EVALUATION OF A NONLOCAL-CLOSURE *K*-SCHEME USING THE MM5

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1. INTRODUCTION

Consistent treatment of atmospheric boundary layer (ABL) processes in meteorological and air quality simulation models is highly desirable. Using one ABL scheme in a meteorological model and a different scheme in an air quality simulation model can lead to undesirable plume structures in the air quality model. In many of the first-order local-closure schemes (e.g., Hong and Pan, 1996; the MRF scheme in MM5), the friction velocity (u_*) scale is used as a closure to the formulation. However, for moderate to strong convective conditions, u_* is not a representative scale. Instead, the convective velocity (w_*) scale is suitable. In some formulations, depending on the magnitude of the scaling parameter *h/L* (*h* is the depth of the ABL, *L* is the Monin-Obukhov length), either u_* or w_* is used (e.g., Hass et al., 1991) in estimating the vertical eddy diffusivity, *K*. Note that this type of approach may not guarantee continuity between the estimated *K* values because of alternating usage of u_* and w_*.

To address these problems effectively, we (Alapaty and Alapaty, 2000) proposed a new velocity scale for use in a first-order nonlocal *K*-scheme. The new velocity scale, termed *turbulence velocity* (e_*), is a function of surface turbulent kinetic energy (TKE). Using the FIFE data, preliminary evaluation of our *K*-scheme was documented in the Alapaty and Alapaty (2000) study.

The objective of the current study is to perform a rigorous evaluation and performance analysis of our ABL scheme using the MM5. In an ongoing study, we are using the same ABL scheme in an air quality model to accomplish our global objective of developing and using a single ABL scheme in both the atmospheric models. The following sections present a brief description of our scheme and discuss the MM5 simulations and evaluation results.

2. BRIEF DESCRIPTION OF ABL SCHEME

The vertical eddy diffusivity equation for momentum in our *K*-scheme is written as:

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$$K_m = \frac{e_* kz\left(1 - \frac{z}{h}\right)^2}{\Phi_m}$$

where e_* is our *turbulence velocity scale*, *k* is the Von Karman constant, *z* is altitude, *h* is the depth of the mixed layer estimated as suggested by Holtslag et al. (1990), and Φ_m is the nondimensional function for momentum. We proposed that e_* be equal to the square root of the surface TKE. Although e_* can be estimated using a prognostic TKE equation, at present we are using a diagnostic method. Following the study of Mailhot and Benoit (1982), e_* for convective conditions in the ABL was estimated from the square root of the following equation:

$$e_*^2 = TKE = 3.75u_*^2 + 0.2w_*^2 + u_*^2\left(-\frac{z_a}{L}\right)^{2/3}$$

and $\Phi_m = 1$. Here, z_a is the height of the lowest layer close to the surface. For nonconvective conditions in the ABL, e_* was estimated from the square root of the equation:

$$e_*^2 = TKE = 3.75u_*^2 \ .$$

In this case:

$$\Phi_m = 0.74 + 4.7z/L$$

The eddy diffusivity for heat, K_h, for convective conditions is estimated as

$$K_h = K_m\left\{1.35\frac{(1-9z/L)^{1/2}}{(1-15z/L)^{1/4}}\right\}$$

and for nonconvective conditions as

$$K_h = K_m\left\{\frac{(1+4.7z/L)}{(0.74+4.7z/L)}\right\}$$

This completes the description of the ABL scheme. Turbulent mixing in the free atmosphere was represented by

$$K_f = K_o + (k\ell)^2(R_c - R_i)S/R_c$$

where K_f is the vertical eddy diffusivity for clear-air turbulent mixing, K_o is a background value, ℓ is the characteristic length scale, R_c and R_i are the critical and formal Richardson numbers, and S is the vertical wind shear. The system of diffusion equations is solved using a semi-implicit scheme (see Alapaty and Alapaty, 2000).

