Boundary Layer Marine Stratus: Diurnal Variability in Microphysics

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LONG-TERM GOALS

The goal of this research is to characterize the diurnal evolution of the microphysics of the marine boundary layer stratus in order to advance our knowledge on this topic and to improve numerical prediction of the diurnal evolution in stratus microphysical structure.

OBJECTIVES

Objectives of the current work are:

1. Describe the diurnal variability of marine boundary-layer stratus (MBS) microstructure (including cloud depth, mean R_e, mean liquid water path (LWP), colloidal stability) and identify diagnostic variables for the presence of drizzle.

2. Test COAMPS performance in forecasting nocturnal MBS during DYCOMS-II (Dynamics and Chemistry of Marine Stratocumulus II) by comparing the results of model simulations to satellite and aircraft data analyses.

3. Simulate the formation and evolution of marine stratus using a cloud-resolving model with binned microphysics that explicitly accounts for radiation and collision-coalescence processes to test the role of radiative cooling at cloud top on the evolution of cloud drop spectra and the formation of drizzle.

4. Adjust the warm rain parameterization coefficients in COAMPS to transfer cloud water to rain water at a rate and threshold that agree with observations (based on aircraft measurements, satellite retrievals of the LWP and the maximum cloud liquid water content (LWC), and the binned model simulations).

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14. ABSTRACT
The goal of this research is to characterize the diurnal evolution of the microphysics of the marine boundary layer stratus in order to advance our knowledge on this topic and to improve numerical prediction of the diurnal evolution in stratus microphysical structure.

15. SUBJECT TERMS

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5. Validate newly developed and improved bulk microphysical parameterizations in collaboration with scientists at the University of Oklahoma.

6. Develop methods for retrieval of cloud physical parameters from night-time satellite remote sensing data for use with the COAMPS mesoscale model to improve short-term forecasting of stratus evolution.

APPROACH

The DYCOMS-II field data will be analyzed in order to describe the diurnal evolution of the MBS system. Graphical displays and thermodynamic parcel analysis of the microphysics data should help us to better interpret the data and characterize the physical processes of stratus evolution.

To simulate the microphysical evolution of MBS, we are using a cloud-resolving, anelastic, non-hydrostatic, Eulerian/semi-Lagrangian (EULAG) model (Smolarkiewicz and Margolin 1997). This model is unique in its use of unified semi-Lagrangian/Eulerian, non-oscillatory-in-time numerical algorithms. These algorithms are second-order-accurate in space and time, and their basic properties of computational stability, accuracy, and efficiency are well established and extensively documented in literature (see Smolarkiewicz and Margolin 1997). The EULAG model currently includes moist precipitation thermodynamics described in Grabowski and Smolarkiewicz (1996) and applied by Grabowski (1999). Recently, a massively parallel version (Anderson et al. 1997) of EULAG has become available. The EULAG model with binned (36 mass categories) microphysics will allow us to explicitly simulate such processes as droplet activation (similar to Cotton et al. 1993 and Feingold et al. 1996), growth by vapor diffusion (after Tzivion et al. 1989), and stochastic collision-coalescence (using the multi-moment technique of Tzivion et al. 1987).

Comparisons of various cloud parameters will be made between the COAMPS operational forecasts and research simulations using different microphysical schemes (e.g., a two-moment scheme developed by Mechem et al. 2000). These results will also be compared with the EULAG simulations for selected cases from COSAT (COAMPS Operational Satellite and Aircraft Test) and DYCOMS-II. EULAG simulations will include both bulk and explicit microphysical schemes. Such comparisons will illustrate the relative importance of mass-resolving microphysical schemes and fine resolution to capture cloud dynamics and ultimately support further improvements in parameterization of warm rain processes in COAMPS.

We are currently implementing and testing latest version (2.0.16) of the COAMPS model on our SGI Origin 2000 with 16 processors. There were some compiler problems in setting up the code on our machine; however, we have recently obtained the revised version of the code and expect the full installation of the new code soon. First, we will focus on the evaluation of COAMPS results that were obtained by NRL, Monterey for selected cases during the DYCOMS II Experiment. The evaluation will include a comparison between predicted and observed cloudiness using satellite and aircraft data. Secondly, we will use this particular case and perform additional in-house simulations consisting of sensitivity studies focusing on improving cloudiness prediction by choosing optimum horizontal and vertical resolutions, model physics options, and possibly better initialization fields. Thirdly, we will examine the possibility of implementing different microphysical schemes that can improve cloudiness prediction.

