NMRF/TR/10/24

TECHNICAL REPORT

Assessment of Radiosonde Data from CAIPEX, Solapur Against NGFS, and NCUM Forecasts

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

December 2024

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

Assessment of Radiosonde Data from CAIPEX, Solapur Against NGFS, and NCUM Forecasts

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

December 2024

National Centre for Medium Range Weather Forecasting Ministry of Earth Sciences A-50, Sector 62, NOIDA, UP-201309, India

Ministry of Earth Sciences
National Centre for Medium Range Weather Forecasting
Document Control Data Sheet

1	Name of the Institute	National Centre for Medium Range Weather Forecasting
2	Document Number	NMRF/TR/10/2024
3	Month of publication	December 2024
4	Title of the document	Assessment of Radiosonde Data from CAIPEX, Solapur Against NGFS, and NCUM Forecasts
5	Type of Document	Technical Report
6	Number of pages, Figures, and Tables	13 Pages, 10 Figures
7	Number of References	8
8	Author (S)	Durgesh Nandan Piyush, Suryakanti Dutta, S. Indira Rani, and Authors from IITM
9	Originating Unit	NCMRWF
10	Abstract	The present work undertakes a comparative study of the radiosonde observations at Solapur, Maharashtra, against the NCMRWF Global Forecast System (NGFS) and NCMRWF Unified Model (NCUM) model forecast and analysis at 06 UTC, both ascend and descend phase. This radiosonde observation was a part of the CAIPEX experiments conducted by the Indian Institute of Tropical Meteorology around the Western Ghats and the Arabian Sea. A 40-day observations Spanning from August 10 to September 30, 2023 are utilized. The study assesses the models performance in predicting temperature, wind speed, and moisture profiles across 12 standard pressure levels. While both models consistently demonstrate accuracy in temperature and wind speed forecasts, challenges arise in upper-level wind speed predictions, and a notable increase in uncertainty and bias is observed in moisture profile forecasting. Particularly, relative humidity forecasting presents difficulties, with the NGFS model exhibiting more errors and bias than NCUM.
11	Security classification	Non-Secure
12	Distribution	Unrestricted Distribution
13	Key Words	NGFS, NCUM, CAIPEX, Radio Sonde

Table of Contents

सारांश

प्रस्तुत कार्य में, सोलापुर महाराष्ट्र में स्थापित रेडियोसोंडे अवलोकनों का तुलनात्मक अध्ययन किया गया है, यह अध्ययन एनसीएमआरडब्ल्यूएफ ग्लोबल फोरकास्ट सिस्टम (एनजीएफएस) और एनसीएमआरडब्ल्यूएफ यूनिफाइड मॉडल (एनसीयूएम) पूर्वानुमानों और विश्लेषण के साथ 06 यूटीसी, दोनों आरोहण और अवरोहण चरणों के लिए किया गया है। यह रेडियोसोंडे अवलोकन भारतीय उष्णकटिबंधीय मौसम विज्ञान संस्थान द्वारा पश्चिमी घाट और अरब सागर के आसपास किए गए सीएआईपीईएक्स प्रयोगों का हिस्सा था। ४० दिनों के अवलोकनों का उपयोग किया गया है जो 10 अगस्त से 30 सितंबर 2023 तक के हैं। इस अध्ययन में दोनों मौसम पूर्वानुमान मॉडलों के तापमान, वायु की गति और नमी के पूर्वानुमानों का मूल्यांकन 12 मानक दबाव स्तरों पर किया गया है। दोनों मौसम पूर्वानुमान मॉडल तापमान और वायु की गति के पूर्वानुमानों में निरंतर सटीकता प्रदर्शित करते हैं, परन्तु ऊपरी दबाव स्तरों पर हवा की गति के पूर्वानुमानों में चुनौतियाँ दिखती हैं, इसी के साथ ही नमी के पूर्वानुमानों में भी अनिश्चितता में उल्लेखनीय वृद्धि पायी गयी है। अगर हम विशेष रूप से सापेक्षिक आद्रता को देखे तो ऊपरी दबाव स्तरों पर एनसीएमआरडब्ल्यूएफ ग्लोबल फोरकास्ट सिस्टम (एनजीएफएस) एनसीएमआरडब्ल्यूएफ यूनिफाइड मॉडल (एनसीयूएम) मॉडल पूर्वानुमानों की तुलना में अत्यधिक त्रुटियां प्रदर्शित करता है।

Abstract

The present work undertakes a comparative study of the radiosonde observations at Solapur, Maharashtra, against the NCMRWF Global Forecast System (NGFS) and NCMRWF Unified Model (NCUM) model forecast and analysis at 06 UTC, both ascend and descend phase. This radiosonde observation was a part of the CAIPEX experiments conducted by the Indian Institute of Tropical Meteorology around the Western Ghats and the Arabian Sea. A 40-day observations Spanning from August 10 to September 30, 2023 are utilized. The study assesses the models performance in predicting temperature, wind speed, and moisture profiles across 12 standard pressure levels. While both models consistently demonstrate accuracy in temperature and wind speed forecasts, challenges arise in upper-level wind speed predictions, and a notable increase in uncertainty and bias is observed in moisture profile forecasting. Particularly, relative humidity forecasting presents difficulties, with the NGFS model exhibiting more errors and bias than NCUM.

