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Evaluating the new test bed radiosonde observations from Bhopal in comparison with NGFS and NCUM forecasts

Durgesh Nandan Piyush, Suryakanti Dutta, S. Indira Rani, and Authors from IITM

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National Centre for Medium Range Weather Forecasting
Ministry of Earth Sciences, Government of India
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10	Abstract	This study performs a comparative analysis of recent testbed radiosonde observations in Bhopal, Madhya Pradesh, with the forecasts and analyses of the NCMRWF Global Forecast System (NGFS) and NCMRWF Unified Model (NCUM) at 06 and 18 UTC. Covering the period from August 10 to September 30, 2023, the research assesses the performance of both models in predicting temperature, wind speed, and moisture profiles across 12 pressure levels. The findings show that both models generally demonstrate accuracy in forecasting temperature and wind speed. However, challenges arise in upper-level wind speed predictions, particularly concerning wind shear and variability at different pressure levels. Furthermore, there is a noticeable increase in uncertainty and bias in moisture profile forecasting, especially in the upper troposphere. Relative humidity predictions are particularly challenging, with the NGFS model exhibiting greater errors and bias compared to the NCUM. The NGFS model shows significant bias and variability in forecasting relative humidity.
11	Security classification	Non-Secure
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सारांश

यह अध्ययन, भोपाल, मध्य प्रदेश में हाल ही में टेस्टबेड रेडियोसोंड अवलोकनों का एनसीएमआरडब्ल्यूएफ ग्लोबल फोरकास्ट सिस्टम (एनजीएफएस) और एनसीएमआरडब्ल्यूएफ यूनिफाइड मॉडल (एनसीयूएम) के पूर्वानुमानों और विश्लेषणों के साथ ०६ और १८ यूटीसी पर तुलनात्मक विश्लेषण करता है। १० अगस्त से ३० सितंबर, २०२३ तक की अवधि को कवर करते हुए, यह शोध दोनों मॉडलों के तापमान, हवा की गति और नमी प्रोफाइलों को १२ दबाव स्तरों पर अनुमानित करने की प्रदर्शनता का आकलन करता है। निष्कर्ष बताते हैं कि दोनों मॉडल सामान्यतः तापमान और हवा की गति के पूर्वानुमान में सटीकता प्रदर्शित करते हैं। हालांकि, ऊपरी स्तर की हवा की गति के पूर्वानुमानों में चुनौतियां उत्पन्न होती हैं। इसके अलावा, नमी प्रोफाइल पूर्वानुमान में अनिश्चितता में उल्लेखनीय वृद्धि पायी गयी है, विशेष रूप से ऊपरी क्षोभ मंडल में। सापेक्ष आर्द्रता के पूर्वानुमान विशेष रूप से चुनौतीपूर्ण हैं, जिसमें एनजीएफएस मॉडल, एनसीयूएम की तुलना में अधिक त्रुटियां दिखाता है।

Abstract

This study performs a comparative analysis of recent testbed radiosonde observations in Bhopal, Madhya Pradesh, with the forecasts and analyses of the NCMRWF Global Forecast System (NGFS) and NCMRWF Unified Model (NCUM) at 06 and 18 UTC. Covering the period from August 10 to September 30, 2023, the research assesses the performance of both models in predicting temperature, wind speed, and moisture profiles across 12 pressure levels. The findings show that both models generally demonstrate accuracy in forecasting temperature and wind speed. However, challenges arise in upper-level wind speed predictions, particularly concerning wind shear and variability at different pressure levels. Furthermore, there is a noticeable increase in uncertainty and bias in moisture profile forecasting, especially in the upper troposphere. Relative humidity predictions are particularly challenging, with the NGFS model exhibiting greater errors and bias compared to the NCUM. The NGFS model shows significant bias and variability in forecasting relative humidity.

1. Introduction

Our understanding of the atmospheric system relies heavily on meteorological data. To comprehend weather, climate processes, variability, extremes, and climate change, we need extensive records of observations. Without these records, gaining insight into these aspects becomes impractical. Radiosonde observations are pivotal in meteorological studies, providing crucial data about the atmosphere's vertical profile. These small, expendable instruments are attached to weather balloons and lifted into the atmosphere, transmitting real-time information on temperature, humidity, and atmospheric pressure as they ascend and descend (Durre et al., 2006). This data is crucial in understanding atmospheric conditions, contributing to accurate weather forecasts and climate research.

