Multispectral Remote Sensing and COAMPS Model Analysis Methods for Marine Cloud Structure, Entrainment Processes and Refractivity Effects

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Award Number: N00014-01-1-0295

LONG-TERM GOALS

The priority goal of this research is to advance the utilization of satellite remote sensing methods and mesoscale simulation models for improved prediction of marine stratus and boundary layer structure. Related goals include the study of marine stratus evolution and analysis of microwave refractivity at the interface of the cloudy marine boundary layer and free troposphere.

OBJECTIVES

High accuracy in 0-30 minute prediction of cloud and inversion structure for the open ocean and coastal regions is required for Navy operations in the vicinity of stratus and fog decks. Knowledge on the probable evolution of cloud cover, cloud vertical profile and microwave refractivity at the top of the marine boundary layer (MBL) is essential for effective logistical and tactical decision-making. Our research objectives focus on the optimum utilization of parameter fields from the Navy's COAMPS (Coupled Ocean/Atmosphere Mesoscale Prediction System) with geostationary satellite data for monitoring and predicting the short-term physical characteristics of boundary layer cloud and thermodynamic conditions in the vicinity of cloud top.

APPROACH

The focus of this research is an integrated analysis of satellite, aircraft and model case study datasets from field measurement programs in both day and night conditions. A successful collaboration is in place between scientists at DRI, NRL, UCLA, NCAR, University of Wyoming and other groups. Datasets have been obtained during the DYCOMS-II (Dynamics and Chemistry of Marine

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 2002**	2. REPORT TYPE	3. DATES COVERED **00-00-2002 to 00-00-2002**

4. TITLE AND SUBTITLE **Multispectral Remote Sensing and COAMPS Model Analysis Methods for Marine Cloud Structure, Entrainment Processes and Refractivity Effects**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Division of Atmospheric Sciences, Desert Research Institute,,2215 Raggio Parkway,,Reno,,NV,89512**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**7**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

Stratocumulus-II) project (Stevens, 2002) and the COSAT (COAMPS Operational Satellite and Aircraft Test) field program (Wetzel et al., 2001). These data are being used to evaluate marine boundary layer structure as observed with satellite retrieval techniques and model forecasts. The data are also being used to identify model-derived gridded fields which can contribute to the information content and reliability of satellite-obtained information. Several excellent datasets on the structure of night-time offshore stratus were collected during the DYCOMS-II experiment. COAMPS model gridded output results were obtained from NRL from real-time simulations conducted during DYCOMS-II. We are also pursuing model implementation for COAMPS at DRI with training of faculty, graduate students and support scientists. The research includes analysis of microphysical parameters using satellite and aircraft data, as well as dropsonde data obtained during aircraft flights in the DYCOMS missions.

WORK COMPLETED

We have developed a large database of 15-minute GOES satellite data with accompanying aircraft and COAMPS model cases for comparative studies of daytime and nighttime stratus evolution. Satellite retrieval methods for estimation of cloud droplet size and cloud liquid water path from the GOES near-infrared and thermal infrared Imager channels have been designed. At the same time, we are conducting model simulations of the DYCOMS-II cases with MM5 at DRI. We are making comparisons of *in situ* and remote sensing data to COAMPS simulations obtained from NRL and MM5 simulations performed at DRI. Case studies indicate some differences in cloud layer formation in these model results, and model experiments to improve the accuracy of the simulations are being carried out at DRI by using observed sea surface temperature data obtained from the TRMM with GOES multispectral Imager retrievals for cloud parameters. Research led by Dr. Steven Chai (DRI) focuses on development of improved numerical methods for representing the physics of the cloud top entrainment process. Numerical representation of the entrainment occurring near the cloud top uses a thermodynamic process method. Based on the analyses, various cloud top entraiment schemes, including that proposed by Telford and Chai (1984), will be tested in a one-dimensional model and then implemented and validated in COAMPS.