1. Introduction

Our understanding of the atmospheric system relies on meteorological data. To grasp weather, climate processes, variability, extremes, and climate change, we need extensive records of the observations. Without these records, gaining insight into these aspects becomes an impractical endeavour. Radiosonde observations play a pivotal role in meteorological studies by 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). These data aids meteorologists in understanding atmospheric conditions, contributing to accurate weather forecasts and climate research. Radiosondes help identify temperature inversions, track air masses, and monitor the development of weather systems. By offering insights into the atmosphere's behavior at different altitudes, radiosonde observations enhance our ability to predict and understand weather patterns, ultimately improving public safety and supporting scientific advancements in meteorology.

Comparisons between radiosonde observations and models have been instrumental in identifying areas where models may need refinement (Santer et al 2008). Discrepancies may arise from various sources, including model parameterizations, numerical approximations, and input data quality. By aligning model simulations with observed radiosonde data, researchers can iteratively adjust model parameters, improving the model's ability to simulate real-world atmospheric conditions.

The present study focuses on the comparison of meteorological variables such as temperature, relative humidity, and wind speed measured from the two of the testbed radiosonde observations deployed at Solapur, Maharashtra.

2. Study Area

The Cloud Aerosol Interaction and Precipitation Enhancement Experiment (CAIPEEX) is a national initiative in India, aimed at studying and applying research related to processes in pre-monsoon and monsoon clouds. We have used the radiosonde observation from Solapur, Maharashtra, which was part of CAIPEX phase 4. The location of the radiosonde is shown in Fig

(1). The radiosonde situated at Solapur, Maharashtra, has been providing observations since 20 July 2023, 06 and 18 UTC. In this study, we have used 06 UTC observations (both ascend and descend) as only 06 UTC data was available at the time of this analysis.

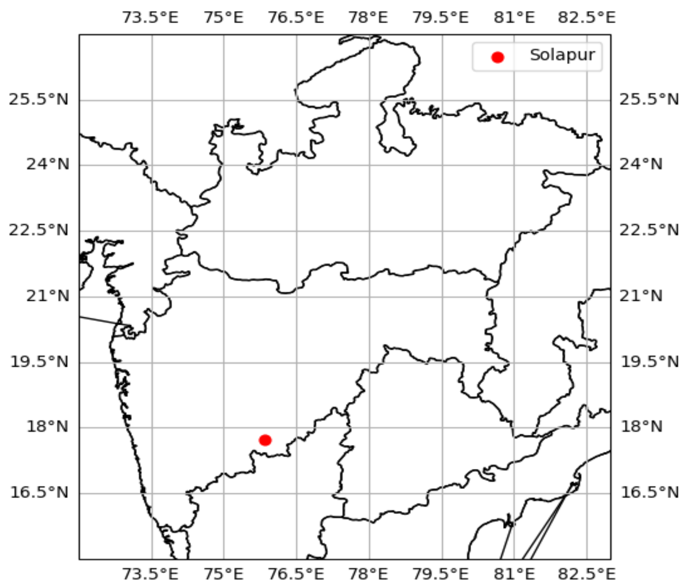

Figure 1 *Location of the Radiosonde at Solapur, Maharashtra*

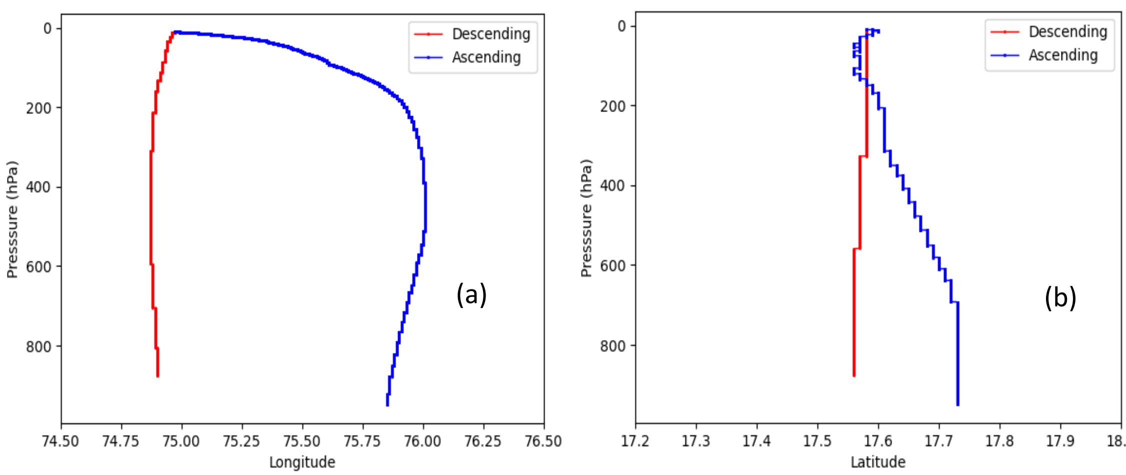

Figure 2 *longitudinal (2a) and latitudinal (2b) deviation of the Solapur radiosonde in ascending (blue) and descending (red) mode with respect to the pressure levels*

Figure 2 illustrates the trajectory covered by the radiosonde ascend and descend. Fig 2a and 2b are longitudinal distance and latitudinal distance travelled in ascend (blue line) and descend (red line). During this free fall, the horizontal distance travelled is significantly less compared to the ascent phase. This plot corresponds to data collected on August 18, 2023.

