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

Melanie A. Wetzel
Division of Atmospheric Sciences, Desert Research Institute
2215 Raggio Parkway, Reno NV 89512-1095
phone: (775) 674-7024 fax: (775) 674-7016 email: wetzel@dri.edu
Steven K. Chai
Division of Atmospheric Sciences, Desert Research Institute
2215 Raggio Parkway, Reno NV 89512-1095
phone: (775) 674-7070 fax: (775) 674-7007 email: chai@dri.edu
Darko R. Koracin
Division of Atmospheric Sciences, Desert Research Institute
2215 Raggio Parkway, Reno NV 89512-1095
phone: (775) 674-7091 fax: (775) 674-7016 email: darko@dri.edu

Award Number: N00014-01-1-029

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 for short-term prediction of cloud and inversion structure in marine environments is required for Navy operations, particularly 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, University of Wyoming, UCLA and other groups. Datasets have been obtained during the DYCOMS-II (Dynamics and Chemistry of Marine Stratocumulus-II) project (Stevens, 2003) 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 fields, which can contribute to the information content and reliability of

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 2003**	2. REPORT TYPE	3. DATES COVERED **00-00-2003 to 00-00-2003**

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
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.

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

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, and MM5 modeling has been conducted at DRI for the same cases. Research studies include analysis of microphysical and thermodynamic structure using satellite and aircraft data obtained during flights in the DYCOMS missions.

WORK COMPLETED

We have conducted intercomparison and validation of the COAMPS and MM5 mesoscale prediction models, satellite remote sensing analyses, and development of new methods to merge satellite observations with model simulation techniques. GOES satellite data at high temporal resolution have been merged with accompanying aircraft, COAMPS and MM5 model cases to study nighttime stratus evolution. In conjunction with other ONR-funded research at DRI (see report by D. Koracin), a technique for assimilating satellite-derived sea surface temperature and cloud top temperature has been applied to model simulations and estimates of MBL microwave refractivity profiles. This ONR project is also linked to a DEPSCOR-ONR project at DRI (see report by S. Chai), and results from analysis of instability-driven entrainment demonstrate the importance of accurate prediction of the boundary layer thermodynamic profiles. The PI is collaborating with Tracy Haack of the Naval Research Laboratory (Monterey) in use of satellite cloud climatology for intercomparison of seasonal variations in marine cloud layer structure with COAMPS model results. The DRI faculty on this project have presented conference papers and the PI served as a session chair at a conference related to this research. DRI has shared data resulting from this project with scientists at multiple institutions including NRL, University of Wyoming, UCLA and Oregon State University.

RESULTS

Use of GOES multispectral satellite data collected during the DYCOMS-II nighttime research flights has allowed development and evaluation for retrieval techniques and improvement in model initial conditions. At night, only thermal infrared and near-infrared satellite observations are available, which reduces the information available for retrieval of cloud microphysical parameters. We have utilized a combination of aircraft and satellite data to investigate cloud structure for multiple research flights during July 2001. Figure 1 shows the results of an estimation procedure that combines GOES 11 micron and 3.9 micron channel brightness temperatures, sea surface temperature (obtained from TRMM satellite data and field measurements), satellite-observed cloud top temperature, and typical lapse rates in the MBL, to map cloud droplet mean diameter in the marine stratus layer. The spatial variation and magnitudes of estimated droplet size during a flight circle (indicated in red on the figure) compares very closely to aircraft measurements in the upper portion of the cloud layer. The major factor in this spatial variation is the difference in the spectral radiance emitted upward from the cloud layer associated with changes in typical droplet size. The 11 micron – 3.0 micron brightness temperature difference (BTD) increases as droplet size decreases due to emissivity differences between these two wavelengths. It is of interest to know whether these signatures also indicate whether cloud droplet growth has reached drizzle stage. The aircraft carried the University of Wyoming cloud radar on these research flights, and comparisons of vertically-averaged radar reflectivity for the cloud layer along the flight path have been made to satellite-observed BTD values, as shown in Figure 2. This scatterplot indicates an increase in radar reflectivity is associated with a decrease in BTD. The radar vertical profiles are being evaluated with aircraft microphysical measurements, and in collaboration with Dr. Gabor Vali (University of Wyoming) to document the occurrence of drizzle.