Upper air soundings are pivotal in understanding the thermodynamic conditions of the atmosphere. Radiosondes help identify temperature inversions, track air masses, and monitor the development of weather systems. The data obtained from it gives a comprehensive view of the vertical structure of the atmosphere, which is crucial for calibrating and assimilating numerical models. Consequently, RS/RW soundings significantly improve model forecasting abilities for short to medium-term predictions. By offering insights into the atmosphere's behaviour at different altitudes, radiosonde observations enhance our ability to predict and understand weather patterns. This ultimately improves public safety and supports scientific advancements in meteorology.

Comparing radiosonde observations with model outputs has been essential for pinpointing where models need improvement (Santer et al., 2008). Differences can arise from multiple factors, including model parameterizations, numerical approximations, and the quality of input data. By calibrating model simulations against observed radiosonde data, researchers can incrementally refine model parameters, thereby enhancing the model's accuracy in representing real-world atmospheric conditions. Durgesh (2024) conducted a similar exercise by comparing radiosonde observations obtained from CAPIEX at Solapur, Maharashtra. Both models (NCUM and NGFS) exhibit consistent temperature and wind speed forecasting accuracy, but the forecasting of moisture profiles introduces increased uncertainty and bias.

The present study compares meteorological variables such as temperature, relative humidity, and wind speed measured from the testbed radiosonde observations deployed at Bhopal, Madhya Pradesh.

2. Study Area

We have used the radiosonde observation from Bhopal, Madhya Pradesh. The location of the radiosonde is shown in Fig (1). This radiosonde is providing data since Aug 2023, at 06 and 18 UTC. Currently, only ascending observations are received at NCMRWF.

