Disclaimer
September 30, 1993

Distribution of this document is unlimited.

Bouder, CO 80303
335 Broadway
R/5/WG
NOAA Wave Propagation Laboratory

Protective Investigator
Robert A. Kropf

Prepared by

(DOE Grant No. DE-AC10-92ER67366)

Washington, DC 20585
Department of Energy
Office of Energy Research
Office of Health and Environmental Research
Atmospheric and Climate Research Division

Prepared for

96-03/07/96

For the period 10/1/95-6/30/96

Maritime boundary layer physics and
Suppression measurements of the cloud-capped

Technical Progress Report
DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.
1. Introduction

ASTEX is a large multi-agency program to investigate all aspects of marine stratus clouds because of their overall importance in regulating the earth's climate system. The program focused on clouds in the Eastern Atlantic during the month of June, 1992 because of the expected frequency of low clouds in that area. The experiment was based on the islands of Santa Maria in the Azores and Porto Santo about 800 km away in the Madeira Archipelago with large complements of remote sensors operated from both islands. To form an equilateral triangle of remote sensors, a ship was used as the third platform.

The intent of our original proposal to DOE was to operate a set of remote sensors on a ship that could be functionally equivalent to a prototype CART system during ASTEX. Experience with modern remote sensors operating on such a platform would be valuable in making decisions about shipboard versus island deployment of CART remote sensors, and it would provide information useful in the selection of remote sensors for a maritime CART. Many of the ASTEX research goals are parallel to those of the DOE/ARM program and the work performed under this proposal will serve both.

The ship originally identified for the task was the R/V Akademik Kurchatov, a large research vessel operated by the former Soviet Union. Instability in the former Soviet Union prior to the ASTEX field program made it impossible for the Kurchatov to participate, and as a result, a reduced set of instruments were deployed on the smaller NOAA research vessel the R/V Malcolm Baldrige. In addition to supporting remote sensors on the Baldrige, this DOE grant made it possible for full participation of WPL remote sensors on Porto Santo.

2. Statement of Work in FY-93

On Porto Santo Island the WPL instruments included an 8 mm wavelength Doppler cloud-sensing radar, a new high pulse rate, scanning CO₂ Doppler lidar, a three-channel microwave radiometer and an IR radiometer. WPL instruments on the Baldrige included a complete suite of surface flux sensors (sonic anemometer-thermometer, fast hygrometer, and solar and IR flux radiometers), a 2-channel microwave radiometer, a 10.6 μm IR radiometer, a 915 MHz Doppler wind profiler, a lidar ceilometer, and an Omega rawinsonde system. In brief, the work performed during this period was devoted to the analysis of these unique data sets, presenting results at Science Team meetings and other conferences, and drafting publications on the results of the analysis.

During FY-93 the complete radar data set comprising approximately 600 hours of observations has been processed, calibrated, and formatted into a "Universal Format" on Exabyte tapes that are compatible with WPL software assembled for radar data analysis.
The complete radar data set has been processed with routines that compute cloud bases, tops, and numbers of layers in preparation for an in-depth statistical analysis of these layers. That analysis will be performed in FY-94. From the first three moments of the Doppler spectrum, drizzle rate profiles were computed as well as the drizzle drop size distribution. Cooling rates caused by the evaporation of drizzle below cloud base were computed, and a paper summarizing this work has been recently submitted to the Journal of Atmospheric and Oceanic Technology. This paper also includes a separate discussion of the retrieval of marine stratus cloud droplet size distributions and liquid water content profiles from radar and microwave radiometer data.

During this year, the morphology of radar-observed "microcells" was refined: the updraft of these long-lasting cells was computed to be about 2 m/s, the updraft size was found to be typically 1 km in diameter supporting a 15 km diameter cloud capped by the strong marine inversion, the core reflectivity was found to be about 10 dBZ, their lifetime was observed to be several hours, and their formation was found to be inhibited by strong MBL shear. Microcells were observed on 10 of the 16 days during which their presence could be detected by the radar.

