An Evaluation of Current Mesoscale Modeling Capabilities

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1. INTRODUCTION

Atmospheric simulation models based on "first principle" dynamics and physics have become an essential tool in both operational and research meteorology during the last 30 years. Because of the limits of computational power and the unresolved problems of atmospheric physics, it is not possible to use just one type of model to adequately capture all scales of phenomena. As a result, specific models have been developed targeting specific atmospheric scales of motion. On one end of the spectrum are the hydrostatic *general circulation models* (GCM), run at very course resolution (e.g., 200 km) with significant parameterization of subgid scale processes. A GCM is designed to investigate large-scale long term evolution of the atmosphere. The other end of the modeling spectrum consists of high resolution (100 meters or less) non-hydrostatic *cloud-scale* models which explicitly calculate virtually all physical and dynamical processes (Fig. 1).

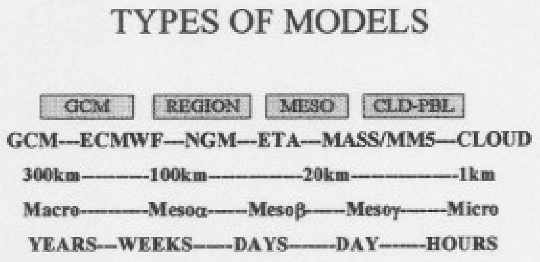

Fig. 1. Spectrum of numerical models.

Regional and *mesoscale* models are designed for the optimal simulation of phenomena that fall between large-scale and cloud-scale models. There is no clear distinction between a regional and mesoscale model. But regional models tend to have model resolution of 50-150 Km while mesoscale models are from 1 - 50 Km.

There are many mesoscale models available today. Currently, the Eta model, which covers North America, provides the highest resolution (29 Km) operational forecasts available from the NWS. Other organizations are running mesoscale models operationally with resolutions ranging from 5-15Km. Two examples are: (1) the Penn State-NCAR model (MM5) by the Pacific Northwest Regional Modeling Consortium, (2) and the Mesoscale Atmospheric Simulation System (MASS) at North Carolina State University.

In addition to the operationally configured models there are a variety of research models, among them the MM5, MASS, HOTMAC (Higher Order Turbulence Model for Atmospheric Circulation), and RAMS (Regional Atmospheric Modeling System). A significant feature of the research models is their configuration flexibility. Their temporal and spatial resolution, as well as the specific configuration of model physics and data assimilation, can all be controlled by the user. In essence there are many variations of MM5s, MASSs, HOTMACs, RAMs etc., based upon the specific model configuration used for a given situation. It is a combination of the resolution and the specific parameterization schemes selected when configuring a model for a given simulation which tends to produce different results among the models. If the configurations are the similar the results usually are similar.

Comparative studies indicate that the key to successful simulations of a particular phenomenon is dependent much more on the specific configuration and options used and not the particular model used (Busch et al., 1994). So the real question one should ask is *"what is the best* *model configuration and support system to use?"* for a specific purpose and not *"which is the best model?"*.

2. NUMERICAL MODEL FORMULATION

All computer based atmospheric numerical models are similar in formulation. Every numerical model is essentially a dynamical and physical computer representation of the atmosphere and the underlying surface. All use the fundamental laws that govern the behavior of the atmosphere. These laws have been derived from observation along with physical and mathematical reasoning which are based upon the fundamental conservation laws of mass, momentum and energy. The fundamental laws governing the atmosphere are: (1) the hydrodynamical fluid dynamic equations based upon Newton's laws of motion, (2) the equation of state relating pressure, temperature and density, (3) the thermodynamic laws relating energy transfer, (4) the radiative transfer laws, (5) the mass continuity relationship, and (6) moisture physics. The physical laws must first be put in the form of a series of mathematical relationships. The mathematical relationships are then transformed so they can be understood by the computer. The two methods typically used are *finite differencing* or *spectral methods* (sine and cosines) (Haltiner and Williams, 1980).

A major factor that influences how well a numerical model simulates the actual observed conditions is the nature of the highly non-linear relationship among the dynamical and physical processes. A non-linear relationship means that there is feedback between the processes causing the atmosphere to be sensitive to initial conditions. This problem was brought into sharp focus by the pioneering work of Edward Lorenz and the concepts now called Chaos Theory (Gleick, 1987). Figure 2 shows a simple schematic that highlight the typical elements of a numerical model and the fact that there is constant feedback among them.

Some people think that Chaos Theory indicates that numerical simulations of the atmosphere are not very useful as a forecasting tool. This is far from true. Chaos Theory just shows that there are limits to the length of time that an atmospheric simulation would be representative of the observed conditions when run in a forecast (predictive) mode.

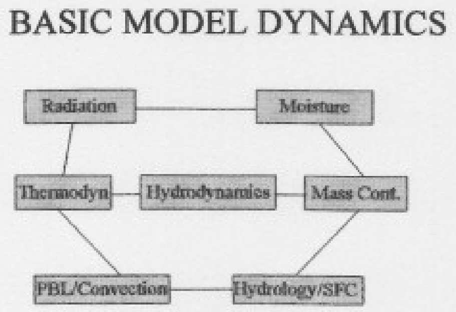

Fig. 2. The basic physical processes that are modeled in all atmospheric models.

However, the length of time a simulation can be used as a reliable forecast is subject to a number of factors. A few of the factors are the coverage and representativeness of the observed data (initial conditions), the size of the domain being forecasted, and the specific sensitivity of the atmosphere to initial conditions at a given moment. Significant strides have been made in determining the sensitivity of the atmosphere and the likely reliability of a numerical forecast through techniques such as ensemble forecasting. Ensemble forecasting involves running a set of simulation which start with slightly different initial conditions for the same day. The faster the forecasts from the simulations diverge from each other, the less predictable the atmosphere. There is, however, much more work needed in this area.

