Integration of the WRF Model into Existing Forecasting and Climate Modeling Systems

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1. Introduction

MESO, Inc. has recently integrated the Weather Research and Forecast (WRF) model into several existing forecasting and climate modeling systems. MESO has accomplished this by creating a modeling system structure that accommodates the integration of multiple regional forecasting models that can be added as the need dictates.

The WRF community model offers some unique advantages over existing regional models. Some of the advantages are: (1) the ability to implement advanced numerical and physical schemes, (2) a strong link between the research and operational community that will allow advances to more quickly be implemented operationally, and (3) increases in performance associated with a parallel environment which WRF has been designed to optimize.

This paper presents an overview of MESO's modeling system, how the system is used, examples of how WRF has been integrated into existing systems and a comparison of WRF results with another well documented mesoscale model.

2. MESO'S System Overview

MESO's modeling system is set up so that it can easily integrate other models into the system. It is also designed so it can be easily configured to be either a regional forecasting system or climate modeling system as the need arises.

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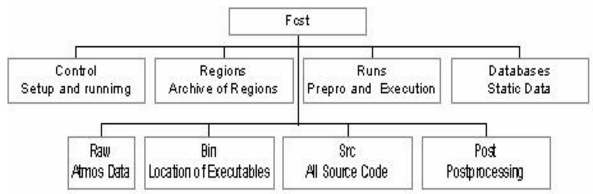
The basic directory structure of the modeling system is as follows:



The parent directory is typically called "fcst", but may be designated by any name that the user desires. The "control" directory contains scripts needed to create a new region and direct a model run, to include which model or models are run. The "regions" directory contains setup and configuration files for all archived regions. The "runs" directory is where the simulations actually take place. The "databases" directory contains the fixed or slowly changing land surface data, such as terrain, land use, sea surface temperature, etc. The "raw" directory contains the atmospheric data. For climate runs this would be linked to historical data; for real-time forecasts it would be linked to current gridded model data and observations. The "bin" directory contains all of the executables; the "src" directory contains all the source code separated by model, and "post" is where the postprocessing takes place.

The sequence of a model simulation is as follows. (1) Create a region of interest or select preexisting region. This step allows the user to configure the model and to select which model(s) would be run. (2) Select the date for a climate run or a real-time run. (3) Select any postprocessing options (this can also be done after the simulations are completed).

3. MESO Modeling Systems Using WRF

3.1 Climate Modeling Systems

MESO has integrated WRF into two modeling systems designed to produce climate statistics. Until the integration of WRF, the core of this modeling strategy had been the Mesoscale Atmospheric Simulation System (MASS) developed by MESO, Inc. MASS is a mesoscale model which ingests both gridded reanalysis and observational data to provide simulations of the hourly weather for any specified geographical region (Kaplan, et al. 2000). Typically, these individual daily simulations are run over a long time-range of multiple months, or even years, and these simulations form the basis for deriving statistical metrics of the underlying climate.

One climate modeling system has been designed to optimize the model output in order to create wind climate statistics, called wind maps, to aid the wind power industry in siting new wind turbines. The other system has been designed for use by the U.S. Air Force to create high resolution regional climate statistics for battle-planning weather scenarios for data sparse regions of the world.

The wind mapping system is produced for AWS TrueWind, a company that specializes in engineering and site selection for the wind industry. WRF has been added as an additional mesoscale model option when producing the wind statistics used to create the wind maps.

MESO also has integrated WRF into the Air Force Combat Climatology Center's (AFCCC) Advanced Climate Modeling and Environmental Simulations program (ACMES) that is used to derive regional climate statistics in areas around the world for which climatology-based observational data is not directly available.

3.2 Forecasting Systems

MESO's real-time systems designed to produce wind energy and agricultural products can now also use the WRF model. The forecasting products using WRF are still being evaluated before going into production use.

4. Comparison of MASS and WRF Output

Using the developed wind forecasting and ACMES/WRF system, an evaluation study was performed comparing the climate statistics obtained from WRF with those produced by MASS over two regions: California from 2001-2002 and Korea from 1987-1996. Both regions have complex terrain, coastal regions, are relatively rich in observational data, and have been previously examined using MASS. These characteristics made both regions ideal for use as comparisons. Because of space limitation, only the results from California are shown, but the Korean results were similar to those from the California simulations.

The first comparisons made with the ACMES using the WRF system correspond to a series of test runs over California for three two-month periods: Nov.-Dec. 2001, Mar.-April 2002, and May-June 2002. Two sets of forecast runs were made on each day during these date ranges: a 60-hour forecast starting at 00Z and a 60-hour forecast starting at 12Z. The comparisons presented herein are categorized into three main components:

- Qualitative spatial analysis of temperature between MASS and WRF for the same period of record.
- Point analysis comparison of WRF and MASS with 10 METAR stations.
- Point analysis comparison with 3 met towers at the surface and at 50 meter intervals above the surface to 150 meters.

For these comparisons, the model configurations were set as identically as possible given the inherent differences between the two NWP models. The model domain used for each set of simulations was a 100x80x25 grid with a 40-km grid spacing. The input data for each model was as similar as possible; however, there were differences because of limitations with the current version of WRF. In particular, the input grib data for the WRF model had to be on pressure levels (as opposed to sigma levels) because WRF can only preprocess pressure-level gridded data. Initial conditions for both the

MASS and WRF runs were derived from global grid point analysis data from the NCAR/NCEP GDAS Reanalysis project. The same data was used to generate lateral boundary conditions every 6 hours beginning at 0000 UTC.

