Boundary Layer Cloud Climatology at the ARM TWP Nauru Site

P. Kollias
Cooperative Institute for Research in Environmental Science/
Environmental Technology Laboratory University of Colorado
Boulder, Colorado

B.A. Albrecht
University of Miami
Miami, Florida

Introduction

Boundary layer (BL) clouds are fundamental in regulating the vertical structure of water vapor and entropy in the lowest 2 km of the Earth's atmosphere. Data on fair-weather cumuli have also received relatively little recent attention compared with marine stratocumulus clouds. Studies made thirty years ago, Barbados Oceanographic and Meteorological Experiment (BOMEX, 1969) and the Atlantic Trade-Wind Experiment (ATEX, 1969), provided key analyses (Augstein et al., 1973; Holland and Rassmusen, 1973; Betts, 1975) for better understanding the effects of shallow clouds on maintaining the large-scale heat and moisture budgets of the trades. But these studies provided no direct observations of the clouds that were responsible for these transports and were made well before the development of the remote sensing systems that have come to be so critical in the definition of cloud properties. The observations from the Atmospheric Radiation Measurement Tropical Western Pacific (ARM TWP)-Nauru site provide a unique opportunity to study the structure of marine BL clouds. Although this site is not located in the classic trade-wind regime, the clouds observed over the site are the result of processes similar to those observed over other areas of the Earth's oceans.

Observation

In this study, data collected from the millimeter wave cloud radar (MMCR), at the TWP-Nauru site (active remote sensing cloud layer [ARSCL] VAP data files) over the past 4.5 years are analyzed to provide a statistical description of the fields of fair weather cumuli observed at this site. In addition, soundings and surface meteorology data from the site were analyzed and used to classify tropical boundary layer structures as a function of simple stability criteria. Statistics on cloud thickness, fractional coverage, updraft-downdraft magnitudes, and cloud reflectivity are estimated for four classes of fair weather cumuli. Seasonal patterns are identified and their relationship to the thermodynamic structure of the boundary layer (wet-dry periods, available buoyancy and wind direction) is investigated. This study provides an observational data set appropriate for testing fair weather cumulus fractional coverage parameterizations in numerical models.

The daily fractional coverage of boundary layer clouds cumulus over the ARM-TWP site for the entire period sampled in around 0.30-0.35 without any significant seasonal variation. The diurnal cycle of fractional coverage exhibits a maximum of 0.4 around local noon and a minimum of 0.3 during the nighttime. The cycle indicates a possible enhancement of the day-time cloudiness due to island heating.

In this study, besides vertical extent, emphasis is given to the fractional coverage of the different cloud types. The temporal resolution of the cloud classification is 1 hour. The principal data set is the ARSCL VAP along with microwave radiometer (MWR), soundings and surface met data. The analysis was performed by applying a classification as follows: *Boundary Layer Clouds* --cloud base < 2 km and cloud top < 2km. Those with drizzle have cloud base at lowest radar detectable range (100 m) and no measurable precipitation at the ground. Non-precipitating boundary layer clouds were further classified as *Stratus* for fractional coverage > 0.75; *Dense* for fractional coverage > 0.3 and <0.75; and *Light* BLC for fractional coverage < 0.3.

Results

The fractional coverage of non-precipitating boundary layer clouds during the observing period is about 20% with some months (e.g. Jan 200) showing a noticeable lack of low clouds. The precipitating boundary layer clouds (Figure 1b) show a high occurrence in 1999-2000 compared with later years in the record. Average cloud base is also about 100 m higher during the 2000-2001 observations than those from 1999-2000, although cloud thickness is about the same for the two periods. Although some BL stratus are observed at the site, they are observed relatively infrequently compared with the dense and light cumulus cloud amounts, which are observed with about equal frequency. To see if the variability of the macroscopic characteristics of the boundary layer clouds are associated with intra-annual variability, the wind direction form the site, the u wind component, and the sea-surface temperature (SST) from the closest Tropical Atmosphere Ocean (TAO) buoy were examined (Figure 3). When plotted with the El Nino-Southern Oscillation (ENSO) classification, it is clear that the winds closely follow the ENSO classification. The variability of the clouds with this ENSO variability is not apparent, however, since most of the cloud observations available are at a time when the ENSO index is low. Thus, within this data set, it will be important to understand factors that control the variability in the boundary layer clouds on time sales les than ENSO. The variability in the occurrence of precipitating boundary layer clouds provides a signal that may lead to a better understanding of the precipitation in boundary layer clouds.

