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A DESCRIPTION OF THE MESO ETA MODEL

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[Editor's Note: The Meso Eta model data is now available on the Western Region server about four and one half hours after the initialization time. Thus, for the first time, sub-synoptic model output is available to National Weather Service (NWS) forecasters in real time. Recent evaluations and studies show the Meso Eta can provide superior guidance for QPFs. SSD asked Mike Staudenmaier (NWSO SAC) to write a series of Technical Attachments (TA) focused on the Meso Eta model. The first TA in the series describes the model's design. The second TA will examine the model's strengths and weeknesses.]

With modern computer power now capable of making mesoscale model output available in real time in the operational environment, increased attention has been given to utilizing these models in order to improve the forecasting ability of meteorologists. The National Centers for Environmental Prediction (NCEP) has developed a step-mountain eta coordinate model generally known as the Eta model. This model replaced the LFM model in June 1993 as the new "early run" model. Efforts proceeded towards the mesoscale regime in order to diagnose those small-scale processes which could not be resolved by current synoptic-scale numerical models like the Nested Grid Model (NGM) or the Aviation Model (AVN). This model, called the Meso Eta, is the outcome of their efforts and represents the first operational mesoscale model available to the entire NWS.

Model Description

The Meso Eta model is a hydrostatic model with a horizontal grid spacing of approximately 29 km and 50 vertical levels, with layer depths that range from 20 m in the planetary boundary layer to 2 km at 50 mb (Fig. 1). The eta coordinate, defined by Mesinger (1984), was used in order to remove the large errors which are known to occur when computing the horizontal pressure gradient force, as well as the advection and horizontal diffusion, along a steeply sloped coordinate surface, such as the sigma surfaces in the NGM model. This coordinate system makes the eta surfaces quasi-horizontal everywhere as opposed to sigma surfaces which can be steeply sloped. Thus, this model should show marked improvements in areas with widely varying topography such as the Western Region of the NWS. Because the eta coordinate is pressure based and normalized (i.e. quasi-horizontal), it leads to a much simpler solution of the equations of motion in areas such as the pressure gradient force, horizontal advection, and diffusion. The eta coordinate is defined by the relationship:

$$\eta = \left(\frac{p - p_T}{p_{sfc} - p_T}\right) \left[\frac{p_{ref}\,(z_{sfc}) - p_T}{p_{ref}\,(0) - p_T}\right]$$

where T refers to the top of the domain (25 mb), sfc is at the model's lower boundary, and ref refers to a reference pressure level that is a function of distance above sea level (Black 1994).

The semi-staggered Arakawa E grid (Arakawa and Lamb 1977) is the basis of the model's horizontal structure. This grid staggers the mass variables and the wind variables and is designed to minimize errors associated with geostrophic adjustment and topographic forcing that occur in other horizontal grid domains. A sample subset of the E grid can be seen in Fig. 2. Each H represents a "mass" variable point (such as temperature or moisture) and each V represents both horizontal components of the wind. The distance "d" is the spacing between adjacent H or adjacent V points, and the magnitude of this distance is commonly used to indicate the model's horizontal resolution, which in this case is approximately 29 km. The E grid lies upon a rotated latitude-longitude framework. This coordinate system is created by simply rotating the earth's entire geographic latitude-longitude grid so as to place the intersection of the equator and the prime meridian (or 0 degrees north and east) over the center of the forecast area, which lies somewhere in north-central Kansas. In doing this, the convergence of the meridians, which occurs as one moves away from the equator towards the poles, is minimized over the forecast area, thus leading to a more uniform and evenly spaced grid. Each grid box consists of a mass point surrounded by four velocity points, all of which lie along parallels and meridians of the rotated latitude-longitude coordinate system.

The model topography is represented as discrete steps whose tops coincide exactly with one of the model's 50 vertical layer interfaces (Black 1994). In determining their elevations, each 29 km horizontal grid box is first divided into 16 subboxes. Mean elevations for each of these 16 subboxes are calculated from official United States Geological Survey (USGS) topographical data. Using these values, the maximum mean value from each of the four rows and four columns are determined, resulting in eight intermediate terrain values. The mean of these eight values are taken to yield an intermediate value for the step height. Having already determined the height of each model layer interface based on the standard atmosphere and the specified distribution of vertical resolution, the final step elevation is found by moving the mean either up or down to match the closest layer interface in the model domain.

