6A.5 A TOTAL ENERGY – MASS FLUX SCHEME FOR STABLE AND FAIR-WEATHER CUMULUS BOUNDARY LAYERS IN MESOSCALE MODELS

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1. INTRODUCTION

We are implementing a new boundary layer scheme called "TEMF" (Total Energy Mass Flux) for the WRF model that incorporates recent advances in the understanding and modeling of both stable and convective boundary layers. The stable side of the scheme is the Total Turbulent Energy closure advanced by Mauritsen et al. (2007). On the convective side, we use an eddy diffusivity – mass flux scheme described by Angevine (2005). The latter also integrates transport by non-precipitating cumulus. The complete scheme should improve model performance in two areas where current models are known to be deficient, that is, stable boundary layers and boundary layers with shallow cumulus. It should also provide the opportunity to eventually converge with BL schemes in other mesoscale and global operational and research models, many of which now have, or soon will have, EDMF schemes. These schemes were pioneered by Siebesma and Teixeira (2000) and Soares et al. (2004)

As the name indicates, an EDMF scheme uses both eddy diffusivity ("K") and mass flux to determine the turbulent fluxes. The eddy diffusivity term accounts for all mixing in stable conditions, and for the small-scale mixing in convective conditions. The mass flux term represents transport by large eddies in the convective boundary layer. It therefore allows for the counter-gradient transport in the upper part of the boundary layer in a natural and physically appealing way. When the top of the boundary layer is above the level at which condensation occurs, clouds form and change the transport and turbulence properties. Clouds are also represented by the mass flux part of the scheme, which then transports heat, moisture, and momentum into the cloud layer and deposits them there.

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In both stable and convective conditions, the TEMF scheme prognoses total turbulent energy. It is used to determine the eddy diffusivity coefficients as in traditional "E-l" or energy-length scale closures. Total energy is transported by the mass flux side of the scheme as are all other prognostic variables.

The use of total energy rather than kinetic energy means that the usual buoyancy destruction term in the kinetic energy budget equation is not present. As a result, there is no critical Richardson number above which turbulence cannot exist, and momentum transport continues even under very stable stratification.

The final element of the closure is the length scale. In stable stratification, the length scale is found by a multi-limit formulation taking into account the height above ground, the Coriolis parameter, and the local stratification. This allows for elevated turbulent layers. In convective conditions, the length scale also includes a term accounting for the distance below the boundary layer top, treating it as a second boundary. This allows the turbulent energy transported upward by the updraft to produce enhanced mixing in the upper part of the boundary layer and in the cloud layer.

The stable part of the scheme has a small number of empirical constants. Their values were chosen based on a series of almost 100 large-eddy simulations of stable and neutral cases.

On the convective side, the EDMF formulation has several parameters whose values must be set empirically. These include the lateral entrainment and detrainment rates; the initial temperature, humidity, energy, and momentum of the updraft at the surface; and the initial mass flux. Only a few well-documented convective test cases exist, and even fewer of these have shallow cumulus. We are in search of collaborators and test cases to improve the selection of these parameters.

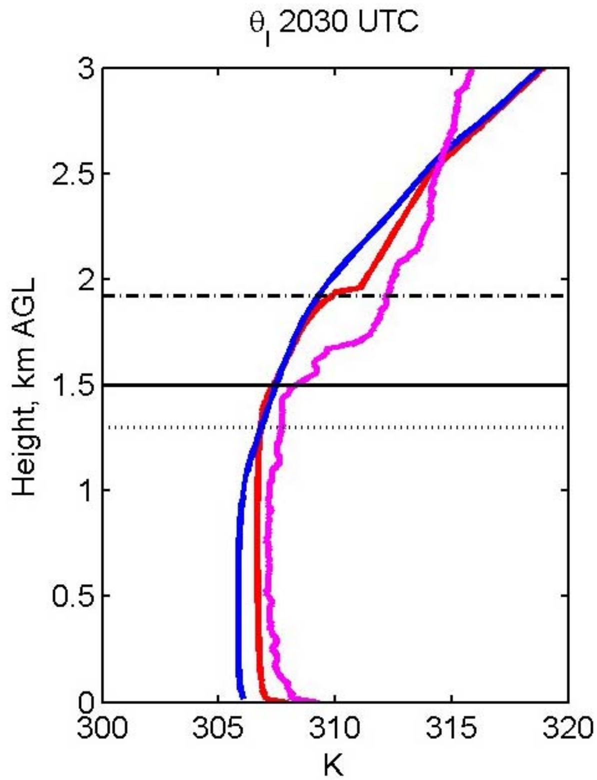

Figure 1: TEMF model results for the ARM case (Southern Great Plains site, 21 June 1997). Left panel: Potential temperature from TEMF (red), KNMI LES (blue), and observed sounding (magenta). Horizontal black lines are dry thermal top, solid; LCL or cloud base, dotted; and cloud top, dashed. Right, total water mixing ratio, same color scheme.

