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Boundary Layer Cloud Studies in Support of ASTEX

Research Goals:

To investigate the effects of drizzle, diurnal decoupling, entrainment and mesoscale processes on the type and amount of marine boundary layer cloudiness using surface-based remote and *in situ* sensors deployed during the Atlantic Stratocumulus Transition Experiment (ASTEX), 1992.

Objectives:

To study mesoscale structure of boundary layer convective systems observed during ASTEX, to compare the mean thermodynamic structure and cloudiness observed during the experiment with other regions, and to characterize drizzle characteristics using Doppler data from the 94 GHz radar.

Approach:

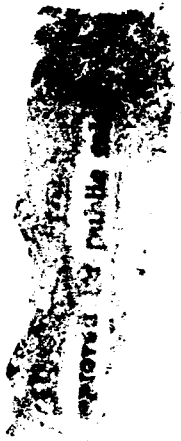
The instrumentation used for this study included a 94 GHz Doppler (cloud) radar, a laser ceilometer, a microwave radiometer, surface meteorological and radiation instrumentation, and an infrared radiometer. Radiosondes launched in support of ASTEX from Santa Maria and from the Valdivia were used in this study.

Tasks Completed:

Radiosonde, ceilometer, and radiometer data have been archived and statistics on cloud characteristics have been compiled. The composite thermodynamic structure observed at Santa Maria and the Valdivia has been compared with composite boundary layer soundings from 1) radiosonde data collected from San Nicolas Island during FIRE, 2) aircraft data obtained off the coast of California during FIRE, and 3) radiosondes launched over the equatorial Pacific during the Tropical Instability and Wave Experiment (TIWE) 1991. The island remote and *in situ* measurements have been used to study the mesoscale convective systems observed over the island and the diurnal variations in those complexes.

Scientific Results:

The composite marine boundary layer structures obtained in this study correspond to sea surface temperatures ranging from 16 to 27C with the average cloud cover ranging from 82% to 26% (Figure 1). Unlike the coastal California stratus, the stratus observed during ASTEX was generally associated with decoupling as indicated by the moisture decrease at about 600 m. ASTEX conditions were clearly intermediate between the solid cloud conditions observed during FIRE and the broken clouds associated with fair-weather cumulus clouds. The remote



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sensing systems operated on the island of Santa Maria in the Azores provided a detailed and unprecedented description of the characteristics of marine boundary layer clouds. Of the approximately 345 hours of radar returns obtained during ASTEX, about 40% of these returns indicate drizzle-sized droplets and about 20% of the radar returns were accompanied by drizzle that was detected at the surface by an optical rainguage. The drizzle events were often associated with mesoscale convective systems (Figure 2) characterized by a strong updraft core and a stratus layer generated by outflow at the base of the inversion. The results indicate that the transition observed during ASTEX is not a simple and rapid transition from solid stratus to broken fair weather cumulus. Instead the transition is from solid stratus associated with well-mixed conditions to stratus that can be generated by long-lived mesoscale convective systems feeding in moist air near the surface in decoupled boundary layers.

Transitions accomplished and expected

The soundings that were obtained during ASTEX are available to researchers at the Naval Air Warfare Center Weapons Division, Point Mugu, CA and other Navy research labs. The composite boundary layer structures should assist in the development and testing of models. Operational boundary layer modeling efforts should consider the impact of boundary layer decoupling and mesoscale convective systems on model performance.

Relationship to other projects

Our development of the 94 GHz Doppler radar under this and previous ONR grants, has facilitated numerous important studies of clouds that have been funded by other agencies. These studies have focused on cirrus clouds (NASA, DOE), shiptracks (ONR) and continental stratus (NSF). A study is in progress to determine the feasibility of using a 94 GHz radar in space for cloud studies.

Publications (Referred)

Albrecht, B.A., 1993: The effects of drizzle on the thermodynamic structure of the trade-wind boundary layer. *J. Geophysical Res.*, **98**, 7327-7337.