The primary activity during the first months of this project has been to participate in the DYCOMS-II research program with respect to the use of satellite data for realtime in-field project logistical planning and for archival to support the research objectives of our own project as well as those of other groups. Dr. Wetzel is primarily working in the area of satellite remote sensing retrievals. Dr. Koracin is focusing on the implementation of the COAMPS model. Dr. Chai is the lead PI on the project and is conducting the studies of 1-D modeling for investigation of COAMPS microphysical parameterizations. Graduate student Tomasz Sikora is working on the EULAG modeling with various microphysics schemes and their intercomparisons.

WORK COMPLETED

We have been active participants in the planning and implementation of the DYCOMS-II field experiment involving several research groups and the NCAR C-130 instrumented aircraft. As part of this participation, M. Wetzel initiated the collection of several satellite datasets. Tom Lee and Joe Turk of the Naval Research Laboratory in Monterey collaborated in the archival of GOES Satellite Imager and Sounder data during the July 2001 field campaign. Radiative transfer (RT) model calculations have been performed to simulate the GOES Imager channel radiances during the research flights. Intercomparison of aircraft thermodynamic and microphysical parameters has been used to evaluate the correspondence of the RT model. We also collected the C130 raw flight data for initial analysis. NCAR is currently performing data processing to provide full archival parameter files.

Graduate student Dong-Chul Kim (who is partially funded by this project during the summer of 2001) wrote the necessary programs by using the IDL (Interactive Data Language) so that the θ_M-θ_A diagram proposed by Telford and Chai (1993) can now be plotted automatically in the IDL environment using aircraft datasets. This will contribute to the characterization of entrainment processes and cloud microphysical evolution during both day and night case studies.

Graduate student Tomasz Sikora spent the summer at NCAR working with Dr. Grabowski on a one-dimensional parcel model and a kinematic model and Dr. Wyszogrodzki on the implementation of the bin-resolving microphysics scheme in the EULAG model.

RESULTS

Initial analysis of the COAMPS model forecasts during DYCOMS-II indicated underprediction of stratus. Detailed runs of the 3-D and 1-D model along with satellite remote sensing retrievals and entrainment studies will be employed to investigate the sources of this model bias.

Temporal analysis of the GOES data reveals that the cloud layer becomes more homogeneous during the night, with a decrease in the areal average, range and standard deviation for both the Channel 2 and Channel 4 temperatures. These observations indicate a strengthening of the inversion and of the radiative cooling process at cloud top. The satellite channel radiances and derived estimates of microphysical conditions can provide observational information on the evolution of the marine boundary layer with better spatial and temporal coverage than otherwise available.

Intercomparison of RT model-estimated and satellite-observed near-infrared and thermal infrared radiances for sampling periods during a DYCOMS-II research flight indicate a slow transition of cloud microphysical properties during the night-time evolution of the marine stratus layer. Figure 1 shows the results of sampling the GOES imager near-infrared Channel 2 (3.79-4.04 μm) and thermal infrared Channel 4 (10.2-11.2 μm) data for 12 UTC 10 July 2001, in a small area surrounding the research aircraft flight sampling track for that night, overlain with radiative transfer model results for idealized cloud layers. The two model curves represent conditions for stratus with (1) droplet effective radius (Re) of 10 μm and cloud top temperature (CTT) of 12 C, and (2) Re of 12 μm and CTT of 10 C.

The satellite observations clustered near the cooler Channel 4 temperatures are those sampled for uniform overcast stratus, while those with larger temperatures are associated with broken and thin cloud areas where transmission from the warmer ocean surface is occurring. Beginning at the Channel 4 temperature of almost 15 C, calculated for the ocean surface with no overlying cloud, the model curves include symbols for increasing cloud liquid water path (LWP). The cluster of observations for overcast cloud suggests a cloud LWP of up to 120 g m^{-2}. These charastics are being validated using NCAR C-130 aircraft data obtained during the DYCOMS-II field experiment.

The θ_M-θ_A diagram can now be plotted automatically in the IDL environment using aircraft datasets and is ready to be used for study of the entrainment processes leading to cloud layer evolution. Results will be applied to selection of model parameteriations for cloud-top entrainment.

The bin-resolving scheme is implemented into the EULAG model and will be tested against aircraft observational parameters.

IMPACT/APPLICATIONS

The satellite remote sensing techniques will contribute to validation of the COAMPS model simulations for the DYCOMS-II study period.

The modeling task will improve our knowledge of the performance of various cloud microphysics schemes and indicate how to improve their performance in predicting the MBS systems.