A schematic vertical cross section through the lowest layers of the domain (Fig. 3) illustrates the various aspects of the horizontal and vertical structures in the model. For each model grid box, T represents "mass" variables such as temperature and moisture, while U represents both horizontal components of the wind; p_s is the surface pressure.

All velocity points that lie on the edge of a step are given the value of zero and retain it throughout the forecast (these are indicated by the circled U's in Fig. 3). This is called the no-slip condition. Because of this condition, if any grid point in the model lies in a "hole", where it is surrounded by steps of greater elevation, all four surrounding velocity points would be zero. If this is the case, this "hole" is raised to the point where at least one of the surrounding velocities is nonzero. This is necessary to ensure that all grid boxes that are above the model surface have some horizontal divergence to produce vertical advections.

The assimilation procedure for the Meso Eta begins 3 hours prior to the actual start of the forecast model run. At t-3 hours, or at 0000 UTC and 1200 UTC, a first guess is provided by the Global Data Assimilation System (GDAS) using all available data and applied to the Meso Eta coordinate system. The model then integrates for 3 hours which provides the first guess to the new "initial" analyses at 0300 UTC and 1500 UTC which utilize all new available data, comprised of numerous aircraft reports, NEXRAD, profiler, and satellite observations. Finally, the 33 hour forecast is run. By allowing the model to adjust gradually to the analyzed data during the 3-hour preforecast period, the typical spinup problems that tend to occur during the early hours of the actual forecast are significantly reduced. An increase from one to three separate 3-hour spinup cycles starting nine hours prior to the actual start of the forecast model run is envisioned in the future.

The model's boundary data on its single outermost row of points are obtained by direct interpolation from the AVN run of the Global Spectral Model (GSM). At inflow boundary points, all of the prognostic variables are determined by the GSM data, while at outflow points, the velocity components tangential to the boundary are extrapolated from the interior of the integration domain. The values of the second outermost row are a blend of those along the boundary and those in the third row which are part of the true integration domain.

Prognostic Variables

The primary prognostic variables in the Meso Eta model are temperature, specific humidity, horizontal wind components, surface pressure, and turbulent kinetic energy. More recently, cloud water and ice have also become prognostic variables. A split-explicit integration approach, which is also used in the 48 km Eta model, is used in producing forecasts based on these quantities. This means that during each time step, after each process is computed, each of the primary variables is updated and the integration continues to the next time step when both the primary variables and any advective processes are updated. The fundamental time step in the Meso Eta model is about 72 seconds, with twice that time step required for advective processes.

Parameterization Schemes

Convective and grid-scale precipitation in the model are predicted quantities. Convective precipitation, based on the Betts-Miller cumulus parameterization (Betts 1986; Betts and Miller 1986) with some of the modifications based on work by Janjic' (1994), is computed every eight adjustment time steps, or about every ten minutes. In this parameterization scheme, non-precipitating shallow convection (i.e. fair weather cumulus) serves to carry moisture upward and maintain low-level temperature inversions. Deep convection (i.e. thunderstorms) transports heat and moisture upward and produces precipitation. For both types of convection, model profiles of temperature and specific humidity are constructed at each grid point using the values that are present in the model. These model profiles are compared to profiles derived from numerous observations based on actual convection. The model profiles are then relaxed toward these field-generated reference profiles. The precipitation is deduced from the net negative change of specific humidity in the model's deep convective cloud; if the net change is positive (i.e. net evaporation occurred rather than condensation), no adjustment of the variables is made at that grid point.

The model calculates grid-scale precipitation by using an explicit cloud water parameterization scheme (Zhao et al. 1991). The mixing ratio of cloud water and ice has recently been added to the temperature, specific humidity, wind components, surface pressure, and turbulent kinetic energy as a fundamental prognostic variable. This explicit cloud water parameterization takes into account the physical processes of evaporation, condensation, melting, freezing, sublimation, and deposition which occur in the atmosphere. The amount of condensed cloud water is predicted throughout the domain and a three-dimensional array indicates whether that condensate is liquid or solid if supersaturation occurs in a model grid box. The cloud phase is strictly a function of temperature: (a) if T>0 C then the cloud is liquid; (b) if T<-15 C then the cloud is ice; (c) for intermediate temperatures, the cloud will be ice only if cloud ice existed in the same grid box or any box directly above during the previous time step. Thus, ice is not allowed to develop in the cloud process until the temperature reaches -15 C. However, if ice exists in the layer above a grid box which is between -15C and 0C, then ice will also form in this grid box. This simulates a process called "seeding" which happens often in nature as ice crystals fall into a warmer cloud below it producing larger ice crystals in that cloud and ultimately precipitation. Cloud water is allowed to evaporate or sublimate when the relative humidity drops below a critical value. This critical value differs for locations in the model which are located above water or above land. The model does not allow for more than one phase of cloud water within any given grid box, although the grid-scale precipitation within a box can be both liquid and solid. It also does not consider supercooled water below -15 C. There is currently no direct interaction between the cloud water scheme and the Betts-Miller convection parameterization, thus the convective scheme produces no cloud water.

