J7.6 EVALUATION OF A NEW PARAMETERIZATION FOR FAIR-WEATHER CUMULUS

Larry K. Berg*[1] and Roland B. Stull[2]
[1]Pacific Northwest National Laboratory, Richland, Washington
[2]The University of British Columbia, Vancouver, BC, Canada

1. INTRODUCTION

A new scheme for predicting the cloud cover, cloud-base height, and cloud-top height of fair-weather cumuli has been developed. The scheme, called the Cumulus Potential (CuP) scheme couples the fair-weather clouds with the boundary-layer turbulence. The CuP scheme does a better job predicting the cloud cover, cloud-base height, and cloud-top height than three other methods.

2. DESCRIPTION OF THE SCHEME

The CuP parameterization consists of two independent modules (Fig. 1), and was originally presented by Berg and Stull (2005). In the scheme, one module represents boundary-layer physics, and the other represents clouds. The boundary-layer physics module combines the virtual potential temperature (θ_v) and water vapor mixing ratio (r) to form a Joint Probability Density Function (JPDF). The JPDF can be compared to the mean environmental profile of θ_v. Parcels with θ_v greater than the mean mixed layer value of θ_v are assumed to rise. If a parcel rises to its lifting condensation level then it forms a cloud, and the parcels thermodynamic properties are passed to the cloud module. The size and shape of the JPDF must be prescribed. Berg and Stull (2004) developed a parameterization that treats the distribution of θ_v and r as a mixing diagram, with the distribution of parcels reaching along mixing lines connecting the boundary layer mean value to both the surface and the entrainment zone properties.

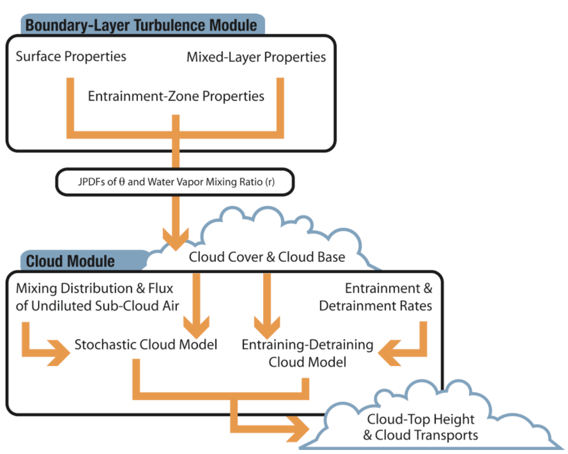

Figure 1. Schematic of the CuP parameterization showing the boundary-layer turbulence and cloud modules. Arrows indicate the flow of information through the parameterization.

*Corresponding Author Address: Dr. Larry K. Berg, Pacific Northwest National Lab, PO Box 999, Richland, WA 99352. e-mail: larry.berg@pnl.gov.

In the CuP scheme, the thermodynamic properties at cloud base are determined from the θ_v and r of the parcels that rise to form clouds. The cloud processes are represented in the cloud module. A simple entraining-detraining cloud model is used here. In this model mixing between the cloud and the environment occurs at a constant rate as the cloud rises (e.g. Malkus 1958). The entrainment and detrainment rates selected for use with the CuP scheme were 1.0 X 10^{-3} m^{-1}, and 3.0 X 10^{-3} m^{-1}, respectively. These values are consistent with estimates found using LES of the trade wind boundary layer for a population of cumuli (Siebesma and Cuijpers 1995; Siebesma and Holtslag 1996). The cloud top height is predicted by determining the level at which all of the parcels convective available potential energy (CAPE) is dissipated.

The cloud cover is determined using the prognostic equation,

$$\frac{d\alpha_{cloud}}{dt} = \frac{\alpha_{active}}{t_{active}} - \frac{\alpha_{cloud}}{\tau_{cloud}}, \qquad (1)$$

where α_{cloud} is the cloud-cover fraction at time, t, and α_{active} is the fraction of parcels that form clouds, as determined from the JPDF. The active cloud time scale is defined to be $t_{active} = z_{top}/w_*$, where z_{top} is the average cloud-top height. The cloud lifetime is modeled after the work of Albrecht (1981) and Haiden (1996), as:

$$\tau_{cloud} = t_* \ln\left[1 + (1+\gamma)\frac{\int l_{cloud}\,dz}{\int \delta r_s\,dz}\right], \qquad (2)$$

where t_* is the boundary layer time scale, l_{cloud} is the cloud liquid water, δr_s is the saturation deficit of the environment ($r_{s,env} - r_{env}$), and $\gamma = (L/C_p)(\partial \bar{r}_{s,env}/\partial \bar{T}_{env})$.

