**H13-42**

# QUALITY ASSURANCE IN THE ATMOSPHERIC MODELING PROCESS

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**Abstract**: This presentation suggests a need for increasing the standards with which atmospheric models are applied. It is motivated by the fact that, during the last decade, it is arguable that there has been a trend toward applying these models with poorly tested configurations, with insufficient verification, and with inadequate peer review of the process and the results.

***Key words:*** *Modeling quality assurance, modeling best practices, verification, standards*

## INTRODUCTION

The suggested trend toward less quality-assurance in the atmospheric modeling process can be attributed to many causes. A particular issue is that model users tend to lack an appreciation of the sensitivity of model solutions to the many decisions that must be made when configuring a model for a particular application. This presentation will summarize the ways in which the modeling process and culture can be improved, through the more-thorough evaluation of the sensitivity of the solution to model configuration, the use of appropriate verification metrics, and the better education of model users about the fundamentals of numerical weather prediction (NWP) and atmospheric predictability.

## THE INCREASING USE OF ATMOSPHERIC MODELS

Ten to twenty years ago, atmospheric models were used primarily by research scientists at government and university laboratories, and by national weather services for operational prediction. The small cadre of model users had degrees in atmospheric sciences, and almost-certainly had benefited from formal courses in NWP. Since that time, many factors have contributed to a rapid increase in the number of model users and in the diversity of their technical preparation. These factors include the following:

- very easy access to turn-key community models;
- the ease with which the models can be applied, through the use of online documentation and short courses;
- rapidly declining costs of high-performance computing hardware;
- the increasing accuracy of models;
- a greater awareness of the value of model-generated weather and climate information;
- the greater maturity of coupled secondary models that allow forecasts of atmospheric variables to be used for prediction of floods, infectious-disease outbreaks, electric-power consumption, air-quality-related health warnings, etc.;
- the realization by every nation that it is being affected by climate change, and the resulting desire to perform climate downscaling to answer practical questions about future water resources, agricultural productivity, etc.;
- the use of atmospheric models by specialists from other scientific disciplines; and
- the maturation of science in developing countries.

This rapid increase in the number of model users, as a result of the above causes, has led to the premise of this paper – many model users are ill-prepared to use the numerical tools.

## SOME REASONS WHY BEST PRACTICES ARE NOT FOLLOWED IN THE MODELING PROCESS

An increase in the number of model users cannot, itself, be responsible for the misapplication of models. But, there are many related factors that are causative. For example, because new users often do not come from an atmospheric-science program at a university, they have not had the benefit of a course in NWP. This is a significant problem because models are obviously flawed tools, and their shortcomings should be understood well by every modeler. An even-more-unfortunate situation is one in which model users, in addition to having no NWP training, have no background in atmospheric sciences. Lastly, in addition to this lack of training as a problem, time and financial pressures experienced by commercial model users sometimes prevent them from carefully applying the models.

## AREAS WHERE MODELING PRACTICES NEED IMPROVEMENT

Most modelers adhere to some of the following good practices, but often steps in the process are omitted in order to save time, or because the modeler is unaware of the importance of the step. The following is not a complete list of all the steps in the design of a model experiment, but rather defines important ones that are often neglected. A common theme that pervades this discussion is that modelers prematurely begin running the model, imagining that that will lead to an earlier completion of a project. In fact, the author's experience is that the sooner that the model is used in the process, the longer the study will take.

### Clearly define the scientific or practical objective of the effort.

Too often, the model configuration is determined and experiments are performed without first writing down 1) the specific questions to be answered and the expected results, 2) a statement about what the end user of the simulations will find of value, and 3) an hypothesis, if this is appropriate. As obvious as this step seems, experimental objectives are often not well defined and articulated.

**Prepare an experimental design**

Prematurely running the model before a careful experimental design or plan is established leads to inefficiency in the process, wasting time and computing resources. This plan should describe the model runs that will be needed to accomplish the previously defined objectives. Specific aspects of the model configuration are defined in later steps, but preparation of this design ensures that the overall process has been thought through.

