3.3 EXPERIENCES IN INTEGRATING WRF MODEL IN UNDERGRADUATE METEOROLOGY CURRICULUM

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1. INTRODUCTION

Atmospheric modeling is now an integral part of meteorology education at the undergraduate level. The 2005 AMS statement for the Bachelor's Degree in Atmospheric Science recognizes that "the use of computers and numerical models in the atmospheric sciences has increased dramatically" and "the students should be strongly encouraged to build skills in computer programming, graphic and web design, data manipulation, statistics, and numerical modeling". The Bachelor's degree program "should provide students with appropriate tools, applications software, and simple or idealized computer models suitable for learning about dynamical and physical processes in the atmosphere" (AMS, 2005). With the advance in computing technology and the development of the open source Weather Research and Forecasting (WRF) model, it has now become possible for undergraduate students to have first hand experience in using the state of the art mesoscale numerical weather forecasting system as a learning tool.

Kean University is a pubic metropolitan university. Academic programs at the University cover the traditional liberal arts, education, and professional programs in business, health, science and technology. The Department of Geology & Meteorology is in the College of Natural, Applied and Health Sciences. The department consists of 10 full–time faculty (4 meteorologists, 3 geologists, 1 oceanographer, 2 geographers) and one technical staff. The student body is drawn heavily on the local community. The department offers B.S. degree in Earth Science (meteorology option or geology option) and B.A. degree in Earth Science (general option or teacher certification option).

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2. WRF OPERATIONAL RUNS AT KEAN

As an undergraduate institution without a graduate program in the department, the resources (both financial and manpower) that are available to us are very limited. Nonetheless, using a typical personal desktop computer from student computer laboratory (Dell Dimension 8300 with a single 2.8 GHz Pentium 4 processor with 2 GB memory), a version of the WRF model is configured locally and is running operationally since the summer of 2005.

The domain of the current Kean operational real time WRF forecasts is mainly over northeastern United Stated and is centered over New Jersey. The model is configured with grid spacing close to 15 km. Model forecast starts at 00 UTC and uses the NCEP 00 UTC NAM run for initial and lateral boundary conditions. WRF model physics includes Ferrier microphysics, RRTM longwave scheme, Dudhia shortwave scheme, Monin-Obukhov (Janjic Eta) surface layer, thermal diffusion land surface, YSU boundary layer and explicit Kain-Fritsch cumulus scheme. The 36 hour forecast typically takes 6-7 hours to complete and hence the forecast from 00 UTC will be available in the morning. The model forecasts are available at the department web server for public access (http://hurri.kean.edu/nwpmodel).

This is the first step for Kean University meteorology program to incorporate interactive, user selected, high resolution (both spatial and temporal) numerical weather prediction model for students' learning, forecasts and research.

3. BUILDING LINUX CLUSTER

The second issue that the department faces is to secure enough powerful computers to run the WRF model in the classroom settings. The time frame for typical classroom exercises or demonstrations is between 1 to 2 hours and we can not spend most of the time just to wait for the WRF model to complete its run.

Moreover, it is very difficult to catch students' attention, particular undergraduate students, if they have to wait for a day to see the results. In order to improve the performance of running WRF model without heavy investment of advance computers, the idea of building a cluster machine using existing PCs is very appealing. It turns out that a Linux cluster can easily be put together using the concept of bootable CD. Dr. Paul Gray from University of Northern Iowa had put together and made available a Bootable Cluster CD (BCCD), which particularly was created to facilitate instruction of parallel computing (http://bccd.cs.uni.edu).

