

CORRIGENDUM

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1. Introduction

Takemi and Rotunno (2003, hereinafter TR03) examined the relative effects of subgrid-scale mixing and numerical filters in squall-line simulations in an idealized condition of a no-shear environment. TR03 found that simulations using common subgrid models with standard values for the model constants and without explicit numerical filters are characterized by poorly resolved grid-scale convective cells. They suggested that this problem should be controlled by setting eddy viscosity coefficients 1.5 to 2 times larger than the standard values. From a recent communication with Dr. G. Bryan of the National Center for Atmospheric Research, we have learned that the early version of the Weather Research and Forecasting (WRF) model (Skamarock et al. 2001) used in TR03 did not have the correct subgrid-scale mixing for some scalar quantities: vertical mixing of potential temperature and water vapor mixing ratio acted on the perturbation fields from the base state, not on the total fields. The purpose of this corrigendum is to reexamine the validity of the conclusions presented in TR03 by presenting some new simulations with corrected subgrid mixing.

2. Results and conclusions

The same experimental setup as that employed in TR03 is used in the present simulations. Here we examine only simulations using the subgrid parameteriza-

tion scheme that predicts turbulent kinetic energy (TKE) and performs simulations of the evolution of an initial line thermal in a no-shear environment. In the no-shear environment, one expects the development of disorganized, scattered convective cells far behind the surface outflow boundary (Weisman and Rotunno 2004).

TR03 experimented with different values of the constants C_k and C_e , which appear, respectively, in the equations for the eddy viscosity K_m ,

$$K_m = C_k e^{1/2} l, \quad (1)$$

and the subgrid-scale energy dissipation,

$$\epsilon = C_e e^{3/2} / l, \quad (2)$$

where e is the subgrid turbulent kinetic energy, and l is a length scale. The values $(C_k, C_e) = (0.094, 0.93)$ were originally derived from theoretical estimates based on inertial-subrange, locally isotropic turbulence (Lilly 1967). Lilly (1966) noted that $C_k = 0.124$, if finite-difference effects are taken into account in the derivation. Based on theory and numerical experiments with stratified flow, Deardorff (1973) determined $(C_k, C_e) = (0.065, 0.7)$ and later used the values $(C_k, C_e) = (0.1, 0.7)$ (Deardorff 1980) for the large-eddy simulations of the planetary boundary layer. Moeng and Wyngaard (1988) revisited the issue and found that $(C_k, C_e) = (0.1, 0.93)$ are more consistent with the available data. Schmidt and Schumann (1989) derived $(C_k, C_e) = (0.0856, 0.845)$ based on the field measurement data, and Stevens et al. (1999) also found the same values in their derivation. Storm-scale and mesoscale cloud simulations have used a variety of values [e.g., Klemp and Wilhelmson (1978) used $(C_k, C_e) = (0.2, 0.2)$]; however, $C_k = 0.1$ seems to be commonly used in cloud simulations, and thus can be regarded as the standard value, although some variety in the choice of the C_k value is noted.

With the fixed value of $C_e = 0.93$, Figs. 1c and 5 of

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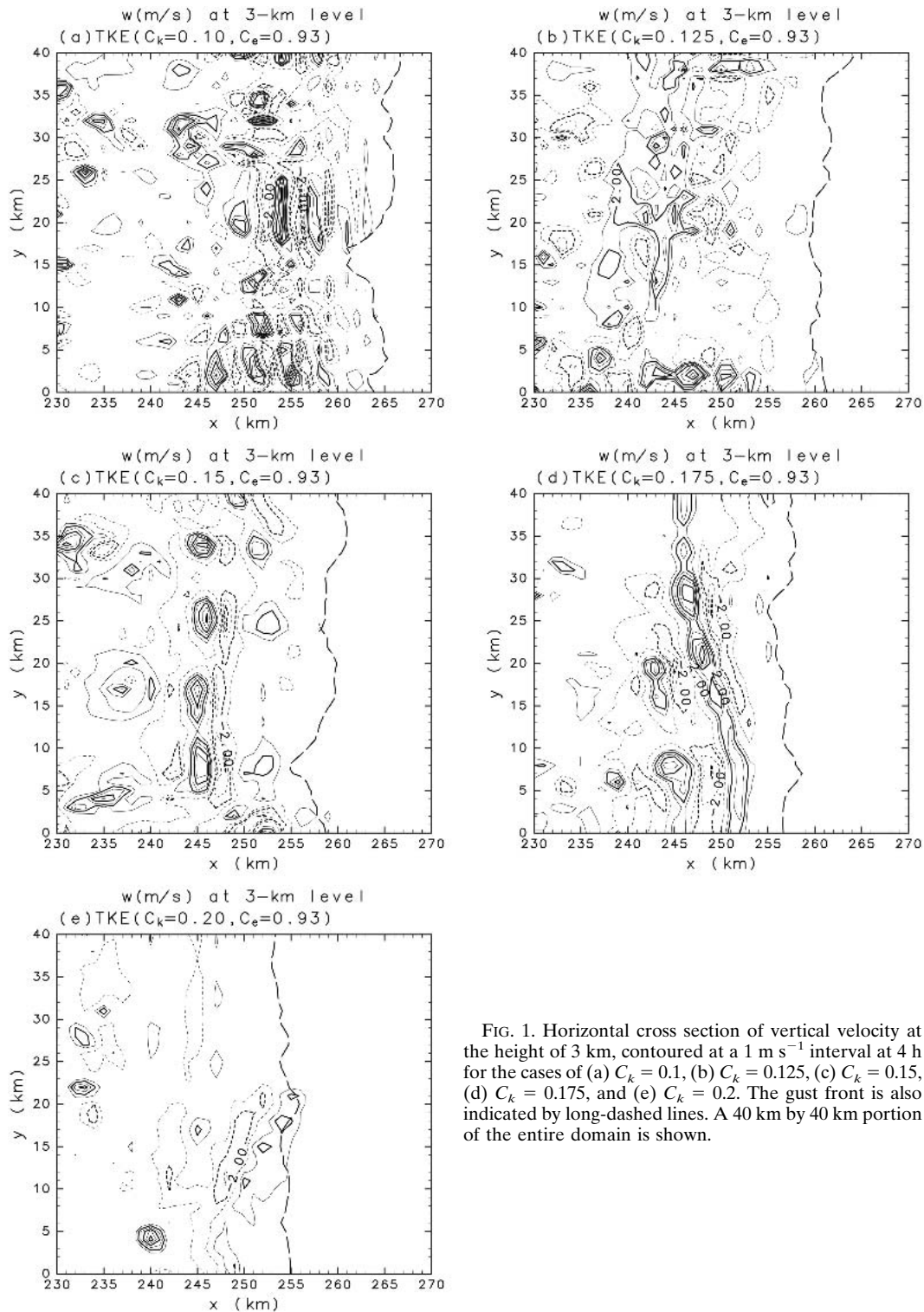


