A New Turbulence Parameterization with Subgrid-scale Condensation and Microphysics For Use in the VVM

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Motivation and Method

Turbulence parameterizations are used within GCMs, mesoscale models, and even LESs to account for unresolved motion on the subgrid scale. They are often responsible for determining major portions of the fluxes of heat, moisture, and momentum and are therefore a key component of a host model.

The turbulent structure of cloudy boundary layers is of particular importance, since boundary layer clouds cover a large area of the Earth's surface and can have a large effect on the Earth's radiative budget. For this reason, it is imperative that GCMs used to study climate have an accurate representation of boundary layer clouds and turbulence.

The goal of the current study is to build and test a new turbulence parameterization that calculates the turbulent and cloud structure of all cloudy boundary layer regimes in a unified way. The following method was followed:

1) Develop a complete turbulence parameterization with subgrid-scale condensation and microphysics capable of running as a one-dimensional model.
2) Test the one-dimensional model using standard cases from the Boundary Layer Cloud Working Group of GCSS and compare against LES results.
3) Adapt the one-dimensional model to the VVM, replacing the current turbulence and microphysics parameterizations.

Model Description

The turbulence parameterization is constructed as a third-order closure scheme. The mean variables and second-order moments are prognosed from their dynamic equations, but the third- and fourth-order moments are diagnosed. Closure for incalculable terms is according to the following table:

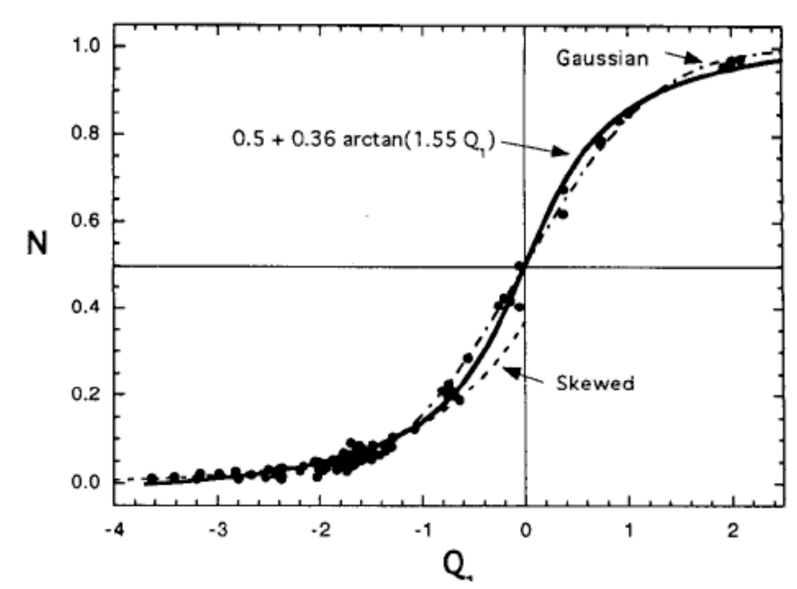
Pressure Correlations	Cheng et al. (2005)
Dissipation Terms	Golaz et al. (2002) [without ad hoc diffusion]
Third-order Moments	Cheng et al. (2005) [diagnosed]
Fourth-order Moments	Cheng et al. (2005) [diagnosed]
Buoyancy Terms	Bougeault (1981)