RESULTS

The project scientists contributed to the design and conduct of the DYCOMS-II field research program and have participated in follow-on project meetings and discussions with investigators from other institutions. The primary accomplishments on the project to date are: *(1)* Satellite retrieval methods for night-time stratus have been developed using combined datasets from GOES and TRMM satellite system; *(2)* satellite and model data are being combined to produce improved analyses of the vertical profile of microwave refractivity for the marine boundary layer environment; *(3)* new diagnositic methods for aircraft-observed entrainment processes in marine stratus have been demonstrated; and *(4)* a new approach to initialization of the marine boundary layer in mesoscale models is being designed and tested.

(1) Multispectral retrieval methods are being used to characterize pixel radiative characteristics and to estimate night-time stratus microphysical properties such as cloud droplet size, cloud liquid water path (Figure 1), cloud top temperature, and the spatial and temporal patterns in these parameters, and these correspond well to aircraft-observed measurements from the DYCOMS-II project.

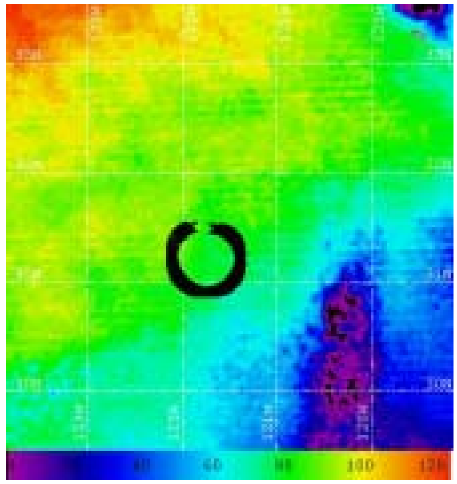

Figure 1. 10 July 2001 GOES satellite retrieval of stratus layer integrated water path (g m^{-2}) at 1145 UTC, with graphic overlay (black) of one aircraft circle track and a latitude/longitude grid (white).

(2) Refractivity profiles across the marine boundary layer influence the propagation of electromagnetic waves. A parameter used to analyze such conditions is the Modified refractivity, M (Hack *et al*., 2001). A negative vertical gradient of this quantity, dM/dZ< 0, causes anomalous propagation of microwave radiation associated with signal ducting (energy trapping) across great distances. The transmitted and backscattered radar signals from meteorological radar and communications can be adversely influenced by ducting radar is affected, causing false or undetected objects or transmissions. Comparisons between GPS dropsonde data and model simulations for a DYCOMS-II case study indicate the COAMPS produced a better forecast of the refractivity profile than MM5 model (Figure 2). For the altitudes above 1000m prediction is near to the observed M profile. Hence, if the inversion base height and temperature for cloudy layers can be estimated from satellite data, these can be combined with model profile parameters above cloud to also diagnose the duct strength (ΔM across the trapping layer defined by the altitude limits of the dM/dZ< 0 condition).

(3) Entrainment instability is typically associated with a condition where a parcel of dry air entrained from above the top of the marine boundary layer cloud deck is cooled by evaporating drops mixed in from surrounding cloud. This situation is satisfied when the air above cloud top has a cooler wet-bulb potential temperature than that of the cloud top air. However, it is found from the DYCOMS-II data set that during nighttime when radiative cooling is active, the cloud deck is cooled very rapidly (Figure 3a) and there is a thin layer just above cloud top that is relatively wet and has been warmed up by the radiation from the cloud deck. This leads to a relatively warm wet-bulb potential temperature layer just above cloud top (Figure 3b). Entrainment of air in this layer should form a buffer layer around the cloud top and prevent further entrainment. But in the presence of a large radiative flux divergence, the buffer layer air can also be cooled rapidly to a lower temperature than the cloudy air below, which causes it to sink into the cloud. This leads to active entrainment (Figure 3c) even when the wet-bulb potential temperature profile shows an entrainment stable condition. A new entrainment instability criterion is under investigation.

