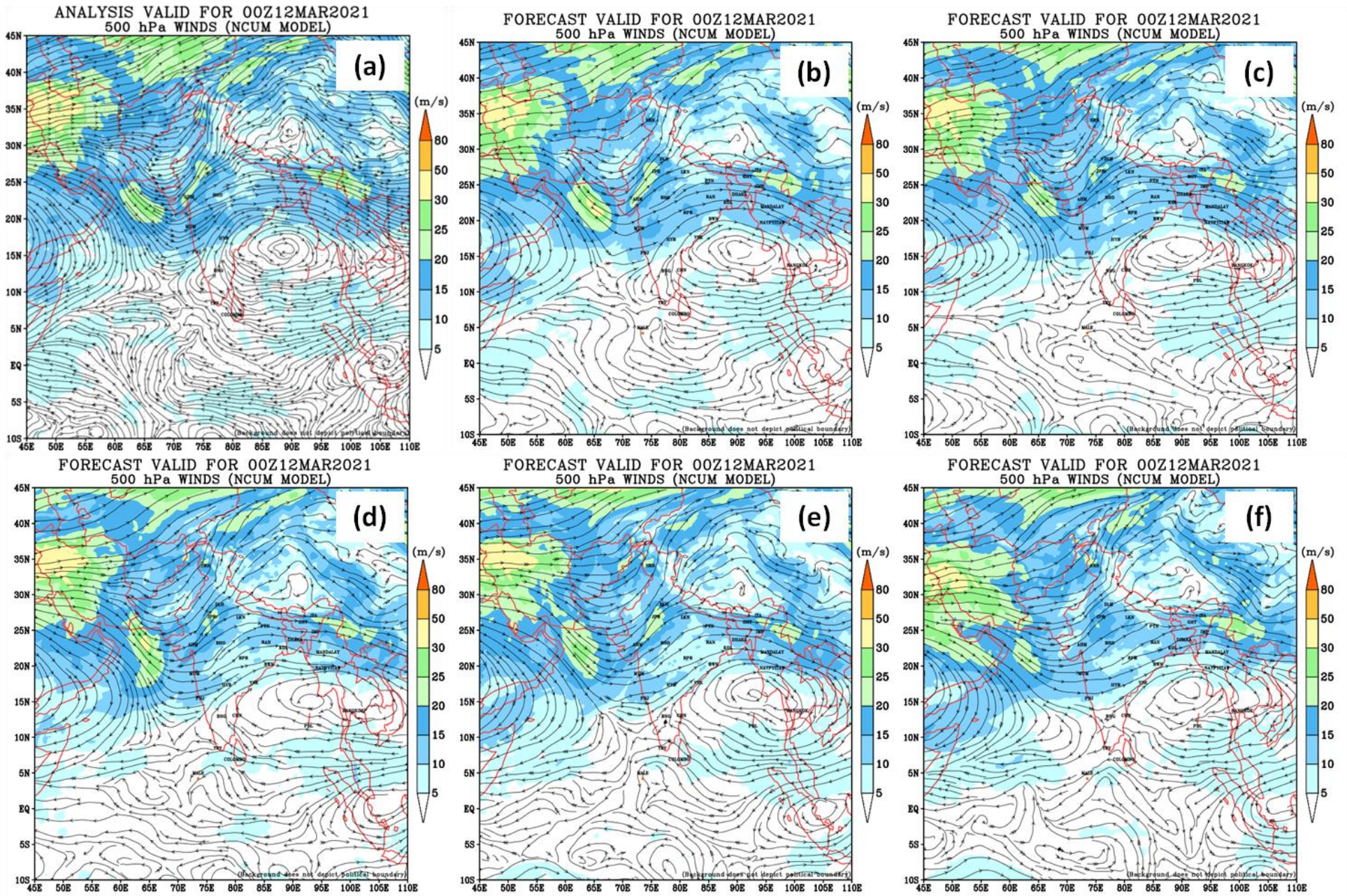


Figure 24. Winds (m/s) at 500 hPa in (a) Analysis (b) Day-1 (c) Day-2 (d) Day-3 (e) Day-4 and (f) Day-5 forecasts valid on 12 March 2021

