Midlatitude Aerosol-Cloud-Radiation Feedbacks in Marine Boundary Layer Clouds

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LONG-TERM GOALS

The development and improvement of cloud microphysical parameterizations for use in cloud and numerical weather prediction models

OBJECTIVES

Conduct detailed studies of marine stratocumulus cloud microphysical processes in order to achieve a better understanding of interactions between microphysical, radiative and boundary layer thermodynamical processes and to improve their formulation in numerical weather prediction models. Develop parameterizations of individual cloud physics processes for use in numerical weather prediction models.

APPROACH

The research is based on the CIMMS high-resolution large eddy simulation (LES) model of marine boundary layer stratocumulus clouds with explicit formulation of aerosol and drop size-resolving microphysics. The LES simulations, as well as observations from field projects are used to study drizzle formation in marine stratocumulus. This year we also started analyzing data from the RICO field project that will be used as a basis for cloud physics parameterizations applicable for shallow convective cumuliform clouds.

WORK COMPLETED

The following tasks have been completed this year:

1. The parameterization of the sedimentation process and radar reflectivity in marine stratocumulus clouds has been developed.

2. The parameterization of the dispersion of drop spectra in drizzling stratocumulus clouds for use in two-moment bulk models has been formulated.

3. A graduate student MS thesis was completed based on the ONR funded research. Previous work has been published and presented at scientific conferences.

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RESULTS

1. Parameterization of the sedimentation process and radar reflectivity in marine stratocumulus clouds

An important part of any formulation of cloud physics processes in numerical weather prediction models is parameterization of the process of drop sedimentation. In addition, models have to be able to provide output of radar reflectivity. The recent advances in application of radar technology and the ever increasing use of radar data in model initialization and verification of its predictions necessitates development of means to relate model's output to radar reflectivity. It is with this goal in mind that we aim to develop parameterizations of the sedimentation process and radar reflectivity. We employ the following approach to this task: 1) finding the best analytical fits to approximate cloud drop size distributions and 2) deducing the rain rates and radar reflectivity based on these analytical fits.

We evaluated the accuracy of drop size distribution approximations in stratocumulus and shallow convective clouds using a combination of lognormal and gamma-type functions. The DSDs are generated using the latest version of the CIMMS LES explicit microphysics model (SAMEX) in simulations of cases observed during the ASTEX and DYCOMS-II projects.

