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A Modeling Study of Marine Boundary Layer Clouds

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1. Background

Marine boundary layer(MBL) clouds are important components of the earth's climate system. These clouds drastically reduce the amount of solar radiation absorbed by the earth, but have little effect on the emitted infrared radiation on top of the atmosphere. In addition, these clouds are intimately involved in regulating boundary layer turbulent fluxes. For these reasons, it is important that general circulation models used for climate studies must realistically simulate the global distribution of the MBL. While the importance of these cloud systems is well recognized, many physical processes involved in these clouds are poorly understood and their representation in large-scale models remains an unresolved problem.

The present research aims at the development and improvement of the parameterization of these cloud systems and understand of physical processes involved. This goal is addressed in two ways. One is to use regional modeling approach to validate and evaluate a two-layer marine boundary layer model using satellite and ground-truth observations; the other is to combine this simple model with a high-order turbulence closure model to study the transition processes from stratocumulus to shallow cumulus clouds.

2. Progress

A regional model of marine boundary layer has been developed. Compared to the one-dimensional version of the model, surface flux parameterization is improved by including the factor of stability. The input of this model are sea surface temperature, wind fields in the boundary layer, large-scale vertical velocity and thermodynamic structure above the boundary layer, which can be derived from ECMWF analyses or other sources. With given large-scale conditions, the regional model predicts turbulent fluxes, thermodynamic structure, cloud fraction and cloud-top heights. This model is applied to the region of 20°N-42°N and 117°W-145°N for the period of the First International Satellite Cloud Climatology Project Regional Experiment (FIRE) marine stratocumulus intensive field observation. The simulated steady-state cloud-top height and fractional cloudiness are compared with available satellite data. The model predicts a realistic pattern of cloud-top height. The overall simulated cloudiness is qualitatively realistic, but the model give excessive cloudiness over cold ocean surfaces. This discrepancy is believed to be due to the exclusion of diurnal variability in the model. The model results also show that marine stratocumulus clouds are sensitive to large-scale subsidence and light precipitation (drizzle).

A one-dimensional third-order turbulence closure model with the parameterization of long and short-wave radiation and precipitation has been developed. The model predicts not only boundary layer mean wind and thermodynamic structure, but also second and third turbulent correlations. Solar warming and drizzle have been suggested to be processes that can decouple the boundary layer and decrease cloud fraction. Thus this high-order model is used to study the MBL decoupling process due to solar warming and drizzle. The sensitivity of simulated clouds to the subgrid-scale condensation scheme is also evaluated.

The simulation of the decoupled structure observed in FIRE show that both solar warming and drizzle contribute to the decoupling process, although solar absorption appears to have larger influence on the modeled mean structure. The effects of drizzle on turbulent structure also depend on the large-scale conditions such as sea surface temperature and wind. Under low sea surface temperature and light wind conditions, drizzle may very effectively decouple the MBL. High SST and strong wind shear increase turbulent kinetic energy production so that the decoupling effect is significantly reduced. Our study also shows that the simulated decoupling and cloud formation process in a high-order model may be sensitive to subgrid-scale condensation scheme.

3. Focus of current research and plans for next year

In the process of developing the two-layer boundary layer model, we have found some undesired features of the model. For example, the model is extremely sensitive to the cloud-base transition layer and mass flux parameter (pointed out by other researchers). Thus we currently try to improve the model formulation to account for the characteristics of different convective regimes. The GLOBE data has been processed to obtain cloud-top and cloud-base heights. The model is being used to simulate these data from the GLOBE observation. This application is intended to verify the model formulation.

We plan to use the regional boundary layer model to study the diurnal variation of stratocumulus clouds. In this practice, we will use ECMWF analyses to provide time-dependent large-scale conditions and SSM/I precipitable water observation to give better estimation of moisture above the cloud-top height. Then we can simulate the diurnal variation of MBL observed during FIRE and study its effects on surface fluxes and cloud albedo. We will also try to extend the one-dimensional high-order turbulence closure model to three dimensional version. Then we can study meso-scale variability of marine boundary layer clouds and compare the results from two type of three-dimensional models.

4. Publications and reports

Wang, S., 1992: The breakup of marine stratocumulus clouds in a two-layer boundary layer model. (accepted by *J. Atmos. Sci.*)

Wang, S., B.A. Albrecht, and P. Minnis, 1992: A regional simulation of marine boundary layer clouds (accepted by *J. Atmos. Sci.*)

Wang, S., and Q. Wang, 1992: Some drizzle effects on the turbulent structure of cloud-topped marine boundary layer: A model sensitivity study. (Abstract submitted to the *Tenth Symposium on Turbulence and Diffusion, Sept. 29-Oct. 2, 1992*)

Wang, S., and D. Fitzjarrald, 1992: Sensitivity of simulated marine stratocumulus clouds to subgrid-scale condensation scheme in a third-order turbulence closure model. (Abstract submitted to the *Tenth Symposium on Turbulence and Diffusion, Sept. 29-Oct. 2, 1992*)