# Explicit Microphysics and Diabatic Initialization

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The presentations I gave at the NetFAM Workshop on Clouds and Precipitation are based on my work, and that of my colleagues, on the Local Analysis and Prediction System (Albers et al. 1996). Equations and graphics from the powerpoint presentation that accompanies this article will not be replicated here; the reader may find additional clarity by referring occasionally to the presentation material.

LAPS is a software package that ingests meteorological observations, creates hourly three-dimensional grids of state variables and clouds, and produces initialization grids for mesoscale models. LAPS is designed for efficiency, specifically to enable real-time numerical weather prediction on affordable computers. For example, it runs on AWIPS, which is the weather forecasting workstation used by the US National Weather Service in all of its forecast offices.

One very attractive reason for using high-resolution mesoscale models is to avoid using parameterizations of deep convection. Algorithms of this type detect conditions suitable for deep convection and then adjust the model's vertical profiles of moisture and temperature to resemble post-convective environments. Surface precipitation is diagnosed as a result of these adjustments. These methods can generate reasonable surface precipitation rates, but the convection is fixed in place (unless the forcing is moving as in the case of a front) because there is nothing the model can advect. Furthermore, there is no way to represent the nonhydrostatic effects that are crucial in steering and configuring deep convection. That is why explicit representation of deep convection is attractive. With explicit microphysics, cloud liquid is created in supersaturated grid boxes, which causes local warming by latent heat release, which causes vertical motions that initiate moist convective updrafts, quite like the sequence of physical processes in nature. As the updrafts continue to rise, they cool, more cloud liquid is generated, which eventually coalesces into rain. If the environment is cold enough, such processes as freezing of rain, generation of cloud ice, and aggregation of cloud ice into snow can occur. Precipitation species like rain and snow begin to respond to gravity, evaporate on the way downward, and may reach the surface. Convective downdrafts, cold pools, anvils, and nonhydrostatic storm steering all occur as a result of modeled processes, and require no additional parameterization. All these similarities to nature appeal to physical scientists who are motivated by the congruence of nature and algorithm.

Historically, explicit microphysics algorithms (e.g., Rutledge and Hobbs 1983; Lin et al. 1983; Reisner et al. 1998) have been associated with large computational burden. They were conceived as fortran manifestations of laboratory results and were coded primarily for faithfulness to theoretical treatments of how particles interact, collision efficiencies, measured rates of diffusion toward liquid and various ice surfaces, etc. This algorithmic complexity, and the associated compute load, was a daunting obstacle to those interested in using them for real-time applications. This motivated the development of the algorithm I call "NWP Explicit Microphysics", or NEM, although unfortunately it seems have been informally renamed to "Schultz microphysics" since the original paper (Schultz 1995). The NEM code is about 700 lines including comments, and is designed to be easy to read, understand, and modify. Gains in efficiency were attained by using simple mathematical functions to replace more complicated formulas.

Although several mostly minor changes have been made since Schultz (1995), there was a major change made recently.

Weisman et al. (1997) document several problems associated with using all-explicit cloud physics (i.e., without a parameterization for deep convection) on grids not fine enough to resolve all moist convection. These problems include late initiation, excessive CAPE buildup, and excessive precipitation rates, often by a factor of two or more. This is because most explicit microphysics algorithms require 100% RH before cloud liquid begins to form. The prevents the model from generating boundary layer cumulus clouds in the preconvective environment. Although these clouds, like all liquid-water clouds, have in-cloud relative humidity of 100%, the saturated volume is quite small relative to grid boxes of 5 km or so; the grid-volume-average relative humidity may be as low as 80%. As a result, the model's earth surface gets direct sunshine while it should be shaded, at least partially. Another important effect of boundary layer cumuli is to release some of the CAPE that normally builds up in the morning boundary layer. The effect, then, is that the vertical mixing and latent heat release that is accomplished in nature by shallow cumuli is erroneously retarded. CAPE builds up artificially and the suppressed latent heat release is eventually aliased into the resolvable scale, which causes explosive and sudden vertical accelerations when condensation finally occurs. This can cause numerical "point-CISK", in which enormous updrafts cause surface pressure drops and straight-line surface winds of 50 m/s or more blowing directly into the updraft.

Thus, the recent change to the NEM algorithm is to allow condensation to occur in grid cells that are moist, but not saturated, and with low static stability. Saturation is still required in stable environments; i.e., conditions associated with stratiform clouds. Early tests show that the modeled convection is still late, but much less so, and still produces excessive precipitation, but much less so. The grid increment is also considered in determining the relative humidity threshold above which condensation can occur, so that a relatively fine grid (with Δx of 1-2 kilometers) uses a higher threshold than a coarser grid (with Δx of 10 or more kilometers).

The original HIRLAM microphysics package (Sundqvist 1978), which facilitates partial cloudiness, has recently been modified along the lines of Rasch and Kristjánsson (1998), and now incorporates consideration of grid-scale static stability.

By design, the water species represented in the NEM algorithm are similar to those analyzed by the LAPS cloud analysis, which enables straightforward model initialization with LAPS grids. However, there are additional steps required to ensure a successful model initialization with active clouds and precipitation processes, or diabatic initialization. For example, simply inserting nonzero mixing ratios of cloud liquid into the model will yield very bad results. Even if the grid box is saturated (or above NEM's threshold), any mixing with dry air will cause evaporation of the cloud liquid, then cooling, then subsidence warming, then more evaporative cooling, and eventually a synthetic downdraft precisely where a cloud was diagnosed. Thus, the paired additional steps of ensuring saturation in grid boxes with nonzero cloud liquid, and inserting upward vertical velocities in cloudy grid boxes, are required. Vertical velocities are estimated empirically in the LAPS cloud analysis, and the full 3D wind field is then variationally adjusted so that the initialized divergence field is consistent with the diagnosed vertical motions. We refer informally to this procedure as "hot start" initialization.

Diabatic initialization of global models, which have grid resolutions that are coarse enough to require deep convective parameterization, is performed by adjusting the model fields of moisture, CAPE, and/or divergence so that the convective parameterization is triggered to produce observed surface rain rates (e.g., Kasahara et al. 1996). Surface rain rates are of little use in the diabatic initialization of fine-grid models using explicit microphysics, because surface precipitation is the result of 15-45 minutes of complex antecedent cloud dynamics. Instead, three-dimensional estimates of cloud properties are required, which is accomplished by using volumetric radar data, satellite data, and METAR reports of cloud bases and layers.

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