Can Triple-Gaussian Based pdf be Used for a Unified Scheme for Cloud Parameterizations?

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1) Motivation

- An advanced cloud parameterization is needed to bridge the gap between the cloud resolving model (CRM) as a cloud parameterization in the Multi-scale Modeling Framework (MMF) and the traditional mass flux approach in general circulation models (GCMs).
- Higher-order turbulence closure (HOC) and mass flux usually have traditionally been developed independently. A unified scheme will be a more powerful tool for climate models.
- A double-Gaussian based pdf has limitations in simulating boundary-layer and deep convective clouds.

A triple-Gaussian based pdf, one Gaussian for the updrafts, one for the downdrafts, and one for the environment, is proposed for parameterizing boundary-layer and deep moisture clouds in a HOC approach. Information from the mass flux approach and the higher-order moment equations is used to find the parameters that are needed to determine the three Gaussians. This study explores the possibilities of using a triple-Gaussian based pdf for cloud parameterizations.

2) Diagnostic Method

Outputs from System for Atmospheric Modeling (SAM) Large eddy simulation (LES) and CRM for two GEWEX (Global Energy and Water-cycle Experiment) Cloud System Study (GCSS) cases are used to diagnose the first- and the second-order moments that can be used to determine the triple-Gaussian based pdf. The updrafts are defined as grid-points with vertical velocity larger than 0.2 m s^{-1}, and the downdrafts as points with vertical velocity less than -0.2 m s^{-1}, respectively. The other grid-points belong to environment. Once the triple-Gaussian based pdf is determined, the cloud fraction and cloud water are diagnosed from the pdf and compared with those obtained directly from CRM and LES.

3) Experiment Design

The following two GCSS cases were simulated with SAM using the initial condition and large-scale forcing provided by the GCSS intercomparison studies.

The ATEX (Atlantic Trade Wind Experiment), a shallow cumulus-to-stratocumulus transition case, was simulated with the LES version of SAM with a horizontal domain of 6.4 km x 6.4 km, a horizontal grid spacing of 100 m and a vertical grid spacing of 40 m. The integration time is 8 hours. The model reached a steady state at hour 5. The LES-simulated cloud fraction of the ATEX case exhibits characteristics of both shallow cumulus and stratocumulus clouds (Fig. 5). There are two maxima in cloud fraction at the bottom and the top of the cloud layer, which are due to shallow cumuli and stratocumuli, respectively. It is very important for an assumed pdf to capture those two maxima.

The Large-scale Biosphere-Atmosphere (LBA) experiment in Amazonia (Rondonia, Brazil), a shallow cumulus-to-deep convective cloud transition case, was simulated with the 2-D version of the SAM-CRM with HOC. The horizontal domain size of the CRM is 256 km, with a uniform horizontal grid size of 1 km. There are 46 vertical levels. The vertical grid size is 100 m near the surface and stretches to 1.5 km at model top. The integration time is 6 hours. The transition stage occurred at hour 5, and deep convection occurred at hour 6. The goal of this experiment is to test if the assumed pdf can capture the transition and deep convective clouds.

4) Results for ATEX

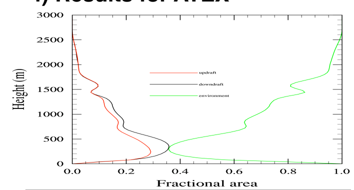

Fig. 1. Fractional area of the updrafts (red), the downdrafts (black), and the environment (green) averaged over the last three hours for ATEX.

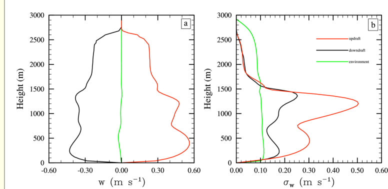

Fig. 2. Vertical velocity (a) and its standard deviation (b) of the updrafts (red), the downdrafts (black), and the environment (green) averaged over last three hours for ATEX.