The idea of using BCCD to build a cluster to run WRF ideal case simulations (supercell thunderstorm simulation in the WRF quarter_ss directory) and real case study (12 hour forecast for February 11, 2006) was tested (Yoh and Ward, 2006; Ward and Yoh, 2006). The BCCD cluster was built using 2 to 16 PCs in the student computer laboratory and the results are very encouraging. The setup time is only about 1 to 2 minutes per PC and the underlying OS and file system of the PC is completely undisturbed upon restart. Real case runtimes had shown an improvement of 2-4 times with 4-8 PCs in the cluster. The setup time per PC can be dramatically reduced and simplified if the bootable CD can be reconfigured locally. Additional tuning to the network file system which is used for file storage for the model should further improve the performance of the cluster. This also turns out to be a very good group project for the students. Instead of working individually, 3-5 students were grouped together to build a cluster using 4 PCs and this newly built cluster became a more powerful tool to run the WRF model than individual computer.

4. VISUALIZATION TOOLS

The most challenging task so far to incorporate WRF modeling at the undergraduate level is the lack of suitable and easy to use visualization tools. Official WRF supported analysis tools (NCL, RIP4, GrADS and vis5d) all require extensive learning time, which makes these tools less user friendly for undergraduate students. For the Kean configured real time forecast, the post analysis is done by using Unidata GEMPAK analysis program after the WRF netcdf output files are converted to GEMPAK format via the wrf2gem program (developed by Steve Decker from the University of Wisconsin and the program is available at http://speedy.aos.wisc.edu/~sgdecker/wrf2gem). Unidata GARP is then used to display model results and to perform post-analysis. However, even GARP has a relative user friendly graphical user interface (GUI), students typically are reluctant to use it because some students just do not feel comfortable working in the Linux environment.

Starting in Fall 2006, Integrated Data Viewer (IDV) from Unidata is used to examine real time WRF output. The software is a Java based program that can be run in the Windows environment and virtually no installation is required (the program can be started and updated via Java Web Start). Because of the relative user friendly GUI, students can start basic examination of WRF output quickly. Another advantage of using IDV is that it can be used to integrate diverse observational data such as satellite and radar with WRF model gridded data, making comparison between model output and observations very easy. However, for more complex display and analysis, particular involving diagnostic calculations, it is still easier for faculty to put together "bundles" and "scripts" ahead of time rather than asking students to start from scratch.

The WRF ideal case simulations can also be used to help students to study various weather phenomena. For example, the supercell simulation in the WRF ideal case directory is a very good tool to study buoyancy and wind shear interaction. But for these ideal case studies, WRF output does not contain enough geographical information such that the model results can not be displayed via GARP/GEMPAK or IDV. As a result, MatLab is used instead to display and analyze the WRF model output. However, despite MatLab is introduced in the sophomore level as a learning tool such that students can perform symbolic calculations, simple graphics and simple scripts, to examine WRF output using MatLab requires far more extensive programming experience. As a result, faculty has to spend extensive time to prepare pre-written scripts such that students can just use the script files directly or at most make minor modification to the script files in the display and analysis of WRF output.

5. CONCLUDING REMARKS

The WRF model can easily be tailored to local needs and interests, even at an undergraduate institution with limited resources. A Linux cluster can easily be built from typical PCs using BCCD to run the WRF model. However, there is still considerable learning curve for undergraduate students to use analysis tools to visualize and diagnose WRF model output.

After the installation and running the WRF model at Kean University meteorology department, numerous additions were made to the curriculum and new opportunities became available to the students. In terms of integrating numerical modeling into the curriculum, at the sophomore level, topics such as parallel programming and high performance computing are introduced. Statistical analysis for model verification was introduced and the students had used that as class projects. In the Fall 2006, WRF supercell simulation is incorporated in the upper level Atmospheric Thermodynamics class. Outside the classroom, students can use the Kean version of WRF simulations as an additional tool to help them to practice forecasting skill. Numerous student research projects have also been started and have involved the use of the WRF model (Yoh et al., 2005; Yoh and Ward, 2006; Croft and Yoh, 2006; Croft et al., 2006). With a locally running WRF model, it is now possible for us to gradually integrate numerical weather forecast modeling into undergraduate curriculum and possibly other outreach activities.

6. ACKNOWLEDGMENTS

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