Validation of Weather Forecasting Products

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ABSTRACT

Meteorological modeling plays a pivotal role in operational safety and emergency response at the Savannah River Site (SRS). This study focuses on verifying the Regional Atmospheric Modelling System (RAMS) Version 4.3 through Mean Bias Error (MBE) and Root Mean Square Error (RMSE) analyses of temperature, dew point, and wind speed over a decade. Using observed data from SRS, we assessed RAMS' accuracy, revealing seasonal biases and error trends. Results indicate RAMS' strengths in mild weather conditions but challenges during seasonal extremes and wind speed predictions due to measurement disparities. Future research aims to expand verification to other models and parameters, advocating for enhanced forecasting accuracy crucial for safeguarding personnel and community well-being.

I. INTRODUCTION

Understanding the complexities of weather is not merely about choosing the right outfit for the day; it is vital for safeguarding lives and ensuring operational integrity, especially at the Savannah River Site (SRS). Meteorology serves as a cornerstone in the daily operations of SRS, guiding everything from routine activities to critical emergency response planning. Through advanced forecasting, modeling simulations, and continuous research advancements within the Atmospheric Technologies Group, we uphold the highest standards of safety and preparedness.

At Savannah River Site, the reliability and precision of our forecasting systems and models are paramount, reinforcing our commitment to excellence and the well-being of our personnel.

The Atmospheric Technologies Group undertakes a variety of daily tasks, including weather forecasting for the 310 square miles of the SRS. Meteorologists utilize advanced models to inform their forecasts, providing predictions for precipitation, temperature, dew point, wind speed, wind direction, and factors influencing heat stress. Meteorology is so important at SRS because it is an integral component in emergency response, not just at SRS but throughout the community. It is noted that the Atmospheric Technologies Group served a critical role in the Chlorine spill from a train derailment in 2005 in Graniteville, SC. Meteorologists at Savannah River Site were able to use weather parameters to predict where the chlorine might spread. Meteorologists at Atmospheric Technologies Group use these modeling systems to assess the impacts of environmental emergencies worldwide. At SRS, the Atmospheric Technologies Group is prepared for the event of an environmental emergency on site. In this readiness, ATG conducts numerous research projects to validate and advance their emergency response technology.

A huge factor in emergency response simulations is the weather model that is implemented in those simulations. The Savannah River Site uses the Regional Atmospheric Modelling System or RAMS for short. RAMS is a mesoscale weather forecasting model created by William R. Cotton and Rodger A. Pielke (citation here). It is a powerful numerical weather model used to simulate and predict atmospheric processes on regional scales. Meteorologist at the Atmospheric Technologies Group uses the RAMS model for daily forecasting emergency response simulation systems. As an intern with the Atmospheric Technologies Group, my mentor David Werth and I accomplished a model verification on the RAMS Model Version 4.3.

Model verification in meteorology refers to the process of evaluating the accuracy and reliability of weather forecasting models against observed weather data. This is crucial because weather forecasting models are mathematical representations of the atmosphere, and their predictions can have significant implications for public safety, emergency response, and various industries.

Verification helps meteorologists understand how well a model performs in predicting various weather parameters. This assessment is essential for determining the reliability of forecast information. By identifying the strengths and weaknesses of forecasting models through verification, we can improve model algorithms and parameterizations. Emergency simulations at SRS use RAMS Model Version 4.3 to create hypothetical scenarios to test response plans and procedures. Model verification ensures that these simulations accurately represent the dispersion of hazardous materials, potential disasters, and other critical situations specific to the site.

On top of emergency response model verification helps meteorologists create more accurate and reliable forecasts. Reliable forecasts derived from well-verified models enable employees at Savannah River Site to gain trust with the meteorologists at Atmospheric Technologies Group knowing they work hard to keep them safe during times of severe weather, extreme heat, etc.

By comparing model bias and completing model verification, the meteorologists of the Atmospheric Technologies Group will be equipped with bias data to create more accurate forecasts, thus furthering the safety of individuals at SRS.