3. RESULTS FOR BLX96

The scheme has been tested using data collected during Boundary Layer Experiment 1996 (BLX96; Stull et al. 1997). In this test, the CuP scheme is used as a stand-alone model driven with thermodynamic profiles measured by the University of Wyoming King Air aircraft. Parameterized JPDFs were created using the methods of Berg and Stull (2004). Equation (1) was then integrated forward in time using Runge-Kutta methods and assuming that τ_{cloud}, α_{active}, and t_{active} changed linearly with time between the individual profiles.

In addition to the results computed using the CuP scheme, cloud properties simulated using three other schemes will also be presented for comparison: 1) the relative humidity-based scheme of the ECHAM4 global climate model (Roeckner et al. 1996), 2) the classical statistical scheme suggested by Sommeria and Deardorff (1977), and 3) the scheme suggested by Albrecht (1981) for trade wind cumuli.

3.1 CLOUD COVER

The CuP scheme and the alternative methods were used to estimate the total cloud cover. Overall, the agreement between the CuP-predicted cloud cover and the cloud cover observed during individual BLX96 flight legs is good, but there is much scatter (Fig. 2).

A number of different methods can be used to quantify the cloud cover errors. The mean bias of each scheme was computed and is reported in Table 1. The CuP scheme had the smallest bias, while the methods of Albrecht (1981) and Sommeria and Deardorff (1977) have the largest bias. The CuP scheme also has the highest sample correlation coefficient of the four schemes, 0.57.

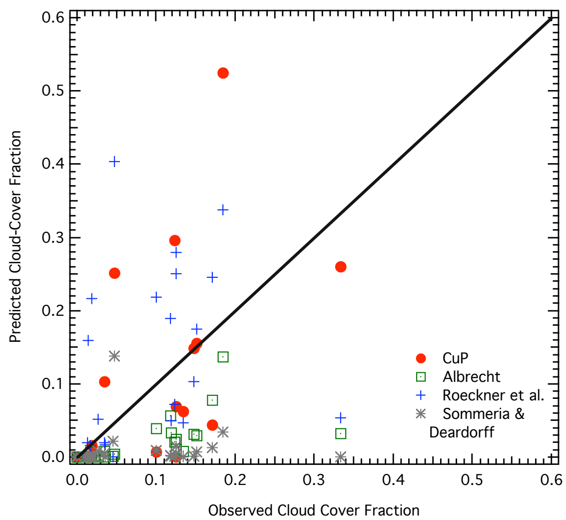

Figure 2. Predicted cloud-cover fraction using the CuP Scheme (red dots), Albrecht (1981; squares), Roeckner et al. (1996; crosses), and Sommeria and Deardorff (1977; asterisks) vs. the observed cloud cover fraction for all BLX96 flight legs. The heavy solid line is the 1:1 line.

Table 1. Mean bias and sample correlation coefficient in predicted cloud cover for each method.

	CuP	Albrecht	Roeckner et al.	Sommeria & Deardorff
Mean Bias	-0.01	-0.07	0.04	-0.08
Cor. Coef.	0.57	0.01	0.32	-0.02

3.2 CLOUD-TOP AND CLOUD-BASE HEIGHT

There is good agreement between the observed cloud-base height and the cloud-base height predicted by the CuP scheme (Fig. 3). The level of agreement is not surprising; Stull and Eloranta (1985) found that the value of the lifting condensation level calculated from surface-layer air did a good job predicting the cloud-base height.

The cloud-base and cloud-top heights were calculated using the CuP scheme and the alternative methods of Albrecht (1981), Roeckner et al. (1996), and Sommeria and Deardorff (1977). Estimates of the cloud heights were more complicated for the alternative methods because the cloud depth is not explicitly predicted. For these methods, the cloud-base height was defined as the height at which clouds first form, and the maximum cloud-top height was defined as the height at which clouds ceased to exist. The CuP scheme seemed to do the best job predicting the cloud-base height. The methods of Roeckner et al. (1996) and Sommeria and Deardorff (1977) underestimated the cloud-base height. The method of Albrecht (1981) overestimated the cloud-base height.

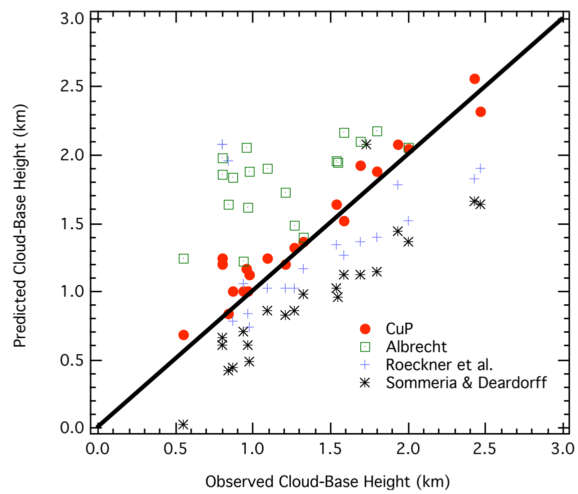

Figure 3. Plot of the Cup (red circles), Albrecht (1981; squares), Roeckner et al. (1996; crosses), and Sommeria and Deardorff (1977; asterisks) predicted cloud-base height vs. observed cloud-base height. The solid line is the 1:1 line.