3. Data and Methodology

NCMRWF generates two sets of NWP model initial conditions/analyses at six-hourly interval using the NCMRWF Global Forecast System (NGFS) and the NCMRWF Unified Model (NCUM). These updates occur four times a day 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.

Analyses 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 in this study for comparing both models.

Every new measurement must undergo a validation process to verify the accuracy of the generated information. This ensures that the data has been produced appropriately and provides the means to take corrective action in the event of erroneous detection (Estévez et al., 2011, Wang et al., 2016). The performance of the variable analyzed in this study 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 departure from the background/Analysis. Positive bias represents under prediction and negative shows over prediction.

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

Where X are the radiosonde observations, Y is 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 for ascending and descending phases. In contrast, 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 and nearly 2000 in descend. Radiosonde observations are assigned to the closest of the common standard pressure levels. During the ascending phase of the radiosonde, the first valid observation near the surface was used to determine the latitude and longitude for the corresponding NGFS/NCUM grid. Conversely, during the descending phase, the latitude and longitude of the first observation on top are considered as it begins its free fall.

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

4. Results and Discussion

The radiosonde, at Solapur, Maharashtra provides data at two time steps on 06 and 18 UTC. This dataset is assessed using in-house NGFS and NCUM global model analysis and forecasts. We have utilized 06 UTC ascending and descending observations.

