4.5

IMPACT OF LIQUID WATER FLUX ON CLOUD MICROPHYSICS IN MESOSCALE MODELS

Shouping Wang, Jerry Schmidt and Jean-Christophe Golaz
Naval Research Laboratory, Monterey, California

1. INTRODUCTION

The prognostic approach has been increasingly popular for the prediction of liquid/ice water content in the mesoscale model community. In this approach, the temporal evolution of the cloud water is determined by the combined contributions from various cloud dynamical and microphysical processes, two of which are the turbulent liquid water transport and condensation. While interacting with each other, these two processes have profound impacts on the cloud dynamics and microphysics, and should be realistically represented in a mesoscale model.

The mixing-length (or down-gradient) approach is generally acceptable for parameterization of the turbulent flux of the quasi-conservative scalars such as liquid water potential temperature. The approach, however, does not represent the nature of the liquid water transport, which is dominated by the turbulence generated condensation as discussed by Wang *et al*. (2003). Despite its severe defect, the down-gradient approach continues to be used in some mesoscale models such as Navy's COAMPS™. In this approach, the turbulent mixing tendency of any variable ϕ is computed from

$$\Delta \overline{\phi} = -\left[\frac{\partial}{\partial z}\left(-K\frac{\partial\,\overline{\phi}}{\partial z}\right)\right]\Delta t \tag{1}$$

where K is a function of turbulent kinetic energy (TKE) and mixing length.

The influence of the liquid water flux on the turbulence dynamics has been well documented. This work is focused on the impact on the cloud microphysical process in a mesoscale model. We first introduce a simple algorithm to compute the liquid water flux based on the non-conservative variables such as potential temperature and liquid water content. We then discuss the impact of the liquid water flux on the condensation and evaporation using a single column version of COAMPS.

2. A CONSERVATIVE MIXING PROCEDURE

COAMPS™ uses the non-conservative variables, potential temperature ($\overline{\theta}$), water vapor mixing ratio ($\overline{q}_v$) and liquid water mixing ratio ($\overline{q}_l$), as prognostic variables. To correctly compute the turbulent fluxes of these variables, one needs to formulate a mixing parameterization using the condensation process-conserved variables like liquid water potential temperature ($\overline{\theta}_l$) and total water mixing ratio ($\overline{q}_t$). Our approach can be described as follows.

After all other (except for the turbulent mixing) dynamic processes are performed, $\overline{\theta}_l$ and $\overline{q}_t$ are computed with the inter-mediate values of $\overline{\theta}$, $\overline{q}_v$ and $\overline{q}_l$. The fluxes of $\overline{\theta}_l$ and $\overline{q}_t$, $\overline{w'\theta_l'}$ and $\overline{w'q_t'}$, are calculated using the normal mixing-length approach. The liquid water flux $\overline{w'q_l'}$ is then computed from

$$\overline{w'q_l'} = \frac{1}{1+\gamma}\left(\overline{w'q_t'} - \frac{C_p\gamma}{L}\overline{w'\theta_l'}\right) \tag{2}$$

where γ is a thermodynamic coefficient weakly dependent on height. Note that (2) does not include any cloud fraction parameterization, and only accounts for the 100% cloud fraction condition. Consequently, the tendency due to the turbulent mixing for $\overline{\theta}$, $\overline{q}_v$ and $\overline{q}_l$ can be obtained from

$$\Delta \overline{q}_l = -\left(\frac{\partial\,\overline{w'q_l'}}{\partial z}\right)\Delta t \tag{3}$$

$$\Delta \overline{q}_v = \Delta \overline{q}_t - \Delta \overline{q}_l \tag{4}$$

$$\Delta \overline{\theta} = \frac{1}{1 - L\,\overline{q}_l / C_p}\left(\Delta\overline{\theta}_l + \frac{L\,\overline{\theta}}{C_p\,\overline{T}}\Delta\overline{q}_l\right) \tag{5}$$

where $\Delta\overline{\theta}_l$ and $\Delta\overline{q}_t$ are computed using the fluxes $\overline{w'\theta_l'}$ and $\overline{w'q_t'}$. After the mixing tendency is computed, a saturation adjustment procedure is followed to calculate the condensation rate to update the microphysical tendency for the three variables. Equation (2) is the key in this procedure, which leads to different results from those obtained by (1), as discussed in next section.

3. SINGLE-COLUMN COAMPS SIMULATIONS

To understand the impact of the new scheme, we use the single column version of the COAMPS™ (Δz=50 m) with the above two different mixing schemes to simulate the stratocumulus case documented in Bechtold *et al* (1996). Although the two mixing schemes are used for the prediction of $\overline{q}_l$, the liquid water flux based on Sommeria-Deardorff approach (Sommeria and Deardorff, 1977) is always used to calculate the buoyancy flux for the TKE production. Therefore, the different mixing schemes should not significantly change the turbulence dynamics. The single column model is run for 6 hours and all the results presented below are computed at the end of the simulations.