2. TEST CASE EXAMPLES

Some examples from the test cases we have run are shown here. Figure 1 presents the results after 6 hours of the ARM case, which was the subject of LES and single-column model intercomparisons (Brown et al. 2002; Lenderink et al. 2004). In mid-afternoon, there is a small fraction of cumulus cloud. The TEMF model produces realistic profiles of temperature and humidity, and has transported heat and moisture into the cloud layer. The turbulence parameters are shown in figure 2 at the same time. The TKE and diffusion coefficient have roughly the shape expected for a convective boundary layer, including some energy and small-scale mixing in the cloud layer.

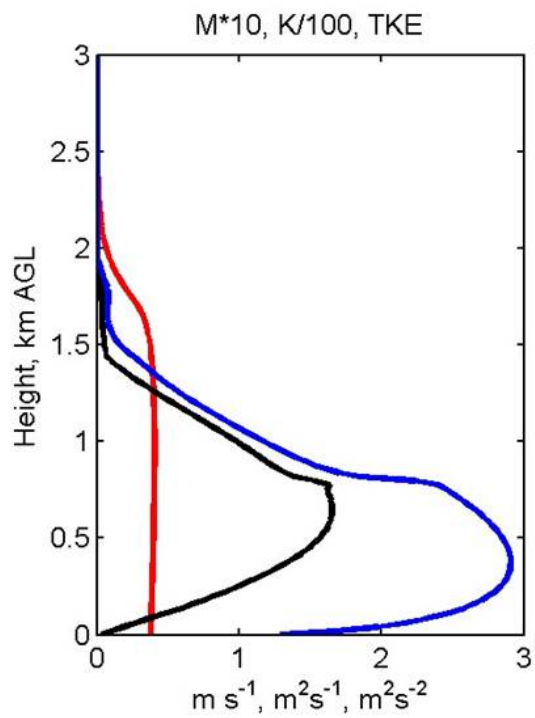

Figure 2: Mass flux (red), diffusion coefficient for heat (black), and turbulent kinetic energy (blue) at 2030 UTC for the ARM case TEMF simulation. Note scale factors used to display the quantities on the same axis.

Another test case comes from the second GABLS single-column model intercomparison. This case includes several complete diurnal cycles, although only 40 hours of simulation are shown here. The TEMF scheme is compared to the other two PBL schemes in WRF, known as YSU and MYJ. TEMF produces a deeper daytime boundary layer, and a more consistent nighttime boundary layer depth. The afternoon transition in TEMF is quite abrupt. The wind speed at 10 m AGL is higher in TEMF, and becomes nearly zero in the early morning in the MYJ scheme because of the way that scheme handles stable BL turbulence. Note the fixed minimum value of friction velocity in the MYJ scheme.

