P5.10 A SIMPLE MODEL FOR A MOIST TURBULENT THERMAL

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1. INTRODUCTION

With the ultimate goal of improving convective parameterization schemes used in atmospheric general circulation models, we have developed a simple model for a moist turbulent thermal. In this short abstract, results from numerical experiments performed using the two-dimensional version of a fully compressible and nonhydrostatic model, the Advanced Regional Prediction System or ARPS (see Xue *et al.*, 2000 for a detailed description of ARPS) are used to evaluate the model's bulk mixing parameterization, *i.e.*

$$\mu_T \equiv \frac{1}{M_T}\frac{dM_T}{dt} = \frac{\alpha_m \rho_0 U_{TKE}}{R_T}, \qquad (1)$$

where M_T is the thermal's mass per unit length, α_m is a non-dimensional mixing coefficient, R_T is the the thermal's equivalent-area-radius, ρ_0 is the density of the air in the thermal's environment, and

U_{TKE} is the root-mean-square velocity of air as measured in a frame of reference moving upwards with the thermal at speed w_T. Note that (1) is formally equivalent to Morton *et al.*'s (1956) "turbulent entrainment hypothesis" (TEH) when U_{TKE} is replaced by w_T. The physical interpretation of both is that the mixing of environmental air into the thermal is driven by turbulence.

2. EXPERIMENTAL SETUP

The model domain is 15 km tall and 30 km wide with 50 m grid spacing in both directions. The base-state atmosphere is in hydrostatic balance and the dry Brunt-Vaisalla frequency, i.e. N =1.2 x 10^{-2} s^{-1}, is constant with height. Momentum advection is performed using a fourth order quadratically conservative scheme while scalar advection is performed using flux corrected transport. The effects of SGS mixing are represented using a 1.5-order turbulence kinetic energy parameterization. Moist physical processes are handled using a simple saturation adjustment scheme with precipitation processes neglected. Sponge layers are added above 10 km to damp the reflection of vertically propagating gravity waves. All boundaries act as rigid walls.

The saturated thermal is generated by introducing a uniform 1 K potential temperature perturbation over a circular area whose radius is 1 km. The thermal is initially centered on the left boundary at height of 1.5 km. The mass of the thermal, M_T, is determined using a passive scalar threshold, $\psi = 0.02$, where, initially, ψ =1 inside the thermal and zero everywhere else.

3. RESULTS

Results from two experiments are presented here. In the first, the atmosphere is dry while in the second the relative humidity is constant with height at 70%. Figure 1a compares the evolution of z_T, the thermal's mean height, in the two experiments. Not surprisingly, the thermal in the moist environment (the ME-thermal) travels higher than the one in the dry environment (the DE-thermal). Two factors contribute to this result: First, environmental air which is mixed into the DE-thermal is drier and thus, there is a potential for larger amounts of evaporative cooling (evidence for this can be found in Figure 1b which show time-series of each thermals net latent heating rate); second, between t = 0-10 mins, the values of μ_T in the ME-experiment are lower than those in the DE-experiment (compare the solid black and grey curves in Figure 1c).

To evaluate our mixing parameterization, we choose α_m = 0.4 and compute time-series of the right hand side of (1) for each experiment. The results, given by the black and grey dotted curves in Figure 1c, show that our (1) captures the larger (smaller) values of μ_T seen in the DE-experiment during early (later) times. Note: although qualitatively similar results are obtained when (1) is used with U_{TKE} replaced by w_T (results not shown), the agreement between the observed and parameterized values of μ_T is not as good in this case.

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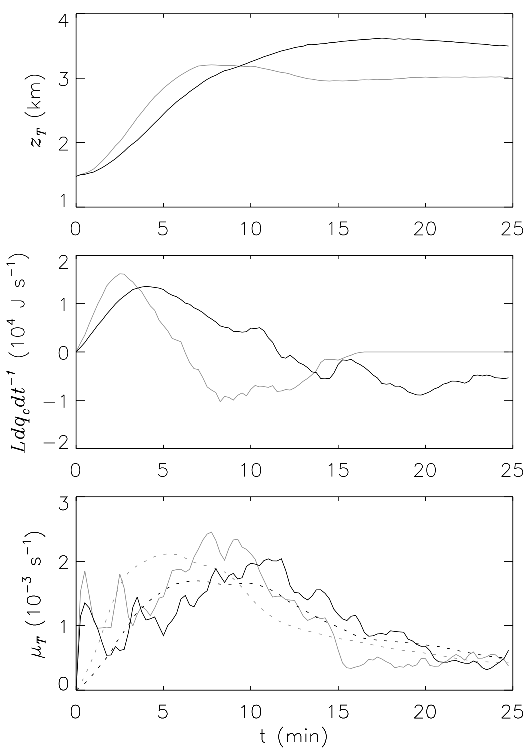