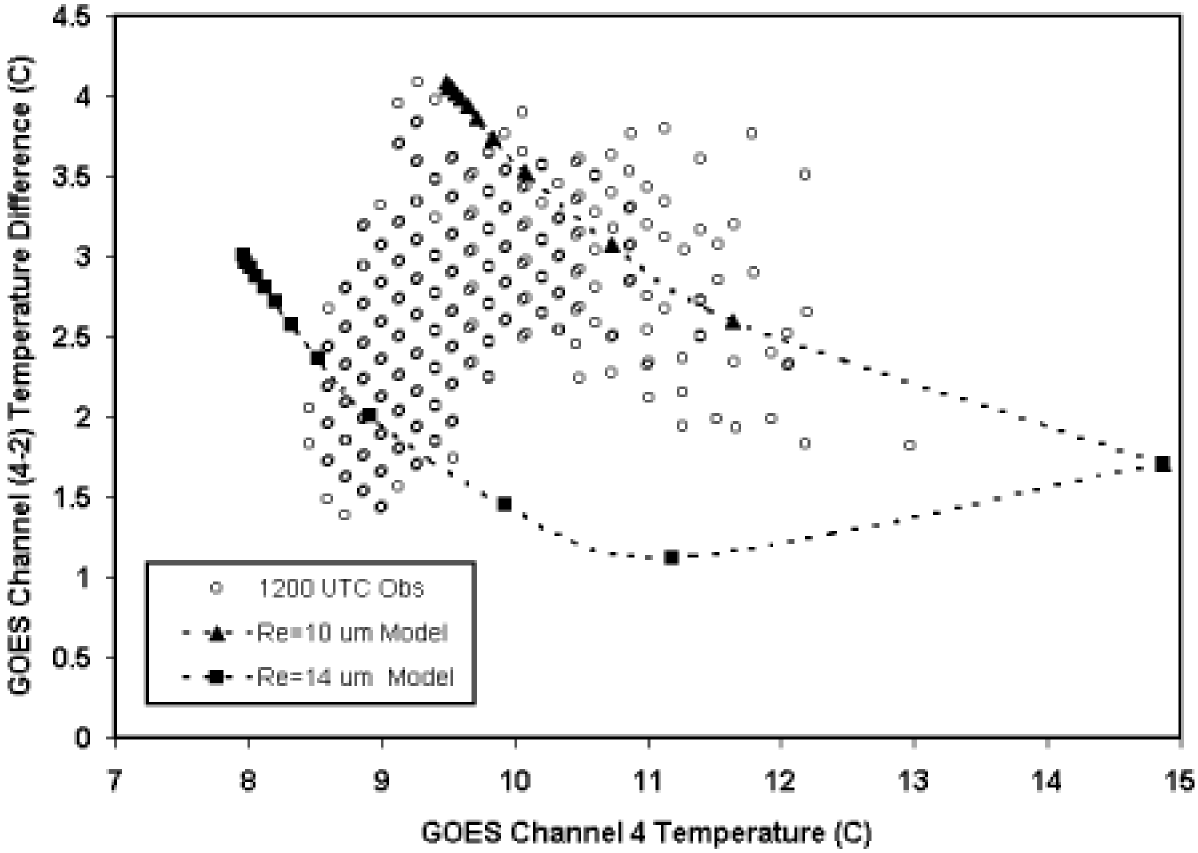

Figure 1: Scatterplot of GOES satellite pixel values of Channel 4 temperature clustered near 8-10 deg C, and Channel 4 minus Channel 2 temperature differences clustered in the range 1.5-3.5 deg C. Two curves are overlaid indicating the correspondence of the satellite observational data to radiative transfer model results for stratus cloud with droplet effective radii in the range 10-14 μm.

TRANSITIONS

The DYCOMS-II data are all posted on the web for use in scientific purposes by the COAMPS-II group. The data will be available to the entire scientific community one year after the July 2001 completion of the field project.

RELATED PROJECTS

This research involves partnership with several other groups through the DYCOMS-II program (www.atmos.ucla.edu/~bstevens/dycoms/dycoms.html ; www.joss.ucar.edu/dycoms).

SUMMARY

Initial evaluation of the satellite remote sensing data collected during the DYCOMS-II field program indicates temporal and spectral variations of observed cloud radiances related to nocturnal strengthening of the boundary layer inversion and evolution of the underlying stratus.

Preliminary analysis has shown that the COAMPS was underpredicting the MBS system during most of the DYCOMS-II period. This may be related to the inadequate initialization of the MBS in their runs. Further investigation on this issue will continue.

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