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THE SOIL MODEL IN THE ETA

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Introduction

Over the past decade, there has been a strong push toward better modeling of land-surface processes, including heat and moisture fluxes, soil moisture evolution, snowpack treatments, and vegetation effects. Numerous papers have been published demonstrating the importance of land-surface effects on mesoscale numerical weather prediction (Mahfouf et al., 1987; Avissar and Pielke, 1989). The primary reason for this research is to improve how mesoscale models realistically model the diurnal evolution and vertical structure of the planetary boundary layer. This can have direct influences on convection, precipitation, and near surface sensible weather, like temperatures and relative humidity. This Technical Attachment will discuss the soil model in the Eta-29 model, including the way that snow cover is handled by the model.

Soil Model Description

In the Eta-29, a new soil model has been developed, replacing the former bucket model which used temporally fixed annual mean soil moisture values and a crude runoff treatment of moisture. The new model is an extended and enhanced version of a model developed over the last 15 years by Air Force Phillips Laboratory (Mahrt and Pan, 1984; Chen et al., 1996; Betts et al., 1996), and is referred to as the OSU or CAPS model.

The model includes physics for two soil layers, along with a vegetation canopy and snowpack. In the current configuration of the model, the soil layers are 10 cm thick (top thin layer) and 190 cm thick ("root zone" layer). The thin top layer is necessary to 1) properly treat surface infiltration/runoff response, and 2) capture the short 1-2 day drying time scales characteristic of bare soil evaporation. The thicker "root zone" layer is needed to properly simulate transpiration from the plant canopy, in particular the canopy's ability to maintain high rates of evaporation during the summer well after the last significant rains (a 2-4 week period).

A single ground surface skin temperature, T_s, is derived using the surface energy balance equation, which represents the sum of surface energy sources/sinks from net surface solar radiation, net surface long-wave radiation, total surface evaporation, surface sensible heat flux, subsurface ground heat flux, and surface heat fluxes from snow melt. The soil temperature in the two soil layers is predicted using the traditional thermal diffusion equation, which uses a soil thermal conductivity that is a function of soil moisture and soil type. Currently there are seven soil textures in the Eta-29 model. For the lower soil temperature boundary condition at a three-meter depth, the annual mean surface air temperature at the given location is used.

The total soil evaporation is the sum of three parts, 1) transpiration through the plant canopy, 2) direct evaporation from bare soil, and 3) the evaporation of standing water on the plant canopy via dew or intercepted rainfall. The time scales for the later two parts are on the scale of a few hours to a few days; however, the time scale of the first part is on the order of weeks. Thus, in vegetative regions such as the Pacific Northwest, summertime surface evaporation can remain high even weeks after the last significant rainfall event due to transpiration.

The relative contributions of these three terms on the total surface evaporation are dictated primarily by the grid-cell fraction of green vegetation. This is where the Eta-29 soil model is far superior to other models. A refined data set of 0.14 degrees, 5-year monthly averaged mean climatology of green vegetation fraction, is used to initialize this value in the model. The monthly averaged values are interpolated to the current day of the year, for a smooth temporal trend on a daily time scale.

Together with this database, there are twelve vegetation classes used with the soil model. The bulk of the United States is covered by seven of the twelve classes: deciduous forest, evergreen forest, mixed deciduous/evergreen forest, grassland, cultivated fields, semi-arid, and desert.

Soil moisture changes in the two soil layers are governed by 1) surface infiltration of precipitation and melting snow, 2) the direct evaporation out of the ground surface or via root uptake by the plant canopy, 3) drainage working downward through the soil, and 4) hydraulic diffusivity, which can act upward or downward through the soil depending on the gradient of the vertical soil moisture. The means of how this is accomplished is beyond the scope of this document.

Finally, the soil model has an additional set of criteria for cases where there is snow cover in the model. First, the surface energy balance equation is modified to account for the possibility of snow melt. If present conditions (i.e., solar radiation and air temperature) are such that in the absence of snow, the skin temperature and the air temperature would rise above freezing, then an appropriate amount of snow is melted to match this "available" surface energy. While snow is melting, the surface skin temperature is held at 0.0 °C and the nearby 2-meter air temperature rarely rises above 2-3 °C. As the snow melt process proceeds in time, the model snow depth decreases. If snowfall occurs during the model integration, the physics increases the Eta-29 snow depth. Thus, snow cover can appear when none existed initially and initial snow cover can disappear although some existed initially. In the NGM model, both snow melt and snowfall accumulations are absent in the model, with the initial snow cover holding constant through the 48-hour model integration.

With the current method of treating a snow pack in the Eta-29, there is an important limitation. The Eta model assumes complete snow cover, even for shallow or patchy snow cover. Thus, when snow cover is light, the model will continue to hold the skin temperature at 0.0 °C which holds the 2-meter temperature near 2-3 °C, even though temperatures with light amounts of snow are not constrained to this rule in reality and may rise well above freezing. An initial fix to this problem has been to only allow this constraint to occur when the snow depth in the model reaches 2.5 inches or greater, thus allowing for temperatures to rise when snow depth is less than 2.5 inches. Forecasters will need to keep this in mind when viewing near surface temperatures under this type of situation. The complete snow algorithm will be looked at and likely restructured before next winter.

Future Refinements

Even with all these refinements already built into the new soil model, additional improvements are likely to be made in the model. These improvements are expected to focus on two major areas, based mainly on the initialization of soil moisture and snow cover. The planned improvements in the Eta soil moisture initialization, are as follows:

1) Replace the 12-hour EDAS initialized from the GDAS (Staudenmaier, 1996) with a continuously cycled EDAS always initialized from a previous cycle of itself. Thus the model will be using soil moisture values already evolved from the Eta model, not always initializing with zero values. Additionally, any biases from the GDAS will be removed from the Eta model.

2) Increase the number of soil layers from two (10 cm, 190 cm) to four (roughly 7 cm, 23 cm, 70 cm, and 100 cm).

3) Assimilate the new EMC hourly, 4-km radar/gage Stage IV National Precipitation Analysis (NPA) into the EDAS. Thus, the precipitation observed will be used to drive the soil model evolution toward reality, rather than only allowing model generated precipitation during the EDAS to modify the soil model.

4) In the continuously cycled EDAS with precipitation assimilation, adopt Office of Hydrology validated strategies for tuning crucial surface infiltration and baseflow runoff parameters, in order to significantly better simulate total runoff in the EDAS, and therefore significantly improve the seasonal and annual cycle of soil moisture in the model. Currently, rainfall and snow melt contribute to forecast runoff in the model, which EMC has used during recent flooding events of the last two winters. This cycled EDAS should improve this forecast runoff.

Looking at the initialization of snow depth, the Eta model currently initializes its snow depth with the USAF 47-km resolution daily Northern Hemispheric snow depth product. Although this product has been adequate for synoptic scale models, NCEP needs a higher resolution product aimed specifically at NWP initialization of mesoscale models. Over the last three years, EMC has worked with NESDIS IPB to develop a new 23-km Northern Hemispheric snow cover analysis. Development of this new NESDIS snow cover product, termed the Interactive Multi-sensor Snow Analysis (IMS), is nearing Phase 1 completion, with formal operational daily production to start by 01 November 1997. It is hoped that the Eta models will be initialized from this new product for next winter.

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