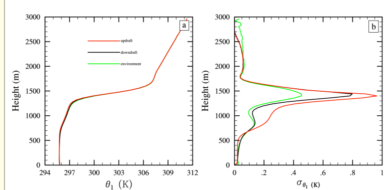

Fig. 3. Same as Fig. 2 except for liquid water potential temperature.

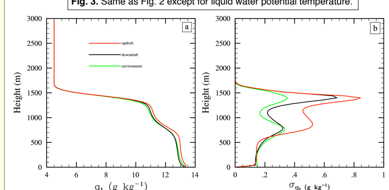

Fig. 4. Same as Fig.2 except for total water.

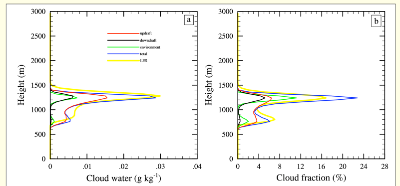

Fig. 5. Cloud water (a) and cloud fraction (b) diagnosed from the triple-Gaussian based pdf for the updrafts (red), the downdrafts (black), and the environment (green), and their sum (blue). Those obtained directly from LES are denoted by yellow lines. All variables are averaged over the last three hours.

5) Results for LBA

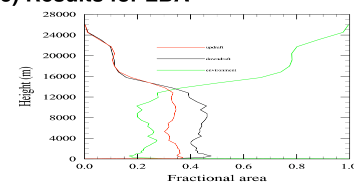

Fig. 6. Fractional area of the updrafts (red), the downdrafts (black), and the environment (green) averaged over the last hour for LBA.

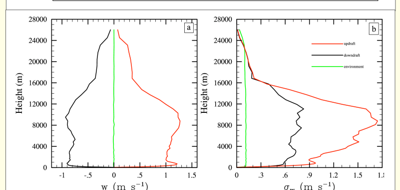

Fig. 7. Vertical velocity (a) and its standard deviation (b) of the updrafts (red), downdrafts (black), and environment (green) averaged over the last hour for LBA.

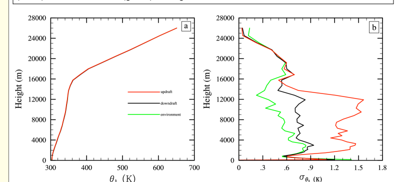

Fig. 8: Same as Fig. 7 except for liquid water potential temperature.

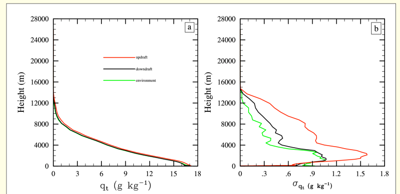

Fig. 9: Same as Fig. 7 except for total water.

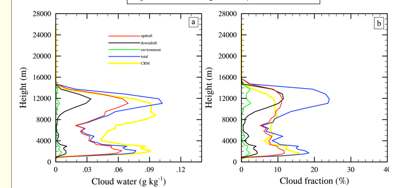

Fig. 10. Cloud water (a) and cloud fraction (b) diagnosed from the triple-Gaussian based pdf for the updrafts (red), the downdrafts (black), and the environment (green), and their sum (blue). Those obtained directly by CRM are denoted by yellow lines. All variables are averaged over the last hour during deep convective stage.

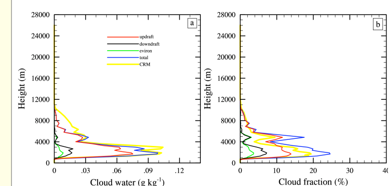

Fig. 11: Same as Fig.10 except averaged over hour 5 during the shallow-to-deep convective transition stage.

6. Conclusion and Discussion

- The assumed triple-Gaussian based pdf can reproduce the cloud fraction and cloud water for boundary-layer and deep convective clouds given the corresponding first-order and second-order moments for each Gaussian. It is a promising technique to be used for a unified scheme for cloud parameterizations.
- The updrafts play the most important role for producing the cloud water and cloud fraction for both boundary-layer and deep-convective clouds. The effects of the downdrafts and the environment can not be neglected although their relative importance differs among different cloud types.
- The three Gaussians have distinct physical meanings and make the diagnostic study easy to understand.