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THE EXPLICIT CLOUD PREDICTION SCHEME IN THE MESO ETA MODEL

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Introduction

An explicit cloud prediction scheme that forecasts the formation and subsequent development of both liquid water and ice particles in the atmosphere has been incorporated into the Meso Eta model. Significant improvements in the model forecasts of moisture, temperatures, clouds, and precipitation have been achieved by using this prognostic cloud scheme. This Technical Attachment will describe the fundamentals of the cloud prediction scheme and discuss the impact to operational forecasters.

Description of the Cloud Prediction Scheme

The primary feature of the cloud prediction scheme is the explicit calculation of cloud water and cloud ice contents in large-scale condensation processes. One predictive variable, the cloud water/ice mixing ratio, is used to represent both cloud water and cloud ice. By using one variable instead of two, model computational time and storage requirements are reduced.

Clouds are produced from large-scale condensation processes. Two three-dimensional fields are calculated: 1) cloud fraction is calculated diagnostically from relative humidity, and 2) cloud water/ice content is represented by the cloud water/ice mixing ratio. Clouds in this scheme are composed of either liquid water or ice particles, depending on the temperature (T) and the cloud top temperature (T_p). Figure 1 shows the distribution of liquid water and ice particles inside model clouds. In regions where $T > 0$ °C, cloud ice is not allowed to form, while in regions where $T < -15$ °C, cloud water cannot exist. In regions where T is between 0 °C and -15° C, however, the phase of any hydrometeors is determined by the cloud top temperature T_p. If $T_p > -15$ °C, then the cloud is assumed to consist of supercooled water. If $T_p < -15$ °C, which means that there are ice crystals above the layer in question, the cloud below cloud top should freeze very quickly because of seeding effects of the ice crystals into the cloud from above. Thus, the cloud is assumed to consist of frozen hydrometeors.

Cloud condensation is allowed to occur when the relative humidity of a grid box reaches a critical value, U_{00}. The value for U_{00} over land is 75%. Since condensation can more easily occur over the ocean than over land, especially in the lower atmosphere because of the abundance of available moisture, the value of U_{00} is set at 80% to avoid excess condensation.

Cloud evaporation is allowed to take place only when the relative humidity falls below the critical value of U_{00}. This is most likely to occur when clouds are advected into a drier region of the atmosphere, or when the relative humidity at a grid point, where a cloud already exists, drops below the critical value U_{00}. Evaporation will cease when the critical value of U_{00} is again reached or surpassed.

The vertical advection of clouds and hydrometeors in this scheme is neglected based on the assumption that there is an approximate balance between the small gravitational fall speed of any cloud particles and the model's large-scale vertical motions (Sundqvist et al.,1989). The horizontal advection of cloud water/ice is calculated using the same techniques as are used in the advection of specific/relative humidity in the model.

Cloud fractions calculated from the relative humidities are indirectly used in the radiational parameterization scheme in the model. Currently, three layers of clouds (low--surface to 642 mb, middle--642 mb to 350 mb, and high--350 mb to 50 mb) are computed from the cloud fractions in each model layer as input to the radiation calculations. A new bundle of changes to the model, expected to be out in the next month, will include changes to cloud fraction so that all vertical layers in the model will be used directly in the radiation package.

Precipitation in this scheme is diagnostically calculated from the cloud water/ice mixing ratio, so that once precipitation is produced from cloud water/ice, it falls to the ground through all the layers of the model below it. Snow and rain are the two forms of precipitation produced from ice clouds and liquid clouds, respectively. The interaction between snow and rain is also considered. Six major microphysical processes, which have been observed in clouds, are used in the parameterization of precipitation production from clouds. These microphysical processes are: autoconversion of cloud water to rain, collection of cloud droplets by the falling rain drops, autoconversion of ice particles to snow, collection of ice particles by falling snow, melting of snow below the freezing level, and evaporation of precipitation below cloud bases. Calculation of precipitation is done level by level, from the layer where precipitation develops to the model surface.

There are two important features in this cloud prediction scheme. First, snow melts gradually, not immediately, when it falls into a warmer portion of the cloud or atmosphere. This treatment allows the co-existence of snow and rain in some regions just below the melting level, allowing for the possibility of mixed precipitation at the model surface. Second, evaporation of precipitation occurs as it falls through the entire unsaturated layer below cloud base, and can reach the ground while it is evaporating.

The advantages of this scheme over the much more simplistic way of representing clouds solely on the basis of the relative humidity of a model atmosphere are threefold. First, it represents the hydrologic cycle much more completely, including microphysical properties inside the cloud. Second, it gives an explicit three-dimensional representation of clouds. Third, it is still simple enough to be used in operational models both in computational speed and storage. Some disadvantages of this scheme are 1) that there may be inconsistencies between the cloud water/ice mixing ratio and the cloud fraction which is calculated (since both are calculated separately), 2) some important processes, such as the advection of precipitation particles and other, more difficult to parameterize, microphysical processes are ignored, and 3) the cloud model is not initialized with any cloud/water information, thus a 'spinup' of clouds must take place during the first few hours of integration. Additionally, since some water is tied up in the cloud water/ice in the explicit model, the relative humidity fields will be slightly lower than relative humidities in other NWP models. More information regarding this difference in relative humidities in NWP models can be found in Staudenmaier (1996). The advantages of this scheme, however, far outweigh the disadvantages, with numerous studies (Zhao and Carr, 1991; Zhao et al., 1996; Zhao, Black and Baldwin, 1996) showing the improvements of this cloud prediction scheme over the previously used schemes in NWP models.

