3.2 IMPLEMENTATION OF THE WRF MODEL FOR TEACHING SCIENTIFIC METHODOLOGY IN AN UNDERGRADUATE TROPICAL METEOROLOGY COURSE

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1. INTRODUCTION

Undergraduate students in the atmospheric sciences tend to understand numerical models of the atmosphere in the context of forecasting. As another primary purpose of models in science is the development and testing of hypotheses, undergraduate students generally need a better comprehension of how models are utilized in this manner within the atmospheric sciences.

To that end, an implementation of the WRF (Weather Research and Forecasting) model has been configured at Creighton University for use in an educational framework. Students develop hypotheses about how some process in the atmosphere works, formulate an experiment and control run of the WRF model that will test this hypothesis, generate graphical output, and deliver oral presentations to the class to communicate their results.

The WRF model has been used in this manner for undergraduate tropical meteorology students at both Creighton University (Omaha, Nebraska) and the University of Cologne (Cologne, Germany). By minimizing the extent to which students interact with the often unfamiliar Unix environment in which the model runs, the implementation of the model is believed to have been a successful teaching tool.

2. THE MODEL

The WRF model has been compiled on a Sun workstation. It is configured to run over a 20°x20° domain (0°N-20°N, 10°W-10°W) at approximately 22km horizontal resolution. The model initializes to conditions at 1200 UTC on September 14, 2002 by importing ECMWF operational analyses at that time.

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3. THE CASE

On September 15, 2002, a large West African squall line propagated across the African nations of Benin, Togo, and Ghana. This squall line was well-observed by both the *in situ* observation network and the NASA TRMM Precipitation Radar. The students in the aforementioned tropical meteorology courses study this squall line when learning about synoptic scale and mesoscale systems embedded within the West African monsoon. Additionally, a strong African Easterly Jet (AEJ) was observed in the midtroposphere at approximately 10°N on that day.

Control runs of the WRF model produced an area of enhanced convection with timing and propagation characteristics similar to that of the observed squall line. The WRF model runs did not reproduce the detailed structures seen in the observed system. The AEJ was well modeled in the control runs.

4. DEVELOPMENT OF HYPOTHESES

Within the lectures of the tropical meteorology course, the students learn about the physical processes within the environment of the West African monsoon that influence the speed of propagation of West African squall lines or maintain the AEJ.

In the case of the squall lines, possible factors influencing the speed of the systems include:

- Speed of the zonal wind at various levels of the troposphere.
- Speed of the meridional wind at various levels of the troposphere.
- Relative humidity anomalies at various levels of the troposphere.
- Phase of any African Easterly Waves embedded within the midtropospheric AEJ.

With regard to the maintenance of the AEJ, students learn that this jet is in thermal wind balance with respect to the strong meridional temperature gradient at the surface between the Sahara desert to the north and the relatively cool rainforests to the south. This meridional temperature gradient is primarily driven by the meridional gradient in soil moisture.

Students are directed to formulate hypotheses, either concerning an environmental factor that would influence the rate of propagation of a West African squall line or concerning the role of soil moisture in the maintenance of the AEJ. Typical hypotheses produced include:

- Reducing the relative humidity at midtropospheric levels will increase the rate of propagation of the squall line due to an enhanced rear-to-front downdraft.
- Increased the easterly winds of the AEJ will increase the rate of propagation of the squall line due to greatly nonhydrostatic lifting along the gust front.
- Decreasing the meridional soil moisture gradient in the model with result in a weakened AEJ.

At this point, the students need to develop a model strategy that tests the hypothesis. This involves configuration of a "control run" and an "experiment run" of the model. Students routinely need guidance in the development of the "experiment run". However, students often intend to change several parameters or input grids for the model, making their results hard to interpret. Similarly, students often change variables within the model to unrealistic values.

5. EXECUTION OF THE MODEL

As undergraduate students are often uncomfortable with the Unix operating system, care was taken to develop a method of adjusting initial and boundary conditions within the model in a manner with which the students were familiar. Ultimately, it was found that the "lowest common denominator" tended to be Microsoft Excel. The remainder of the discussion in this section will focus on a model experiment concerning initial soil moisture values, although the same procedure would be used to modify other inputs to the model.

Students are given an Excel spreadsheet file that contains a realistic grid of soil moisture values for the domain of the WRF model over West Africa. For their "control run", many students will rightly choose not to change these values of soil moisture, but a modification of the initial soil moisture grids is usually necessary for the "experiment runs" of the model.

Within the familiar environment of Excel, students can modify the initial soil moisture conditions. They can edit individual points, or they can modify the overall meridional gradient of the soil moisture, depending on the particular hypothesis they have formulated. When they have finished modifying the soil moisture grids, they save the Excel file and a macro copies the contents of their grid to the clipboard on the PC.

Using the ssh client Putty, students log into the Unix workstation where the model runs. A small script guides the student into a text editing program (typically vi or pico). By simply right-clicking on the Putty window, the contents of the PC's clipboard (i.e., the modified grids of soil moisture) are pasted into the text file, which will be assimilated into the WRF model at run time.

Once the modified initial conditions have been incorporated into an appropriate text file, the student starts the model with a single command. The model executes, typically producing a 48 hour run in a few hours. During this time, the model reports various diagnostics to the Putty window so that the student can see the progress of execution of the model.

When execution of the model is complete, another script automatically bundles the output files into a tar file, which is transferred to another Unix workstation for postprocessing and graphical production. The resulting images are accessed via a web server and a series of web pages.

6. SUMMARY/CONCLUSIONS

By utilizing an implementation of the WRF mesoscale model, students in an undergraduate tropical meteorology course have learned about the basics of hypothesis development and testing in the atmospheric sciences. This exercise has proven to be an effective framework within which the class can discuss the nature of models, their input and output variables, and the scientific method.