Study of midlatitude and Arctic aerosol-cloud-radiation feedbacks based on LES MODEL WITH explicit ice and liquid phase microphysics

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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. It is then used 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.

WORK COMPLETED

The comparison of the CIMMS LES microphysical model with observation of marine stratocumulus in the Northern Atlantic revealed the deficiency of the existing numerical schemes for calculation of drop growth by condensation. A new variational optimization method (Liu et al, 1997) has been developed and implemented in the model. The validation against observations of boundary layer dynamics, microphysics and radiation from ASTEX and MAST field programs showed significant improvement in the prediction of cloud microphysical structure. An important part of the work is the development and testing of the drizzle parameterization for stratocumulus clouds. Two versions have been developed. The first one is designed for the use with LES models and can reproduce such microphysical details as the drop mean radius, dispersion, and supersaturation. This parameterization predicts five-moments of the cloud drop spectra, as well as CCN concentration. The second parameterization is intended for use in mesoscale models, like COAMPS, and predicts four-moments of the cloud drop spectra. The mesoscale drizzle parameterization has now been implemented in the ARPS mesoscale model and has showed an improved drizzle prediction compared to the conventional Kessler scheme.

Another component of our work is investigation of the interactions between aerosols and clouds. An enhanced version of the model capable of tracking the aerosol particles during cloud processing has been developed. We have completed a 3D experiment where the effects of cloud processing on aerosol spectra have been studied in the course of an eight hour long simulation. The results provide an estimate of the effects of aerosol transformations on the marine boundary layer visibility and cloud albedo.

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Finally, a new research has started based on the coupled 3D Monte-Carlo radiative transfer and explicit microphysics cloud models. The goal is to investigate the effects of cloud inhomogeneity on cloud radiative properties. At present, we have completed simulations of radiative transfer in a case of a solid deck stratocumulus cloud and in a case of a broken cloud field. We have also made the preliminary analysis of the effects of cloud inhomogeneity on the commonly Independent Pixel Approximation (IPA) of radiative transfer.

RESULTS

Significant efforts were devoted to test the model and verify its fidelity. A new variational optimization method for cloud drop growth by condensation was shown to significantly improve the accuracy of the LES model predictions of microphysical properties. The fidelity of the model has also been verified in a study showing the effect of radiative cooling on the drop growth rate by condensation (Kogan and Liu, 1997). The effective increase in supersaturation due to radiative cooling was substantial for large drops. The overall effect on cloud dynamics and drizzle was most significant in cases where drizzle is moderate; for non-precipitating clouds or clouds with heavy drizzle, the radiative cooling effect on drop condensation is negligible.

The aerosol processing by clouds has been studied using the version of the CIMMS LES model with a 2-D distribution function depending both on the drop mass and the mass of the solute inside each drop. An eight hour long simulation showed that due to cloud processing a polluted air mass with total CCN concentration of 700 cm-3 is transformed within about two days into a clean air mass with CCN concentration reduced by about 90%. The mass of fine particles in the 0.05 ðmð to 0.5 mð radius range signifiantly which has an important effect on atmospheric visibility. As Fig. 1 shows, the visibility range is increase by a factor of 4.6 during the six hours of coalescence processing.

An important research theme was to improve the drizzle parameterization in stratocumulus clouds. The commonly used Kessler-type parameterizations are based on prediction of cloud and drizzle water. Although computationally inexpensive, they lack some important physical parameters essential for accurate drizzle prediction. The new cloud microphysical parameterization is based on a five-moment scheme that predicts cloud and drizzle concentrations, cloud integral radius, in addition to cloud and drizzle liquid water mixing ratios. The extended parameter set permits a highly accurate, yet computationally inexpensive, formulation of the drizzle process in LES models. Simulations of drizzling cloud layers showed that the CIMMS five-moment parameterization was able to reproduce both dynamical and microphysical parameters very close to the explicit microphysical model.

Fig. 1. Evolution of the visibility range and total CCN salt mass content.

Finally, the results from the linked Monte-Carlo and CIMMS explicit microphysical model showed that the inhomogeneity of marine cloud layers is an important factor in determination of the cloud layer heating rates. The two simulations, one for a solid stratocumulus cloud deck and another for a broken cloud field, revealed the significant differences between the case when the full 3-D cloud structure is accounted for and the case when the cloud vertical inhomogeneity is neglected in the radiative transfer calculations. The latter case is approximately equivalent to the IPA method commonly used in mesoscale models. The difference between the two approaches is illustrated by Fig. 2 for a simulation of a broken cloud field. It is evident that the cloud inhomogeneity significantly affects not only the heating rate profile, but also the column averaged values. The improvement of current radiative parameterization by accounting for the effects of cloud inhomogeneity will be a challenging task and an important part of our research in the coming years.

Impact

The improved parameterization of the physical processes in marine stratocumulus clouds will result in more accurate weather prediction for the 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 joint test study of the cloud physical parameterization for mesoscale conditions is now under preparation.

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.

Fig. 2. Vertical profile of the solar heating rates in a 3D cloud model and in a vertically homogeneous cloud approximated by the IPA method.

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