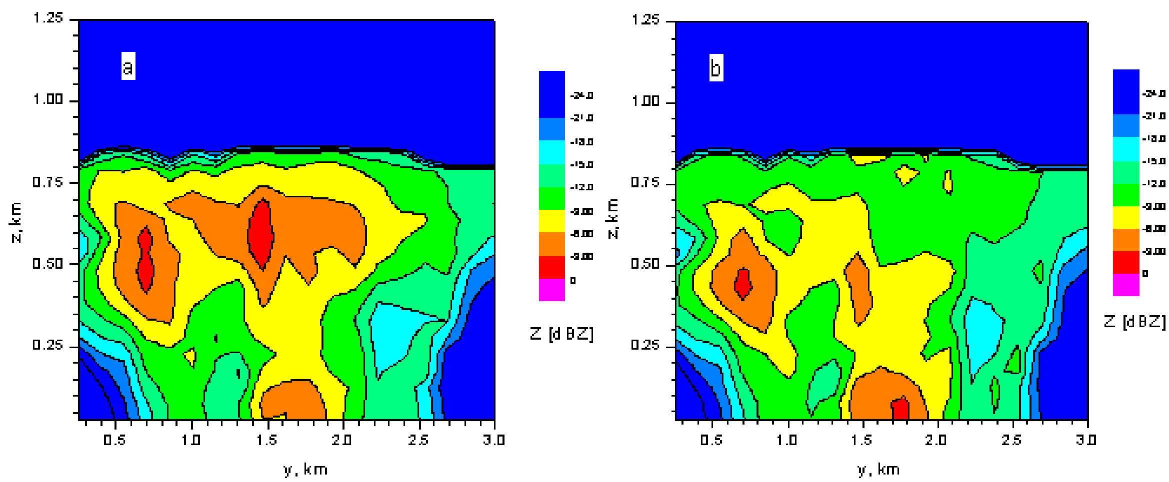

Fig 1. The vertical cross-section of radar reflectivity Z in two simulations: a) benchmark case with Z defined from LES predicted DSDs; b) parameterized Z based on the 3-parameter gamma fit to drop size distributions. [graph: parameterized radar reflectivity reasonably well represents the structure of the stratocumulus cloud layer]

In a series of experiments characteristic for Sc clouds with light, moderate and heavy drizzling conditions, we have shown that approximating drop spectra by Gamma-type distributions (*G-fit*) proved to be much more accurate than approximation by the lognormal distribution. Based on the *G-fit* the sedimentation flux can be approximated quite accurately, even in heavy drizzling cases. A more difficult task is to represent radar reflectivity *Z* based on the model prognostic variables. In two moment microphysical schemes these variables include concentrations and mixing ratios for the cloud droplet and drizzle categories, namely, N_c, Q_c, N_d, Q_d. We use these prognostic variables and the dispersion parameterization (see the section below) in order to derive the radar reflectivity.

Figure 1 shows the fidelity of the model derived reflectivity fields by contrasting the *G-fit* parameterization with the benchmark case where Z is calculated as a 6^{th} moment of the DSD predicted by the explicit microphysics LES model. The three-parameter *G-fit* correctly shows the general structure of the Z field with the exception of one area below the cloud top. This is the region where due to early coagulation the cloud and drizzle modes in the DSD overlap and are not distinctly separated. The three-parameter *G-fit* is more accurate in areas near cloud base. Here because of the further coagulational growth of drops and consequent sedimentation, the two modes overlap less which leads to more accurate three-parameter *G-fits*.

2. Parameterization of dispersion of drop spectra in drizzling stratocumulus clouds for use in two-moment bulk models

In numerical models which use two-moment microphysical parameterization schemes, the six parameters defining the two-mode Gamma distribution can be expressed through the four predictive microphysical variables describing concentrations and mixing ratios of cloud and rain drops. The remaining two parameters have to be expressed by parameterizing the cloud and drizzle mode drop spectra dispersion. Our results show that the dispersion of the cloud drop size distribution σ_c is a decreasing function of N_c. In the $N_c < 30$ cm^{-3} range the dispersion can be roughly approximated by a linear function of drop concentration:

$$\sigma_c = 0.54 - 0.0094\, N_c \qquad (1)$$

For $N_c > 30$ cm^{-3} σ_c can be approximated by a constant equal to 0.25.

The dispersion σ_d of the drizzle drop spectra ($r \geq 25\mu$) is also a decreasing function of drizzle drop concentration N_d. The linear fit to the dispersion a function of N_d is shown in Fig. 2 by a solid blue line.

$$\sigma_d = a - b\, N_d \qquad (2)$$

The same figure shows that the dependence of σ_d on drizzle drop concentration N_d is more meaningful when σ_d is stratified by drizzle drop mixing ratio Q_d. In this case, the coefficients a and b of the linear fit (2) can be expressed as a quadratic function of drizzle drop mixing ratio:

$$a = 0.33+3.76\, Q_d - 13.5\, Q_d^2 \qquad (3)$$
$$b = -1.02 +8.63\, Q_d - 22.9\, Q_d^2$$

Here Q_d varies in the range from 0 to 0.2 g m^{-3}.