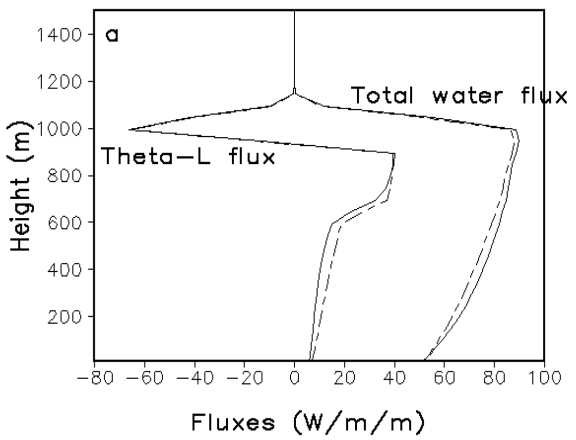

Fig. 1. Turbulent fluxes of θ_l and q_t . Solid lines denote the results from the old scheme, dashed the new scheme.

Fig. 1 shows that the different schemes result in the essentially the same turbulent fluxes $\overline{w'\theta_l'}$ and $\overline{w'q_t'}$. This is because these conservative fluxes are approximately linear combinations of the fluxes of q_v, θ and q_l, and thus can be represented even by the down-gradient mixing formulation of the non-conservative fluxes. This also reflects the fact that the buoyancy flux is always calculated based on the conservative fluxes $\overline{w'\theta_l'}$ and $\overline{w'q_t'}$ in both runs. Consequently, the two simulations predict the same well-mixed mean thermodynamic structure as shown in Fig. 2.

Although the mean structures from the two runs are the same, the turbulent fluxes of the non-conservative variables are dramatically different as demonstrated in Fig. 3.The down gradient scheme (denoted by "old") leads to large positive water vapor and large negative heat flux due to the $\overline{q}_v$ and

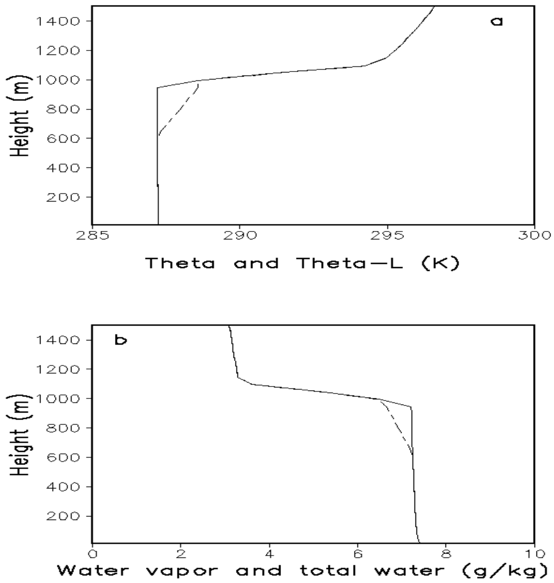

Fig. 2. Mean thermodynamic structure at the end of simulations. The structures from the two simulations are essentially same and only one is presented here.

$\overline{\theta}$ gradients in the cloud layer (as shown in Fig. 2). The values of $\overline{w'\theta'}$ and $\overline{w'q_v'}$ based on the

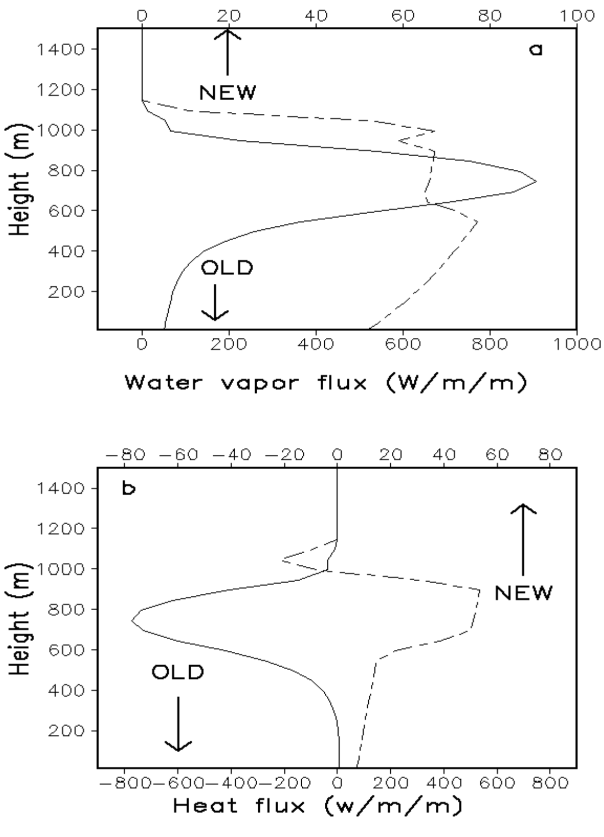

Fig. 3. Water vapor (a) and heat (b) fluxes resulting from the old and new mixing schemes.