II. MATERIALS AND METHODS

In order to complete model verification for the RAMS Model Version 4.3 my mentor and I decided to use Mean Bias Error (MBE) and Root Mean Square Error (RMSE) to statistically observe the bias and overall error between the predicted and observed data, which in our case, was RAMS Model Version 4.3 and the observed weather data from the climatology tower in N-Area on site. For our project, we decided verifying the model from the past ten years would give the most accurate results. We chose to verify dew point, wind speed, and temperature over the past ten years from January 2014 through December 2023.

A. Window Application Suite (WAS):

Gathering observed weather data from the past ten years is easy and convenient with the Atmospheric Technologies Group. We gathered observed data from the Window Application Suite, better know as WAS. Because WAS has the tendency to crash during large data retrieval, we decided to grab the ten-year data with respect to each month.

B. Weather Verification Variables:

1. Temperature and Dew Point

We chose to verify dewpoint, temperature, and wind speed for the RAMS Model Version 4.3. We chose temperature and dewpoint because they are a necessity in daily weather forecasting for meteorologists. By calculating dew point and temperature, we can find other important meteorological parameters like relative humidity. Identifying and having accurate temperature and dew point values allows for accurate relative humidity predictions, which in turn will establish more reliable heat index forecasts. At SRS, heat index forecasts are issued each day, ranging from a category zero to a category five. Heat index is an integral part of SRS personnel safety especially with our southern geographical location, by allotting time for heat breaks ensuring employees do not suffer from heat stress.

2. Wind Speed

We also chose to verify wind speed for the emergency response component at Atmospheric Technologies Group. When hazardous material is being released into the environment via chemical spills, burns, etc. it is important to know the speed at which these particulates might be traveling. There are multiple variables that make up the speed of particulates in the air like matter chemistry and molecular weight, but another huge factor in particulate spread dispersion in wind speed. Making sure our predicted wind speed is the most accurate it can be in the RAMS Model Version 4.3 will allow the most accurate emergency response simulations which will in turn save countless lives in the event of an SRS-related disaster.

C. Root Mean Square Error:

Root Mean Square Error (RMSE) is a statistical metric providing a rather straightforward interpretation of the model's overall error through the quantification of observed values and the models' values (Fig. 1). A journal in the Geoscientific Model Development states that RMSE has been used as a common and standard metric to measure a model's error.

D. Mean Bias Error:

Unlike RMSE which measures model error, Mean Bias Error (MBE) is used to model bias. In model verification, analyzing both error and bias is integral to success. Error is the overall inaccuracy, while bias is the trends of these errors. MBE is the statistical metric used to measure the bias of a model through the averaging of a models predicted and observed values. It is extremely important to note specific trends and amount of bias a weather model has in order to forecast accurately and update the version of models for weather prediction for overall accuracy.

E. Calculation:

We decided to calculate both RMSE and MBE in the Python programming language. I chose to use Anaconda Navigator which is an open-source Graphical User Interface (GUI) where I found the environment called Spyder to write and execute the code for the Model Verification Project. A small portion of the project is in Unix, where we had to retrieve the RAMS Model Version 4.3 forecasts. My mentor shared a Unix script which I edited which would allow me to sort the RAMS data into each month from 2014 to 2023. I then went to Spyder and used created a for loop to create an outfile using the glob.glob function to conglomerate the data from the past ten years for each month. For example, I created a new outfile which would have January first through thirty-first for each year from 2014-2023.

For our verification efforts, we used the time between twelve to zero Coordinated Universal Time (UTC). That is seven am to seven pm or eight am to eight pm depending on daylight savings time. Because RAMS Model Version 4.3 forecasts in 36-hour timeframes, I used a for loop to only grab the twelve hour increments I needed. That way I could ensure the verification was running from the most accurate forecast the RAMS Model Version 4.3 had to offer. To ensure there were no errors in the forecast due to model failure, I used a for loop, which would print where there was an error, and automatically drop that index. I used this loop twice to use as a double-checking method.