Wang, S., B.A. Albrecht and P. Minnis, 1993: Regional modeling of boundary layer clouds. *J. Atmos.Sci.* **50**, 4022-4043.

Wang, Q. and B.A. Albrecht, 1994: Observations of cloud-top entrainment in marine stratocumulus. *J. Atmos. Sci.*, **51**, 1530-1547.

Clothiaux, E.E., M.A. Miller, B.A. Albrecht, T.P. Ackerman, J. Verlinde, D.M. Babb, R.M. Peters, W.J. Syrett, 1994: An evaluation of a 94-GHz radar for remote sensing of cloud properties. *J. Atmos. Ocean Technol.* (accepted)

Miller, M.A., and B.A. Albrecht, 1994: Surface-based remote sensing of mesoscale cloud structure during ASTEX. *J. Atmos. Sci.* (submitted)

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Albrecht, B.A., M.P. Jensen and W.J. Syrett, 1994: Marine boundary structures and fractional cloudiness. J. Geophysical Res. (submitted)

Albrecht, B.A., C.S. Bretherton, D. Johnson, W.H. Schubert and A.S. Frisch, 1994: The Atlantic stratocumulus transition experiment -- ASTEX. Bull. Amer. Soc. (conditionally accepted)

Syrett, W.J., B.A. Albrecht and E.E. Clothiaux, 1994: Vertical cloud structure in a midlatitude cyclone from a 94 GHz radar. Mon. Wea. Rev. (submitted)

Ackerman, T.P., R-F Lin, and B.A. Albrecht, 1994: A simulation of the shortwave reflectivity of a marine stratocumulus layer. J. Geophysical Res. (submitted)

Publications (Non-referred)

Albrecht, B.A., 1993: Maritime and continental stratocumulus. ECMWF/GCSS Workshop on Parameterization of the Cloud-topped Boundary Layer, Reading, UK, 8-11 June 1993.

Peters, R.M., B.A. Albrecht and M.A. Miller, 1993: Marine boundary layer cloud profiling with a 94 GHz radar. Eight symposium of Meteorological Observations and Instrumentation, Anaheim, CA, January 17-22, 1993.

Albrecht, B.A., C.S. Bretherton and D.W. Johnson, 1994: An overview of the Atlantic stratocumulus transition experiment - ASTEX. Second International Conference on Air-Sea Interaction and on Meteorology and oceanography of the Coastal Zone, Lisbon, Portugal, 22-27 September 1994.

Jensen, Michael P, 1993: Thermodynamic structure and cloud characteristics of the undisturbed marine boundary layer. M.S. thesis, The Pennsylvania State University, 81 pp.

Miller, Mark A., 1994: Measurements of marine cloud structure using surface based remote sensors. Ph.D. thesis, The Pennsylvania State University, 129 pp.

Moyer, Kerry A., 1993: Observations of mesoscale cellular convection from the marine stratocumulus phase of FIRE. Ph.D. thesis, The Pennsylvania State University, 96 pp.

Number of graduate student: Five

Presentations/Briefings

Peters, R.M., B.A. Albrecht, M.A. Miller, 1993: Marine boundary layer cloud profiling with a 94 GHz radar. Eight Symposium of Meteorological Observations and Instrumentation, Anaheim, California, January 17-22, 1993.

Albrecht, B.A., 1993: Marine and continental stratocumulus. ECMWF/GCSS Workshop on Parameterization of the Cloud-topped Boundary Layer, Reading, UK, 8-11 June 1993, 21-49.

Albrecht, B.A., 1993: ECMWF/GCSS Workshop on Parameterization of the cloud-topped boundary layer. "Marine and Continental Stratocumulus", Reading, UK, 8-11 June 1993. (Invited)

Albrecht, B.A., 1993: Spring AGU Meeting, Baltimore, Maryland, "The Atlantic Stratocumulus Transition Experiment (ASTEX)--An Overview." May 24-28, 1993.

Q. Wang and B.A. Albrecht, 1993: 1993 Spring AGU Meeting, Baltimore, Maryland, "The Role of Convective Updrafts and Downdrafts in Marine Stratocumulus-topped Boundary Layers." May 24-28, 1993.