Every model typically follows three main steps: preprocessing, processing and post-processing (Fig. 3). During preprocessing the grid is prepared for location, size, resolution and surface characteristics. Databases with information about the terrain, land-water distribution, and vegetation are used to define the surface characteristics of the grid. The next part of preprocessing is preparing the atmospheric data. There are two components to preparing the atmospheric data. The first component typically uses some form of objective analysis to

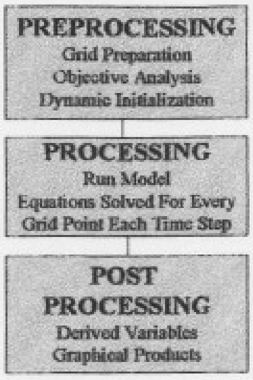

Fig. 3. The three steps of a numerical model.

take all the irregularly spaced surface and upper air observations and interpolates them to the regularly spaced grid. The next component, called *initialization,* makes sure the gridded fields are dynamically consistent across the grid. Once the initialization is completed, processing (running the model) begins. The model runs as an iterative series solving all of the model equations at each grid point for the duration of the simulation. A typical "time step" for solving the equations is on the order of a minute, being more or less based on the requirements of simulation. It can be thought of as the model making a forecast every minute throughout the simulation. Postprocessing of the data consists of deriving more complex atmospheric descriptors (such as "*divergence*" and "*vorticity*") from the basic model output of temperature, winds, humidity and precipitation. The information is then presented in various forms such as charts, graphs and simulated observations as needed by the user.

3. UNIQUE ASPECTS OF MESOSCALE MODELS

The atmosphere is governed by the same laws at all scales, so the question that is often asked is why not have one model? The answer is the lack of sufficient computing power to meet every need. A global climate simulation that takes place over tens of years must sacrifice resolution in order to run on today's computers. Mesoscale models are designed to run for smaller domains (grids areas), therefore more physical processes are explicitly calculated in the mesoscale model than in the larger scale models. Peilke (1984) and Perkey (1990) are two publications that go into the formulation of mesoscale models in detail.

Two issues must be faced by each type of model: (1) How to handle information that flows into the domain from the larger scale (lateral boundary conditions)? and (2) How to handle processes that take place on a scale smaller than the grid scale (sub grid) can resolve? For global simulations, lateral boundary conditions are not an issue, but it is definitely an issue for mesoscale models. Subgrid processes are an issue for all models.

If a mesoscale model is being used on historical cases lateral boundary conditions are available from output fr0m large-scale models and can prevent the mesoscale model from "drifting" away from the observed weather. However, one consequence of the need for lateral boundary conditions is it limits how long a mesoscale model can be run as a forecasting tool and still produce a representative forecast to about 48 hours. This doesn't mean that the mesoscale model produces unreasonable weather beyond 48 hours; it is just different from the observed.

The key to a mesoscale model is how it handles all of the processes of involving the atmosphere as shown in figure 4.

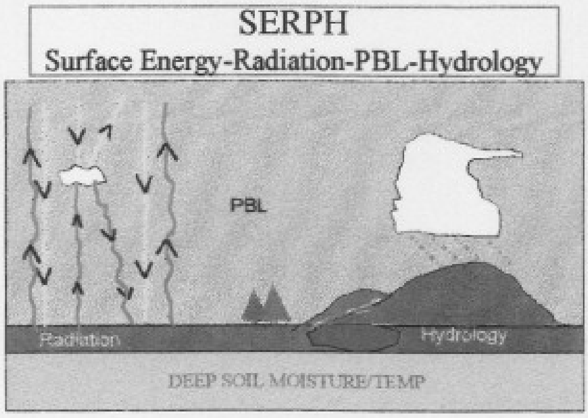

Fig. 4. The many processes that the model must capture to effectively model the atmosphere on the mesoscale.

More of the processes are explicitly calculated in the mesoscale model than for the larger scale models. But there are still many processes that are subgrid for the mesoscale model. The need to account for subgrid scale processes is typically done through a method called parameterization. When model elements such as temperature, moisture and stability reach a certain threshold, a specific parameterization scheme is triggered that provides a value for a physical process that occurs at the subgrid. The courser the resolution of a model, the greater the need to parameterize.

An example of a process that is parameterized in many models is subgrid scale convection (showers and thunderstorms). In this case, if a specified threshold of moisture, temperature and stability is reached, it triggers a scheme in the module (a sub-routine) that accounts for the showers along with the physical consequences of the showers such as latent heat release. It has been determined by both theory and research that showers are typically produced when the threshold conditions are reached. Also, the values used for precipitation and latent heat release are obtained through observation and theoretical derivation. A variety of parameterization schemes have been developed and have several different options for each mesoscale model.

The continual increase in computational power has caused a blurring of the mesoscale and cloud-scale models' capabilities. Currently most mesoscale models can run at high enough resolution and have non-hydrostatic configurations. This allows them in essence to explicitly calculate all the physical processes found in convection on a grid scale. Regardless of the resolution of the model there will always be a need to account for some processes that are smaller than the grid scale through parameterization. The goal is to limit the parameterization as much as possible and to make the parameterization schemes as representative as possible.

4. SUMMARY

Currently there are many models designed for what is called the mesoscale. They all have utility as research and forecasting tools. They also have a number of specific uses for utility companies. These include: (1) improving high resolution forecasting of temperature to help forecast power loads, (2) improving dispersion modeling and (3) understanding the impact of land utilization on the local climate for planning future power production.

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