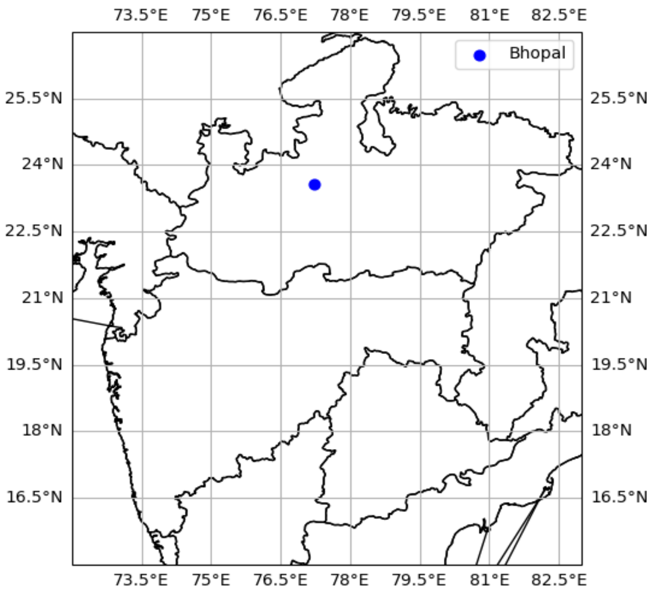

Figure 1 *Location of the Bhopal, Madhya Pradesh (Blue) Radiosonde*

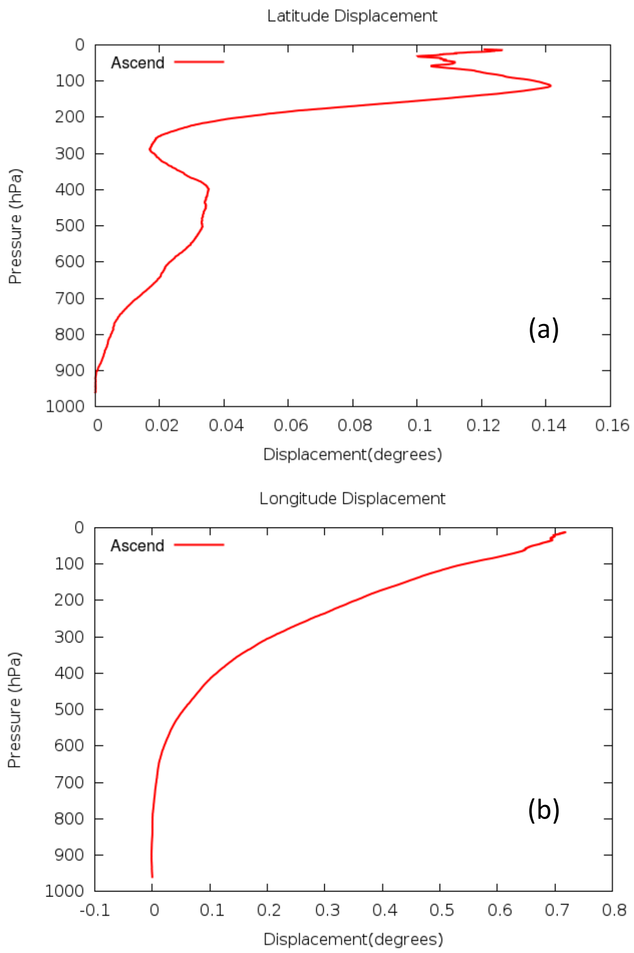

Figure 2 *latitudinal (2a) and longitudinal (2b) deviation of the Bhopal radiosonde in ascending mode with vertical pressure levels*

Figure 2 illustrates the trajectory covered by the radiosonde. The depicted plot corresponds to data collected on August 18, 2023. From bottom to top, the longitudinal displacement is almost 0.7^o, whereas latitudinal displacement is 0.12^o for this day.

3. Data and Methodology

NCMRWF generates two sets of NWP model initial conditions/analyses at six-hour intervals using the NCMRWF Global Forecast System (NGFS) and the NCMRWF Unified Model (NCUM). These updates occur four times daily at 00, 06, 12, and 18 UTC. Further information and upgrades to NGFS and NCUM can be found in Prasad and Johny (2016), Prasad et al. (2016, 2014), and Rajagopal et al. (2012).

NCMRWF assimilates diverse conventional and satellite observations received within the cutoff time (± 3 hours) of each assimilation cycle (Rani et al., 2019). Although the assimilation techniques differ between the two models, Hybrid 4D-EnVar based on the Gridpoint Statistical

Interpolation (GSI) technique in NGFS and Hybrid-4DVar in NCUM, both the models assimilate nearly the same number of observations from various platforms.

Analysis and forecasts from both NCUM and NGFS models are available at their respective parent resolutions and coarser resolutions. The NCUM model has a horizontal grid spacing of 0.12 × 0.18 in the horizontal and 70 levels in the vertical, reaching up to 80 km at the model top. For NGFS, the horizontal grid spacing is 0.12 × 0.12, with 64 levels in the vertical. The six-hour forecasts and analysis at 06 UTC and 18 UTC were used for comparison.

Every new measurement must undergo a validation process to ensure the accuracy of the generated information. This process verifies that the data has been produced correctly and allows for corrective action in case of erroneous detection (Estévez et al., 2011, Wang et al., 2016). In this study, the performance of the analyzed variable was evaluated using RMSE (Root Mean Square Error) and Bias. The RMSE of the observation was computed against the model background and the analysis using Equation 1.

Bias refers to a systematic error or deviation from the true value in measurements or observations. It can result from various factors such as instrumentation limitations, environmental conditions, or inherent flaws in the data collection process. Bias introduces a consistent inaccuracy, affecting the reliability and validity of results. The bias is computed as the departure from the background/analysis. A positive bias indicates underprediction, while a negative bias indicates overprediction.

$$RMSE = \sqrt{\sum_{i=1}^{n} \frac{(X_i - Y_i)^2}{n}} \qquad (1)$$

Where X are the radiosonde observations, Y are the model analysis/forecasts, and n is the total number of pairs of data points.

A total of 40-day observations from 10 Aug to 20 Sep 2023 are used for this comparison study. The radiosonde observation was available at a very high vertical resolution whereas the model fields are at 64 pressure levels for NGFS and 70 pressure levels for NCUM. To do a three-way comparison, all three datasets are kept at standard pressure levels, from 925 - 30 hPa, for 12 pressure levels. The radiosonde observations were available for almost 5000-6000 vertical pressure levels in ascend phase. Radiosonde observations are assigned to the closest of the common standard pressure levels. During the ascent phase of the radiosonde, the initial observation near the surface was used to determine the latitude and longitude for the corresponding NGFS/NCUM grid.

The proceeding section discusses comparison diagnostics of relative humidity (RH), temperature (TEMP) and wind speed of the radiosonde observations with NCUM and NGFS forecasts and analysis.

4. Results and Discussion

The testbed radiosonde, which IITM manages, provides data at two-time steps at 06 and 18 UTC. This dataset is assessed using in-house NGFS and NCUM global model analysis and forecasts.