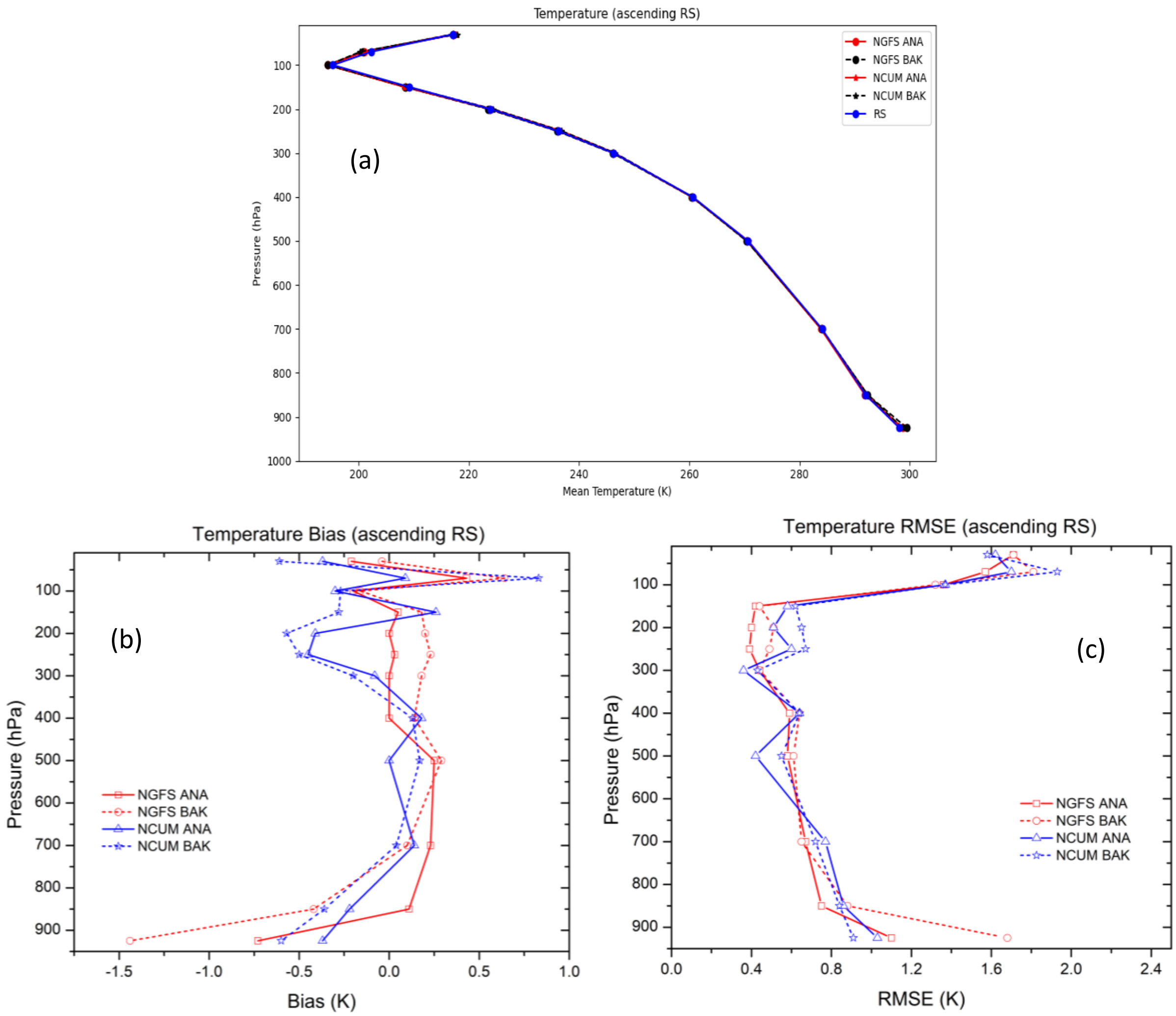

Figure 3 *40 day mean temperature from RS/NGFS/NCUM (a), Bias and RMSE of NGFS/NCUM temperature analysis/forecast with 06 UTC Radiosonde from Solapur ascend (b and c) BAK and ANA in the plots represents background and Analysis, respectively*

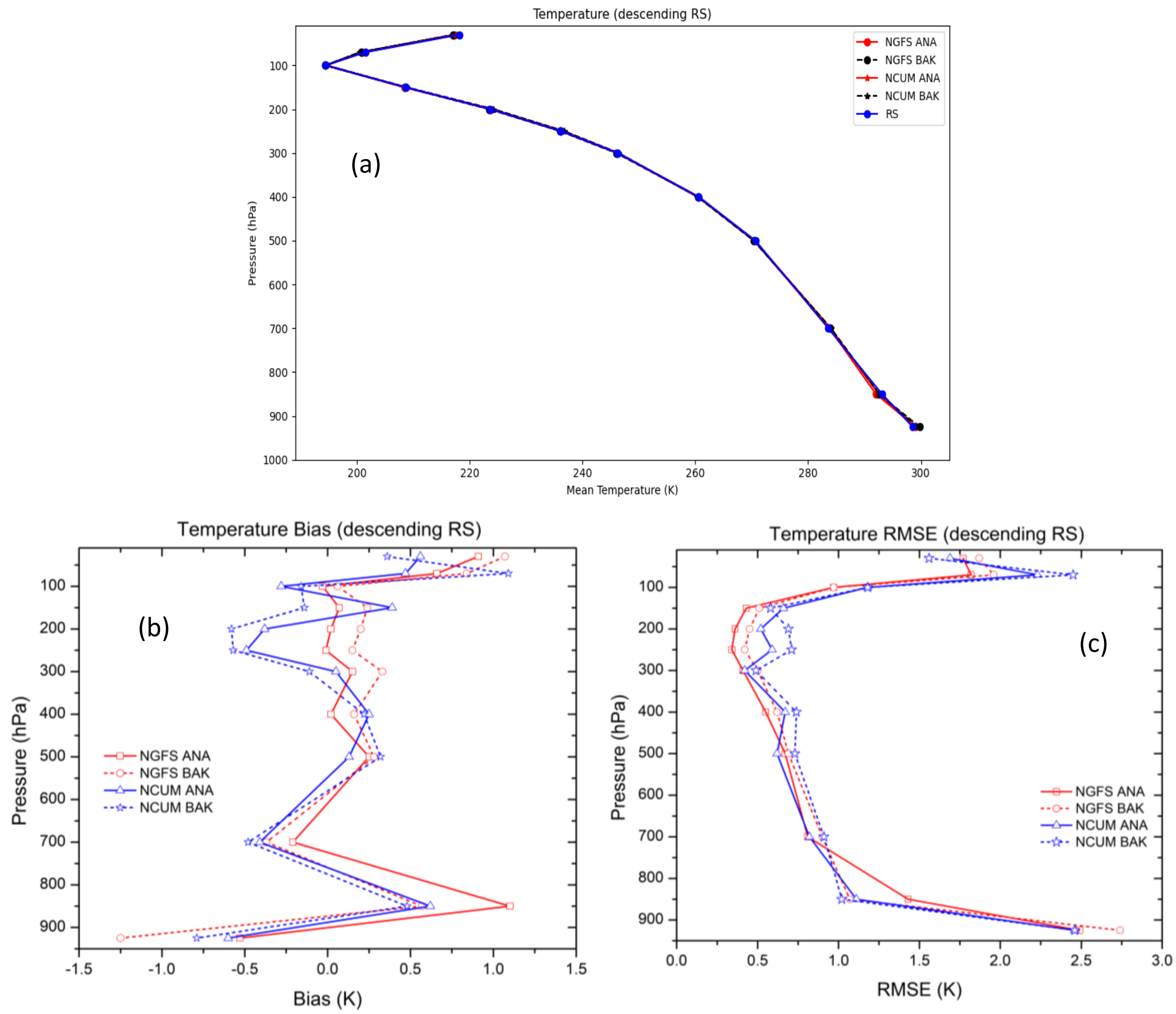

Figure 4 *40 day mean Temperature from RS/NGFS/NCUM (a), Bias and RMSE of NGFS/NCUM temperature analysis/forecast with 06 UTC Radiosonde from Solapur descend (b and c).*