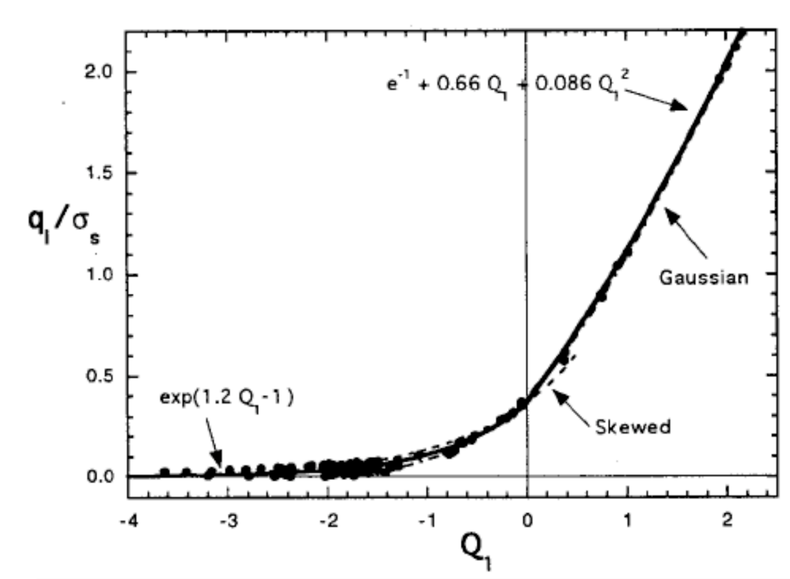
References

Bougeault, P., 1981: Modeling the trade-wind cumulus boundary layer. Part I: Testing the ensemble cloud relations against numerical data. *J. Atmos. Sci.*, **38**, 2414-2428.
Cheng, Y., V. M. Canuto, and A. M. Howard, 2005: Nonlocal convective PBL model based on new third- and fourth-order moments. *J. Atmos. Sci.*, **62**, 2189-2204.
Cuijpers, J. W. M., and P. Bechtold, 1995: A simple parameterization of cloud water related variables for use in boundary layer models. *J. Atmos. Sci.*, **52**, 2486-2490.
Golaz, J.-C., V. E. Larson, and W. R. Cotton, 2002: A PDF-based model for boundary layer clouds. Part I: Method and Model Description. *J. Atmos. Sci.*, **59**, 3540-3551.
Jakob, C., and S. A. Klein, 2000: A parameterization of the effects of cloud and precipitation overlap for use in general-circulation models. *Quart. J. Roy. Metero. Soc.*, **126**, 2525-2544.
Sommeria, G., and J. W. Deardorff, 1977: Subgrid-scale condensation in models of nonprecipitating clouds. *J. Atmos. Sci.*, **34**, 344-355.

SGS Condensation

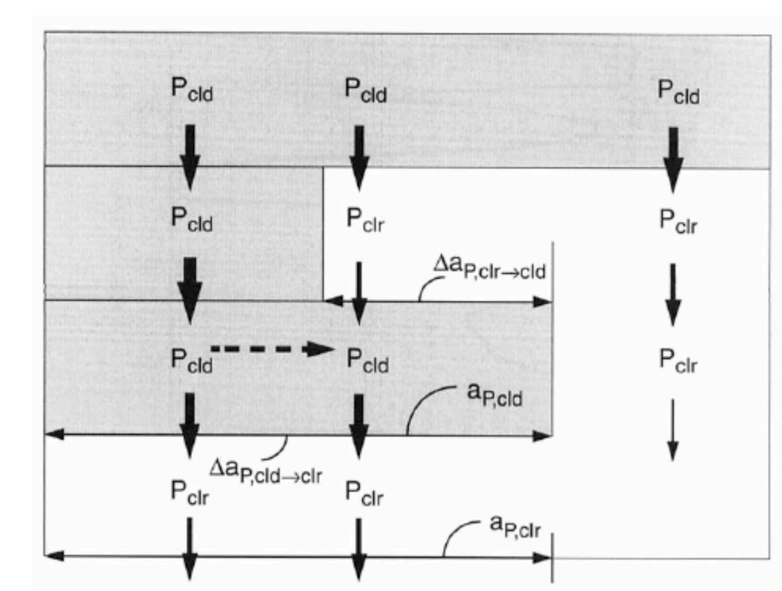
The parameterization of the buoyancy terms requires covariances involving the liquid water content. These quantities, together with the cloud fraction and mean liquid water content are diagnosed according to a modified form of Cuijpers and Bechtold (1995). This work expands upon the assumed joint Gaussian PDF method of Sommeria and Deardorff (1977) and uses LES data to determine a general functional form for the cloud fraction and liquid water content.