Table (1) and Table (2) show RMSE and Bias for the NGFS forecast and analysis for relative humidity (RH), temperature (Temp) and wind speed (WS). At 925 - 850 hPa level, the model tends to under-predict RH while over-predicting temperature and WS. The RMSE values for temperature and wind speed along 925 hPa and 850 hPa remain relatively low, indicating consistent accuracy in these predictions. However, there is a noticeable increase in RMSE for relative humidity, signifying a disparity between model forecasts and actual observations for the moisture fields. At higher altitudes (700 hPa and above), the RMSE values for all three parameters experience fluctuations. While temperature predictions generally exhibit good accuracy, there is an upward trend in RMSE for relative humidity and wind speed, suggesting increasing discrepancies between the NGFS forecasts and radiosonde observations. At these levels, there is an over-prediction of relative humidity and wind speed, while temperature is slightly under-predicted. At the 500 hPa level, RH and WS continue to be under-predicted, while temp displays a slight overestimation. One prominent feature of the RH is the wet bias of ~50 %. From 400 hPa to 100 hPa, the wet bias increases from 18 % to almost 50 %. Huge over prediction is found in the NGFS RH at these levels.

Table 1 *RMSE of NGFS relative humidity (red), Temperature (blue), and Wind Speed (green) computed against the 06 UTC Bhopal Radiosonde*

	RH		**Temp**		**WS**	
	Analysis	*Forecast*	*Analysis*	*Forecast*	*Analysis*	*Forecast*
925	18.47	19.03	1.97	2.04	3.67	3.81
850	12.23	13.24	1.47	1.36	4	4.17
700	30.88	31.04	2.52	2.34	3.46	3.56
500	39.86	39.08	1.78	1.73	4.71	4.7
400	37.89	36.17	1.9	1.94	4.1	3.92
300	51.23	49.92	2.08	2.14	4.1	4.28
250	49.43	47.1	2.17	2.26	6.17	6.26
200	47.09	46.16	2.08	2.29	8.08	8.01
150	47.96	48.34	1.61	1.81	11.22	11.09
100	51.61	49.73	1.65	1.74	9.69	9.92
70	6.26	6.04	2.88	2.69	6.32	6.42
30	1.24	1.24	4.46	4.38	4.32	4.48

Table 2 *Bias of NGFS relative humidity (red), Temperature (blue), and Wind Speed (green) computed against the 06 UTC Bhopal Radiosonde*

	RH		**Temp**		**WS**	
	Analysis	*Forecast*	*Analysis*	*Forecast*	*Analysis*	*Forecast*
925	12.89	13.64	-0.08	-0.4	-0.35	-0.81
850	6	7.78	0.87	0.49	0.66	0.32
700	-3.25	-3.11	2.1	1.89	-1.32	-1.53
500	1.39	2.57	1.22	1.19	1.84	1.81
400	-16.78	-15.02	1.62	1.65	3.2	3.09
300	-38.23	-38.64	1.92	2.01	-0.55	-0.21
250	-37.75	-37.75	1.99	2.11	-3.01	-3.04
200	-40.51	-40.77	1.96	2.18	-5.49	-5.39
150	-44.76	-44.84	1.46	1.7	-8.11	-8.15
100	-49.7	-47.51	-0.52	-0.62	-7.63	-7.86
70	-1.33	-1.44	-1.26	-1.13	-4.57	-4.73
30	0.8	0.8	-0.9	-0.75	-3.03	-3.18

Table 3 and Table 4 show the RSME and bias computed against the 06 UTC NCUM analysis and forecast. The NCUM model demonstrates a close agreement with the observed values for temperature. At 925 -850 hPa, for RH, RMSE is between 5-7 % with a bias of less than 2.5 %. The temperature and wind speed forecast match well with the radiosonde observations, with very little bias and low RMSE.

As we ascend to the 700 hPa and 500 hPa levels, the NCUM model maintains generally accurate temperature and wind speed forecasts. Still, a gradual increase in RMSE for relative humidity is noticed. The model exhibits resilience in capturing the vertical structure of the atmosphere, with RMSE values for temperature and wind speed consistently lower. There is an over-prediction of 2-4 % in relative humidity at 700 hPa. At the 500 hPa level, relative humidity and temperature are under-predicted, while wind speed displays a negative bias of 0.21 m/s.