I then used the resample function to create datetime “objects” and add hours of missing data. When the hours of missing data are added, it “inplaces” NaN values. I replaced the NaN values with -999, and dropped that data from each data frame, both predicted and observed.
I then did a very similar code with the observed data using the resample function to add hours of missing data. Then dropping the days from each data frame.

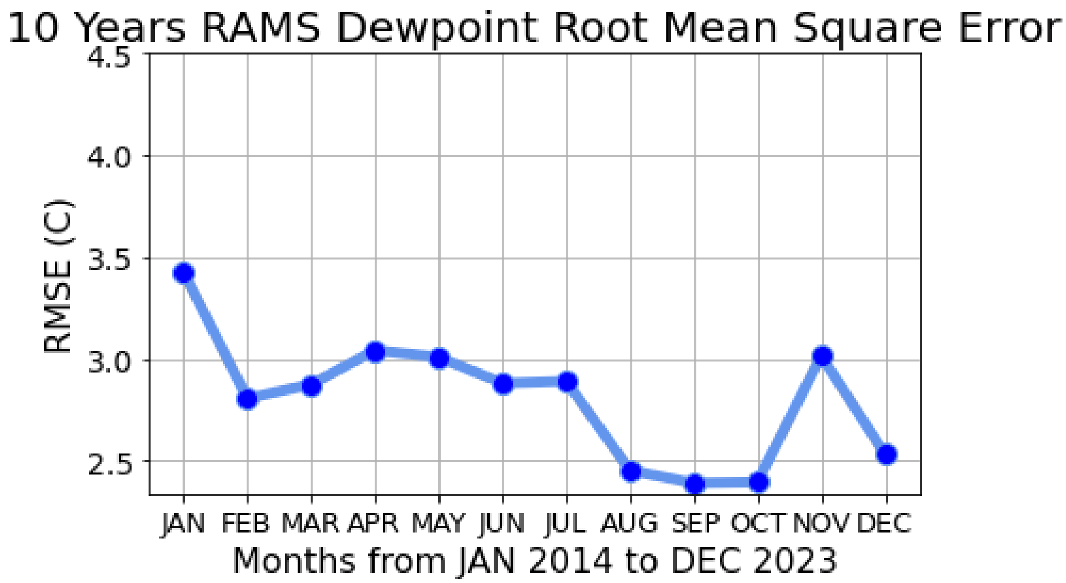
I converted the predicted and observed data frames to lists and assigned them as predicted_list and observed_list. To calculate RMSE I took the square root of the mean_squared_error function from the scikit-learn library. I then calculated MBE by subtracting the predicted_list and observed_list values and taking the mean through the NumPy library.

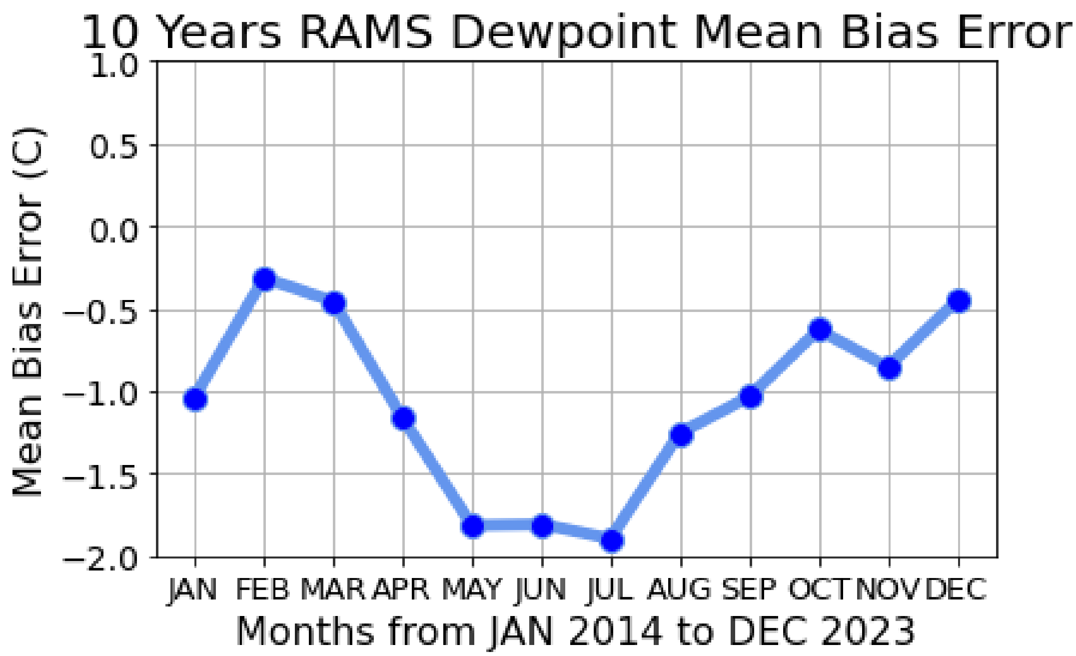
I completed these steps for each of the months over the past ten years. Once I calculated the RMSE and MBE for each month for each of the parameters: dewpoint, temperature, wind speed from the past ten years, I graphed these values using the matplotlib.pyplot library.

