A Shallow Convection Parameterization for the Non-Hydrostatic MM5 Mesoscale Model

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A shallow convection parameterization suitable for the non-hydrostatic Pennsylvania State University (PSU)/ National Center for Atmospheric Research MM5 mesoscale model is being developed at PSU. The parameterization is based on parcel perturbation theory developed in conjunction with a 1-D Mellor-Yamada 1.5-order planetary boundary layer (PBL) scheme and the Kain-Fritsch (KF) deep convection model (Kain and Fritsch 1990).

Development is done within a 1-D framework to allow efficient experimentation in a prescribed (constant or time-dependent) large-scale environmental state. Later, the 1-D model will be introduced into the 3-D MM5 for fully interactive testing and evaluation. The first step was to incorporate the KF scheme into the Gayno-Seaman PBL. This composite PBL-convective model was run over Oklahoma for the convective case of June 10, 1993, beginning at 1200 Greenwich Mean Time (GMT). The initial profile (not shown) had an inversion in the lowest 60 mb. Figure 1 shows the simulated mixed layer at 1800 GMT (+6 h). By 2100 GMT, after the inversion is eliminated, parcels in the mixed layer with small positive temperature perturbations (1°C) and moisture perturbations (1 g kg $^{-1}$) become unstable (Figure 2). Convective available potential energy is then released by activating the KF scheme. Although the full impact of the convection on the environment cannot be represented in the 1-D model, the sounding is stabilized by evaporative cooling in moist downdrafts, thus halting the convection and drying the middle levels (not shown).

The model assumes shallow convection is mostly surface-based. Key variables include the cloud-parcel perturbation temperature, perturbation mixing ratio, and the vertical velocity at cloud base and the cloud-base height. For the first stage of the development, over land, we assume that the parcel perturbation temperature (T) and mixing ratio (q) are given by the simulated surface-layer values (level KL). The cloud-base height, Z_c, after Wang (1993), is given by

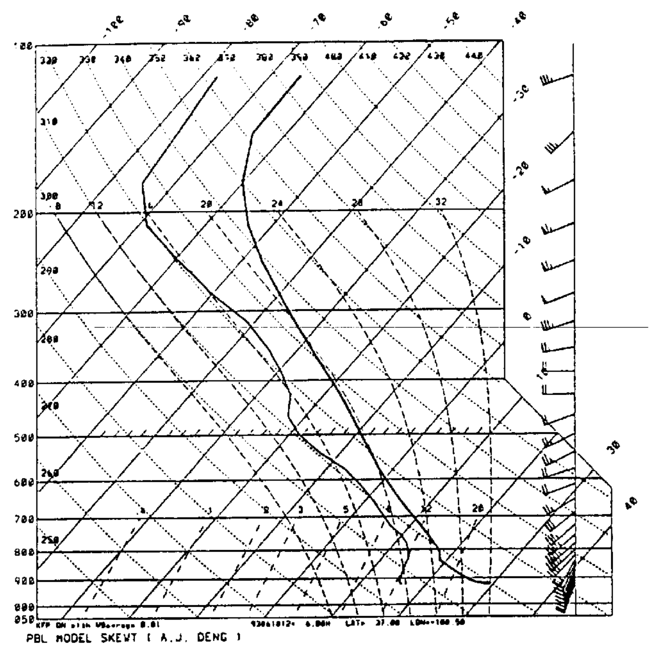

Figure 1. Simulation at 1800 GMT, +6 hrs.

$$Z_c \quad \frac{T_{KL}\mathrm{In}[q_{KL}/q_{SO}]}{\left[1 \quad \frac{q_{SO}}{0.622}\right]\frac{Lg}{R_v T_{KL} C_p} \quad \frac{g}{R_D}}$$

Between a non-disturbed state and the initiation of deep convection, three states of shallow convection are hypothesized: 1) turbulent PBL, but no cloud (no condensation); 2) shallow stable cloud (does not reach level of free convection, LFC); and 3) deep non-precipitating cloud (reaches LFC, but too shallow to trigger KF parameterization - less than 4 km deep). As clouds grow through Types 1-3, they transition smoothly to KF deep convection.