At higher altitudes (400 hPa to 200 hPa), the RMSE values indicate varying degrees of model accuracy. NCUM performs well in forecasting temperature and wind speed, with RMSE less than 3 m/s for wind speed and less than 1 K for temperature. Moreover, challenges in predicting relative humidity become more apparent, particularly at higher pressure levels. NCUM shows a wet bias of ~ 4-10 % at these levels. Generally, there is a tendency to over-predict relative humidity, while wind speed and temperature show variations with a mix of negative and positive biases.

Table 3 *RMSE of NCUM relative humidity (red), Temperature (blue), and Wind Speed (green) computed against the 06 UTC Bhopal Radiosonde*

	RH		**Temp**		**WS**	
	Analysis	*Forecast*	*Analysis*	*Forecast*	*Analysis*	*Forecast*
925	4.92	4.01	0.52	0.61	2.23	2.17
850	7.76	7.97	0.46	0.58	2.01	2.46
700	16.96	19.79	1.03	1.05	2.79	3.21
500	19.94	22.46	1.11	1.18	2.82	3.06
400	16.65	17.26	0.66	0.68	3.14	3.29
300	15.05	16.27	0.48	0.49	2.45	2.66
250	13.26	13.73	0.54	0.61	2.28	2.59
200	14.23	14.77	0.63	0.64	2.28	2.38
150	16.36	14.44	0.65	0.78	3.19	3.08
100	17.6	16.03	2.61	2.71	3.54	3.42
70	9.85	8.2	2.49	2.47	5.23	5.29
30	11.13	11.13	6.9	6.74	4.64	4.46

Table 4 *Bias of NCUM relative humidity (red), Temperature (blue), and Wind Speed (green) computed against the 06 UTC Bhopal Radiosonde*

	RH		Temp		WS	
	Analysis	*Forecast*	*Analysis*	*Forecast*	*Analysis*	*Forecast*
925	2.17	1.84	-0.28	-0.45	0.45	0.24
850	-1.01	0.81	0.05	-0.23	0.05	-0.11
700	-2.47	-4.29	0.3	0.4	-0.74	-1.06
500	2.12	3.83	0.05	0.1	-0.21	-0.52
400	8.27	8.79	-0.03	-0.03	-0.08	-0.12
300	-2	-2.59	-0.07	-0.15	-0.57	-0.66
250	-1.07	-1.39	-0.41	-0.45	-0.05	-0.27
200	-4.73	-5.21	-0.53	-0.53	-0.23	-0.03
150	-5.32	-6.35	0.14	-0.18	-0.29	0.09
100	-8.52	-7.31	0.47	0.47	-0.98	-0.57
70	-2.52	-2.04	-0.68	-0.78	-1.34	-1.28
30	3.53	3.53	-3.17	-2.9	-1.61	-1.98

Table 5 *RMSE of NGFS relative humidity (red), Temperature (blue), and Wind Speed (green) computed against the 18 UTC Bhopal Radiosonde*

	RH		Temp		WS	
	Analysis	*Forecast*	*Analysis*	*Forecast*	*Analysis*	*Forecast*
925	13.03	13.38	1.53	1.79	1.66	1.8
850	11.8	12.09	0.82	0.9	1.73	2.43
700	15.06	15.68	0.89	0.84	1.63	2.07
500	13.87	13.74	0.61	0.62	1.99	2.2
400	16.56	17.74	0.49	0.61	2.55	2.34
300	20.39	24.21	0.36	0.38	2.23	2.64
250	29.32	28.33	0.34	0.38	1.82	1.98
200	40.32	41.32	0.3	0.37	2.4	2.42
150	47.73	48.64	0.38	0.55	3.45	3.6
100	55.63	56.09	0.91	0.94	2.86	3.11
70	14.77	14.47	1.67	1.62	3.59	3.66
30	0.67	0.66	2.14	2.15	2.68	2.79

Table 6 *Bias of NGFS relative humidity (red), Temperature (blue), and Wind Speed (green) computed against the 18 UTC Bhopal Radiosonde*