M.A. Miller, B.A. Albrecht and R.M. Peters, 1993: 1993 Spring AGU Meeting, Baltimore, Maryland, "Observations of Marine Boundary-Layer Convective Complexes During ASTEX: Data From Multiple Remote Sensors." May 24-28, 1993.

D.M. Babb, M.A. Miller and B.A. Albrecht, 1993: 1993 Spring AGU Meeting, Baltimore, Maryland, "Marine Boundary Layer Cloud Characteristics Defined from Surface-Based Remote Sensors." May 24-28, 1993.

Albrecht, B.A., 1993: "Lectures on Boundary Layer Clouds", NCAR, UCAR Summer Colloquium on Clouds and Climate, July 1993. (Invited)

Albrecht, B.A., 1994: 1994 Spring AGU Meeting, Baltimore, Maryland, "Modeling the Downstream Evolution of a Decoupled Boundary Layer." May 23-27, 1994.

Albrecht, B.A., C.S. Bretherton and D.W. Johnson, 1994: An overview of the Atlantic stratocumulus transition experiment - ASTEX. Second International Conference on Air-Sea Interaction and on Meteorology and oceanography of the Coastal Zone, Lisbon, Portugal, 22-27 September 1994. (Invited)

Service on committees

Chairman, NSF Steering Committee for the Role of Clouds in Climate Workshop, Reno, Nevada, 1993; Member, Marine Meteorology Study Panel, National Research Council, 1993-1994; Member, GEWEX Panel, National Research Council, 1993-1995; Member, Executive Committee of the International Commission on Clouds and Precipitation, 1992-present.