Discussion

These observations demonstrate the utility of using the ARM Nauru data to study the characteristics of marine boundary layer clouds. The high resolution MMCR data now being generated with the new processors will provide the data base needed to test parameterizations of fractional cloudiness associated with fair-weather cumulus (e.g. Albrecht, 1981; Haiden 1996; Slingo 1980,1987). To accomplish this, it is necessary to characterize both cloud properties and boundary layer structure. Thus, to test these parameterizations, we plan to use the high resolution MMCR observations to 1) retrieve liquid water content in the cloud (using simple Z-LWC formulations), 2) obtain vertical velocities that can be used to determine if the cloud is in an active or decaying phase, and 3) identify drizzle or any precipitation that may be falling from these clouds. Identification of the drizzle mode will be important since drizzle may impact fractional cloudiness and boundary layer structure (Albrecht 1989,1993).

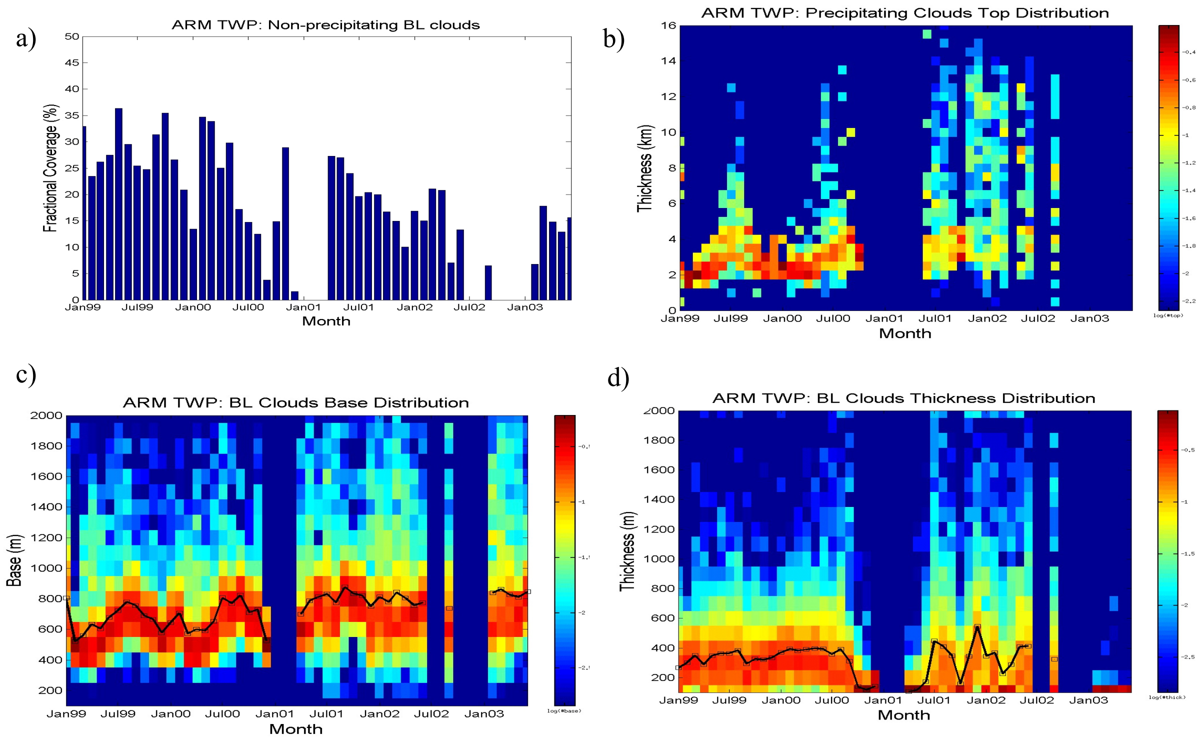

Figure 1. Monthly fractional coverage of non-precipitating BLC (a), monthly distribution of hourly averaged precipitating clouds tops (b) monthly distribution of hourly averaged BLC bases (c) monthly distribution of hourly averaged BLC thickness (d).