III. RESULTS & DISCUSSION

A. Dew Point

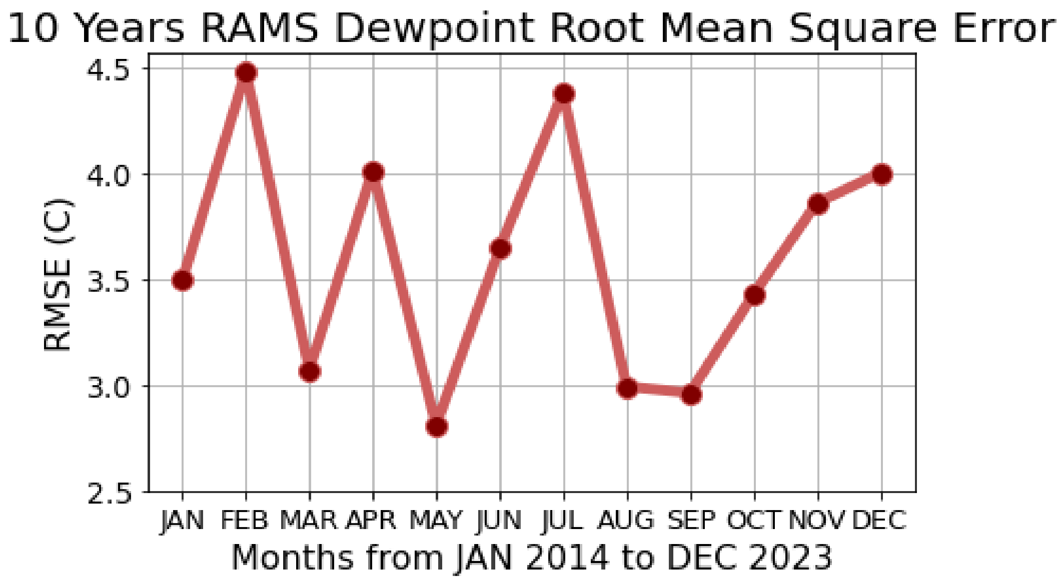
The most accurate month according to RMSE is August with the RMSE value of 2.45, with the largest error value of 3.52 during the month of July. A large concept to understand and notice in Model Verification is RMSE and MBE are not the same, nor do they measure the same. So, our MBE do not align with RMSE values in each month. A notable pattern in the Dewpoint MBE values in the RAMS Model Version 4.3 is the tendency of under forecasting dewpoint temperatures during the summer by almost two degrees Celsius. You can see these in figures _ and _.

