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

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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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retrievals of the LWP and the maximum cloud liquid water content (LWC), and the binned model simulations).

5. 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

We are using the DYCOMS-II observational data set (both aircraft and satellite remote sensing), the COAMPS model, and the Eulerian/semi-Lagrangian (EULAG) model (Smolarkiewicz and Margolin 1997) with various cloud microphysics schemes to assess the diurnal variability of the microphysics of the marine boundary layer cloud systems.

WORK COMPLETED

- Analyzed the DYCOMS-II aircraft data sets for all the research flights, with detailed analysis performed for flights 1 and 2.
- Developed methods of nighttime satellite remote sensing data retrievals for cloud liquid water path and mean droplet diameter.
- Diurnal variability in cloud microstructure is illustrated by simulations of an offshore stratus clouds with implementation of a mass-resolving microphysical scheme. Extensive testing of numerical influence on results, using 1-D and 2-D setups, was performed to ensure correctness of the code.
- D. Koracin, T. McCord, and students N. Adhikari and T. Sikora attended the COAMPS training workshop.
- Performed MM5 model simulation for DYCOMS-II July 10-11, 2001 case with 9km and 3 km resolutions.

RESULTS

Nighttime satellite retrievals: Nighttime satellite remote sensing data retrievals utilize the infrared and near-infrared GOES channels to estimate cloud liquid water path and cloud droplet size. A gridded field of estimated cloud droplet mean diameter a night-time flight during DYCOMS-II is shown in Figure 1. The circular graphic overlay depicts an aircraft flight path segment centered in the time series of droplet mean diameter and liquid water content shown by Figure 2. The aircraft was conducting level flight at 760 m during the time period 11.05-11.65 UTC. The range of droplet diameter indicated for this time period in Figure 2 is 12-17 μm, with the lower values observed at mid-point of the time segment while the aircraft was at the southern extent of the flight circle. This magnitude range and spatial pattern matches that indicated by the droplet diameters shown in Figure 1.

Correct estimation of cloud droplet size can provide a valuable tool in short-term forecasting of cloud evolution. Temporal trends in observed cloud microphysical conditions indicate the formation and dissipation of updrafts and the spatial organization of cloud cells. Since the COAMPS model does not currently represent changes in cloud droplet size, satellite methods or subjective classification of cloud type offer the only source of microphysical information. COAMPS forecasts of cloud liquid water can be examined, through vertical integration of this parameter to produce cloud liquid water path. Liquid path in stratus can be estimated from GOES and TRMM satellite data. At night, the information content of GOES is limited to the infrared and near-infrared channels. Values of cloud liquid water path estimated for the area sampled by the flight circle are in the range 60-100 g m^{-2}, with smaller values in the southern portion of the flight circle, corresponding to smaller values of cloud liquid water content and droplet size indicated in Figure 2. These conditions also are very similar to the magnitude and spatial gradient of cloud liquid water path obtained from the TRMM Microwave Imager (TMI). The COAMPS model profiles of cloud liquid water content and horizontal distributions of cloud water path can be compared to these products.

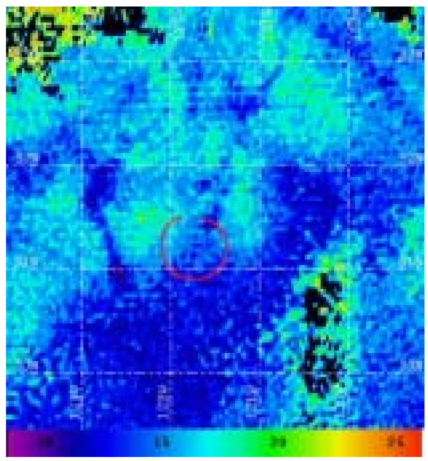

Figure 1: Cloud droplet mean diameter (µm) retrieved from the GOES infrared and near-infrared channels for 1145 UTC on 10 July 2001, with graphic overlays of a coincident flight circle (red) and the latitude/longitude grid (white).