OBS & NCUM RAINFALL(cm) FCST FOR 03Z12Mar2021

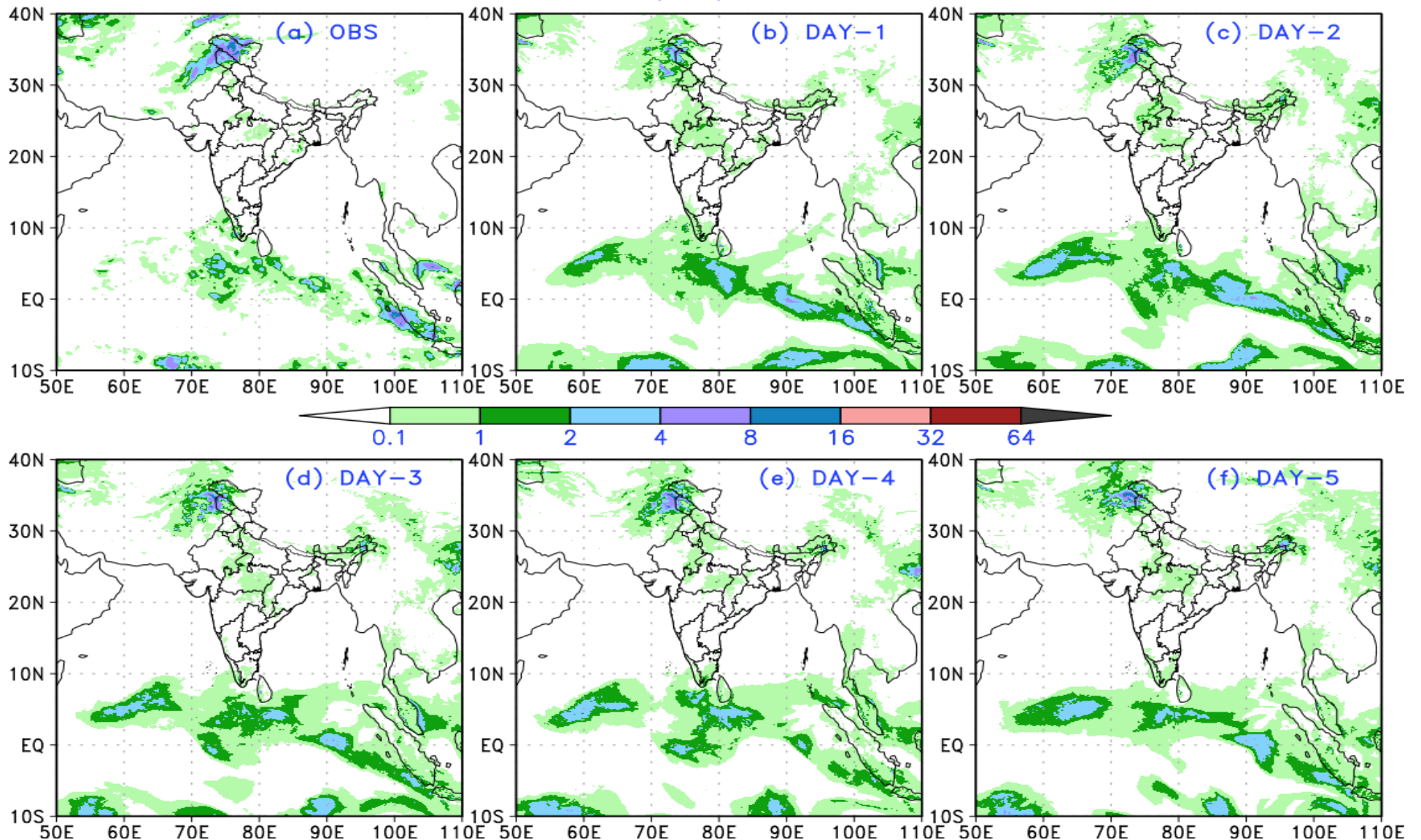


Figure 25. Rainfall (mm) (a) Observed (b) Day-1 (c) Day-2 (d) Day-3 (e) Day-4 and (f) Day-5 forecasts valid on 12 March 2021