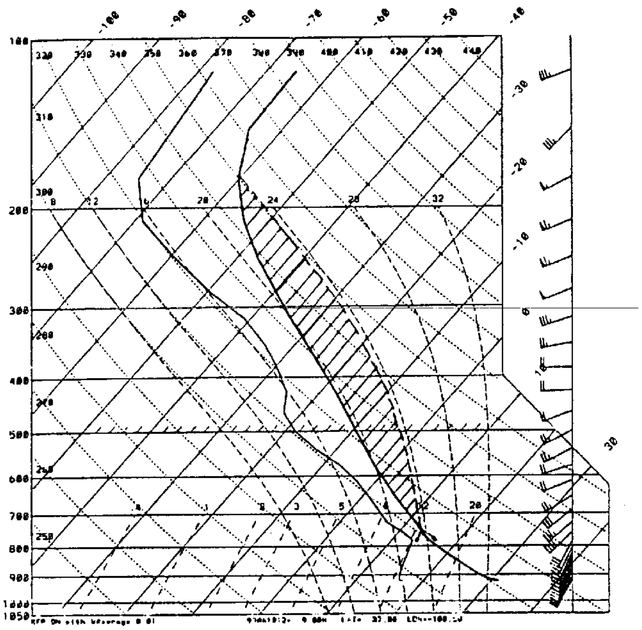

Figure 2. Simulation at 2100 GMT, +9 hrs., showing perturbation temperature and moisture. Hatched area indicated convective available potential energy (CAPE).

Current work involves testing and evaluation of the vertical-velocity calculations. The vertical velocity of a parcel is determined as the sum of five contributing factors: 1) sub-grid scale PBL turbulence due to surface heating, 2) resolved-scale vertical velocity at cloud base, 3) sub-grid scale effects due to land-use inhomogeneities, 4) sub-grid scale effects detectable from the resolved-scale terrain, and 5) sub-grid scale effects undetectable from the resolved-scale terrain. The dominant contribution to the parcel's cloud-base vertical velocity normally is from the turbulent component, $W_T^{/}$ 0.816 $E_{max}^{0.5}$, where E_{max} is the maximum turbulent kinetic energy in the PBL. An example of the evolution of $W_T^{/}$ is shown in Figure 3. Along with the temperature and moisture perturbations and the cloud-base calculation, this will enable determination of equilibrium cloud tops for undiluted clouds. Subsequent work will add entrainment with the environment.

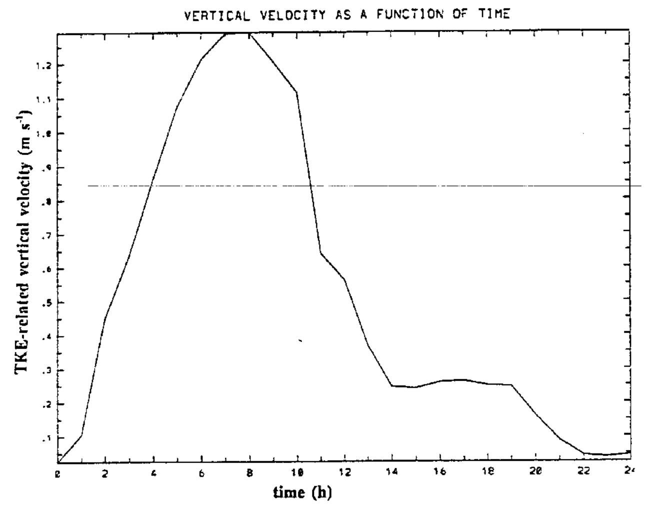

Figure 3. Turbulence-induced vertical velocity perturbations, $W_T^{/}$, calculated for June 10, 1993.

When completed, the model will allow prediction of cloud coverage, cloud base and top, mass flux at cloud base, distribution of detrained cloud mass, and liquid water content. These parameters will better represent effects of non-precipitating cloud on radiation processes (and other meteorological or other chemical impacts) in numerical models than is currently possible. The scheme will also distinguish between cumulus and stratocumulus clouds and be applicable in continental and marine environments.

References

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Wang, S. 1993. Modeling marine boundary-layer clouds with a two-layer model: A one-dimensional simulation, *J. Atmos. Sci.*, **50**, 4001-4021.