Turbulence, a critical control on the formation and breakup of marine stratus clouds, was examined in detail in the Doppler radar data set during this work period. MBL clouds were observed to have increased turbulence relative to the sub-cloud layer. These important results are consistent with theory quantifying the effects of diabatic processes (radiation). Diurnal effects were diagnosed, and it was determined that the daytime cloud-layer exhibits lower levels of turbulent mixing (as compared to the turbulence levels at night). This data is consistent with theory and will provide important verification for MBL models containing radiation and cloud microphysical parameterizations. Velocity skewness in the cloud layer was also examined and was found to be consistent with narrow, downward-accelerating parcels (again consistent with theory) associated with cloud-top cooling. A journal article on the radar observations of MBL turbulence is in preparation and will be submitted during FY-94.

Most of the shipboard data has been processed and preliminary studies have revealed that the diurnal variations of cloud properties in ASTEX were quite different from those observed in the equatorial Pacific region. Previous investigations there have shown that diurnal variations of cloud optical thickness and cloud fraction were negligible so variations in system albedo and transmission coefficient were dominated by solar zenith angle effects. In ASTEX, the cloud fraction had a substantial diurnal variation with a maximum of about 0.55 at sunrise and a minimum of 0.28 well after sunset. This led to a steady decrease of system optical thickness during the daytime and a skewing of the albedo and transmission coefficient curves.

Entire microwave and infrared radiometer data sets were
re-calculated using final calibration factors; time series of measured brightness, precipitable water vapor, and liquid water were prepared. Radiometer liquid water data were computed to provide a comparison with radar-derived liquid water content. Brightness temperatures were calculated from radiosonde data using absorption models of Liebe (1987) and Liebe (1993). Measured clear-sky radiances were compared to calculated values. RMS differences between brightness temperature measurements and the 1993 absorption model are generally less than one degree Kelvin at 20 and 31GHz. However, at 90 GHz the 1987 model yields even better agreement.

Statistical distributions of liquid and water vapor were calculated for land- and ship-based data. These distributions are nearly identical indicating small, if any, effect of the island upon the radiometric observations. Liquid water values measured by the radiometer were compared to solar flux measured by pyranometer. Further comparisons of the observations with predictions from current parameterizations are underway.

Analysis of lidar data obtained during ASTEX continues. Because the effort marked the first application of a small, stand-alone lidar, much of the initial work has focused on characterization of the instrument (characterization of the capabilities of optical sensors to operate in remote marine environments was a primary goal of the ASTEX effort). The lidar operated with parallel signal processing systems during ASTEX, intended for different applications. A hardware processor measured and recorded estimates of lidar measured velocities for conically-scanned estimates of subcloud winds, turbulent kinetic energy, while a digitizer recorded raw intermediate frequency information for post processing of vertical motion statistics and cloud base heights.

We have spent considerable amount of effort in quantifying the accuracy of the lidar. Using relatively complex processing techniques, we have been able to correct for colored noise background and laser frequency drift. Currently, we estimate the laser velocity accuracy to be several tens of centimeters per second, which is greater than the goal of 10 cm s^{-1} goal. During the next few weeks, we will insert noise cancellation to improve the signal accuracy.

3. Plan for FY-94

A statistical analysis of MBL cloud bases, tops, and numbers of cloud layers observed will be performed and published. Frequencies of occurrence, lifetimes, and other features of the radar-observed "microcells" will be documented. From the unexpectedly large number of cirrus cloud observations taken during ASTEX ice particle characteristic size and concentration will be estimated from the combined radar and IR radiometer measurements.
The complete ASTEX radar data set will be included in the drizzle analysis and the analysis of cloud liquid water content with radar and microwave radiometer measurements as well. An enlarged data set will also be examined to confirm the preliminary conclusions concerning the nature of MBL turbulence.

Preliminary comparison of lidar and radar measurements of cloud base seems to indicate some differences, probably due to increased radar sensitivity to drizzle descending from the clouds. A complete comparison of cloud bases measured by lidar and radar is planned. We are also in the midst of obtaining time series of lidar measured wind profiles in the subcloud boundary layer, from which we will be attempting to estimate turbulence properties. Goal of the lidar processing effort is to complete processing by early 1994, then prepare a paper interpreting the results of the measurements.

A NOAA Technical Memorandum describing the radiometric measurements from Porto Santo and R/V Malcolm Baldrige is in preparation and will be completed during FY-94. The relationship between liquid water path and cloud reflectivity measured by satellites will be studied; parameterizations used in current GCMs will be examined.

Fractal characteristics of the stratocumulus clouds in the North Atlantic will be examined and compared with previous results from San Nicolas Island during FIRE I (1987).