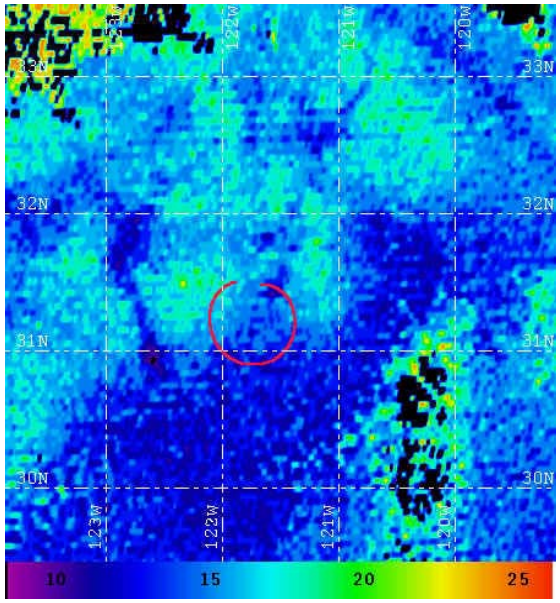

Figure 1. Mapped distribution of cloud droplet mean diameter (microns) estimated from GOES brightness temperature difference data at 1145 UTC on 10 July 2001 over the DYCOMS II study region. The red overlay designates the aircraft track during 1145-1214 UTC. Droplet diameter values range from near 18 microns (light green) near the beginning and end of the flight segment to as low as 13 microns (dark blue) in the middle period of this segment.

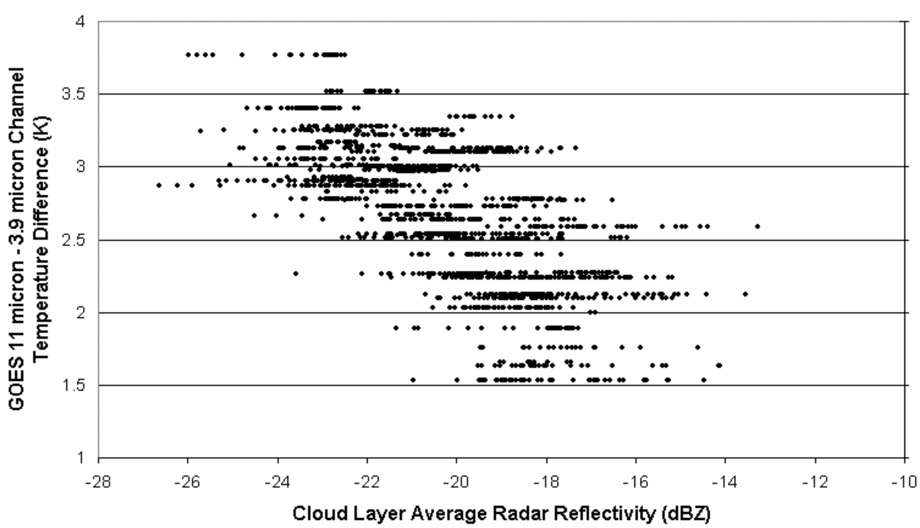

Figure 2. Scatterplot of cloud layer average radar reflectivity and satellite-observed brightness temperature differences for the 10 July 2001 flight segment shown in Figure 1. The periods of enhanced radar reflectivity correspond to smaller brightness temperature differences in the satellite signature and larger estimates of droplet size. Radar data is courtesy of Dr. Gabor Vali, University of Wyoming.