The down-gradient mixing are clearly not realistic, as they fail to represent the condensation and evaporation associated with the turbulence mixing. The flux $\overline{w'\theta'}$ derived from the new mixing procedure (2) – (4) is positive and $\overline{w'q_v'}$ slightly decrease with height in the cloud layer because the condensation (evaporation) in the turbulent updrafts (downdrafts) results in more heating (cooling) and less (more) water vapor.

The down-gradient liquid water flux is largely negative and unrealistic (Fig. 4a) The positive flux calculated from (2) reflects the nature of the condensation and evaporation associated with the turbulent updrafts and downdrafts. Due to the significant downward liquid water and heat transport, and upward water vapor transport, there is considerable evaporation at the cloud base and condensation at the cloud top in the “old” simulation. This condensation profile is clearly unrealistic, as the major condensation should occur at the cloud base and evaporation at the cloud top. The new mixing scheme results in condensation at the cloud base and evaporation at the cloud top, which is consistent with our basic understanding of the cloud microphysics and with the results from the coupled large-eddy simulation and bin microphysics model. The large condensation rate at the cloud top is related to the strong radiative cooling there.

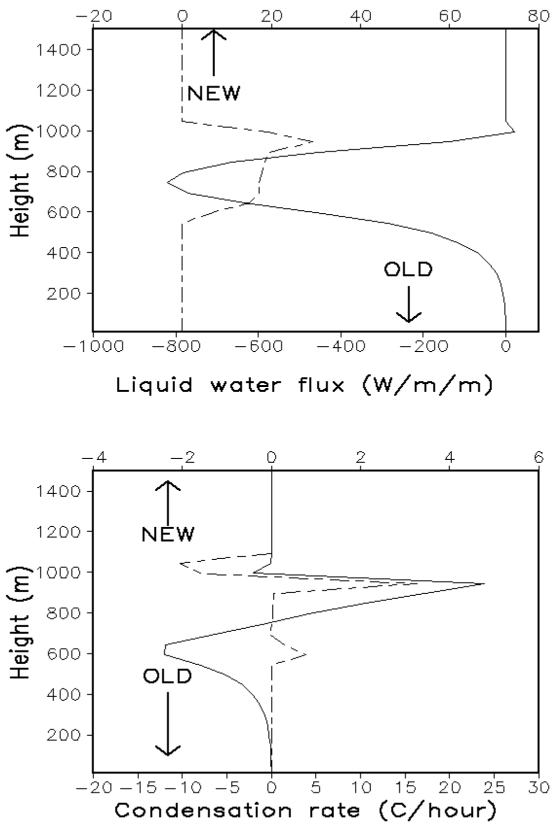

Fig. 4: Liquid water flux and condensation rate.

Although the condensation profiles are very different for the two simulations, the mean liquid water contents are same as shown in Fig. 5. This occurs because the mean thermodynamic structures are same (Fig. 2). The inter-mediate values of $\overline{\theta}$, $\overline{q}_v$ and $\overline{q}_l$ from the old scheme (after the mixing and before the condensation) can be very unrealistic due to the erroneous down-gradient mixing for these non-conservative variables.

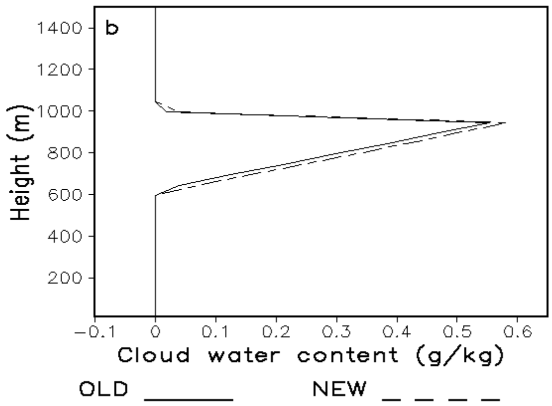

Fig. 5: Mean liquid water content.

These single-column simulations show that the turbulent flux parameterizations have significant impact on the computed condensation profile due to the close coupling between the turbulence and the condensation.

ACKNOWLEDGEMENTS

This work was supported by the Office of Naval Research and the Naval Research Laboratory through CBLAST and Cloud/Aerosol projects. This work was performed while J-C Golaz held a National Research Council Research Associateship Award at NRL, Monterey, CA.

REFERENCES

Bechtold, P. and others, 1996: Modeling a stratocumulus-topped PBL: Intercoparison among different 1 D codes and with LES. *Bull. Amer. Meteor. Soc*., 77, 2033-2042.

Sommeria, G., and J. W. Deardorff, 1977: Subgrid-scale condensation in models of nonprecipitating clouds. *J. Atmos. Sci.*, 34, 344-355.

Wang, S., Q. Wang and G. Feingold, 2003: Turbulence, condensation and liquid water transport in numerically simulated non-precipitating stratocumulus clouds. *J. Atmos. Sci.*, **60**, 262-278.