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Geoscientific Model Development Discussions

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Interactive Comment

Interactive comment on "A dynamic probability density function treatment of cloud mass and number concentrations for low level clouds in GFDL SCM/GCM" *by* H. Guo et al.

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Dear Editor and Reviewers,

We greatly appreciate the constructive comments from the anonymous reviewers, and have addressed all the reviewers' comments. The details are as follows. We also include the pdf file of our response to two reviewers in the supplement.

Anonymous Referee 2
Received and published: 7 July 2010
This paper presents initial tests for the new joint treatment of boundary layer turbulent and cloud processes (CLUBB) in the GFDL AM3 single column model (SCM). The

performance of the new scheme, or more precisely, the droplet activation part of the scheme, is demonstrated using three cases with different cloud types and cloud fractions, with an LES model serving as a benchmark. The tests include simulations with two aerosol loadings as well as CLUBB runs at low and high resolutions. While treating subgrid vertical motions is clearly necessary for any realistic SCM simulations of clouds, the goals and benefits of the specific approach needs to be identified more clearly to be useful for the modeling community. The outlined model development seems viable, but a major revision of the manuscript is needed to bring it to the publication level.

General comments:
1. The study is motivated by the need to have a droplet activation scheme driven by the sub-grid turbulent motions. Other models have use pdfs of vertical velocity to predict droplet activation. As pointed out in the manuscript, such pdf often take a form of a Gaussian distribution with a width related to some measure of turbulence intensity (e.g., TKE). The CLUBB treatment discussed here is different because it uses a pdf which is bi-modal and multi-variate. Unfortunately, neither feature is discussed in the context of droplet activation. A double Gaussian vertical velocity pdf is quite apparent in figure 4 but never mentioned in the paper. A multi-variate nature of CLUBB's pdf is mentioned and reflected in Eq. 3, but its role in treating droplet activations is not discussed. These are the two unique aspects of the new treatment, which this work should focus more instead of concentrating on a comparison with a somewhat artificially simplified parameterization with a prescribed updraft.

Response: The bi-modal and multi-variate features of CLUBB are based on the published work on large eddy simulations and analyses of aircraft data (Larson et al., *J. Atmos. Sci.*, 2001, 2002; Golaz et al., *J. Atmos. Sci.,* 2002a, 2002b).

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The double Gaussian functional form probably confers the most benefit in the case of cumulus clouds, which are highly skewed. A single Gaussian is always unskewed.

The multivariate PDF is useful because only the updrafts in the saturated regions matter for droplet activation. The multivariate PDF is most useful whenever i) there is partial cloudiness; or ii) there is a strong correlation between vertical velocity and any thermodynamic variables that influence droplet activation.

Examples of PDFs from aircraft data show that some PDFs are skewed and correlated (Larson et al., 2002). We will add some discussion in the revised manuscript.

2. The main conclusion of the paper, that the proposed implementation is promising and feasible, is rather weak. What aspects of the simulations were improved using the new scheme? What is the reason for these improvements? Does the bi-modality or the use of a joint vertical velocity – temperature – moisture pdf plays a larger role? In the introduction it is mentioned that the droplet number transport is also handled by CLUBB. Does this have any effect on the results?

Response: The revised manuscript will show additional, precipitating cases that better illustrate links between cloud drop activation, microphysics, and cloud properties. Use of the same underlying sub-grid PDF for sub-grid scale transport, cloud properties, and activation is new. Comparisons with aircraft

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data and LES (Larson et. al *J. Atmos. Sci.,* 2001, 2002) have shown that using a PDF with variable skewness, such as a double Gaussian, is important in order to accurately represent shallow cumulus layers. Using a joint PDF of vertical velocity (w), liquid potential temperature (θ_l), and total water mixing ratio (q_t) allows for the coupling between the dynamics and thermodynamics. A key term leading to the production of turbulence is the buoyancy term which involves the coupling of all three variables.

As we noted on p.543 (Ramanathan et al., 2001, Fig.5) of the original manuscript, diagnostic methods based only aerosol concentration can not capture the observed range of cloud droplet number. The dynamics PDF method has the potential to do so. We will also discuss in more detail in the revised manuscript the importance of the relationship between distributions of vertical velocity and droplet number.

Cloud droplet transport term is an important term for the cloud drop number budget. New cloud drops nucleate near cloud base and are transported upward by turbulence.

3. Adopting a higher order turbulence closure parameterization obviously requires extra computations. How much does the CLUBB slow down the SCM?

Response: CLUBB slows down the entire SCM simulations by about 14%. However, the computational costs of single column simulations are not representative of those of global simulations, since in the single column simulations, a majority of CPU time occurs during the initialization process ($> 80\%$). Also the SCM includes microphysics but not detailed radiative transfer.

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For the main dynamic and thermodynamic loops (except initialization, termination, and restart), incorporating CLUBB slows down single column simulations by a factor of ~ 2.5 on average.

