Midlatitude Aerosol-Cloud-Radiation Feedbacks Mechanisms in Marine Stratocumulus Clouds

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LONG TERM GOALS

The development and improvement of cloud microphysical and radiative parameterizations for use in mesoscale models

OBJECTIVES

Investigation of marine stratocumulus clouds microphysics and radiative processes using the CIMMS LES model with explicit microphysics and radiation. The data from FIRE II/ASTEX and MAST field experiments will be used to validate the model and to improve our understanding of the interactions between the microphysical, radiative, and thermodynamical processes.

APPROACH

The modeling part of the research is based on the CIMMS 3-D LES model of boundary layer stratocumulus clouds with explicit formulation of aerosol and cloud drop size-resolving microphysics. The model has been thoroughly tested against observations from ASTEX and MAST field programs. Use the model to generate 3D data fields, including the rates of various microphysical processes needed to find relations between bulk variables that can be forecasted in numerical weather prediction models. Use the 3D drop size distributions to calculate the optical properties of clouds and study radiative transfer in inhomogeneous cloud media based on a 3D Monte Carlo radiative transfer model.

WORK COMPLETED

A parameterization of the cloud drop activation process in marine stratocumulus in terms of mesoscale model prognostic variables has been developed. The parameterization accounts for the dependence on CCN concentration, as well as intensity of turbulence in the boundary layer.
A design of a new parameterization of cloud physics processes based on the integral moments of the drop spectra, as opposite to the partial moments used in Kessler-type parameterizations have been developed. The importance of probability distribution functions (*pdf*) of prognostic variables in applying the cloud physics parameterization in heterogeneous broken cloud fields has been demonstrated using LES model data.
The effect of inhomogeneous cloud media on 3D radiative transfer was studied using the coupled 3D Monte-Carlo radiative transfer and explicit microphysics cloud models. We have showed the impact of cloud vertical inhomogeneity on satellite retrieval of cloud fraction.

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RESULTS

a. Parameterization of the cloud drop activation process

The number of activated cloud drops, N_{cd} is parameterized in terms of the domain average number of CCNs at 1% supersaturation, N_{ccn}, and turbulence intensity characterized by the domain average vertical velocity variance, $<w^2>$. We have considered environments N_{ccn} in the range from 25 to 1000 cm^{-3} and values of $<w^2>$ in the range from 0.06 to 0.27 m^2/s^2. The drop concentration averaged over the whole cloud layer was related to N_{ccn} and $<w^2>$ using regression analysis, resulting in the following link:

$$N_{cd} = N_{ccn}^{0.72} < w^2 >^{0.15}$$

Fig. 1 shows the number of activated drops for three levels of turbulence intensity depicted by different symbols. The best fit to the empirical data obtained in various field programs by Martin et al (1994) and O'Dowd et al (1996) is also shown. The derived parameterization agrees well with both empirical fits in the range of CCN concentrations up to 500 cm^{-3}. The latter covers the most commonly observed marine environments. The dependence of drop concentration on the intensity of vertical motions, $<w^2>$, is stronger for more polluted environments. The mesoscale grid averaged ambient aerosol concentration, as well as the level of turbulence intensity, is available in the current version of the ARPS model where the parameterization has been already implemented. The parameterization can also be easily included in the Navy COAMPS model.

b. Effect of subgrid scale inhomogeneity

The conversion rates that form the basis of a cloud physics parameterization are derived and applied locally, i.e., relating variables defined on a cloud scale. The extrapolation of a cloud-scale parameterization to a mesoscale model requires empirical knowledge or theoretical prediction of statistical distributions of cloud prognostic variables, e.g., *pdf*. The scale dependence of cloud parameterization, as well as the effect of partial cloud cover in a grid box has been emphasized in many studies (e.g., Sundqvist 1993; Randall 1995). Even for cases with total cloud cover, the neglect of cloud microstructure inhomogeneity may lead to serious errors in grid average values.

We demonstrated the impact of cloud microstructure inhomogeneity by expanding the cloud-scale stratocumulus parameterization of Khairoutdinov and Kogan (1998a) to a mesoscale grid of several kilometers. As an example we used the autoconversion rate from the above-mentioned parameterization which is a non-linear function of cloud prognostic variables.