**Given the above-defined objectives of the project, identify the atmospheric processes that must be accurately simulated by the model.**

This information about relevant physical processes will be essential for making decisions about model configuration, such as the necessary vertical and horizontal resolution, and the most-appropriate parameterizations. It is also necessary in order to calculate the performance of the model relative to particular processes. This step must be based on a good understanding of the atmospheric phenomena that prevail for the geographic area and season of the model simulation, and on having first carefully defined the objective of the modeling study (see earlier step). Without this step, many subsequent choices in the process will be made arbitrarily and incorrectly.

**Perform a thorough analysis of all available observations before using the model.**

Quality-check and study all observations for the proposed simulation period. Using the observations, perform the best possible overall analysis of the vertical and horizontal structures of the processes being studied - this could require considerable time. Avoid the tendency to run the model before this phase is complete; running the model prematurely is a very common mistake (modelers like to model)! Figure 1 illustrates the often-forgotten concept that there are three complementary approaches for studying an atmospheric process, which involves the use of observations, models, and theory. Any conclusions from a study that involves the use of models will be much stronger if an analysis of observations and the use of theoretical concepts are also part of the process.

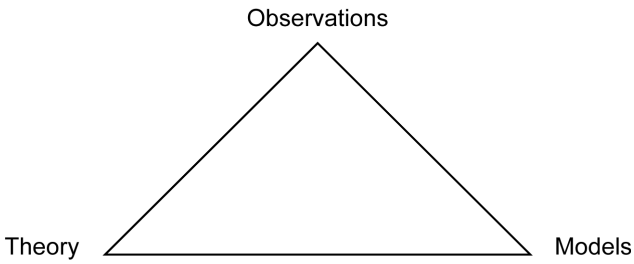


Figure 1. Illustration of the equal importance of the analysis of observations, theory, and models as tools in atmospheric research. From Warner (2010).

**Define the required horizontal and vertical resolutions of the model based on knowledge of the typical length scales of the (above established) specific processes that must be simulated well.**

If air quality in a coastal city must be simulated, boundary-layer processes associated with the land-sea breeze and urban-heat-island circulations will be important. This knowledge would guide the modeler to perhaps employ 1) more model layers within the lowest 1-2 km above the surface in order to resolve the shallow, thermally driven boundary-layer circulations; 2) a better-than-average urban-canopy model; and 3) improved sea-surface temperatures. The estimate of the required vertical and horizontal grid increments should be based on knowledge of the "effective resolution" of the specific model being used, and not simply on the grid increment. That is, a number of aspects of a model configuration (such as the amount of explicit and implicit diffusion, the order of the differencing scheme, etc.) control the filtering of the model solution. The resolution should be chosen such that all physical processes that are relevant to the study are adequately rendered by the model.

Figure 2 shows the effective resolution for the Weather Research and Forecast (WRF) model, which has perhaps less smoothing than many models. Here, the effective resolution is 7 $\Delta x$ in the context of the kinetic-energy spectrum. Obviously computational limitations exist for every project in terms of available computing power, so an outcome of this analysis may be that it is not feasible to accomplish the stated objective with the available time and computing hardware.

**If a limited-area model is being used, run test simulations to evaluate the sensitivity of the model solution to the computational-domain size (i.e., lateral-boundary location).**

The solutions from limited-area models (LAM) are notoriously sensitive to the locations of the lateral boundaries, and tests should be conducted to define the optimal locations of the boundaries. The sensitivity will depend on the prevailing flow at the lateral boundaries, so different weather regimes may need to be evaluated and a compromise solution found. Figure 3 shows examples of a jet streak simulated by two versions of a LAM. One simulation (panel a) employed lateral boundaries that were removed a large distance from the geographic area of interest (shown in the figure) and the other (panel b) had the lateral boundaries located at the edge of the area shown in the figure. The narrower jet streak in panel (a) is more realistic, as confirmed by radiosonde observations. In both cases, the boundary conditions were provided by a coarser-resolution global model.