4. The sensitivity of the simulations to CLUBB's vertical resolution is an interesting aspect of the study but needs to be put into context. The changes appear to be not that large – much smaller than the difference between the SCM and LES benchmark. Does this improvement worth extra computing power? Also, since one would expect the simulations to improve at higher resolution, should the high resolution CLUBB be compared with the high resolution SCM with a diagnostic sigma$_w treatment?$

Response: In the main text of the revised manuscript, we will focus on the performance of high resolution CLUBB with high resolution SCM, and we will also compare the high resolution CLUBB with the high resolution SCM with a diagnostic σ_w treatment.

The performance of low resolution CLUBB with low resolution SCM will be discussed in the Appendix.

An assessment of the benefits and costs of high resolution awaits studies with a general circulation model (GCM). In practice, GCM construction entails trade-offs between accuracy and computational speed. Our purpose here is only to provide a general indication of the robustness of the simulation to reduced vertical resolution and to suggest that some reduction in resolution is possible without fundamentally altering the character of solutions.

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Specific comments:// 1) Consider a more specific title since the manuscript covers only one aspect of the number concentration treatment (i.e., droplet activation). Also GCM could be removed from the title; otherwise readers may expect to see results from global simulations.

Response: We will change the title to
“A dynamics probability density function treatment of cloud droplet activation for large-scale models: Single Column Tests”

2) The meaning of ”dynamic pdf” or ”dynamics-pdf” in title and text is not clear. Is it the same as “multi-variate”?

Response: They are not the same.
The term “dynamics pdf” conveys its most unique attribute, namely that it includes a PDF of motions (vertical velocities). It does use a multi-variate joint PDF of vertical velocity (w), liquid potential temperature (θ_l), and total water mixing ratio (q_t), in the interest of keeping the characterization short we have not included the adjective “multi-variate” in the description. We will define “dynamics pdf” more clearly in the revised manuscript.

3) p. 551, ln. 4: A plot of time series of cloud fraction or liquid water path could be useful to illustrate the “quisi-steady states” of the cloud fields.

Response: We will add the time series of liquid water path to illustrate that cloud fields have reached “quasi-steady states” for the last hour for BOMEX, RF01, and ATEX.

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4)p. 552, last paragraph: Aerosol activation spectrum, or, at least, a size distribution spectrum would be helpful to show in addition to providing the mass loadings.

Response: The aerosol size spectrum basically follows what is adopted in the GFDL AM3 (Ming et al.,*J. Atmos. Sci.* 2007). But some modifications have been made.
i) Sulfate is assumed to be entirely in the accumulation mode. ii) Sulfate aerosol spectrum consists of two lognormal modes ($N_1 : N_2$=17:3, $D_{g,1}$=0.01 μm, σ_1=1.6, $D_{g,2}$=0.07 μm, σ_2=2.0) in Ming et al., 2007. But in this study, the diameter of the second mode ($D_{g,2}$) is changed from 0.07 μm to 0.11 μm .

5) p. 553, lns. 20-25: I am not convinced that it is justified to abandon a more realistic diagnostic treatment for the σ_w in favor of a constant σ_w for the sake of simplicity. Is this what is used in GFDL GCM? If not, then why not use a TKE-diagnosed σ_w?

Response: Like many GCMs, the GFDL GCM estimates σ_w from the boundary layer eddy diffusivity coefficients and imposes a lower bound on σ_w. In the GFDL GCM, the lower bound is invoked 98% of the time. The parameterization thus essentially behaves as if σ_w was fixed. This may also be the case in other GCMs. Some GCMs directly use a constant variance which is not related to boundary layer turbulence (e.g. Chuang et. al *J. Geophys. Res*, 1997, 2002).

6) p. 555, ln. 5: Do you mean the positive skewness is indicative of turbulent structure of a convective boundary layer?

Response: We mean the vertical velocity skewness is often indicative of turbulent structure. It can be positive, negative, or neutral (Moeng and Rotunno,

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1990, *J. Atmos. Sci.*).

7) p. 556, lns. 3-5: Are there any global models that use a constant velocity for droplet activations? If so, a reference is needed here.

Response: We will clarify the text in the revised manuscript. As mentioned above, some GCMs use a constant variance. Some also replace the subgrid w PDF with a single characteristic w related to TKE or CAPE (Lohmann et al., 1999, *J. Geophys. Res.*; Lohmann, 2002, *J. Atmos. Sci.*). Based on LES work of Jiang and Cotton (*J. Geophys. Res,* 2005), it might be difficult to find a single characteristic w applicable for a wide range of regimes.

8) Figure 3: The two dark-colored lines are hard to distinguish. Consider changing color or using markers to make these lines more easily identifiable.

Response: We will re-plot Fig.3 using different color lines.

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Please also note the supplement to this comment:
http://www.geosci-model-dev-discuss.net/3/C248/2010/gmdd-3-C248-2010-supplement.pdf

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