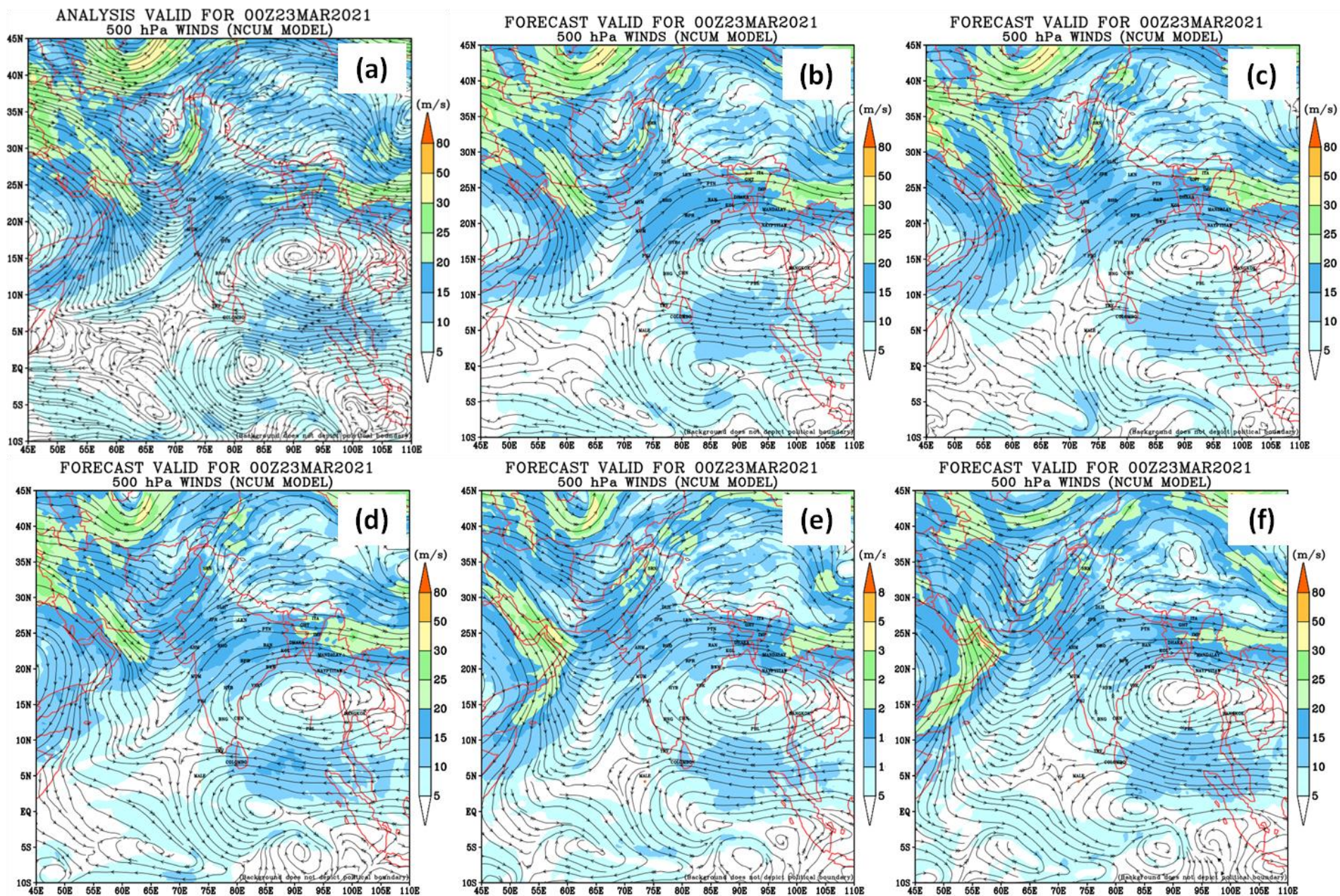


Figure 26. Winds (m/s) at 500 hPa in (a) Analysis (b) Day-1 (c) Day-2 (d) Day-3 (e) Day-4 and (f) Day-5 forecasts valid on 23 March 2021