In Figure 3 and Figure 4, a comparison of temperature profiles from the Solapur Radiosonde (ascend and descend both) is presented alongside the NGFS and NCUM forecast and analysis. 40-day mean temperature from radiosonde, NGFS and NCUM (Background and Analysis both) are plotted in figure 3(a) and 4(a) for ascend and descend phase, respectively. In both the phases of radiosonde, temperature profiles are close to the NGFS/NCUM BAK/ANA profiles, some discrepancies can be seen at the lower levels. The bias and RMSE are depicted in Fig 3(b) and 3(c) for the ascending phase of radiosonde, whereas 4(c) and 4(d) shows bias and RMSE for the descending phase, respectively. Notably, for the lower troposphere, the RMSE for the NGFS analysis improves in comparison to NCUM temperatures. Below 850 hPa, both NGFS and NCUM exhibit warm bias of 0.5 K and RMSE around 1 K. NCUM also shows warm bias of 0.5 K near 200 hPa. However, in the atmosphere between 700-150 hPa, the RMSE is less than 1 K for both models. Both models display a cold bias below 750 hPa, while the NGFS analysis indicates almost no bias between 400-150 hPa. Additionally, between 400 to 600 hPa, both models exhibit a warm bias of ~0.2 K.

When it comes to the descending phase of the radiosonde, there seems to be a slight change in the bias values below 600 hPa. At 850 hPa, it is 0.5 K, whereas at below 900, it is around -0.5 K. The RMSE is more or less similar to that of the ascending phase, except for the lowest level at 925 hPa. At this level, RMSE is more than 2 K for NGFS and NCUM forecasts as well as analysis.

In Figure 5 and Figure 6, a comparison of relative humidity is presented. The relative humidity from the NCUM analysis was found to be the closest match to the RH from the radiosonde data (both ascending and descending). Above 500 hPa, huge differences can be seen in the NGFS BAK/ANA RH compared to the other two datasets. Above 500 hPa, relative humidity is increasing in NGFS as opposite to RS and NCUM relative humidity. These differences of RH in the NGFS forecast and analysis are visible in Bias and RMSE as well.

In the ascending phase (Fig 5) of the radiosonde, the NGFS exhibits a wet bias of 10 % at 400 hPa, which reaches 50 % at around 100 hPa, and the RMSE ranges from 10-50 % for the pressure level of 400-100 hPa. The moisture forecast of the NCUM surpasses that of the NGFS, displaying an RMSE of less than 20% across all pressure levels (figure 5c). A notable feature in the NGFS is a substantial over-prediction in the upper atmosphere (above 500 hPa), where the bias is very high, ~50%. The NCUM analysis demonstrates a 5% wet bias as compared to the forecast at 700 hPa. Between 300 to 100 hPa, NCUM shows 5-10 % of wet bias.

Figure 6b (bias) and Figure 6c (RMSE) illustrate the comparative analysis of relative humidity during the descent phase of the radiosonde. Both NGFS and NCUM show comparable bias statistics up to the 500 hPa pressure level. Similar to the ascent phase, NGFS bias continues on the same trend during the descent, ranging from -10% at 400 hPa to -50 % at 100 hPa. In contrast, NCUM displays a consistent wet bias of 10 % within the same pressure levels.