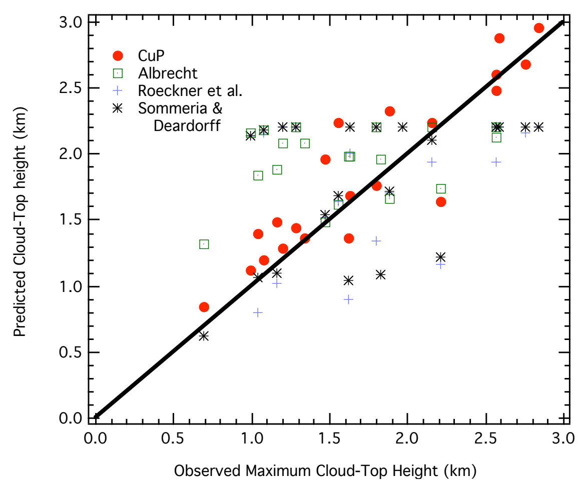

Figure 4. Plot of the Cup (red circles), Albrecht (1981; squares), Roeckner et al. (1996; crosses), and Sommeria and Deardorff (1977; asterisks) predicted cloud-top height vs. observed cloud-top height. The solid line is the 1:1 line.

The CuP scheme does the best job of the four schemes predicting the cloud-top height (Fig. 4). As described above, the cloud tops shown for the schemes of Roeckner et al. (1996), Sommeria and Deardorff (1977), and Albrect (1981) are the maximum cloud-top heights. There is more scatter in the cloud-top results of alternate methods than for the CuP-predicted cloud top heights.

4. CONCLUSIONS

A simple parameterization to predict the cloud-cover fraction and the cloud-depth distributions of boundary-layer cumuli over heterogeneous land surfaces has been introduced. The new parameterization uses two modules to couple the boundary-layer cumuli to the boundary-layer turbulence.

The CuP scheme did a better job predicting the cloud-base height and cloud-top height than the three alternative methods of Albrecht (1981), Roeckner et al. (1996), and Sommeria and Deardorff (1977) when compared with data collected during BLX96. The agreement between the observed and CuP predicted cloud cover is not as good. However, the CuP scheme had a smaller bias and higher sample correlation than the three alternative methods.

Acknowledgments: This work was supported through grants from the National Science and Engineering Research Council (NSERC), Meteorological Service of Canada, the Canadian Foundation for Climate and Atmospheric Science, Environment Canada, and the U.S. Department of Energy (DE-AC05-76RL01830) as part of the ARM Program under contract DE-AC06-76RLO at the Pacific Northwest National Laboratory which is operated for the U.S. Department of Energy by Battelle Memorial Institute. The BLX96 field program was funded by the U.S. National Science Foundation under Grant ATM-9411467.

5. REFERENCES

Albrecht, B. A., 1981: Parameterization of trade-cumulus cloud amounts. *J. Atmos. Sci.*, **38**, 97-105.

Berg, L. K, and R. B. Stull (2004): Parameterization of joint frequency distributions of potential temperature and water vapor mixing ratio in the daytime convective boundary layer. *J. Atmos. Sci.*, **61**, 813-828.

Berg, L. K, and R. B. Stull (2005): A simple parameterization coupling the convective daytime boundary layer and fair-weather cumuli. *J. Atmos. Sci.*, **62**, 1976-1988.

Haiden, T., 1996: Generalization of Albrecht's cumulus cloud amount parameterization. *J. Atmos. Sci.*, **53**, 3164-3167.

Malkus, J. S., 1958: On the structure of the trade wind moist layer. *Pap. Phys. Oceanogr. Meteor*. **13**.

Roeckner, E., and Coauthors, 1996: The atmospheric general circulation model ECHAM-4: Model description and simulation of present-day climate. Tech. Rep. 218, Max-Planck-Institut fur Meteorologie, 90 pp.

Siebesma, A. P., and J. W. M. Cuijpers, 1995: Evaluation of parametric assumptions for shallow cumulus convection. *J. Atmos. Sci*, **52**, 650-666.

Siebesma, A. P., and A. A. M. Holtslag, 1996: Model impacts of entrainment and detrainment rates in shallow cumulus convection. *J. Atmos. Sci*, **53**, 2354-2364.

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

Stull, R. B., and E. Eloranta, 1985: A case study of the accuracy of routine, fair weather cloud-base reports. *Natl. Wea. Dig.*, **10**, 19-24.

Stull, R. B., E. Santoso, L. Berg, and J. Hacker, 1997: Boundary Layer Experiment 1996 (BLX96). *Bull. Amer. Meteor. Soc.*, **78**, 1149-1158.