OBS & NCUM RAINFALL(cm) FCST FOR 03Z23Mar2021

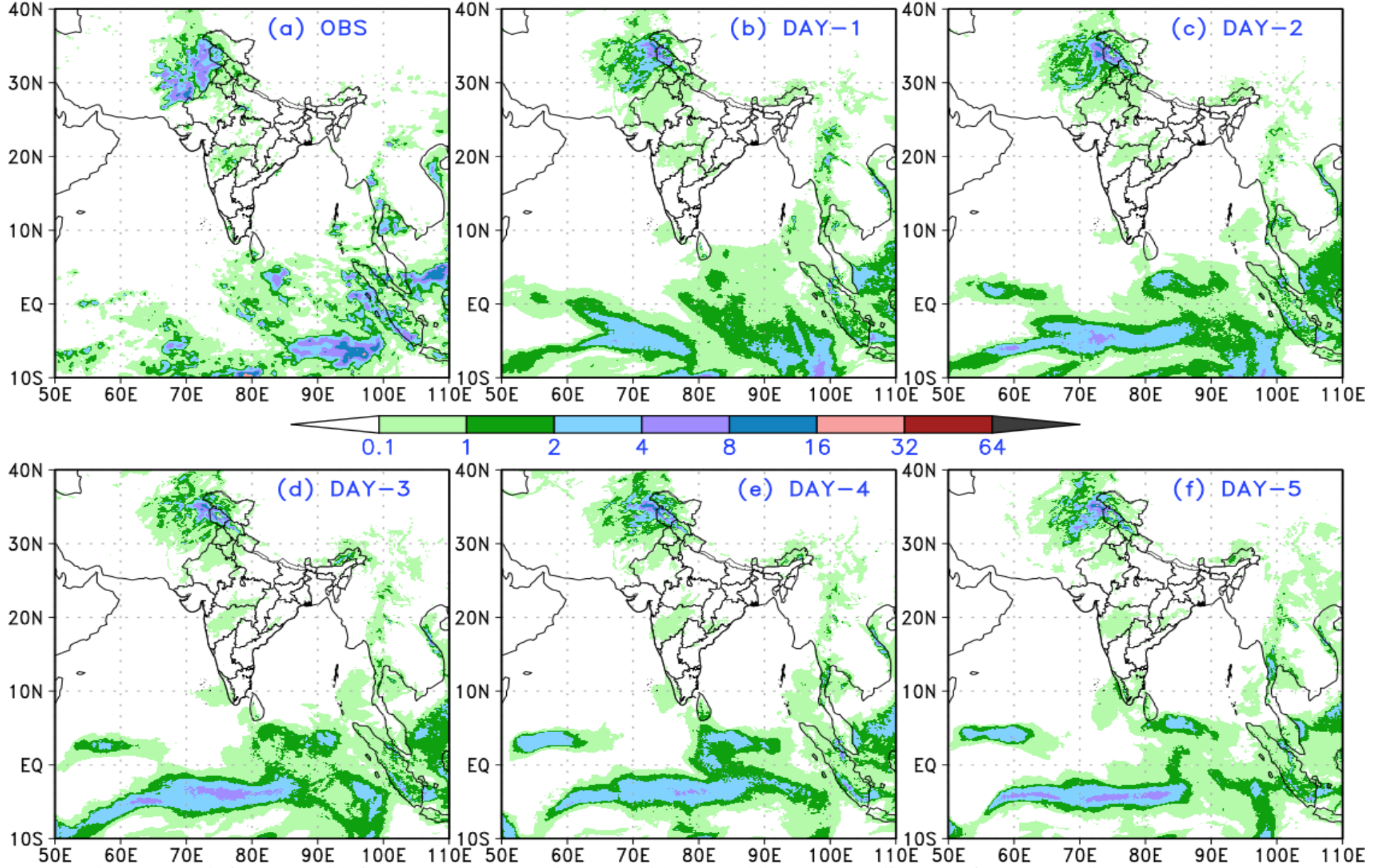


Figure 27. Rainfall (mm) (a) Observed (b) Day-1 (c) Day-2 (d) Day-3 (e) Day-4 and (f) Day-5 forecasts valid on 12 March 2021