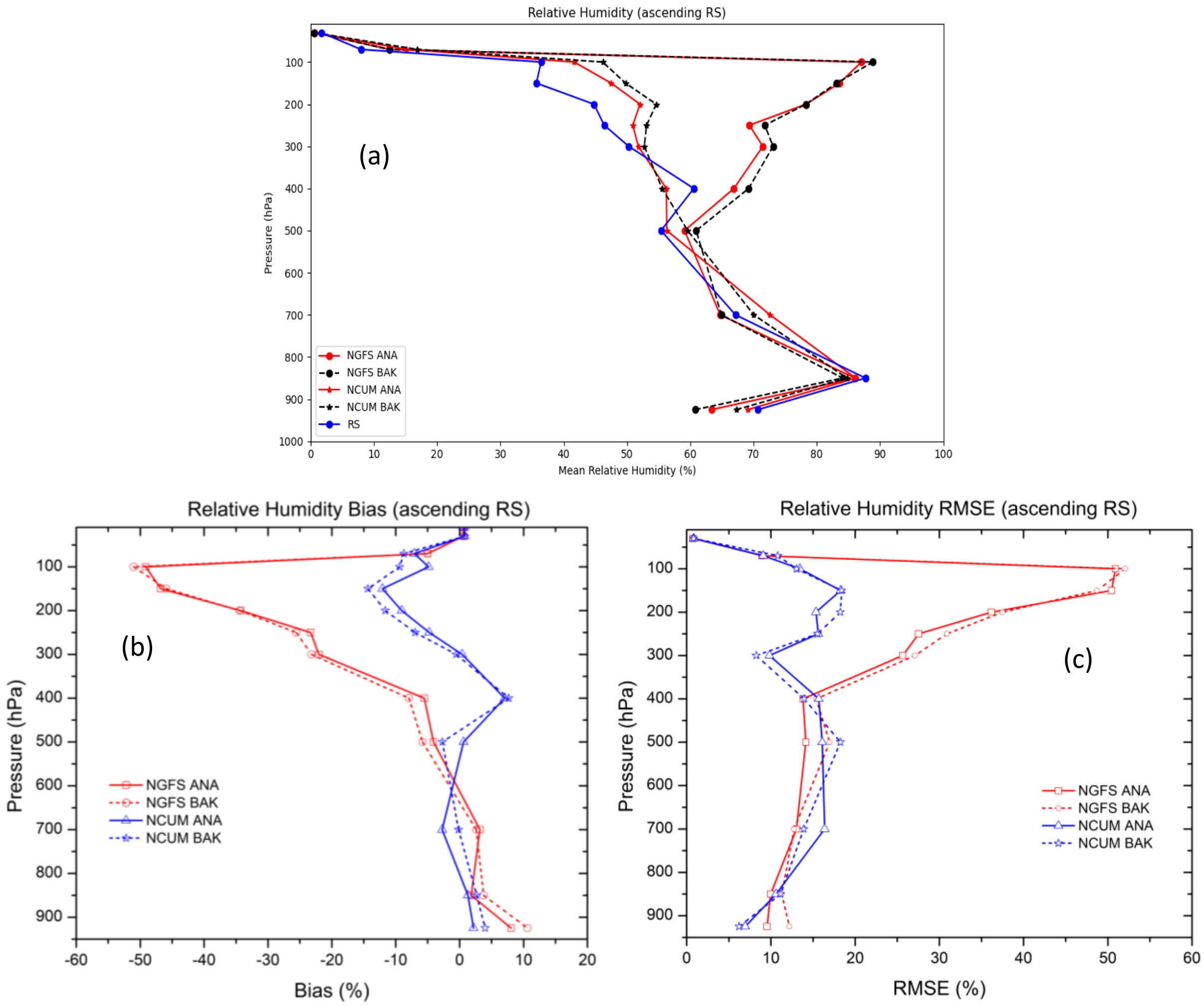

Figure 5 *40 day mean relative humidity from RS/NGFS/NCUM (a), Bias and RMSE of NGFS/NCUM analysis/forecast relative humidity with 06 UTC Radiosonde from Solapur ascend (b and c)*