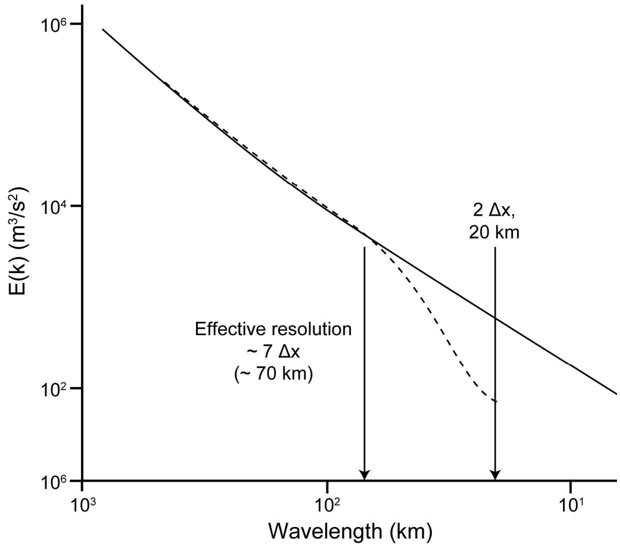


Figure 2. The effect of diffusion on the kinetic-energy spectrum for a WRF-model forecast having a 10-km grid increment. The expected slope of $k^{-5/3}$ is shown as a reference, and is reproduced by the model for wavelengths greater than 7 Δx. But the energy between the 2 Δx and 7 Δx wavelengths has been damped by the diffusion, resulting in an effective resolution of 70 km, not 20 km. Adapted from Skamarock (2004).

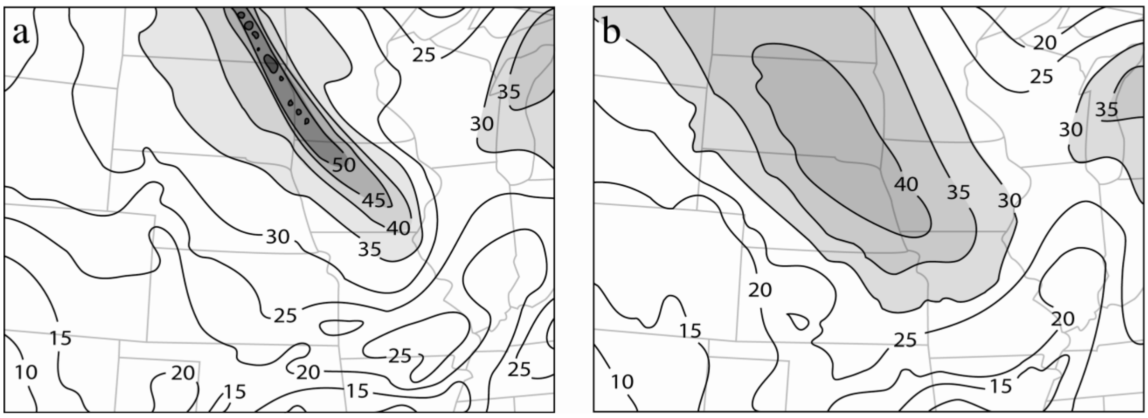


Figure 3. Twelve-hour simulations of 250-hPa winds (m $s^{-1}$) from the 40-km grid increment Eta Model initialized at 1200 UTC 3 August 1992, based on experiments that used a large (a) and small (b) computational domain. The isotach interval is 5 m $s^{-1}$. From Treadon and Peterson (1993).

**Based on a review of the literature, estimate the most appropriate physical-process parameterizations for the geographic area, the horizontal and vertical grid resolutions, and the process being simulated.**

Evaluate the sensitivity of the model solution to the use of alternative physical-process parameterizations for convection, radiation, land surface, cloud microphysics, and boundary layer. This is necessary because the performance of some parameterizations can depend on season and the meteorological processes that prevail in specific geographic regions. The "default" parameterizations suggested in the user documentation for a particular modeling system will not necessarily provide the best model simulation. As an example, Fig. 4 illustrates the potential sensitivity of the accuracy of precipitation forecasts to the choice of the convective parameterization. The rain rate is plotted for a spring-season convective event (panel a), based on observations and for five simulations that used different treatments for the convection - four different parameterizations, and no parameterization. At specific times in the simulations, the rain rate varied by as much as a factor of three or four among the different parameterizations. Also depicted is the bias score averaged for three warm-season convective events (panel b), again for each of the four parameterizations and for the use of no parameterization. Both the simulation-average scores on the right, as well as the time-dependent curves, show a substantial dependence of the simulated precipitation amount on the parameterization that was employed.