The autoconversion rate averaged over the mesoscale grid is given by

$$<\left(\frac{\partial Q_r}{\partial t}\right)>_{auto} = \int \varphi(Q_c,N_c)\ f(Q_c,N_c)\ dQ_c dN_c$$

where $\varphi(Q_c,N_c)$ is the joint *pdf* of Q_c and N_c and $f(Q_c,N_c)$ is the cloud-scale autoconversion rate. Table 1 shows the average autoconversion rate calculated using: 1) the joint *pdf* $\varphi(Q_c,N_c)$; 2) the separate *pdf* for Q_c and N_c; and 3) the domain averaged values $<Q_c>$ and $<N_c>$. As one might expect, the autoconversion rate depends significantly on the type of *pdf* used in calculations (joint *pdf* versus separate *pdf*) and varies with time reflecting the evolution of drizzle in the simulation of a stratocumulus cloud layer and the corresponding changes in *pdf* .

Table 1. The dependence of autoconversion rates on subgrid statistics

Time, hrs	Joint *pdf*	Separate *pdf* for Q & N	Constant <Q> and <N>
3.0	2.88×10^{-8}	3.72×10^{-8}	0.61×10^{-8}
4.5	8.82×10^{-8}	11.11×10^{-8}	0.58×10^{-8}
6.0	21.25×10^{-8}	13.88×10^{-8}	0.90×10^{-8}

The above example emphasizes the need for experimental studies of statistical distribution of cloud parameters inside a mesoscale grid box. Another possibility to obtain the subgrid statistics is to use the grid embedded models (GEM). The rapid progress in computer power makes practical the incorporation of, at least, a 2D cloud-resolving model into a fraction of a mesoscale model grid cells. The resolvable variables of the mesoscale model can serve as the ambient parameters for the GEM, while the *pdf* and other subgrid characteristics calculated by the GEM (e.g., surface fluxes, TKE) will enter the parameterizations used in the parent mesoscale model.

c. Investigation of the role of subgrid inhomogeneity on radiation parameterizations
This study explores how the grid averaged radiative parameters depend on cloud microstructure vertical inhomogeneity. The radiative parameters are calculated by the 3D Monte Carlo radiative transfer model that uses as input the 3D field of cloud drop distributions provided by the LES model. The difference between the fully inhomogeneous benchmark case, *3D*, and the vertically homogeneous case, *2D*, (see Fig. 2) illustrates the problem of cloud satellite retrieval of cloud fraction. The retrieval algorithms classify pixels as cloudy or non-cloudy depending on the threshold value of albedo R_C. The pixels with albedo exceeding R_C are flagged as cloudy, while those with albedo less than R_C as clear-sky. As evident from Fig. 2, there is a much larger number of non-cloudy pixels in the *C2D* case than in the *C3D* case. This suggests that neglect of vertical stratification of the extinction coefficient may lead to overestimation of cloud fraction. Our results also show that vertical profiles of both the mean and the variance of the extinction coefficient are important in cloud fraction retrieval.

IMPACT

The improved parameterization of the physical processes in marine stratocumulus clouds will result in more accurate weather prediction for Navy operations. In particular, the work is aimed at improved prediction of atmospheric visibility, precipitating cloud layers, and cloud optical and radiative parameters.

TRANSITIONS

Our work is known to the COAMPS development team at NRL. The developed parameterizations are planned to be implemented in the COAMPS model as part of the MURI Grant to the University of Oklahoma.

RELATED PROJECTS

The current proposal is aimed at development of physical parameterizations for cloud scale (LES) models. It is closely related to the ONR project "Remote sensing and prediction of the coastal marine boundary layer" (N00014-96-1-1112). The latter project's goal is to formulate the parameterizations for application to mesoscale prediction models.