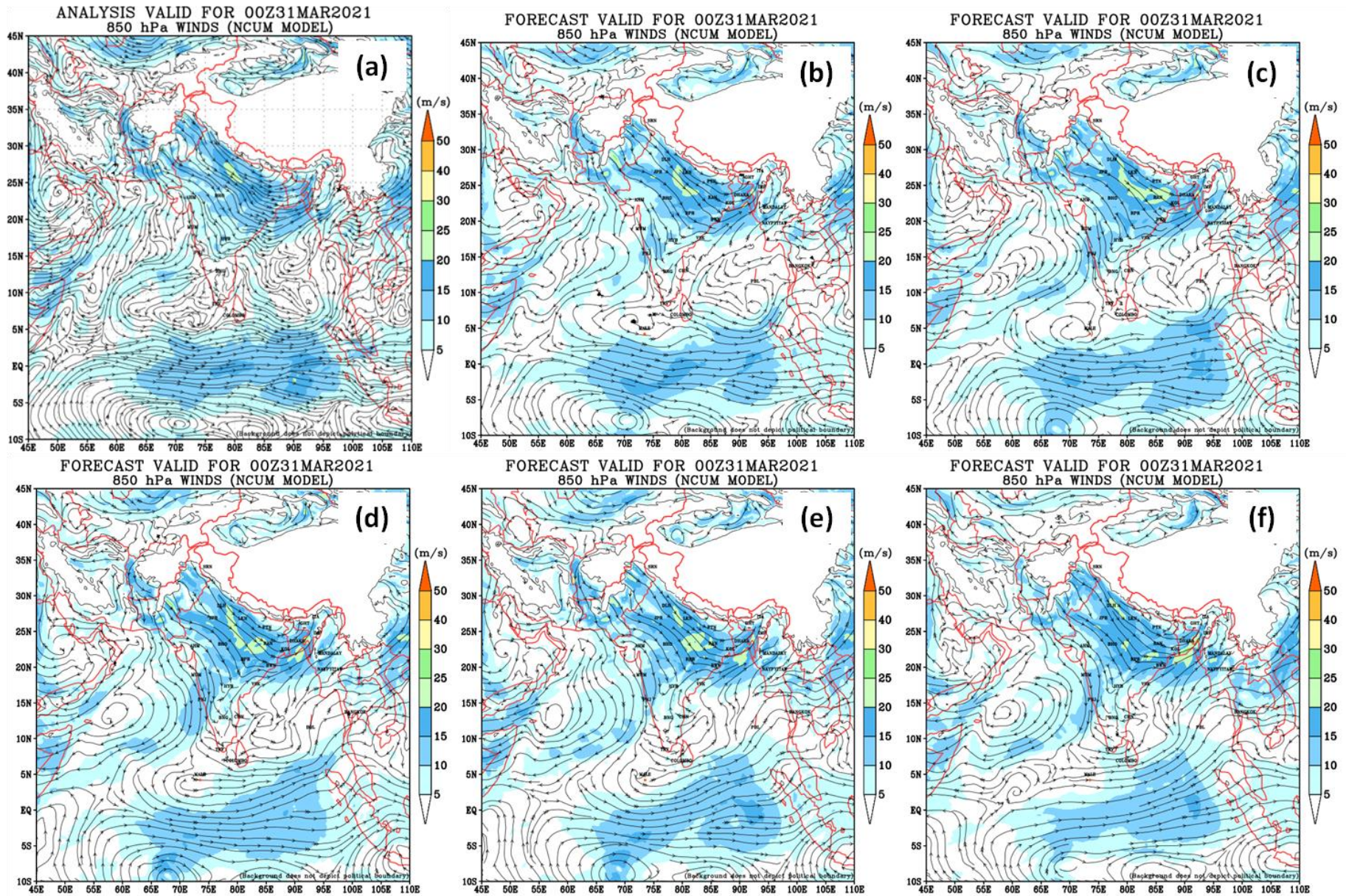


Figure 28. Winds (m/s) at 850 hPa in (a) Analysis (b) Day-1 (c) Day-2 (d) Day-3 (e) Day-4 and (f) Day-5 forecasts valid on 31 March 2021