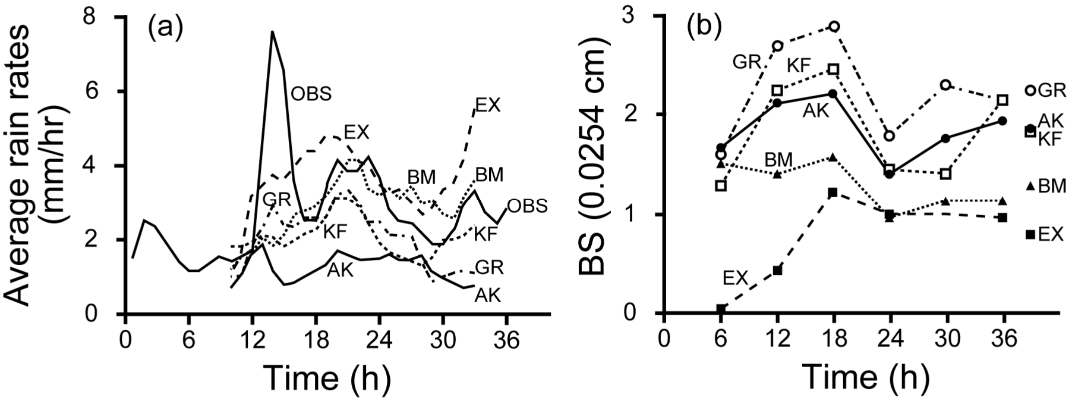


Figure 4. Average rain rate, for a spring-season convective event (a), based on observations (OBS) and for five simulations that used different treatments for the convection - four different parameterizations, and no parameterization (EX). Also depicted is the bias score averaged for three warm-season convective events (b), again for each of the four parameterizations and for the use of no parameterization. The four convective parameterizations were the Grell (GR), Kain-Fritsch (KF), Betts-Miller (BM), and Anthes-Kuo (AK) schemes. Adapted from Wang and Seaman (1997).

**Perform a thorough verification of the model solution using all available observations.**
The objective and subjective verification of model forecasts or simulations is essential for a variety of reasons, where the following list is from Warner (2010).

- Most models are under continuous development, and the only way modelers can know if routine system changes, upgrades, or bug fixes improve the forecast or simulation quality is to objectively and quantitatively calculate error statistics.
- For physical-process studies, where the model is used as a surrogate for the real atmosphere, the model solution must be objectively verified using observations, and if the observations and model solution correspond well where the observations are available, there is some confidence that one can believe the model where there are no observations. This is a necessary step in most physical-process studies.
- When a model is being set up for a research study or for operational forecasting, decisions must be made about choices for physical-process parameterizations, vertical and horizontal resolutions, lateral-boundary placement, etc. Objective verification statistics are employed for defining the best configuration.
- Forecasters learn, through using model products over a period of time, about the relative performance of the model for various seasons and meteorological situations. This process can be made easier through the calculation of weather-regime-dependent and season-dependent verification statistics for the model.
- Objective decision-support systems, that utilize model forecasts as input, can benefit from information about the expected accuracy of the meteorological input data from the model.

The verification should place special emphasis on the variables and processes that are relevant to the specific purpose of the model application. If there are significant errors, adjust the model configuration accordingly (resolution, parameterizations) and rerun the simulations. Inadequate verification is a common and unfortunate compromise that is sometimes made by modelers who are in a hurry to complete a project or who have unwarranted trust that the model will always perform well.

## SUMMARY

In this paper was provided a discussion of common errors that are associated with the use of atmospheric models, where the hope is that it will encourage model users to become more aware, either through self study or through enrolment in a formal course in NWP, of practices that will enable them to use these numerical tools more effectively.

## REFERENCES

Skamarock, W. C., 2004: Evaluating mesoscale NWP models using kinetic energy spectra. *Mon. Wea. Rev.*, **132**, 3019-3032.

Treadon, R. E., and R. A. Petersen, 1993: Domain size sensitivity experiments using the NMC Eta model. Preprints, Proc. 13th Conf. on Weather Analysis and Forecasting, Vienna, VA, US, Amer. Meteor. Soc., 176–177.

Wang, W., and N. L. Seaman, 1997: A comparison study of convective parameterization schemes in a mesoscale model. *Mon. Wea. Rev.*, **125**, 252-278.

Warner, T. T., 2010: *Numerical Weather and Climate Prediction*. Cambridge University Press, Cambridge, UK. In press.