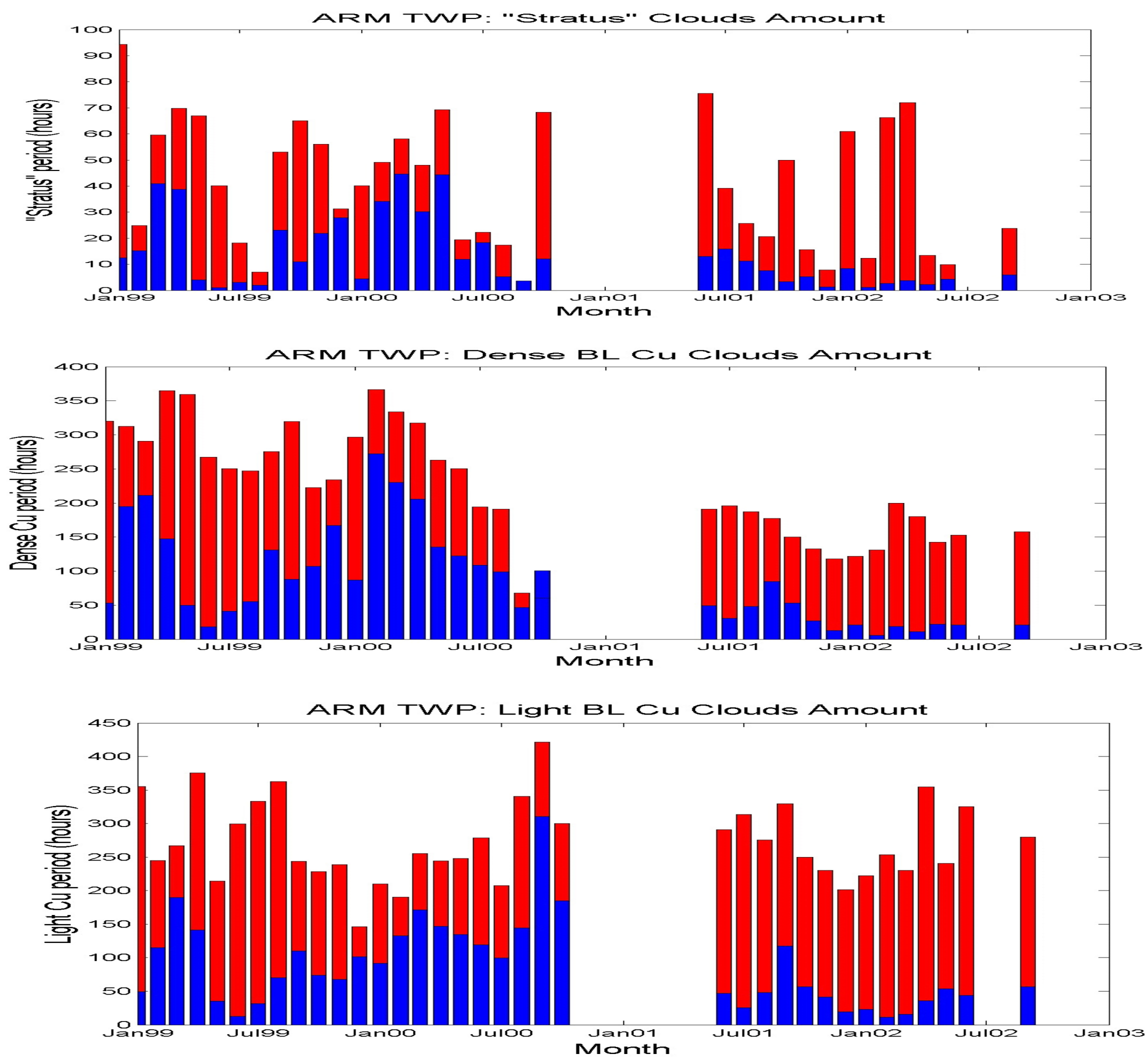

Figure 2. Month total hours of "stratus" BLC (a), month total hours of "Dense" Cu BLC (b) and month total hours of "Light" Cu BLC c) Red shows total hours and blue shows single layer month total hours.