3. MM5 SETUP AND SIMULATIONS

We performed the MM5V3.4 simulations for six days starting from July 10, 1997. We used 26 vertical layers; there were 12 layers between the surface and ~2.5 km altitude, with the lowest half-level placed at about ~18 m AGL. We used the NMC Eta model analysis (see http://dss.ucar.edu/datasets/ds068.0/) to prepare model inputs. The climatological soil moisture scheme (Carlson and Boland, 1978) was used to estimate the surface latent heat fluxes, and the Grell scheme was used to account for subgrid-scale cumulus convection. The FDDA option was used in the free atmosphere. However, only the winds were nudged in the ABL using the surface data. Temperature and moisture were not assimilated within the ABL so that the new ABL scheme (hereafter referred to as AAPBL) and other model physics could determine the structures of the ABL. The horizontal resolution used in these simulations was 36 km. The modeled domain included over 80% of the continental Unites States. However, we present the evaluation results for an eastern U.S. subdomain (see Fig. 7), which is being used as a domain for air quality model simulations.

4. RESULTS AND DISCUSSION

We evaluated some of the most important meteorological parameters that affect air quality simulations. This abstract presents statistical evaluation of surface variables, analysis of boundary layer depths, and intercomparison of observed and modeled rainfall. In preparing various statistics for the surface variables, we used the Techniques Development Laboratory (TDL) (see http://dss.ucar.edu/datasets/ds472.0/) data comprising 1, 3, and 6 hourly measurements. Thus, the modeled hourly air temperature and moisture for the lowest layer, which are not nudged, are linearly interpolated to the respective altitudes of surface measurements for comparison with observations. Measurements from an average of over 300 surface stations and corresponding model grids were used in preparing all time series plots.

Figure 1 shows the temporal variation of spatially averaged near-surface air temperature from the observations and from the model. In general, temperature minima are well reproduced compared to temperature maxima. Modeled cooling during the evening hours in each of the days happens a little earlier than in the observations. Overall, modeled near-surface air temperatures are very close to the observations. Figure 2 shows various statistical measures for spatially averaged near-surface air temperature obtained using the model simulations and TDL data. The quantity $(M-O)$ is used in preparing many statistics, where M represents the modeled value and O the observed/measured value of a variable. Thus, if $M-O$ is positive, the model is overpredicting that variable, and if $M-O$ is negative, the model is underpredicting. The ME indicates that during the daytime the model underpredicted near-surface air temperature maxima by about 2-3 K, while during the nighttime predicted errors decreased from about –2 to +0.5 K. Consistent results can also be found in the RMSE distribution and in the variation in IA.

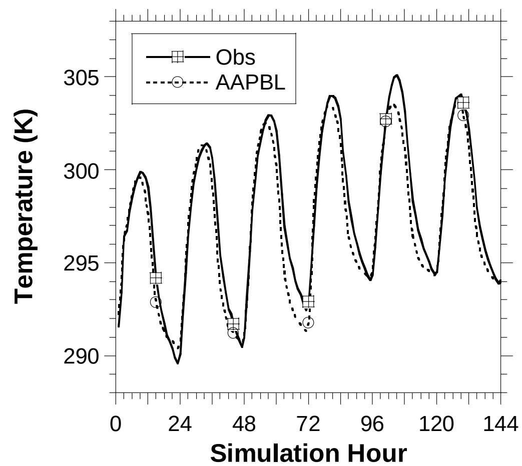

Figure 1. Temporal variation of observed and modeled spatially averaged near-surface air temperature. The zero hour on the *x*-axis corresponds to 1200 UTC 10 July 1997.

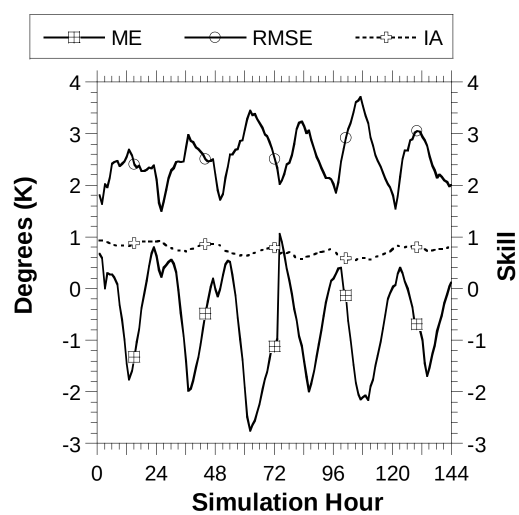

Figure 2. Temporal variation of statistical measures for spatially averaged near-surface air temperature. ME=mean error; RMSE=root mean square error; IA=index of agreement.