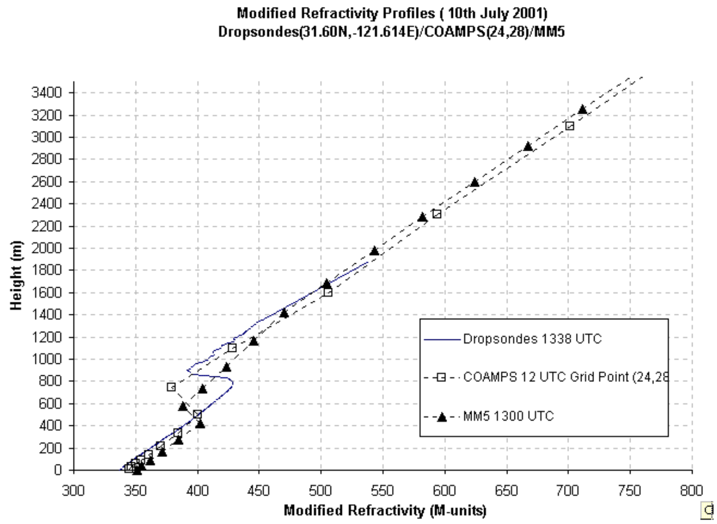

Figure 2. Vertical profiles of modified refractivity calculated from aircraft-deployed GPS dropsonde data for the 10 July 2001 night-time research flight during DYCOMS-II, compared with two profiles obtained from model (COAMPS, MM5) simulations.