	RH		**Temp**		**WS**	
	Analysis	*Forecast*	*Analysis*	*Forecast*	*Analysis*	*Forecast*
925	10.36	10.36	-0.8	-1.05	-0.55	-0.75
850	4.49	4.43	0.08	-0.17	0.25	-0.09
700	6.12	7.79	0.09	-0.16	0.4	0.76
500	0.6	0.75	0.19	0.27	1.11	1.08
400	-5.16	-7.05	0.13	0.32	0.87	0.95
300	-14.26	-16.36	0.09	0.15	0.51	0.83
250	-21.24	-21.65	-0.02	0.11	0.78	0.75
200	-34.86	-36.04	-0.08	0.11	0.79	0.72
150	-44.34	-46.01	0.19	0.37	1.26	1.18
100	-54.41	-54.96	-0.21	-0.17	0.59	0.26
70	-11.51	-10.97	-0.24	-0.2	1.53	1.51
30	0.11	0.15	-0.63	-0.56	-0.57	-0.93

Table 7 *RMSE of NCUM relative humidity (red), Temperature (blue), and Wind Speed (green) computed against the 18 UTC Bhopal Radiosonde*

	RH		**Temp**		**WS**	
	Analysis	*Forecast*	*Analysis*	*Forecast*	*Analysis*	*Forecast*
925	9.58	9.35	1.47	1.55	1.57	1.72
850	9.93	10.58	0.69	0.95	1.98	2.36
700	17.71	15.59	0.98	1.04	2.26	2.56
500	11.81	14.36	0.83	0.88	1.8	1.7
400	13.03	12.59	0.51	0.52	2.23	2.21
300	10.79	14.72	0.43	0.5	2.36	2.42
250	15.76	16.6	0.56	0.65	1.89	1.81
200	18.53	21.89	0.65	0.74	2.41	2.63
150	15.35	17.98	0.58	0.44	3.01	3.4
100	16.86	16.14	1	1.02	2.82	3.28
70	8.43	8.62	1.96	1.93	4.11	4.04
30	0.76	0.75	2.27	2.21	2.62	2.81

Table 8 *Bias of NCUM relative humidity (red), Temperature (blue), and Wind Speed (green) computed against the 18 UTC Bhopal Radiosonde*

	RH		**Temp**		**WS**	
	Analysis	*Forecast*	*Analysis*	*Forecast*	*Analysis*	*Forecast*
925	7	7.56	-0.88	-1.06	-0.29	-0.55
850	5.13	5.87	-0.42	-0.6	0.11	-0.2
700	6.75	5.22	-0.26	-0.37	0.1	-0.06
500	1.3	-0.98	0.42	0.46	0.1	-0.27
400	5.72	4.1	0.22	0.09	-0.28	-0.32
300	-1.37	-3.13	-0.01	-0.21	-0.27	-0.08
250	-6.03	-8.64	-0.38	-0.49	0.58	0.35
200	-8.75	-12.35	-0.54	-0.66	0.75	0.64
150	-8.17	-12.13	0.41	-0.01	0.89	0.83
100	-7.85	-12.36	0.22	0.26	-0.38	-0.81
70	-4.23	-4.68	-0.81	-0.51	2.1	1.9
30	0.7	0.7	-0.98	-1	-0.76	-0.82

Tables 5 to 8 provide detailed comparison diagnostics for NGFS/NCUM forecast/analysis fields with radiosonde observations, focusing on 18 UTC. Notably, the relative humidity from NGFS exhibits higher RMSE compared to NCUM forecast/analysis across nearly all pressure levels. Both models display wet biases in the middle to the upper atmosphere (300 - 70 hPa), with NGFS showing more pronounced biases than NCUM. However, it is noteworthy that both models demonstrate accurate temperature and wind speed forecasts, highlighting precision in these aspects of atmospheric prediction.

5. Conclusion:

The report provides a comprehensive comparison of new testbed radiosonde observations over Bhopal, Madhya Pradesh, with the NGFS and NCUM models for 06 and 18 UTC over 40 days in August and September 2023. This comparison was conducted across 12 pressure levels, ranging from 925 to 30 hPa. The high-resolution radiosonde observations and NGFS/NCUM analysis/forecast fields were aligned at the same pressure levels for evaluation. Both models consistently show accurate forecasts for temperature and wind speed, though they face minor challenges in predicting upper-level wind speeds. However, the forecasting of moisture profiles present increased uncertainty and bias. Despite the models' proficiency in predicting temperature and wind speed, accurately predicting relative humidity remains a significant challenge, with the NGFS model displaying more errors and biases than the NCUM. It should be noted that radiosonde data was available only for the ascent phase at both time steps (06 and 18 UTC). Descent phase observations are expected to be more accurate due to less longitudinal and latitudinal deviation compared to the ascent phase. In the future, when data becomes available from IITM, it will be compared in a similar manner.

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