4.1 Qualitative Spatial Analysis

To quantify the spatial differences between the two models, the average 2 meter surface temperatures were computed during the months of November and December 2001. In general, the overall mean thermal patterns were similar between MASS and WRF. One difference observed, however, was that the WRF model tended to be colder over land, especially in the higher elevations. Some of this difference may be attributed to the differences in the handling of the terrain by each model.

4.2 METAR Station Comparison

A point-wise comparison was made between WRF and MASS output using ten METAR stations distributed across California. At each METAR location, mean climate values of surface pressure, temperature, dew point, and 10 meter wind speeds were derived from the MASS and WRF forecasts. Overall, results of the comparisons for each of the two-month periods considered were similar with MASS performing better at some stations, and WRF better at others. Surface pressure and temperature results from the first two-month period of November/December 2001 are summarized in Table 1. These results show that the mean surface pressures from both WRF and MASS were quite similar to the observed values with a maximum difference of less than 1.2%. The WRF model tended to have slightly lower surface pressures, while MASS had slightly higher values. The mean surface temperature values showed greater deviations from the observations with WRF and MASS tending to have a low temperature bias. The mean dew point temperature and 10 meter wind speeds, and the dew point temperatures predicted by both WRF and MASS were lower than observational values in all cases except Lake Tahoe. On average, however, the WRF results are closer to the observed dew point temperatures. Of the four atmospheric variables compared to METAR observations, the 10 meter wind speeds showed the most deviation, with an overall MASS deviation of 31.7% versus a value of 39.3% for WRF.

In addition to comparing the overall means for all hours of the day, the ability to capture the daily temperature variability was also examined. To quantify this diurnal cycle, temperatures for each hour of the day from 61 days of simulation over Bakersfield, CA between 1 March and 30 April 2002 were compared against the METAR values. In general, the MASS results were closer to the observed values than WRF, particularly during the warmest time of the day. However, some of the model bias may be attributed to the difference in the terrain elevation used by MASS as compared to WRF. The actual elevation listed for the Bakersfield location point is 127.5 meters closer to the MASS elevation than the WRF elevation, and this difference may account for some of the cooler WRF bias.

4.3 Wind Tower Data Comparison

A comparison was also made using data from three wind towers in California at 100 meters above ground level. One tower was located in San Gorgonio Pass near Palm Springs; two were located in Altamont Pass near Livermore. MASS and WRF forecast outputs were used to derive average 100 meter wind speeds. The average results from November-December 2001 are summarized in Table 2. To illustrate the daily variability, Figure 1 shows a time history of the hourly wind speeds through the month of December 2001 at the Altamont Pass location. From this plot, the peak wind speeds are seen to be under-predicted by both MASS and WRF but both models track similar variations that roughly follow the observational trends.

Stat	Obs	MASS	WRF	Obs	MASS	WRF
BFL	1019.2	1020.1	1017.1	52.6	52.1	48.9
FAT	1019.7	1020.1	1018.3	51.1	51.4	50.8
LAX	1018.0	1019.5	1017.8	57.6	58.8	55.4
RIV	1018.1	1019.7	1016.1	53.3	52.5	48.8
SAC	1018.7	1019.6	1017.1	54.4	53.8	51.3
SFO	1018.8	1020.0	1017.2	54.1	54.4	52.5
TVL	1019.0	1020.9	1007.0	31.9	35.9	33.0

Table 1: Mean values comparisons for surface pressure and temperature between MASS, WRF, and METAR observations for November-December 2001.

Wind Tower	OBS m/s	MASS m/s	WRF m/s
San Gorgonio Pass	6.30	7.07	5.90
Altamont Pass 427	5.42	4.39	3.93
Altamont Pass 438	9.51	8.50	7.92

Table 2: Mean wind speed comparisons between MASS, WRF, and three wind towers, November-December 2001.

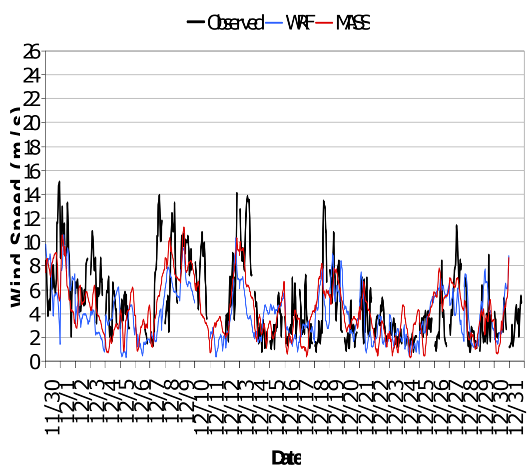


Figure 1: Wind speed comparisons at the Altamont Pass Met Tower #427, December, 2001.

5. Summary

The Weather Research and Forecast (WRF) model has been integrated into several systems designed by MESO including a wind forecasting, a wind mapping system and the Advanced Climate Modeling and Environmental Simulations program (ACMES). Results from these comparisons of WRF with MASS were quite encouraging in that similar results were derived with the WRF model, indicating that WRF and MASS can both be used to derive quality climate statistics through the ACMES method. The results, however, should be viewed with the understanding that the model configurations and input data were similar, but not completely identical. In addition, the results of these comparisons are from a WRF model that is still rapidly evolving. Improvements in the model in terms of physics, configuration options, and improved design will likely improve the capabilities and performance of WRF over the next few years.

6. Acknowledgements

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7. References

Kaplan, M. L., Y.-L. Lin, J. J. Charney, K. D. Pfeiffer, D. B. Ensley, D. S. DeCroix, and R. P. Weglarz, 2000: A Terminal Area PBL Prediction System at Dallas-Fort Worth and its application in simulating diurnal PBL jets. Bull. Amer. Meteor. Soc., 81, 2179-2204