SGS Microphysics

The microphysics scheme takes advantage of the partial cloudiness information provided by the SGS condensation scheme to prognose two species of rain water: the quantity falling through cloudy air and the part falling through clear air. It uses the bulk formulas of Khairoutdinov and Randall (2003) to calculate the warm rain processes only where they occur: autoconversion and accretion in cloud, and evaporation in clear air. The fluxes of rain into and out of cloudy air are calculated using the cloud overlap assumption of Jakob and Klein (2000).



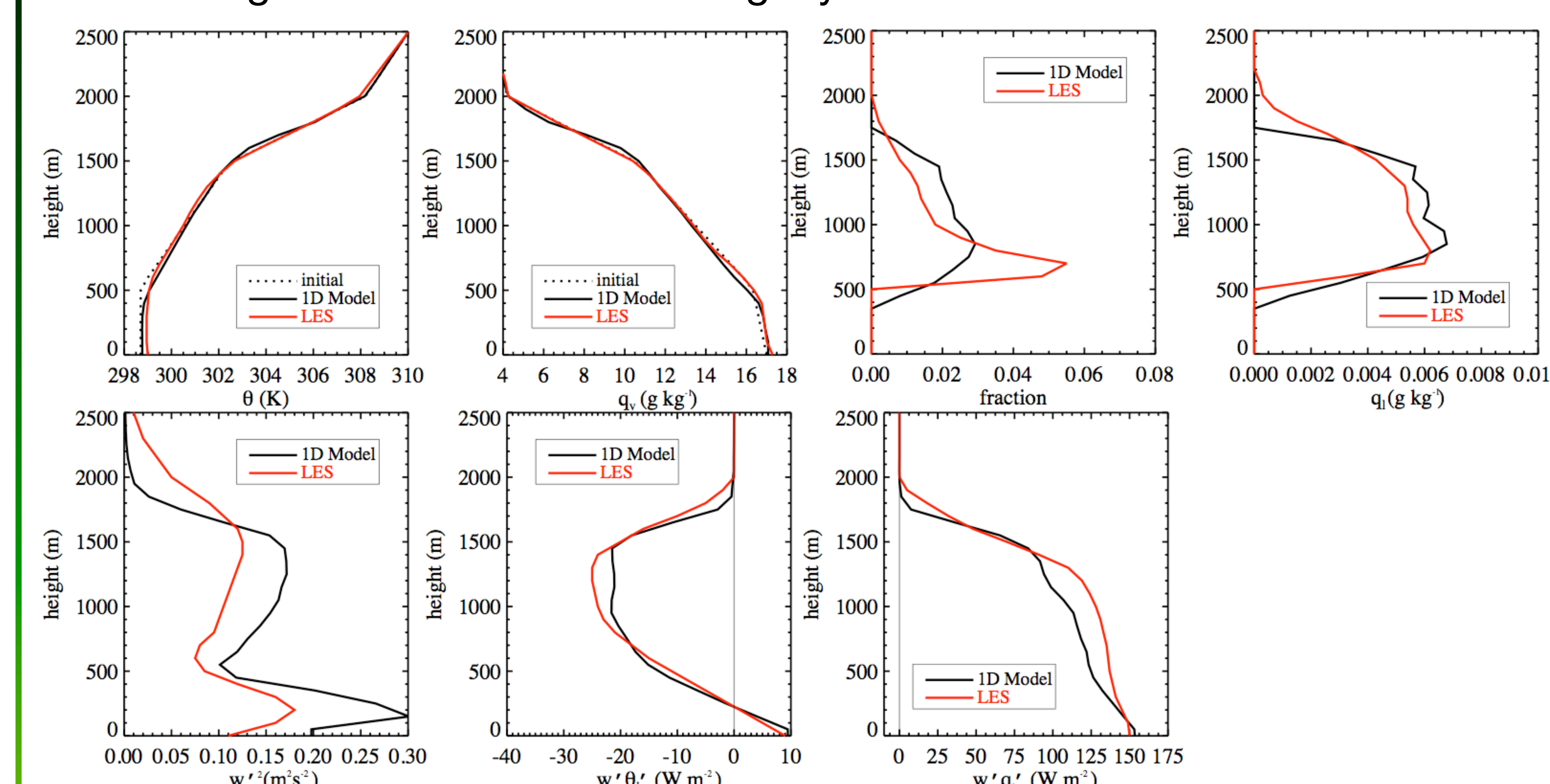
Selected Results

The one-dimensional model was tested using 5 standard cases: a clear convective case (Wangara), a smoke cloud case, a nocturnal drizzling stratocumulus case (DYCOMS RF02), a non-precipitating trade wind cumulus case (BOMEX), and a precipitating trade wind cumulus case (RICO). Selected results from the BOMEX and DYCOMS RF02 cases are presented here.