Figure 1. Bulk evolution of the thermal in the ME- (black curves) and DE-experiment (grey curves).

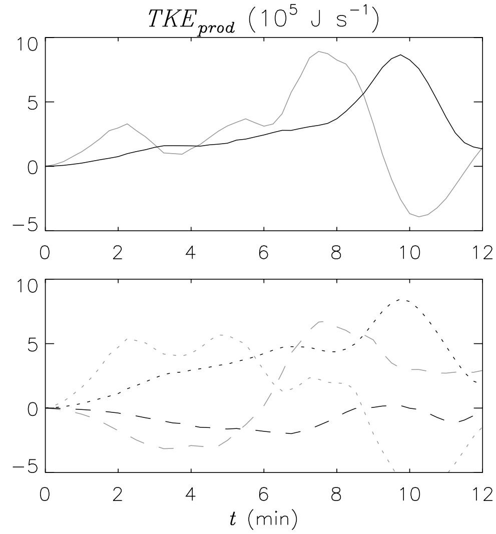

Figure 2. Top panel: Time-series of TKE_{prod} in the ME (black curve) and DE (grey curve) experiment. Bottom panel: Time-series of U_TKE_{prod} (dotted curve) and D_TKE_{PROD} (dashed curve) in the two experiments.

The consistency between our mixing parameterization and the results of the two experiments suggests that the enhancement in the DE-thermal's fractional mixing rate between t = 0-10 mins is primarily driven by higher levels of turbulence. To explain why this is true, Figure 2a shows time-series of each thermal's net upward turbulent buoyancy flux, *i.e.*

$$TKE_{prod} \equiv \sum_i \overline{\rho}_i (w'_i b'_i) \Delta x \Delta z, \qquad (2)$$

where i is a summation index over all grid points inside the thermal, $w_i' = w_T - w_i$ is the vertical velocity in the thermal's moving frame of reference, b'_i is the buoyancy, and $\overline{\rho}_i \Delta x \Delta z$ is the mass of the ith grid cell, respectively. As expected, the DE-thermal is characterized by larger values of TKE_{prod} between t=0-8 mins. In Figure 2b, we consider the evolution of the turbulent buoyancy flux associated with upward (U_TKE_{prod}) and downward (D_TKE_{prod}) motion. Somewhat surprisingly, we find that the initially larger values of TKE_{prod} in the DE-thermal are primarily attributable to warmer updrafts, *i.e.* larger values of U_TKE_{prod} (presumably this is because, initially, the ME-thermal's buoyancy is larger owing to virtual temperature effects). The larger values of TKE_{prod} between t = 6-8 mins, on the other hand, are attributable to a dramatic intensification in D_TKE_{prod}. Because this intensification roughly coincides with the transition in the ME-thermal's net latent heating rate from positive to negative (Figure 1b), we conclude that the sharp increase in the ME-thermal's TKE_{prod} at t ~ 7 mins is a result of the generation of evaporatively driven cold downdrafts.

4. Discussion

Both Lin (1999) and Gregory (2001) have recently aimed to improve formulations for describing entrainment in simple plume models used in convective parameterization schemes. A common feature in both of these studies is that the plume's fractional entrainment rate depends on coefficients which must be empirically adjusted depending on either the type of convection or the properties of the large-scale environment.

Here, we have tested a physically based cloud mixing parameterization that may be applicable to all forms of cumulus convection (shallow or deep, squall or non-squall). Our poster at the 11th American Meteorological Society Cloud Physics Conference describes our simple model for a moist turbulent thermal in more detail and compares its predictions against the results of the numerical experiments described herein.

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5. REFERENCES

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