Honors/Awards

NASA Exceptional Scientific Achievement Medal, 1992

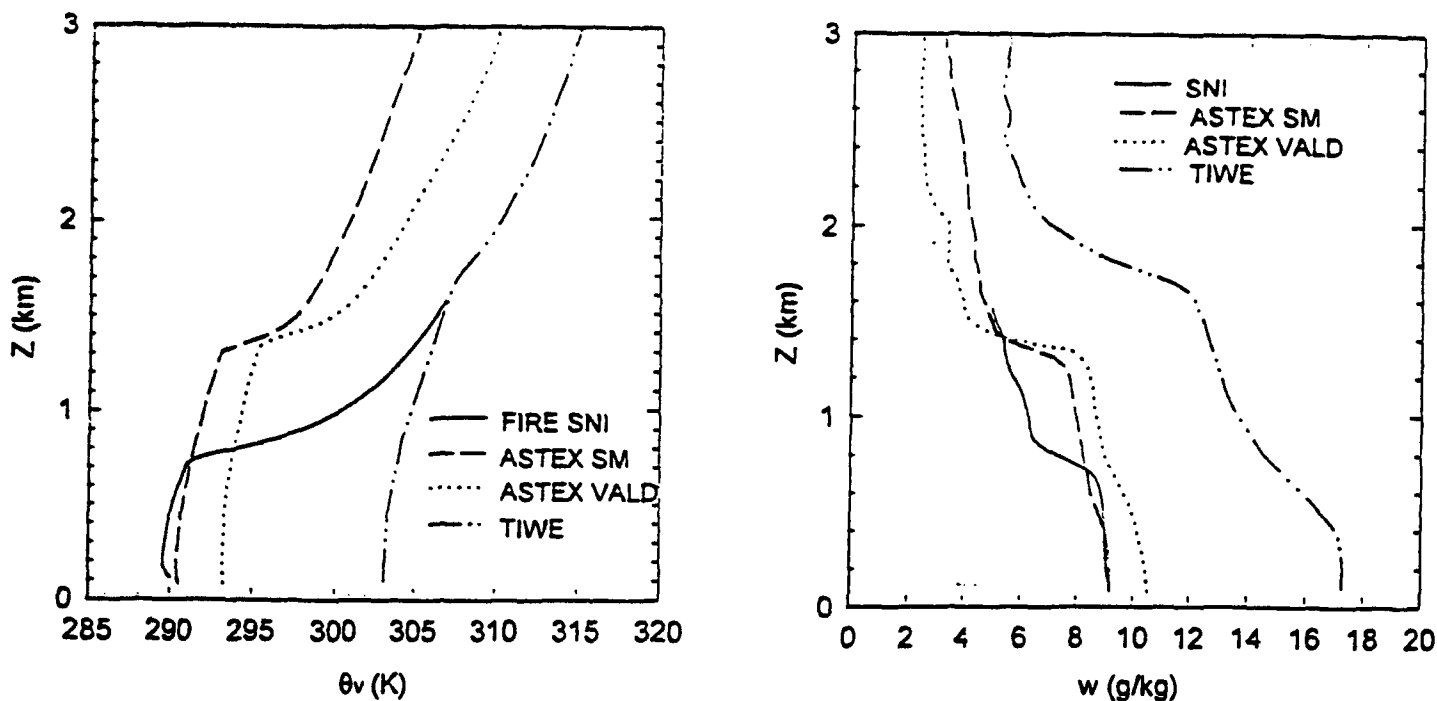


Figure 1. Composite vertical profiles of virtual potential temperature and mixing ratio for San Nicolas Island (FIRE, 65 soundings), Santa Maria (ASTEX, 119 soundings), Valdivia (ASTEX, 58 soundings), and TIWE (44 soundings). Structure at the inversion was preserved in these soundings by scaling the height by the inversion height for each sounding and then rescaling the composite soundings by using the average inversion height. Average fractional cloudiness corresponding to each of these four soundings is 0.83, 0.67, 0.40, and 0.26 respectively.

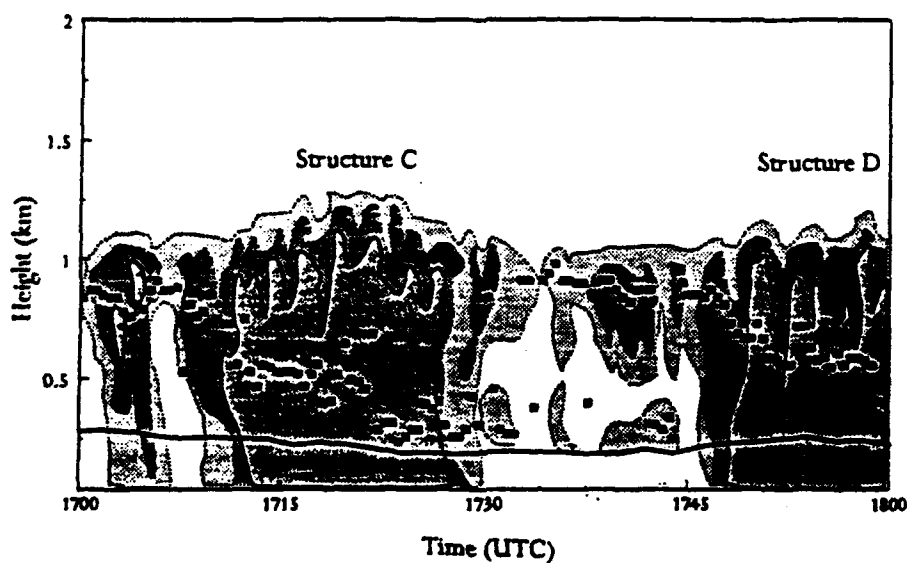


Figure 2. Structure of two marine boundary mesoscale convective systems observed from the island of Santa Maria during ASTEX. Shaded areas are reflectivities from the 94 GHz radar. The solid symbols are the cloud base height from a laser ceilometer. The solid line is the lifting condensation level calculated using surface temperature and moisture. The horizontal scale of these systems is about 10 km. Convective scale structure with horizontal scales of about 1 km are imbedded in the mesoscale complexes. Decoupling is indicated when the LCL deviates from the ceilometer cloud base. Substantial drizzle was observed from these structures and results in radar returns that extend to the surface.