A second area of research on this project is the use of satellite data to improve model simulations of MABL thermodynamic structure. Information on the vertical and horizontal distribution of modified refractivity can provide excellent diagnosis of the microwave signal trapping that often occurs due to temperature and humidity gradients at the top of the MABL (Helvey et al., 1995; Burk and Thompson, 1996). However, temperature and humidity profile observations in the MABL are sparse over the majority of oceanic regions, and hence the motivation to incorporate satellite remote sensing data where possible, and the use of these data as input to model simulations. Modified Refractivity (M) is defined as:

$$M = \frac{77.6}{T}\left(P + 4810\frac{e}{T}\right) + \left(\frac{Z}{R_e} \times 10^6\right)$$

where T= air temperature (K), P= pressure (mb), e= water vapor pressure (mb), Z = altitude (m), and R_e= mean radius of earth (m). MM5 simulations have been conducted which define the initial MABL temperature profile by applying cloud top temperature from GOES-observed cloud top temperature, TRMM-observed sea surface temperature, and applying an adiabatic lapse rate to determine the height of the inversion base (for more description of this method, see report in this volume by D. Koracin). This method improves the short-term prediction of temperature and humidity in the MABL (see Figure 3 and Figure 4), so that the MM5 simulations follow the observed profiles more closely than COAMPS simulations run in real-time during the DYCOMS-II field project. Note that the MM5 simulations also benefited from greater vertical resolution in the MABL. However, the COAMPS forecasts were run in continuous mode and demonstrate a much better representation of the humidity profile (Figure 4) above the inversion, as compared with the MM5 simulations that were run in "cold-start" mode each day. This has a strong influence on the predicted refractivity profile (Figure 5). While the M profile is improved up to the inversion base, the MM5 does not forecast the negative M gradient. Next steps in this research will be to test model simulations with the satellite-enhanced MABL profile data in routine model assimilation over multiple cycles as in operational mode, and to test the potential application of satellite-derived sounding profile data to characterize the dry layer above the subsidence inversion.

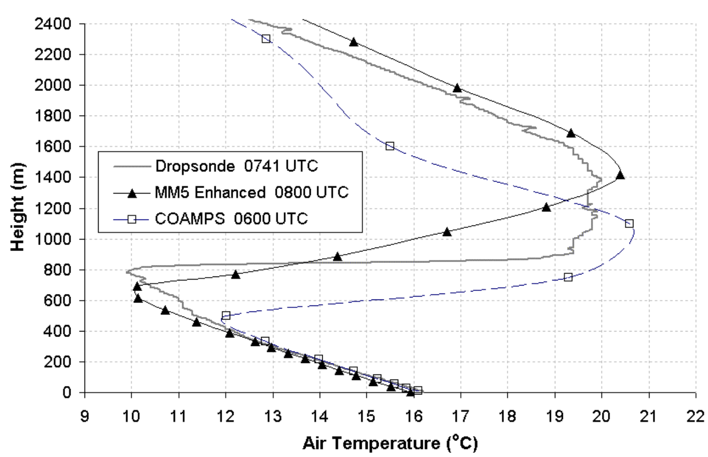

Figure 3. Vertical profiles of air temperature obtained from model simulations and aircraft dropsonde measurements during the DYCOMS-II case study on 10 July 2001. The MM5 predicted profile was enhanced by use of initial conditions obtained from GOES satellite cloud top temperature and TRMM satellite sea surface temperature.

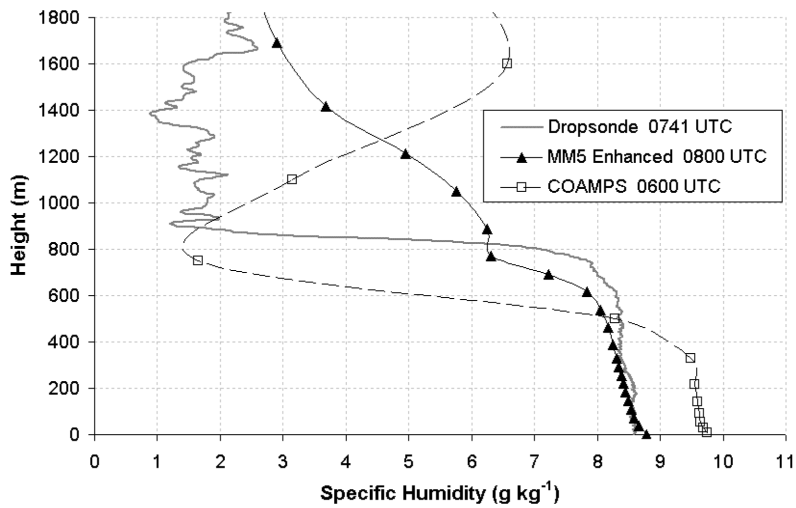

Figure 4. Vertical profiles of specific humidity obtained from model simulations and aircraft dropsonde measurements during the DYCOMS-II case study on 10 July 2001.