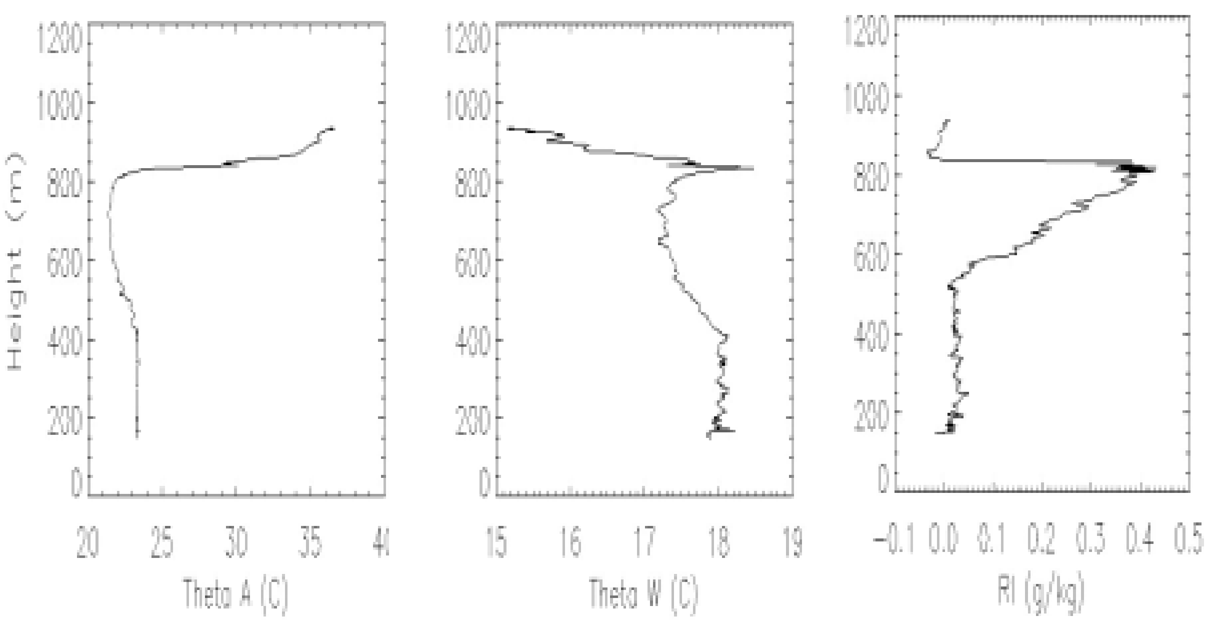

Figure 3. (a) This figure shows the vertical profile of the absolute potential temperature through the marine boundary layer cloud. The absolute potential temperature is the temperature of an air parcel brought adiabatically to 1100 hPa with the consideration of water droplets inside it. A cooler cloud deck (520m-830m) shows the effect of rapid radiative cooling. (b) This figure shows the wet-bulb potential (defined at 1100 hPa) profile. It is clearly seen that the cloud deck has a lower wet-bulb potential temperature due to radiative cooling. The thin layer just above cloud top shows a warm wet-bulb potential temperature. (c) This figure shows the vertical profile of the liquid-water mixing ratio. The zigzag pattern indicates entrainment activity.

(4) Initial conditions of MBL inversion base height are being experimentally produced from a combination of TRMM SST and GOES cloud top temperature and liquid water path, in combination with assumptions on lapse rates in the MBL and model-input free troposphere temperature profiles aloft, to provide a more consistent and accurate initialization for stratus simulations. The estimated inversion base height product is shown in Figure 4, and compares well with aircraft observations.

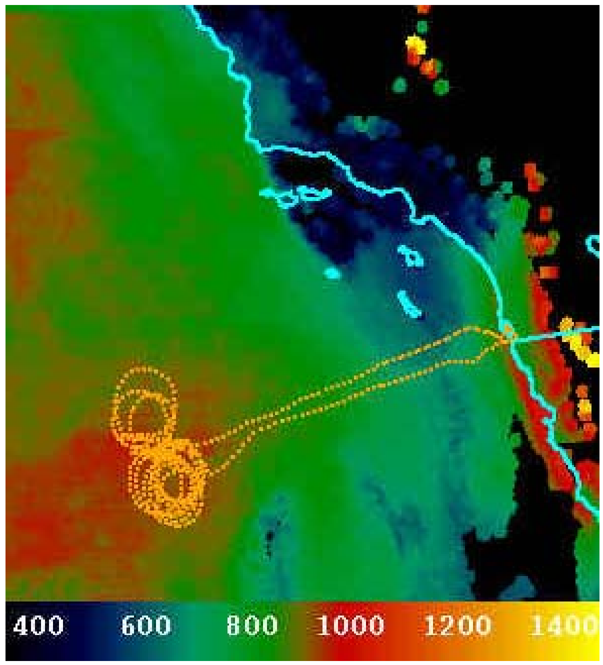

Figure 4. Gridded estimates of MBL inversion base height (m) obtained by an algorithm using satellite-derived sea surface temperature (TRMM), cloud top temperature (GOES) and cloud liquid water path (GOES).

IMPACT/APPLICATIONS

This research will provide improved methods for obtaining and utilizing GOES satellite remote sensing products and COAMPS model results to predict entrainment to the cloud-topped marine layer. These studies also advance our ability to characterize fine-scale structure in microwave refractivity conditions associated with evolution of the MBL inversion (Haack et al., 2001).

TRANSITIONS

None at this time.

RELATED PROJECTS

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

SUMMARY

Remote sensing and thermodynamic analyses demonstrate the importance of radiational cooling on stratus entrainment and the importance of high vertical resolution in mesoscale prediction models to predict instability and refractivity conditions.

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Stevens, B., D.H. Lenschow, G. Vali, H. Gerber, A. Bandy, B. Blomquist, J.-L. Brenguier, C.S. Bretherton, F. Burnet, T. Campos, S. Chai, L. Faloona, D. Friensen, S. Haimov, K. Laursen, D.K. Lilly, S.M. Loehrer, S.P. Malinowski, B. Morely, M.D. Peners, D.C. Rogers, L. Russell, V. Savic-Jovcic, J.R. Snider, D. Straub, M.J. Szumoswki, H. Takagi, D.C. Thorton, M. Tshudi, C. Twohy, M. Wetzel, and M.C. Van Zanten, 2002: Dynamics and chemistry of marine stratocumulus -- DYCOMS-II. *Bull., Amer. Meteor. Soc.*, in review.

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