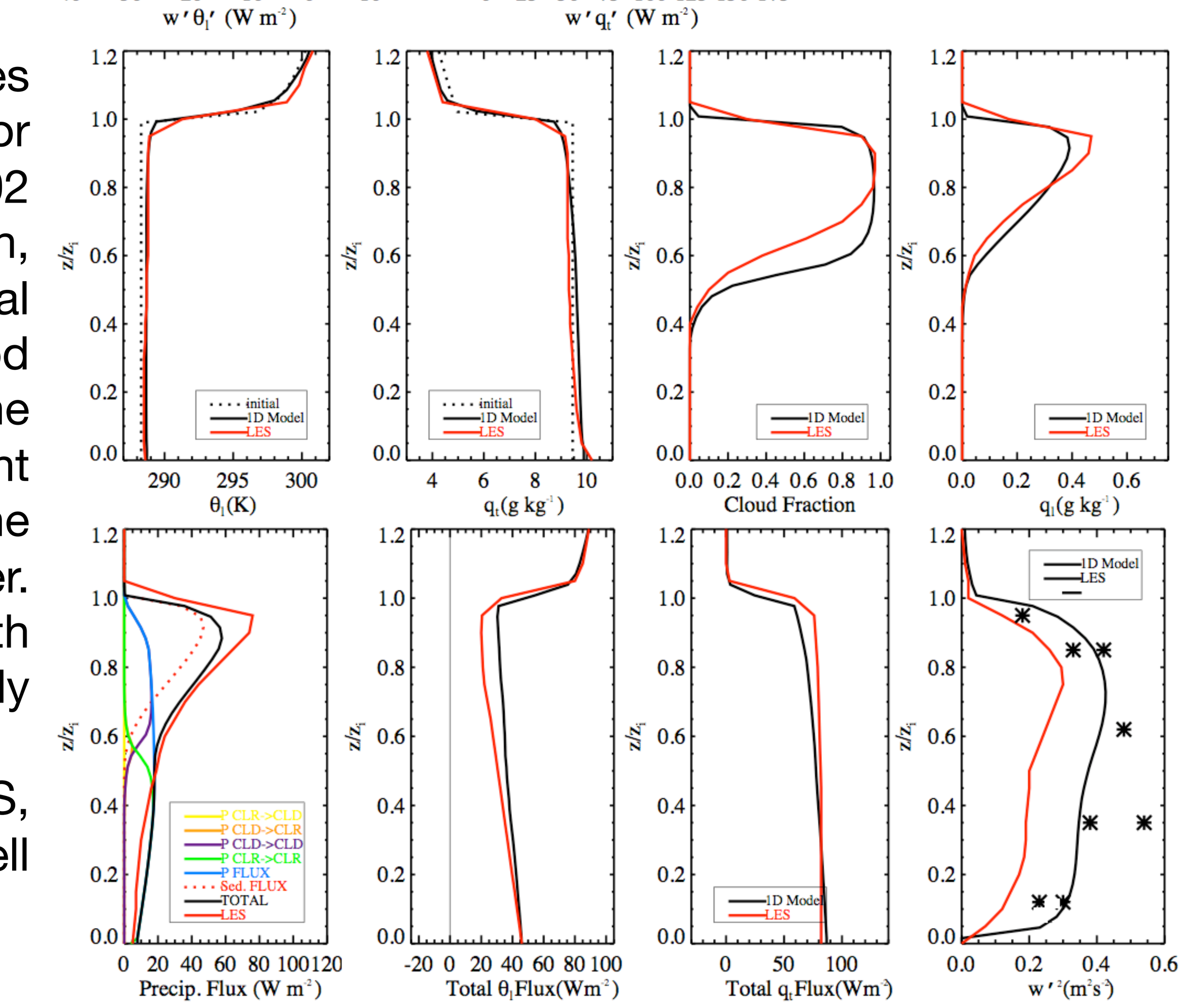
Preliminary results from the new turbulence parameterization adapted to VVM are included for DYCOMS RF02 case as well.