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IN-HOUSE/OUT-OF HOUSE RATIOS

100% of work is done by out-of-house organization (University of Oklahoma)

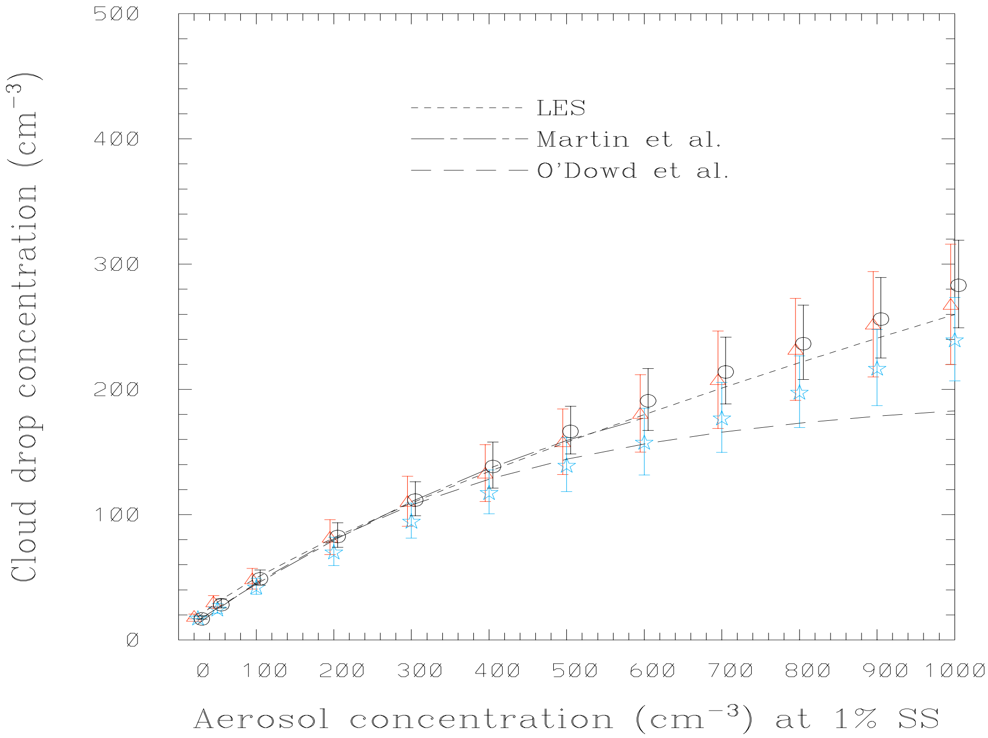

Fig. 1. The concentration of activated cloud drops as a function of CCN concentration and turbulence intensity. The LES parameterization is shown by the dashed line, three levels of turbulence intensity are depicted by different symbols. The best fit to the empirical data obtained from Martin et al (1994) and O'Dowd et al (1996) is also shown.

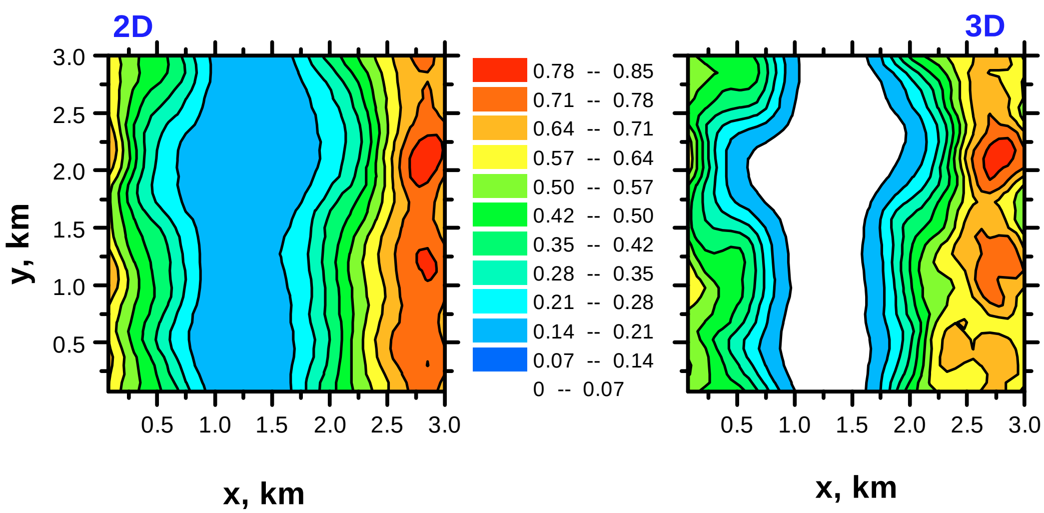

Fig. 2. Spatial distribution of the albedo field for the inhomogeneous cloud (right, 3D) and the vertically homogeneous cloud (left, 2D).