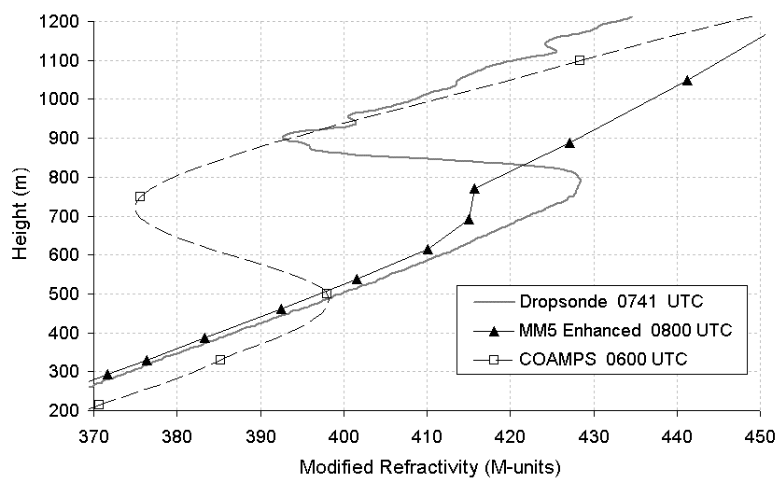

Figure 5. Vertical profiles of Modified Refractivity obtained from model simulations and aircraft dropsonde measurements during the DYCOMS-II case study on 10 July 2001, calculated from model conditions of humidity and temperature. The profile of refractivity is improved within the MABL but does not adequately represent the negative gradient in the 800-900 m layer associated with the dry air above the inversion.

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 and Burk, 2001).

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).

REFERENCES

Haack, T. and S.D. Burk, 2001: Summertime marine refractivity conditions along coastal California. *J. Appl. Meteor*., **40**, 673-687.

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.,* **84**, 579-593.

Wetzel, M.A., G. Vali, W. Thompson, S.K. Chai, T. Haack, M. Szumowski and R.Kelly, 2001: Evaluation of COAMPS forecasts using satellite retrievals and aircraft measurements. *Weather and Forecasting*, **16**, 588-599.

PUBLICATIONS

Adhikari, N.P., M.A. Wetzel, D.R. Koracin and S.K Chai, 2003: Analysis and prediction of microwave refractivity profiles in nocturnal marine cloud layers. Fifth Conference on Coastal Atmospheric Prediction and Processes. 8-12 August 2003, Seattle, WA, Amer. Meteor. Soc. [published]

Chai, S.K., M.A. Wetzel and D. Koracin, 2003: Observed radiative cooling in nocturnal marine stratocumulus. Fifth Conference on Coastal Atmospheric Prediction and Processes. 8-12 August 2003, Seattle, WA, Amer. Meteor. Soc. [published]

Gonzales, A., J.C. Perez, F. Herrera, R. Rosa, M.A. Wetzel, R.D. Borys and D.H. Lowenthal, 2001: Stratocumulus properties retrieval method from NOAA-AVHRR data based on the discretization of cloud parameters. *Intl. J. Rem. Sens.,* **23**, 627-645. [published, refereed]

Koracin, D., J. Powers, M.A. Wetzel, S. Chai and N. Adhikari, 2003: Improving prediction of the marine coastal clouds using satellite and aircraft data. Fifth Conference on Coastal Atmospheric Prediction and Processes. 8-12 August 2003, Seattle, WA, Amer. Meteor. Soc. [published]

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*., **84**, 579-593. [published, refereed]

Wetzel, M.A., G. Vali, W. Thompson, S.K. Chai, T. Haack, M. Szumowski and R.Kelly, 2001: Evaluation of COAMPS forecasts using satellite retrievals and aircraft measurements. *Weather and Forecasting*, **16**, 588-599. [published, refereed]