FIG. 1. Horizontal cross section of vertical velocity at the height of 3 km, contoured at a 1 m s^{-1} interval at 4 h for the cases of (a) $C_k = 0.1$, (b) $C_k = 0.125$, (c) $C_k = 0.15$, (d) $C_k = 0.175$, and (e) $C_k = 0.2$. The gust front is also indicated by long-dashed lines. A 40 km by 40 km portion of the entire domain is shown.

TR03 show the sensitivity of the simulated moist convection for $C_k = 0.1, 0.15, 0.2, 0.25, 0.3$. The simulations with $C_k = 0.1$ produced convective cells that were poorly resolved, while the simulations with $C_k = 0.3$

appeared to be more damped than necessary to control the noise in the solution.

With the correct physical mixing formulation now implemented in the WRF model (vertical mixing per-

formed on the full scalar fields) we reexamine in Fig. 1 the behavior of the model-simulated moist convection for $C_k = 0.1, 0.125, 0.15, 0.175, 0.2$. Figure 1 shows that even with the corrected physical mixing, the solution with the standard value of $C_k = 0.1$ is still noisy and has many grid-scale structures in the no-shear case, as found in TR03. With C_k slightly increased to 0.125, there is a significant reduction in the number of grid-scale cells; however, there is still some small-scale noise in the solution. Increasing the constant C_k further to 0.15 results in smoother cellular structures and well-resolved features; however, with $C_k = 0.2$, the present simulations produce an overly damped solution, as few cells even survive.

As was done in TR03, the power spectral density of the vertical velocity at the 3-km level is calculated in the across-line direction in a $80 \text{ km} \times 80 \text{ km}$ area around the rightward-moving surface outflow. Figure 2 shows the power spectral densities for the cases depicted in Fig. 1. Similar to the result of TR03, a significant energy buildup is seen at short wavelengths in the case using the standard C_k value. This energy buildup in short scales can be avoided by increasing the constant above the commonly used value. These results are basically the same as those presented in TR03, even though the C_k value suggested as optimal in TR03 produces an overly damped solution with the correct subgrid-turbulence formulation.

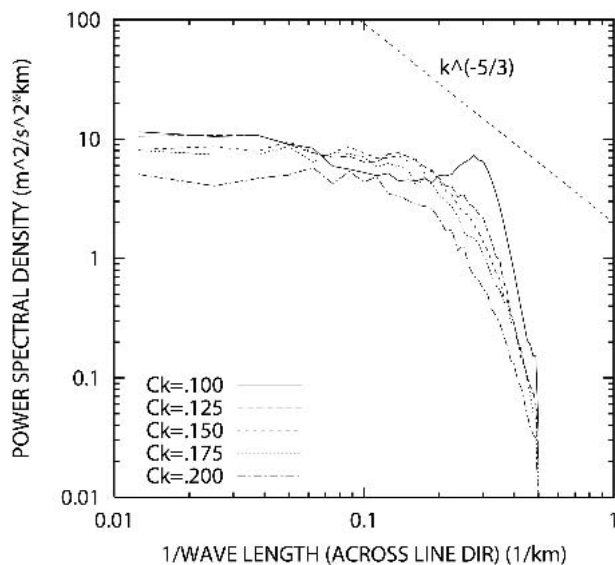


FIG. 2. Power spectral density of vertical velocity at the 3-km level for across-line (x) direction obtained using the TKE scheme with various C_k values. A $k^{-5/3}$ line is also plotted for reference.

In summary, new simulations with corrected physical mixing using the standard subgrid model constants produces a noisy solution (as found in TR03), and some method to avoid (or control) the noise is still necessary. The experiments reported in Figs. 1 and 2 lead us to believe that TR03's suggestion of adjusting the subgrid-model constants is still a viable method, but that TR03's suggested values for the subgrid constants need to be revised downward. Apparently, the suggested values in TR03 (i.e., 1.5 to 2 times larger than the widely used standard values) are too large and provide overly strong damping when the correct subgrid mixing formulation is used. From the results of the present simulations, the suggested value for the constant should be approximately 1.5 times larger than the standard value.

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