WATER VAPOR SOURCES AND SINKS, AND HYDROMETEOR LOADING IN THE ETA MODEL

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The eta system equations of Mesinger (1984; also in Mesinger at al., 1988) were arrived at with the assumptions that (a) effects of sources and sinks of water vapor, and of the presence of liquid water/ice are neglected, (b) that discretization to follow will be of the step-mountain type, so that the eta vertical velocity at the ground surface is zero, and (c) that the hydrostatic approximation is made. The removal of (b) was discussed in Mesinger (2000). The objective here is to generalize equations so that the assumption (a) be removed.

We shall introduce the generalizations involved one at a time, starting with the effects of water vapor sources and sinks in the continuity equation, and then moving on to the water/ice loading effects in the hydrostatic and the pressure tendency equations.

For reference, we shall first write down the eta system continuity equation with no mass sources or sinks, (2.5) in Mesinger et al. (1988),

$$\frac{\partial}{\partial\eta}\left(\frac{\partial p}{\partial t}\right)+\nabla\cdot\left(\mathbf{v}\frac{\partial p}{\partial\eta}\right)+\frac{\partial}{\partial\eta}\left(\dot{\eta}\frac{\partial p}{\partial\eta}\right)=0. \tag{1}$$

We want to allow for the sources and sinks of water vapor, such as tend to be assumed by various precipitation schemes. Following a standard mass budget consideration , and using q for specific humidity, we arrive at

$$\frac{\partial}{\partial\eta}\left(\frac{\partial p}{\partial t}\right)+\nabla\cdot\left(\mathbf{v}\frac{\partial p}{\partial\eta}\right)+\frac{\partial}{\partial\eta}\left(\dot{\eta}\frac{\partial p}{\partial\eta}\right)-\frac{dq}{dt}\frac{\partial p}{\partial\eta}=0. \tag{2}$$

Note a slight difference compared to Savijarvi's (1995) sigma system equation: in (2) q is specific humidity, as opposed to the mixing ratio of Savijarvi.

To obtain the surface pressure tendency equation we need to integrate (2) from the top to the bottom of the model atmosphere. To handle the singularity at the surface, we integrate only to $\eta_S-\varepsilon$, ε being small, obtaining

$$\frac{\partial p_S}{\partial t}=-\int_0^{\eta_S}\nabla\cdot\left(\mathbf{v}\frac{\partial p}{\partial\eta}\right)d\eta+\int_0^{\eta_S-\varepsilon}\frac{dq}{dt}\frac{\partial p}{\partial\eta}d\eta+gE, \tag{3}$$

as a replacement of (2.8) in Mesinger et al. (1988). Here E is the mass of water vapor evaporated into the atmosphere per unit area and unit time.

Integrating (2) from 0 only to η, and rearranging terms, we obtain

$$\dot{\eta}\frac{\partial p}{\partial\eta}=-\frac{\partial p}{\partial t}-\int_0^{\eta}\nabla\cdot\left(\mathbf{v}\frac{\partial p}{\partial\eta}\right)d\eta+\int_0^{\eta}\frac{dq}{dt}\frac{\partial p}{\partial\eta}d\eta. \tag{4}$$

Note that this replaces (2.9) of Mesinger et al. (1988).

Various hydrometeors if carried in a model, e.g., cloud water/ice, add weight to columns of air, affecting pressure. The total mass in a volume element as above is then

$$m_t=m_d+m_v+m_w, \tag{5}$$

where m_w is the mass of hydrometeors in the volume. A prognostic variable of the Eta is Òspecific cloud water/iceÓ

$$w\equiv m_w/(m_d+m_v). \tag{6}$$

It is convenient to define an effective density, the density of the mixture of moist air and hydrometeors,