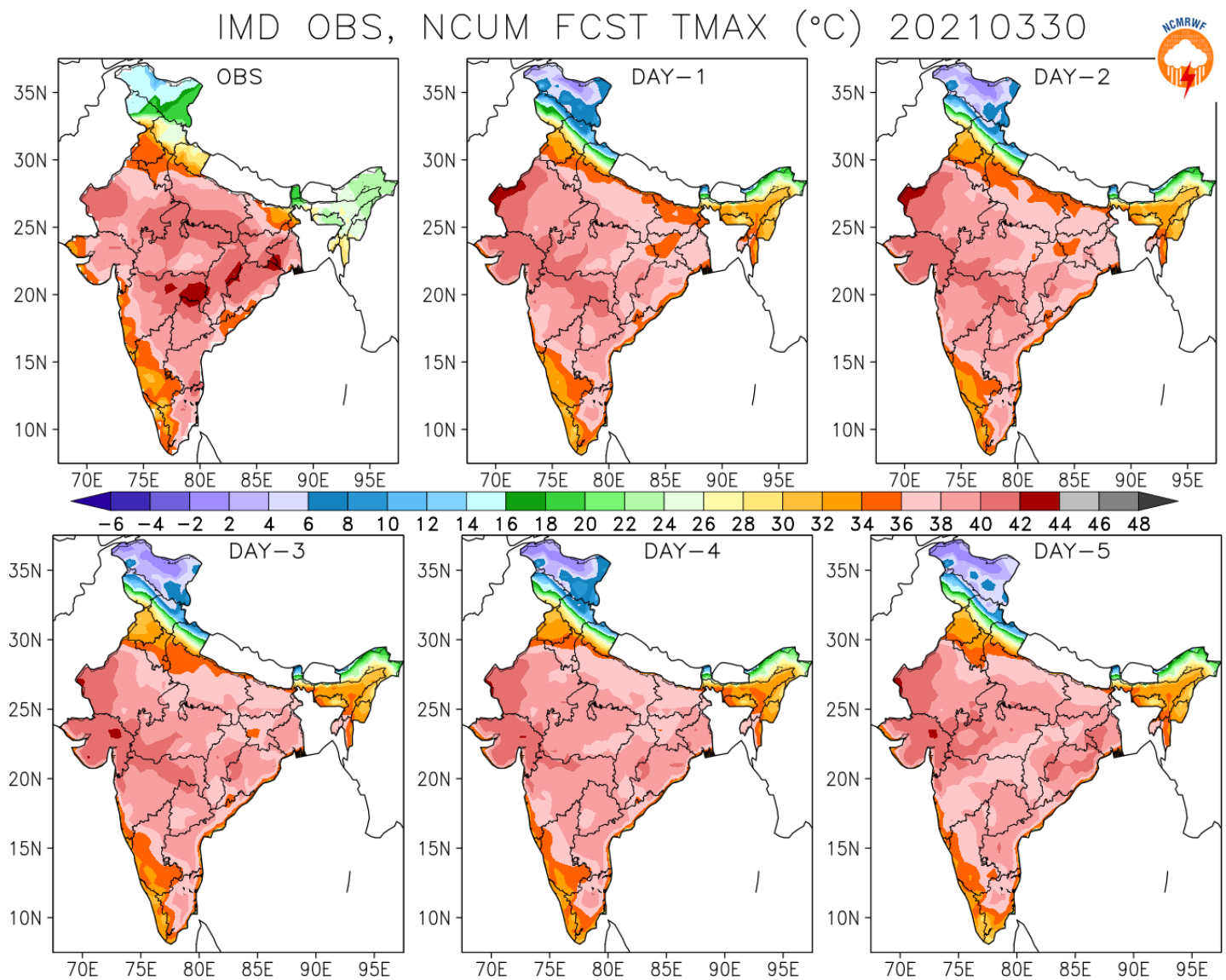


Figure 29. Maximum Temperature($^{\circ}\text{C}$) from (a) IMD-observations (b) Day-1 (c) Day-2 (d) Day-3 (e) Day-4 and (f) Day-5 forecasts of NCUM on 30 March 2021

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