Conclusion

The explicit cloud prediction scheme in the Meso Eta model has been shown to have improved precipitation forecasts while producing much more realistic three-dimensional model clouds and a greatly improved hydrological cycle. This has also led to slight improvements in temperature fields, wind fields, and the radiational balances in the model. Further refinement of the scheme, including initializing the cloud model with water/ice mixing ratios deduced from observed precipitation fields, should reduce the cloud 'spinup' problem and produce more accurate precipitation forecasts.

Acknowledgments

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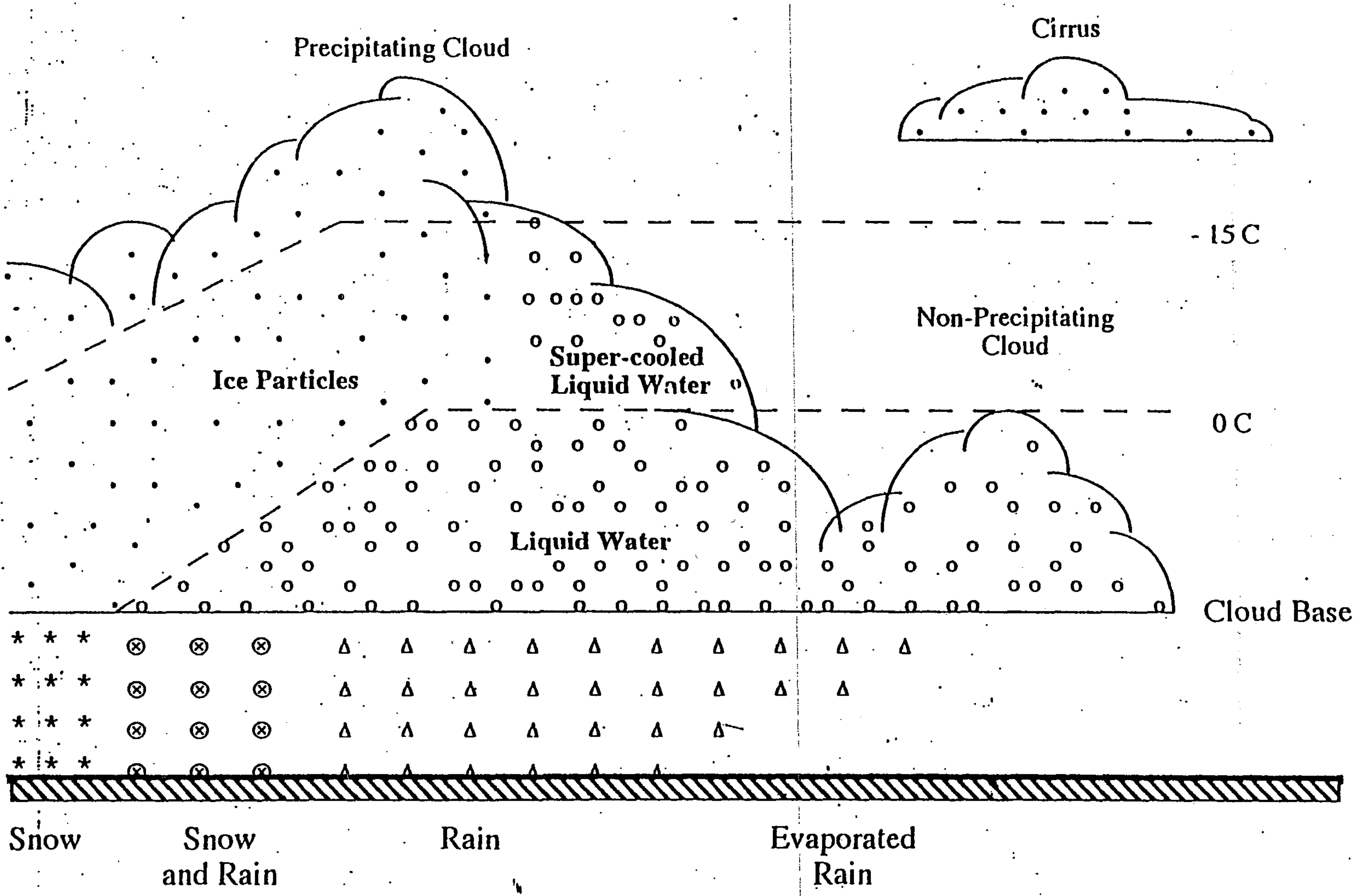
Precipitating Cloud
Cirrus
- 15 C
Non-Precipitating Cloud
Ice Particles
Super-cooled Liquid Water
0 C
Liquid Water
Cloud Base
Snow
Snow and Rain
Rain
Evaporated Rain