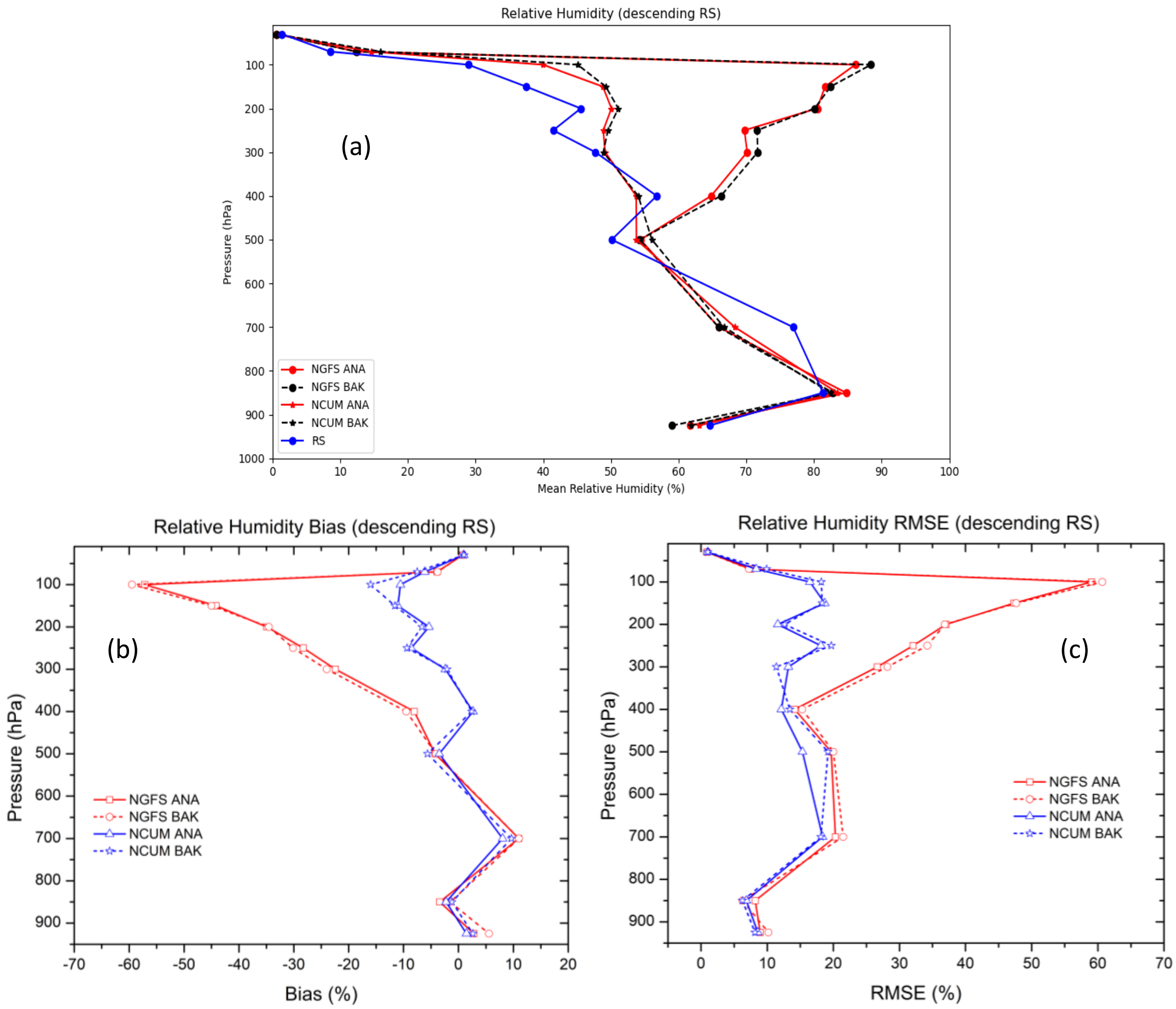

Figure 6 *40 day mean relative humidity from RS/NGFS/NCUM (a), Bias and RMSE of NGFS/NCUM analysis/forecast relative humidity with 06 UTC Radiosonde from Solapur descend (b and c)*

Figure 7, highlights wind speed comparison diagnostics. During ascent Bias and RMSE are presented in Fig 7(a) and Fig 7(b) respectively. At 850 hPa, both models exhibit a slow bias of ~1 m/s, but below 850 hPa, NCUM shows almost no bias, while NGFS has a fast bias of 0.5 m/s. Between 700 and 300 hPa, NGFS displays less bias than NCUM, with NCUM showing a fast bias of 0.5 m/s. At 100 hPa, NCUM demonstrates a swift bias of 2 m/s. RMSE ranges between 1-2 m/s throughout the atmosphere for NGFS and ~2 m/s for NCUM. In the upper atmosphere, around ~100 hPa, both NGFS and NCUM analysis and forecasts exhibit very high RMSE (~5 m/s).