Figure 3 shows the temporal variation of the spatially averaged near-surface water vapor mixing ratio. The temporal tendency in the observations is well replicated in the model values; however, the model atmosphere is too dry by about 2-3 g/kg, which is apparent in the corresponding statistics (Figure 4).

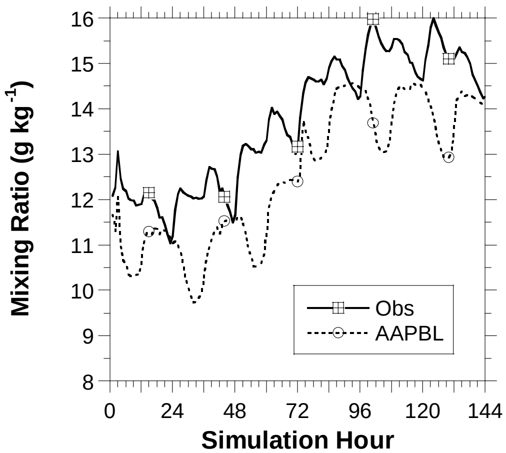

Figure 3. Temporal variation of observed and modeled spatially averaged near-surface water vapor mixing ratio.

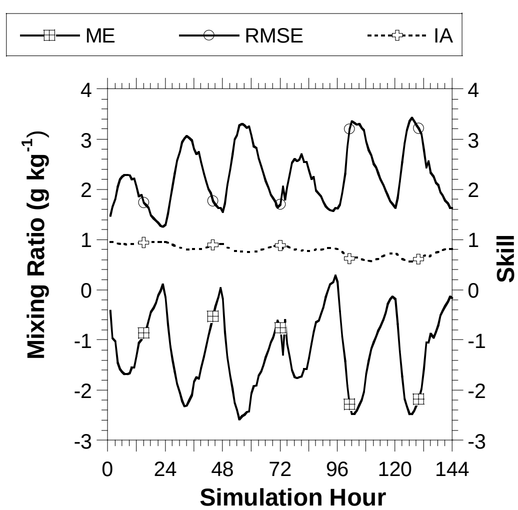

Figure 4. Temporal variation of various statistical measures for spatially averaged near-surface water vapor mixing ratio.

Near-surface wind speed and its direction statistics are shown in Figures 5 and 6. The ME in near-surface wind speed consistently ranges from about –0.75 to +1.0 m/s while the time-averaged ME in wind direction is about 5 degrees. Figure 7 shows the ABL depths at 20 UTC 15 July; these are within the range of general variability. During the simulation period, high ozone levels are observed at various sites in the eastern United States and these are associated with relatively dry conditions. Modeled rainfall is accumulated for six hours (0000 and 0600 UTC 15 July); the corresponding observations (diamond symbols) are shown in Figure 8. A majority of the time, modeled rainfall is found to be in good qualitative agreement with observations.

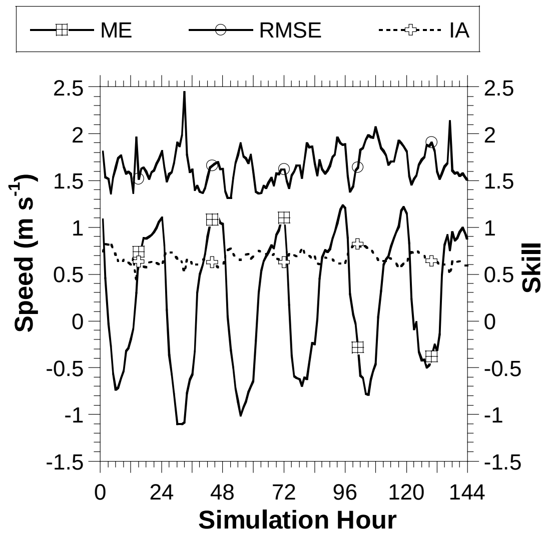

Figure 5. Temporal variation of various statistical measures for spatially averaged near-surface wind speed.