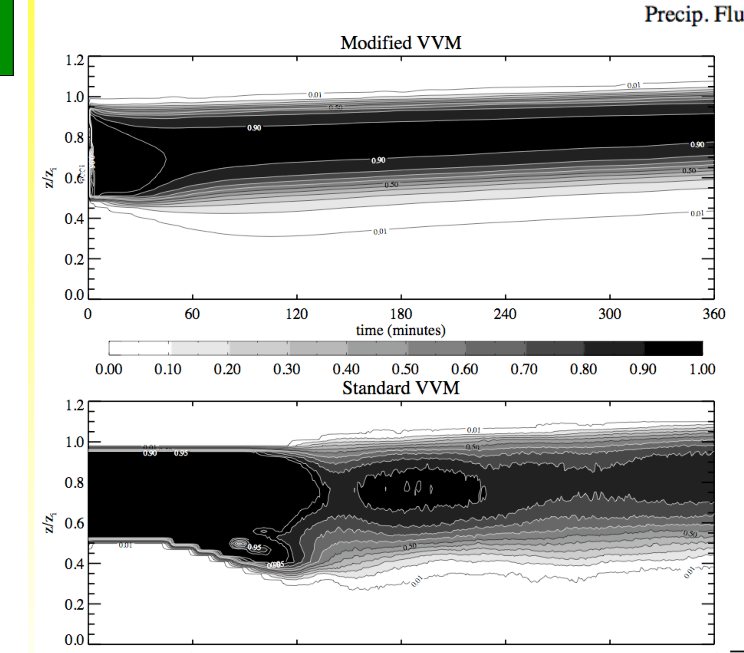
Results (continued)

The mean thermodynamic state and selected second-order moments from the BOMEX case are presented below. The one-dimensional model was able to capture the mean state nearly perfectly compared with LES, while the strength of the turbulence is slightly overestimated.

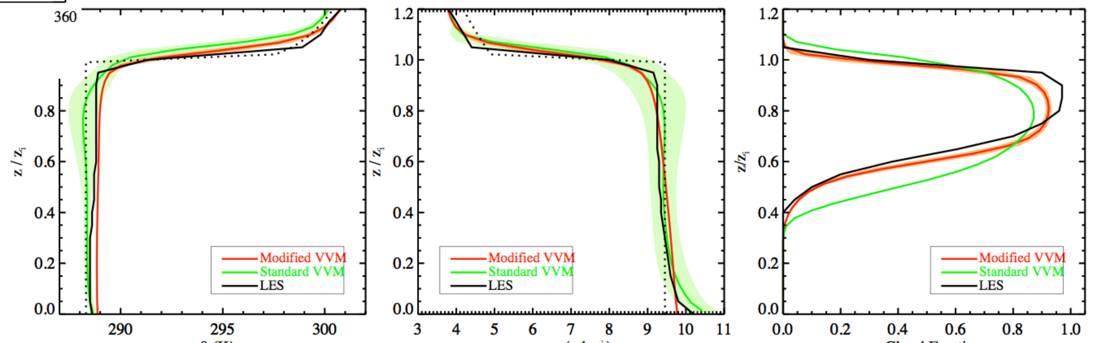


The same variables are shown here for the DYCOMS RF02 case. Once again, the one-dimensional model does a good job capturing the mean and turbulent state of the boundary layer. Turbulence strength is slightly overestimated compared to LES, but matches well with observations.





Shown here are a time-height cross section of cloud fraction (left) and mean profiles of the thermodynamic state from both standard and modified versions of the VVM for the DYCOMS RF02 case. While both models simulate this case well, the modified version matches the LES mean state slightly better, especially in the cloud layer. In addition, the cloud field varies in a smoother fashion, eliminating noise found in the standard VVM.



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