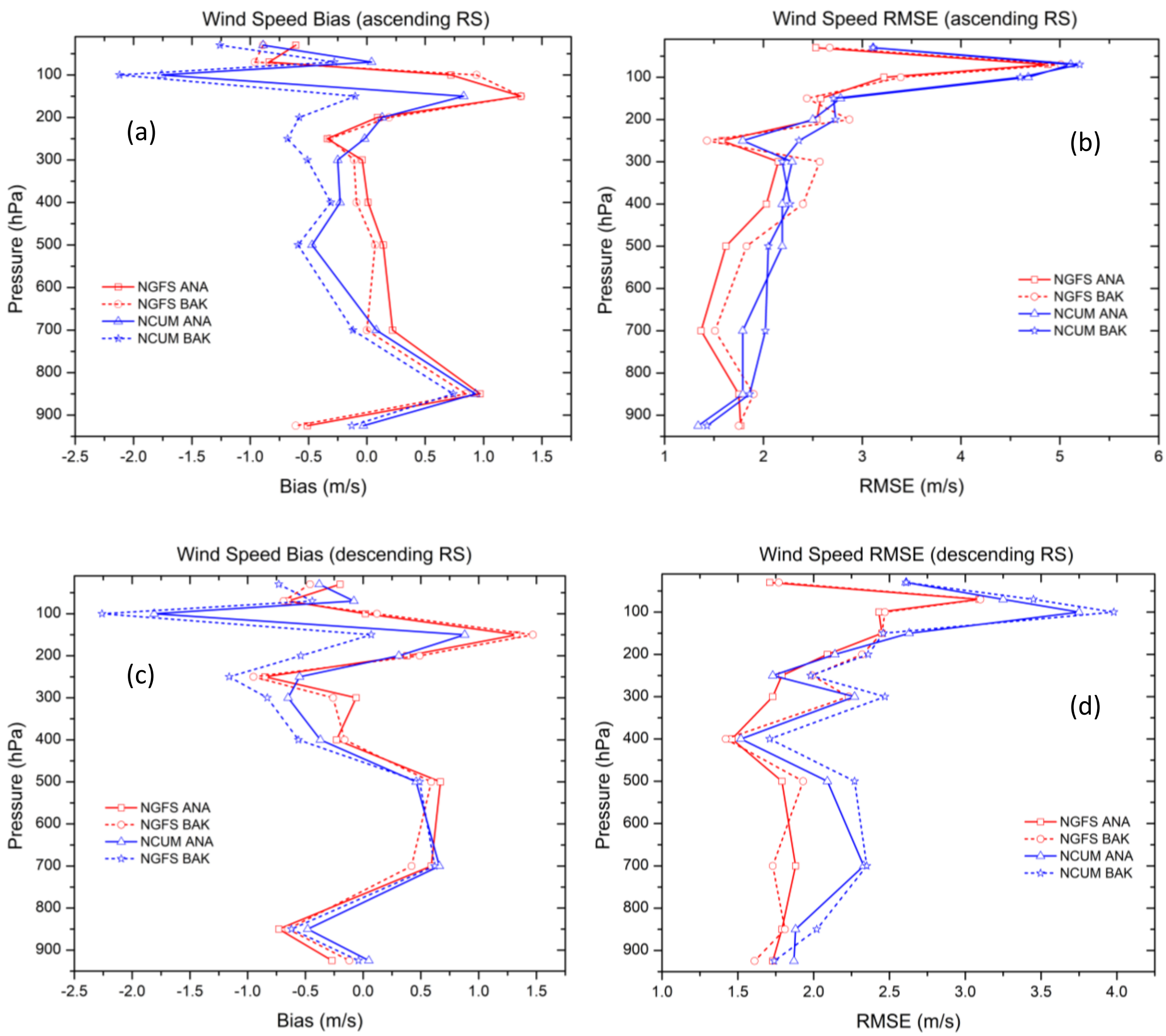

Figure 7 *Bias and RMSE of NGFS/NCUM relative humidity analysis/forecast with 06 UTC Radiosonde ascend (5a and 5b) and descend (5c and 5d) from Solapur Maharashtra, Red is for the NGFS and Blue is for the NCUM*

Figure 7(c) and 7(d) illustrate the comparative diagnostic analysis of wind speed during the descent phase of the radiosonde. At 850 hPa, both the NGFS and NCUM display a swift bias of 0.4 m/s. Below 850 hPa, NGFS demonstrates a negative bias of approximately 0.25 m/s, while NCUM exhibits no bias. Within the pressure range of 700-500 hPa, both NGFS and NCUM show a gradual bias of 0.5 m/s. At the upper level, around 100 hPa, NCUM indicates a fast bias of 2 m/s, whereas NGFS reveals no bias at this altitude. The root mean square error (RMSE) ranges between 1.5 - 2 m/s up to 200 hPa for NGFS, while for NCUM, it varies between 1.5-2.5

m/s. Overall, NGFS outperforms NCUM in wind speed forecasting. The RMSE is more or less similar for the analysis as well as the forecast of the relative humidity. Improvement is noticed in the analysis for all three parameters in consideration.

5. Conclusion:

The report conducts a comparison of radiosonde observations over Solapur, Maharashtra, with the NGFS and NCUM models for 06 UTC over forty days in August and September 2023. The comparison was conducted across 12 standard pressure levels ranging from 925 to 30 hPa. The vertically high-resolution radiosonde observations and NGFS/NCUM analysis/forecast fields were aligned at the same pressure levels for the evaluation. Both models exhibit consistent temperature and wind speed forecasting accuracy, albeit with minor challenges in upper-level wind speed predictions. However, the forecasting of moisture profiles introduces increased uncertainty and bias. Despite the model’s proficiency in predicting temperature and wind speed, accurate relative humidity predictions pose a growing challenge, with the NGFS displaying more error and bias than NCUM. Observations from radiosonde at 06 and 18 UTC are relatively fewer in number, as the majority of global radiosonde observations are typically available at 00 and 12 UTC, consistently feeding into the data assimilation system. Introducing new observations during these time steps can enhance the forecasting system and improve the analysis within the data assimilation system.

Acknowledgements

The authors express their sincere gratitude to the India Institute of Tropical Meteorology for providing Radiosonde data. Additionally, the authors acknowledge the valuable support offered by the Head of the National Centre for Medium Range Weather Forecasting (NCMRWF).

References

Durre, I., Vose, R., & Wuertz, D. (2006). Overview of the Integrated Global Radiosonde Archive. Journal of Climate, 19(1), 53–68. doi: 10.1175/jcli3594.1

Wang, J., Zhang, Y., & Zeng, X. (2016). Evaluating and understanding top-of-atmosphere cloud radiative effects in observations and climate models. Journal of *Geophysical Research: Atmospheres*, 121(10), 5698–5716. doi: 10.1002/2016jd024783

Santer, B. D., et al. (2008). Consistency of modelled and observed temperature trends in the tropical troposphere. *International Journal of Climatology*, *28*(13), 1703–1722. doi: 10.1002/joc.1756

Estévez, J.; Gavilán, P.; Giráldez, J.V. Guidelines on Validation Procedures for Meteorological Data from Automatic Weather Stations. *J. Hydrol.* **2011**, *402*, 144–154.

Rani, S.I., Taylor, R., Sharma, P., Bushair, M.T., Jangid, B.P., George, J.P., Rajagopal, E.N., 2019. Assimilation of INSAT-3D imager water vapour clear sky brightness temperature in the NCMRWF's assimilation and forecast system. *J Earth Syst Sci* 128, 197.

Prasad, V. S., and C. J. Johny, 2016: Impact of hybrid GSI analysis using ETR ensemble. *Journal of Earth System Science*, 125(3), 521-538

Prasad, V. S., C. J. Johny, and Jagdeep Singh Sodhi, 2016: Impact of 3D Var GSI-ENKF Hybrid Data Assimilation system. *Journal of Earth System Science*, 125(8), 1509-1521.

Prasad, V. S., C. J. Johny, P. Mali, Sanjeev Kumar Singh, and E. N. Rajagopal, 2016: Retrospective Analysis of NGFS for the years 2000-2011. *Current Science*, 112(2), 370-377