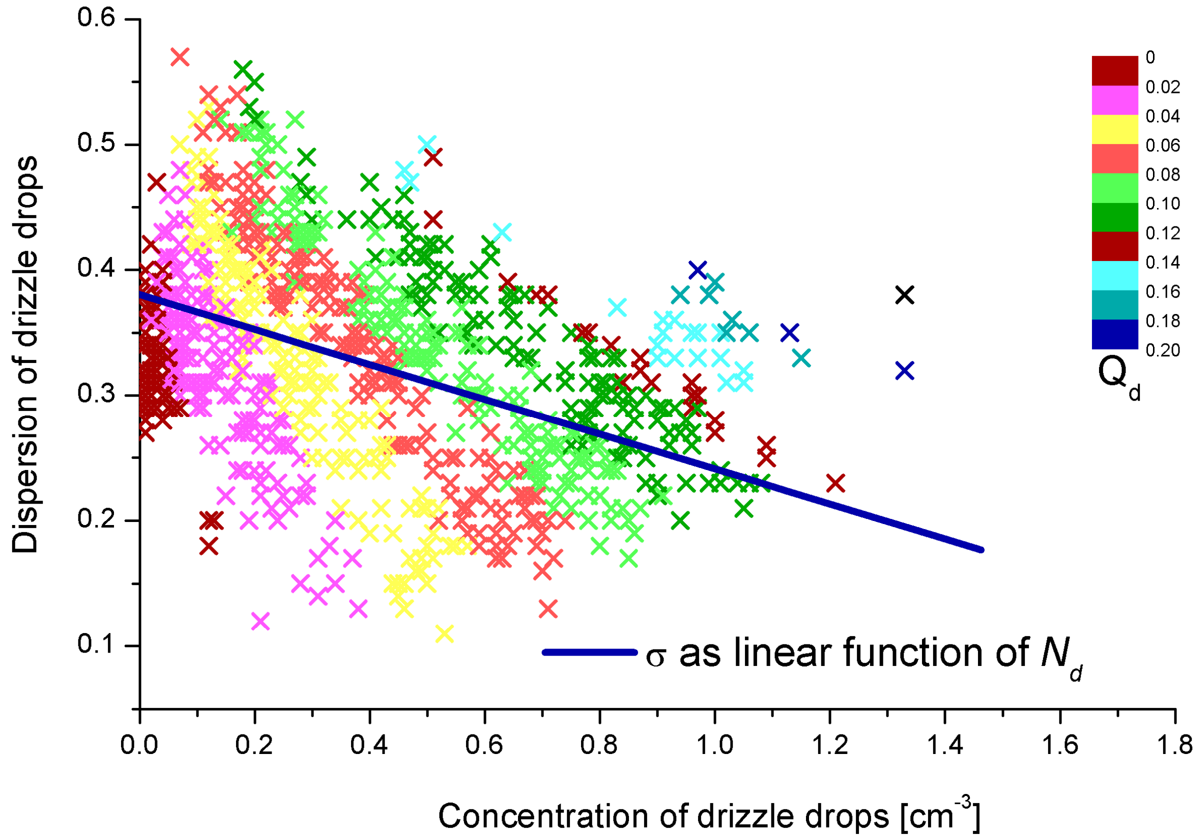

Fig. 2. Scatter plots of the drizzle drops dispersion as a function of concentration. The data points are stratified by the value of Q_d in the range from 0 to 0.2 g m^{-3}. [graph: the drizzle drop dispersion can be parameterized reasonably well as a function of two prognostic variables]]

Our results show that the drizzle mode dispersion can be rather accurately parameterized as a function of drizzle drop concentration and drizzle mixing ratio. The proposed parameterization of the dispersion of the drop spectra will allow more accurate representation of cloud physics processes in numerical weather prediction models.

IMPACT

The improved parameterization of the physical processes in marine stratocumulus clouds will lead to more accurate numerical weather predictions for Navy operations.

TRANSITIONS

Our results have been published in three refereed scientific journals, three conference proceedings, and reported at five scientific meetings. The results of the study formed the basis of the MS thesis defended by the OU graduate student Danielle Corrao.

PUBLICATIONS

Mechem, D. B. and Y.L. Kogan, 2008: A bulk parameterization of Giant CCN, *J. Atmos. Sci*, 65, 2458-2466.

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