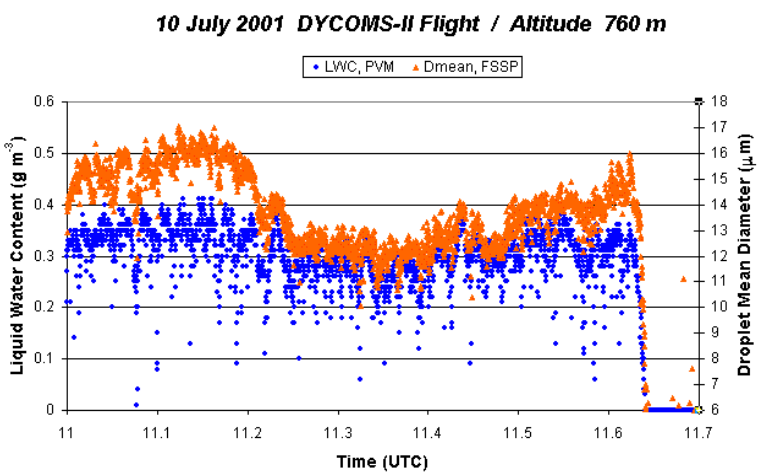

Figure 2: Time series of aircraft-measured cloud liquid water content and droplet mean diameter during a flight circle on 10 July 2001.

DYCOMS-II data analysis: Analyzing the nighttime data of July 10, 2001 has shown that the air inside the whole cloud is cooled by strong radiative loss through cloud tops. This can easily be seen in the θ_M-θ_A diagram (Figure 3), where θ_A is the temperature of a parcel brought down adiabatically to 1100 hPa with the consideration of liquid water in it and θ_M is the wet-bulb temperature of that parcel at 1100 hPa (Telford and Chai, 1993). The point at around $\theta_A = 25^oC$ represents the air right above cloud top in the entrainment buffer region and the points clustered around $\theta_A = 23.4^oC$ and $\theta_M = 18^oC$ are data from below the cloud deck. Data measured inside cloud are stretched along constant total mixing ration lines (the dashed lines) toward low temperatures. This indicates that the air inside cloud has been cooled by active cloud top radiative cooling. The air in the buffer zone has been wetted by evaporating droplets during active entrainment processes and followed by warming from radiations emitted from the underneath cloud deck. This feature was discovered frequently through the field season, especially around the first couple soundings at around local midnight.

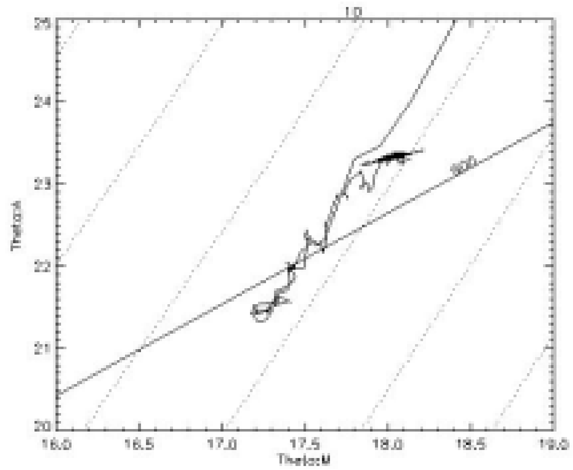

Figure 3: The θ_M-θ_A diagram shows that the air inside the marind stratus deck has been cooled by cloud top radiation. This is shown by the alignment of these points along the dashed total mixing ratio lines.

Detailed warm rain microphysics sensitivity analyses:

(i) Three collection kernels were tested for warm rain formation: Long (1974), Hall (1980) and the data of Ochs and Beard (2000). It is found that the Long's method forms drizzle the fastest while the Hall's method is closely following behind. The Ochs and Beard method is the slowest to form drizzle.

(ii) The bin-resolving microphysical scheme was implemented and tested in a one-dimensional version of the three-dimensional, second-order turbulence closure mesoscale model developed by Yamada (1983). A detailed description of the model is given by Koracin and Rogers (1990). Results show that, for most of the time, saturation was not reached, except around 19th hour of simulation, where amount of liquid water is close to amount given by bulk scheme. Possible causes of failure of binned scheme were investigated.