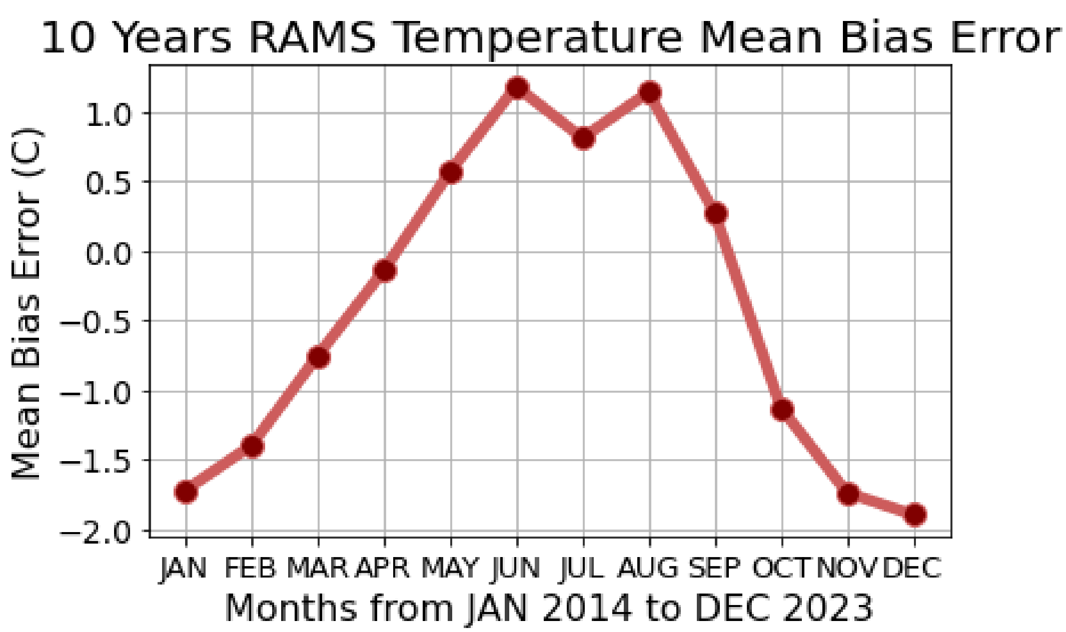




B. Temperature

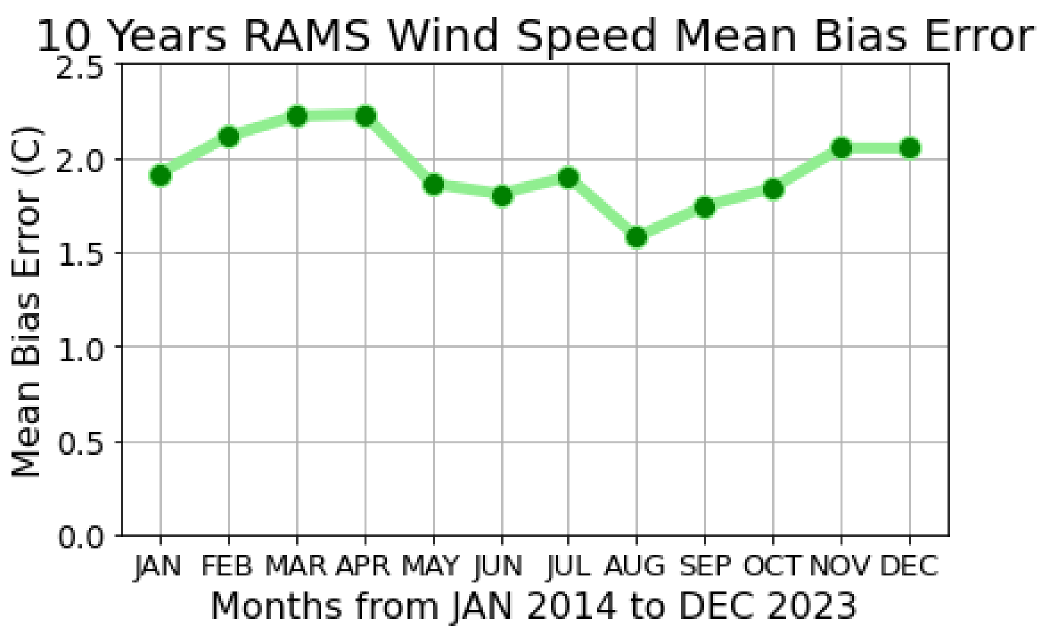
The RAMS Model Version 4.3 had the highest RMSE values out of each of the variables with error values at 4.5 degrees Celsius indicating a high error. The RAMS Model ends up having the most amount of bias during the two seasonal extremes of winter (too cold) and summer (too hot). However, a success to note is the near 0-degree bias error during the milder months of April and September, which is impressive for a model. (Fig. _