The current version of the radiation package used in the model is one developed at the Geophysical Fluid Dynamics Laboratory. It requires the specification of only three levels of cloud (low, middle, and high). These are determined from the cloud amounts in all of the model layers which in turn were calculated by a simple relation based on the relative humidity. The model's carbon dioxide and ozone distributions are taken from climatology and held constant. The initial surface albedo is also taken from climatology, but is allowed to evolve during the forecast. However, snow cover is calculated from analyzed data allowing the albedo to reflect some reality. The atmospheric temperature tendencies arising from the radiative effects are applied after every adjustment time step. A newer version of the radiation package that directly utilizes cloud in all model layers is being tested.

A new soil package has been developed for the Meso Eta which provides a more rigorous description of the ground processes (Chen et al. 1995). The model now employs two predictive soil layers. The upper layer is 10 cm thick and the lower layer is 190 cm thick. The prognostic temperature for these layers is valid at their centers. Internal vertical heat and moisture fluxes are computed. The initial soil temperature and moisture are taken from the 6-hour forecast from the Global Data Assimilation System. Soil type, vegetation type, and green vegetation fraction are specified as functions of geographic location and the latter also as a function of time. Variability in these quantities permits a much improved handling of such factors as ground permeability, transpiration effects, and albedo. Heat exchange with the atmosphere takes place either at the bare ground interface or on the plant canopy surface. Moisture exchange occurs with the bare soil and with condensed water on plant surfaces as well as through transpiration via leaf pores. Future improvements will include the addition of a third predictive layer and basing the initial soil conditions on the previous Meso Eta forecast rather than on the GDAS. Currently, the soil and vegetation fields are derived from 1 X 1 degree data which are then extrapolated to the model grid points, but are expected to be taken from much higher resolution sources in the future.

The vertical turbulence exchange in the Meso Eta uses a modified Mellor-Yamada Level 2.5 scheme (Black 1994). In this approach, turbulent kinetic energy (TKE) is a fully prognostic variable which is recalculated every eight advective time steps. The predicted TKE is then used to compute the exchange coefficients for the transfer of heat, moisture, and momentum between adjacent model layers. The exchange coefficients are used to modify the prognostic variables in the grid box through which the transfer is occurring. Surface fluxes of moisture and heat between the model surface and the first model layer are computed using Monin-Obukov functions (Black 1994).

Conclusion

A new mesoscale model has been developed for use by the NWS to help forecasters examine and diagnose sub-synoptic weather phenomena. Preliminary results indicate that the mesoscale model is capable of capturing some small-scale circulations, forced by either dynamics alone or by terrain, with reasonable accuracy. Like all models, the Meso Eta has strengths and weaknesses inherent in its design. This puts limits as to what forecasters in the field should expect from the model output data. In the next TA on this topic, the strengths and weaknesses of the Meso Eta will be examined.