$$\rho_{eff}\equiv m_t/V. \tag{7}$$

Combined with (5) and (6), this gives

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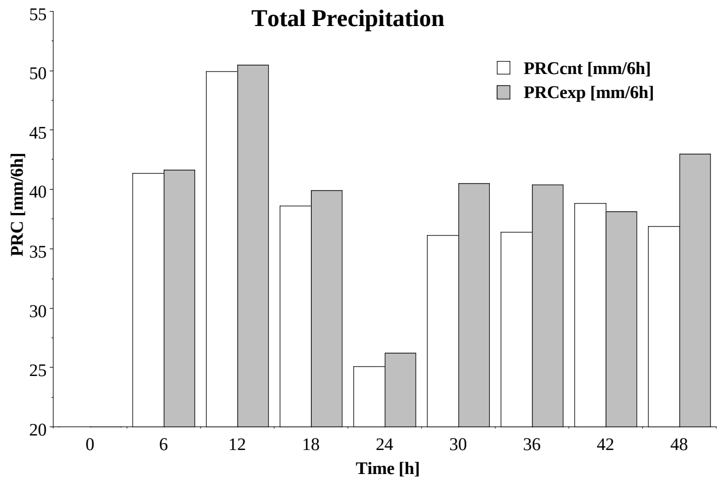
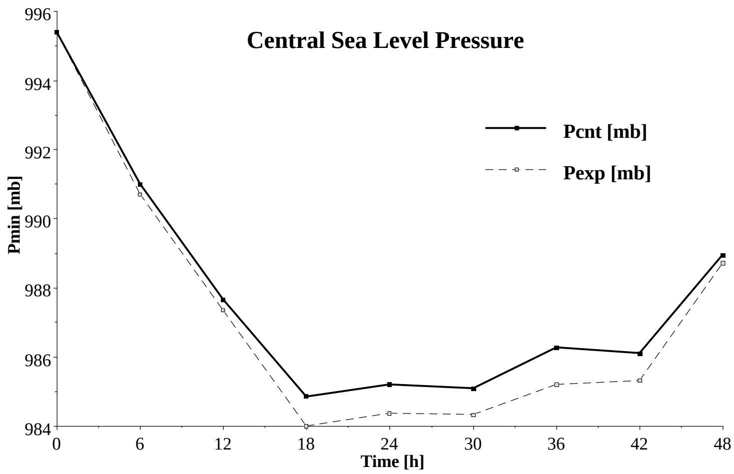
$$\rho_{eff} = \rho(1+w). \quad (8)$$

Use of (8) in the hydrostatic equation, and in the mass convergence terms of the pressure tendency equation, instead of the air density, will account for the effects of the hydrometeor loading on pressure.

Given that in the Eta code the evaporated water vapor is not added explicitly to the atmosphere but instead the latent heat flux is used as a boundary condition for the vertical diffusion of moisture, the total column water vapor needs to be calculated before and after the diffusion loop, and the evaporation obtained as the difference between the two.

Initial conditions for a sensitivity experiment we ran are those of 0000 UTC 18 January 1987, selected in an earlier study for their featuring the tropical cyclones *Connie* and *Irma* from the Australian Monsoon Experiment (AMEX). Figures below show total precipitation and central sea level pressure of *Connie* in our control and experiment during 48 h forecasts.





References

Mesinger, F., 1984: A blocking technique for representation of mountains in atmospheric models. *Riv. Meteor. Aeronautica*, **44**, 195-202

Mesinger, F., 2000: The sigma vs eta issue. Research Activities in Atmospheric and Oceanic Modelling, WMO, Geneva, CAS/JSC WGNE Rep. 30, 3.11-3.12.

Mesinger, F., Z. I. Janjic, S. Nickovic, D. Gavrilov and D. G. Deaven, 1988: The step-mountain coordinate: Model description, and performance for cases of Alpine lee cyclogenesis and for a case of an Appalachian redevelopment. *Mon. Wea. Rev.*, **116**, 1493-1518.

Savijarvi, H., 1995: Water mass forcing. *Contrib. Atmos. Phys.*, **68**, 75-84.