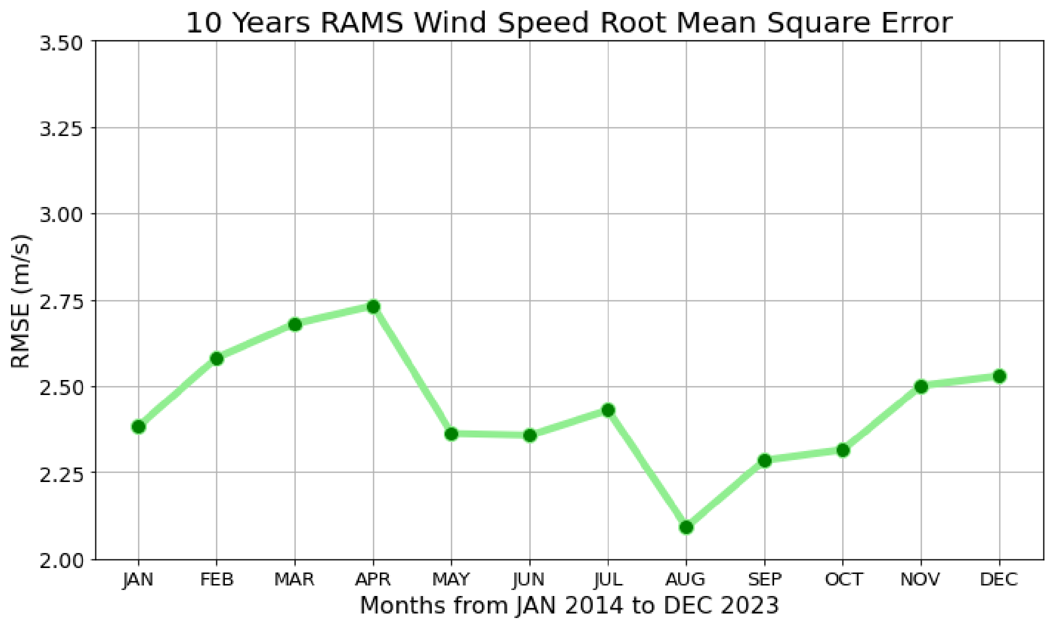




C. Wind Speed

With the wind speed parameter, it is a noticeably high RMSE and MBE. This is occurring for a few reasons. First, the predicted data was for 10 meters, but the observed data was measured at 4 meters. Knowing that winds increase as the height increases in the atmosphere, it makes sense meteorologically that our wind speed RMSE and MBE would have higher error and a bias that predicts wind speed too fast. Second, there is no negative windspeed unlike dewpoint and temperature, so there is less room to cancel and balance values. I think it is important to note the pattern of the graph shape is very similar in both error and bias. These are evident in figures _ and _.





IV. CONCLUSION & FUTURE RESEARCH

In the future, we hope to expand verification to the Weather Research and Forecasting (WRF) and Model Output Statistics (MOS) models while adding the wind direction parameter as well. We hope to use this research to demonstrate the necessity of having the Atmospheric Technologies Group here at Savannah River Site. We hope to showcase the need and inspire other National Labs to value personnel/citizen safety and implement their own Atmospheric Technologies Group. There are also hopes to compare the RAMS 4.3 and RAMS 6.2 and complete model verification between the two, to see if there is a need to update the emergency response modeling technologies from the current weather model RAMS 4.3 to a newer, updated RAMS 6.2.

Forecasting weather is so difficult because there are numerous miniscule physical processes needed. Completing model verification on models that are used for daily forecasting and emergency response can create more accurate and reliable forecasts each day and in times of dire need.

V. ACKNOWLEDGEMENTS

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VI. REFERENCES

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