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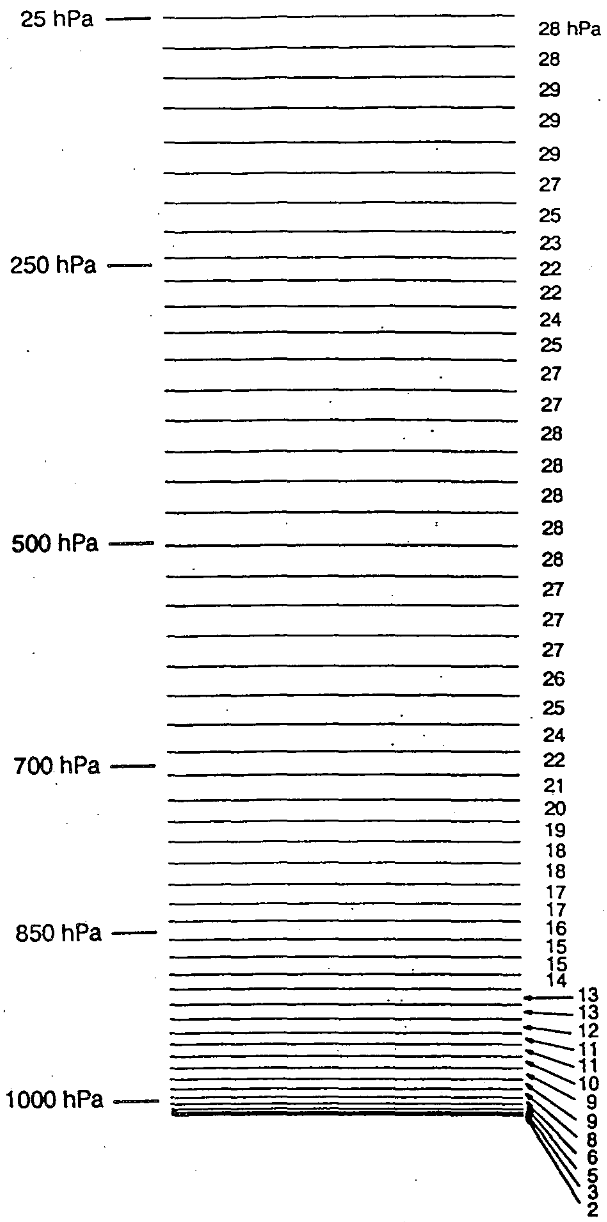

FIG. 1. A sample distribution of the 50 layers in the mesoscale Eta Model. The pressures on the left side indicate the layers' positions with respect to the standard atmosphere, while the numbers on the right give the approximate pressure depth of each layer in hectopascals.

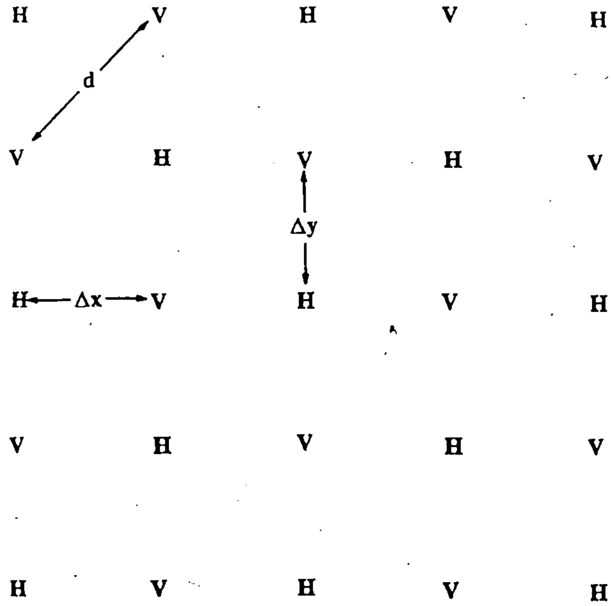

FIG. 2. A subset of the model's Arakawa E grid. Each "H" represents a mass variable, while each "V" represents both horizontal wind components. The values Δx and Δy are the grid increments in the model's rotated latitude–longitude space, while the distance "d" indicates the resolution.

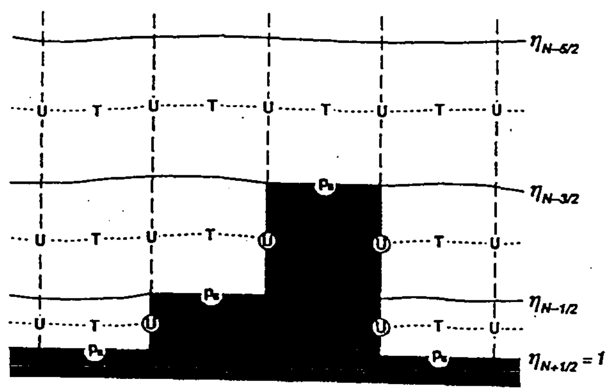

FIG 3 An idealized vertical cross section of the model's step topography. Each T indicates a "mass" variable within each grid box, while each U represents both horizontal wind components. The quantity p_s is the surface pressure. The circled U's on the sides of steps indicate wind points that are defined as zero at all times.