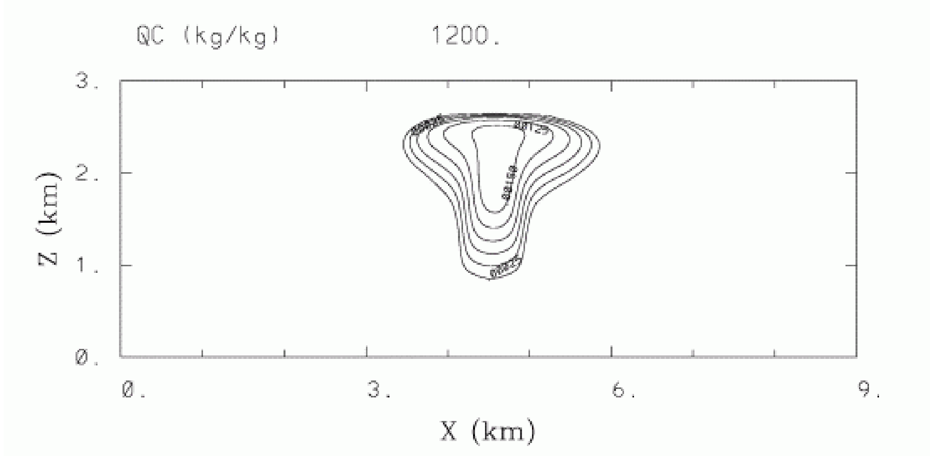

Fig. 4. Contours of the cloud water mixing ratio at simulation time equal to t=25 min. Contour interval is 0.25 g kg^{-1}. The test was performed in a computational domain 9 km wide and 3 km deep with the resolution of 50 m (181 by 61 grid). The idealized flow pattern consists of low level convergence, upper level divergence, and a narrow updraft located in the center of the domain. 30 mass categories covering droplet sizes up to 50 μm were used.

(iii) The binned microphysics was used in a 2-dimensional kinematic framework described in Szumowski et al., (1998). Series of benchmark simulations with bulk model were conducted. Parcel model simulations with simple activation scheme were conducted. Number of active nuclei was given by $n = a \times S^b$, and where a=300 kg^{-1} is the concentration at 1 percent supersaturation and b =0.5. Microphysical scheme includes droplet activation after Cotton et al. (1993) and Feingold et al. (1996), condensation after Tzivion et al. (1989) and stochastic collision-coalescence after Tzivion et al (1987) with the collection kernels using the data of Beard and Ochs (2000). Figures 4 and 5 show the revolution of cloud water mixing ratio in the simulation.

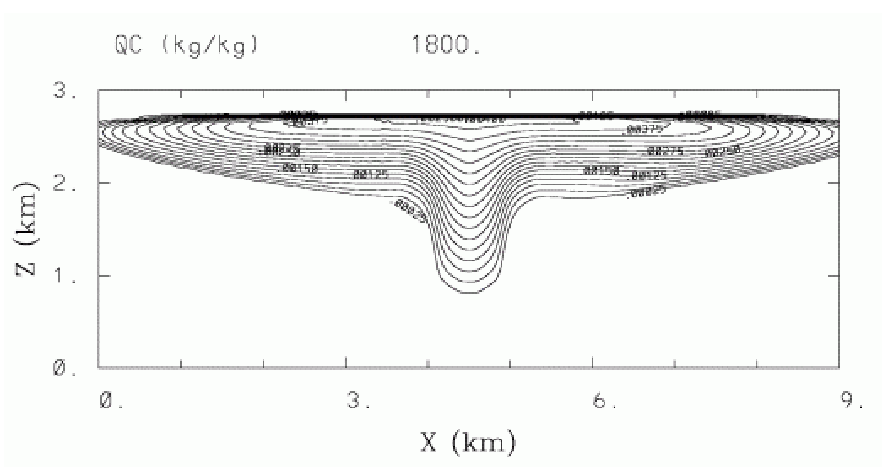

Fig.8. Contours of the cloud water mixing ratio at simulation time equal to t=30 min. Contour interval is 0.25 g kg^{-1}.

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.

TRANSITIONS

The DYCOMS-II data are posted on the web for use in scientific purposes by the COAMPS-II group. The data will be available to the entire scientific community soon.

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).

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