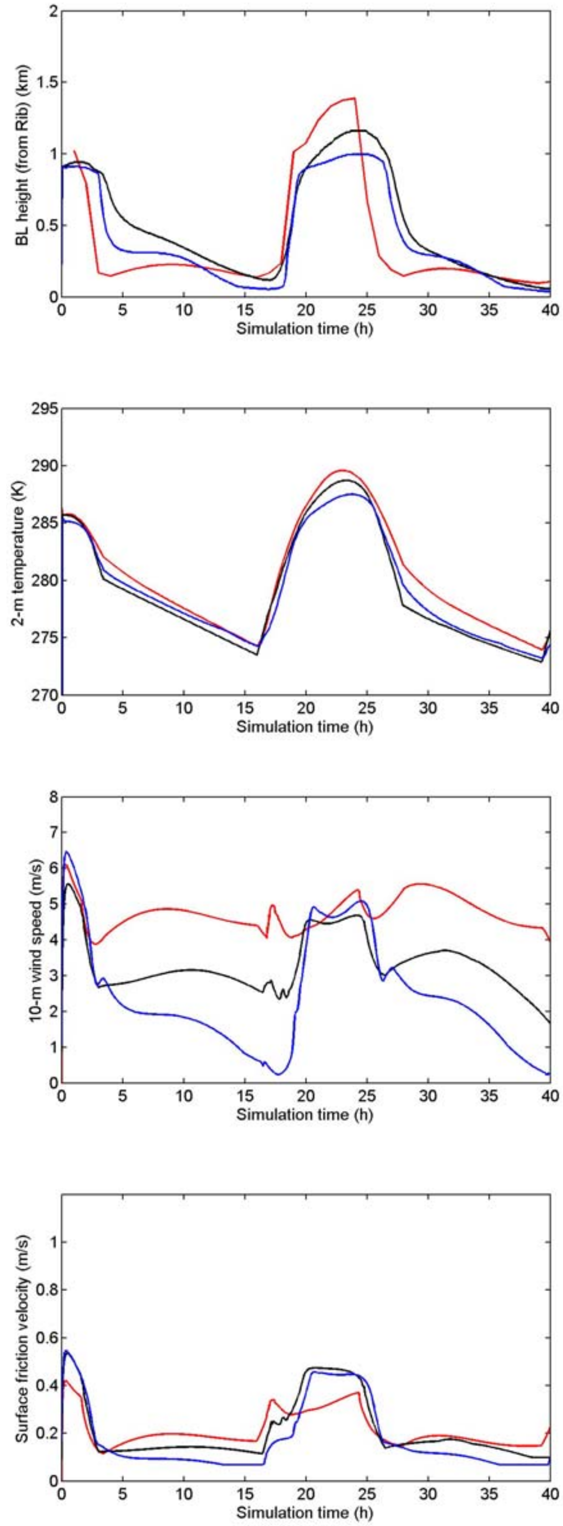

Figure 3 (right): GABLS2 case results from TEMF model (red), WRF with MYJ PBL scheme (blue), and WRF with YSU PBL scheme (black). Top panel is BL height diagnosed with bulk Richardson number. Second panel is 2-m temperature. Third panel is 10-m wind speed. Fourth panel is surface friction velocity.

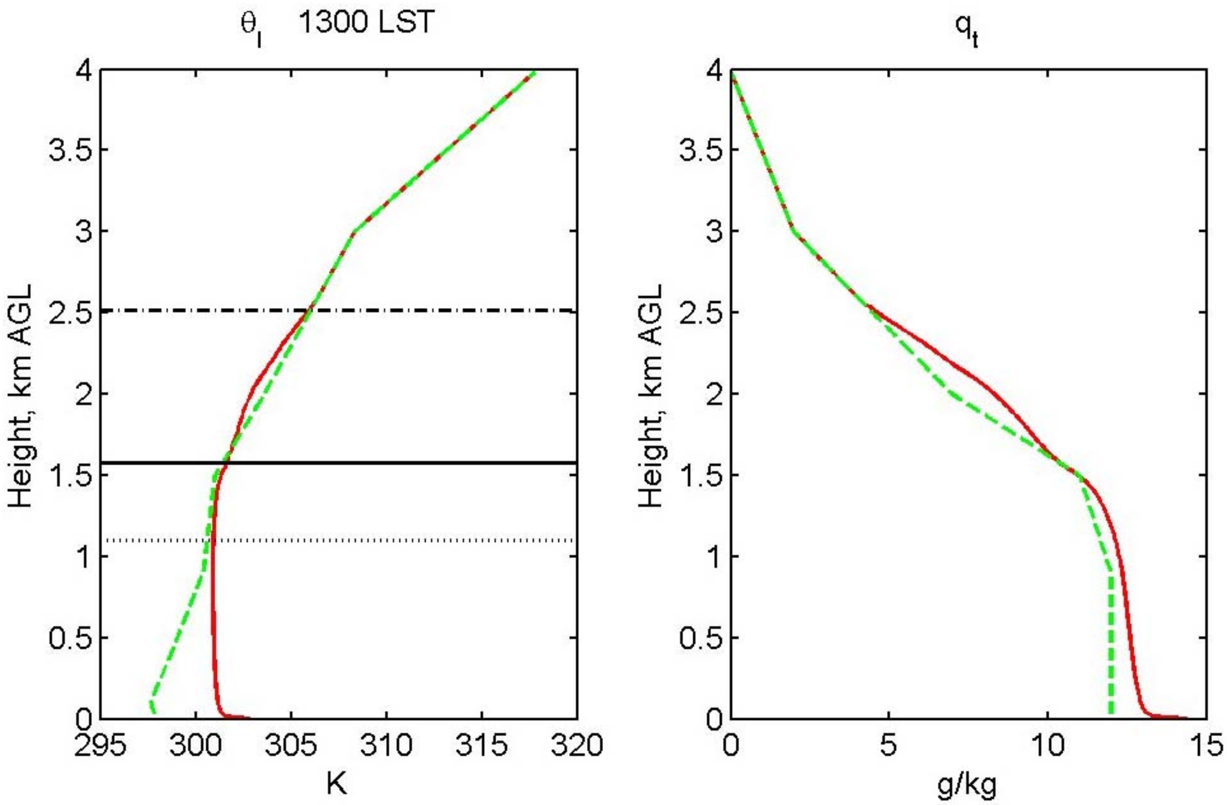

Figure 4: TEMF results at 1300 LST and initial profiles for the Nashville case. Left, potential temperature; right, total water mixing ratio.

A case of non-precipitating cumulus transporting pollutants through a relatively deep layer occurred on 14 July 1999 during the Southern Oxidants Study Nashville Intensive campaign. Simulation results for this case are shown in figure 4. The TEMF model transports appropriate amounts of heat and moisture upward into the cloud layer.

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