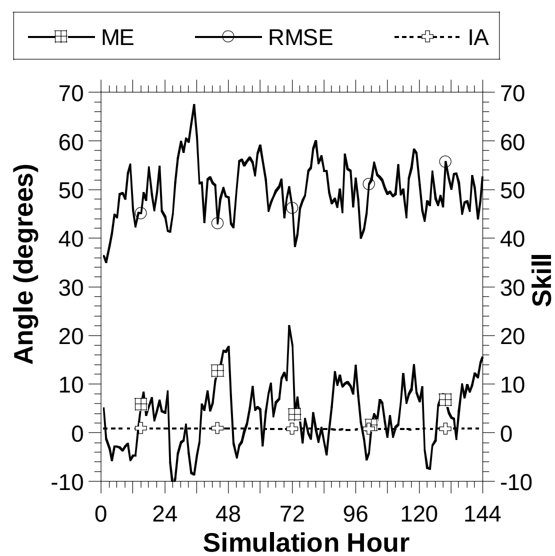

Figure 6. Temporal variation of various statistical measures for spatially averaged near-surface wind direction.

Analysis of modeled surface turbulent heat fluxes indicated that the spatial and temporal variation of these fluxes is well within the range of general variability. Modeled horizontal winds at the 850 and 500 hPa altitudes are also found to be consistent with observations. Intercomparison of modeled and observed soundings at various locations and times also revealed that simulated thermal and dynamical structures are in good correlation with observations.

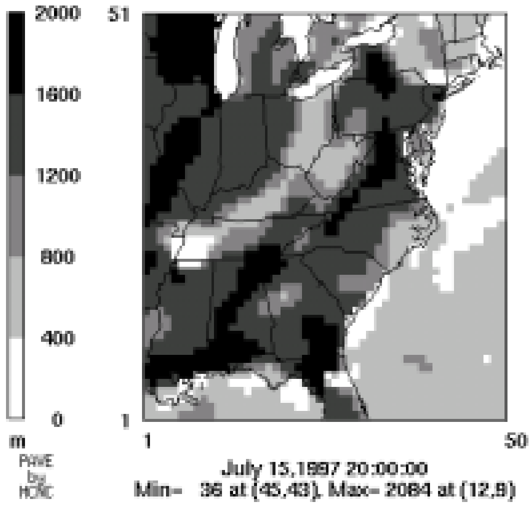

Figure 7. Spatial distribution of ABL depth at 1500 EST 15 July 1997 simulated by AAPBL.

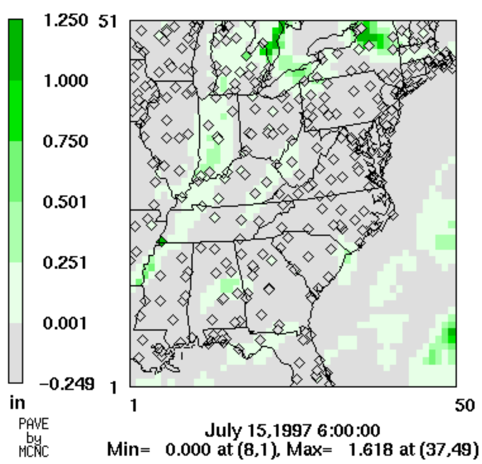

Figure 8. Observed and modeled 6-hour accumulated precipitation during 0000 and 0600 UTC 15 July 1997.

In general, model predictions with the new AAPBL scheme are found to compare well with observations. In our future work, we will be performing 12- and 4-km grid resolution simulations for further evaluation. Also, we will repeat these simulations using the MRF scheme to facilitate a direct intercomparison with the AAPBL scheme.

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