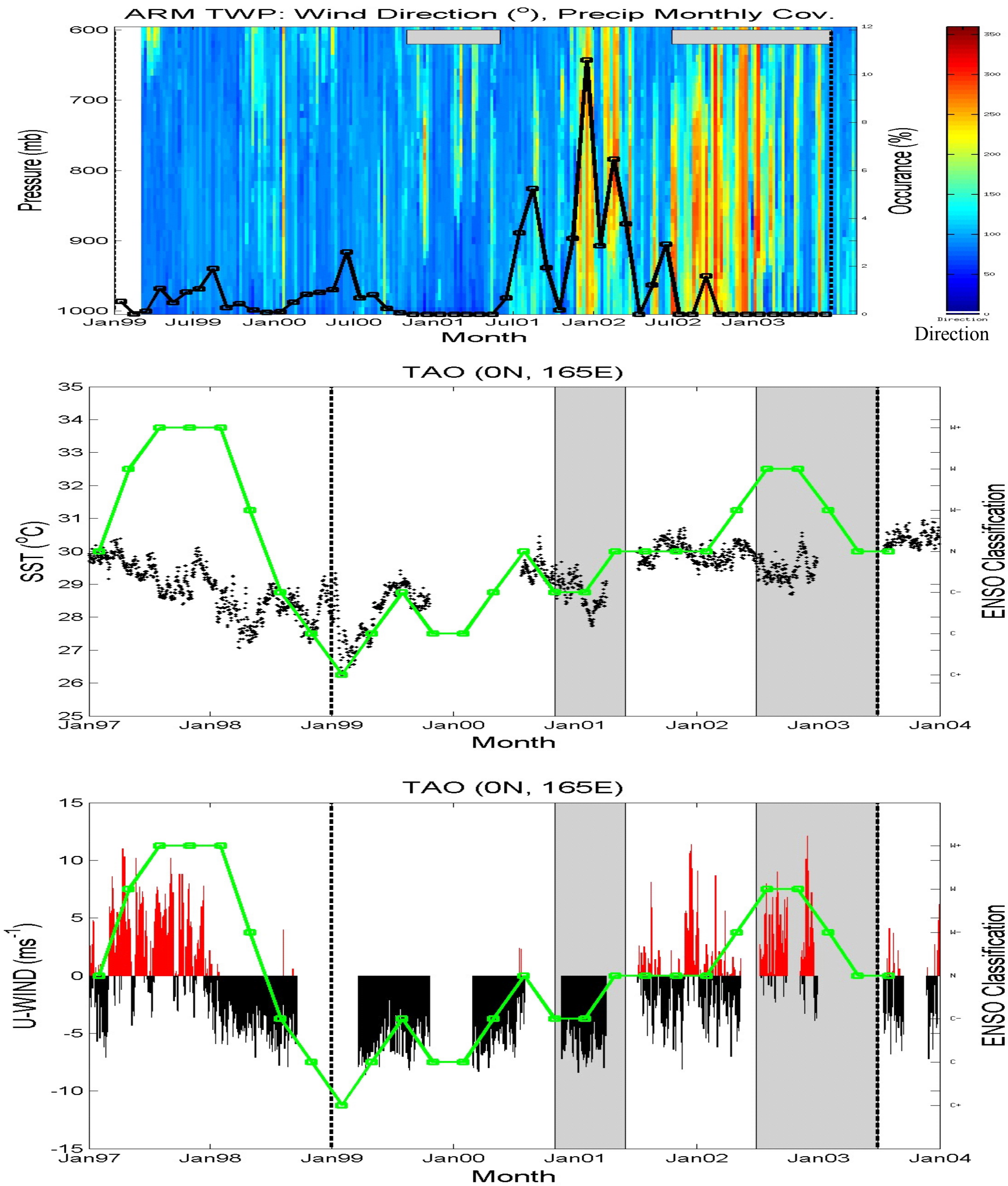

Figure 3. Wind direction from the soundings during the analysis period (top). Gray shaded areas indicate periods with little or no MMCR observations. SST observations (middle) and U-wind component measurements from the TAO buoy at (0N, 165E) (bottom). Green line shows the ENSO Classification from NOAA/CPC.

Contact

Dr. Pavlos Kollias; pkollias@rsmas.miami.edu; (305) 361-4038

Acknowledgment

This research was supported in part by DOE Grant: DEFRG0297ER62337.

References

Albrecht, B.A., 1981: Parameterization of trade-cumulus cloud amounts. *J. Atmos. Sci.*, **38**, 97-105.

Albrecht, B.A., 1989: Aerosols, cloud microphysics, and fractional cloudiness. *Science,* **245**, 1227-1230.

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

Augstein, A., H. Riehl, F. Ostapoff and V. Wagner, 1973. Mass and energy transports in an undisturbed Atlantic trade wind flow. *Mon. Wea. Rev.,* **101**, 101-111.

Betts, A.K., 1975: Parametric interpretation of trade-wind cumulus budget studies. *J. Atmos. Sci.*, **32**, 1934-1945.

Haiden, T., 1996: Generalization of Albrecht's cumulus cloud amount parameterization. *J. Atmos. Sci.*, **53**(21), 3164-3167.

Holland, J. and E. Rasmusson, 1973: Measurements of the atmospheric mass, energy, and momentum budgets over a 500-kilometer square of tropical ocean. *Mon. Wea. Rev.*, **101**, 44-55.

Slingo, J.M., 1980: A cloud parameterization scheme derived from GATE data for use with a numerical model. *Quart. J. R. Meteor. Soc.*, **106**, 747-770.

Slingo, J.M., 1987: The development and verification of a cloud prediction scheme for the ECMWF model. *Quart. J. R. Meteor. Soc.*, **113**, 899-927.