Observations of the Diurnal Cycle of Marine Stratocumulus During the VOCALS Regional Experiment

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I) Motivation

The cloud-topped boundary layers (CTBL) in the SE Pacific exhibit a strong diurnal cycle because of vertical mixing driven by cloud-top radiational cooling. The diurnal evolution of the cloud deck has been previously documented in numerous observational and modeling studies. The VOCALS Regional Experiment obtained a unique ship-based data set in which multiple facets of the diurnal cycle were measured simultaneously. Our work documents new details of diurnal variations in marine stratocumulus based on data sets collected on the NOAA ship Ronald H. Brown (RHB).

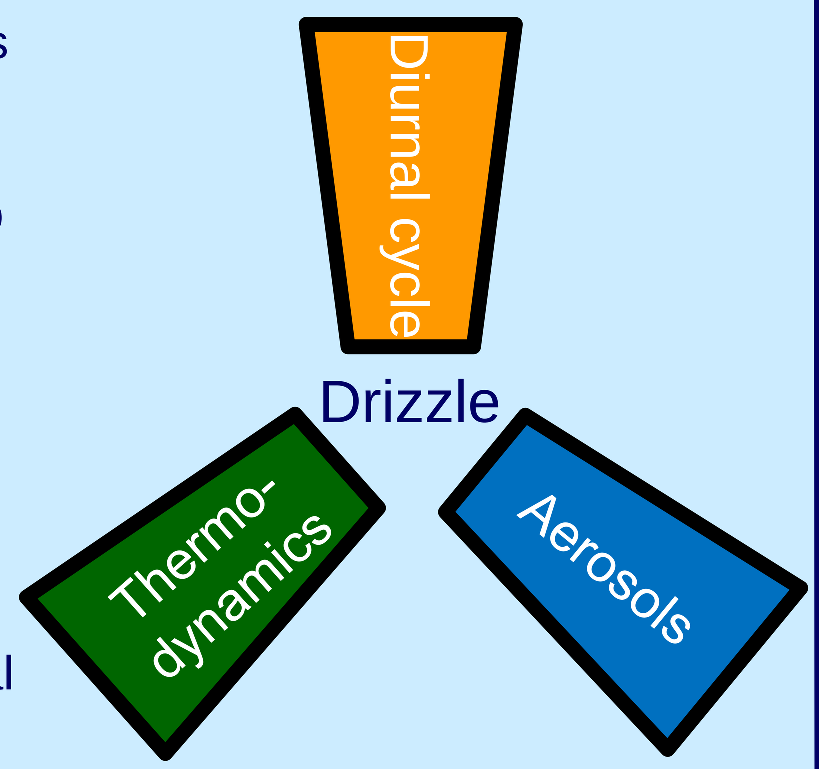


Figure 1 – The diurnal cycle, aerosols, and thermodynamics are three key forcings that jointly determine the characteristics of the CTBL system. Detailed documentation of the diurnal cycle and its variation with longitude will aid in isolating the roles of aerosols and thermodynamics.

II) Instruments

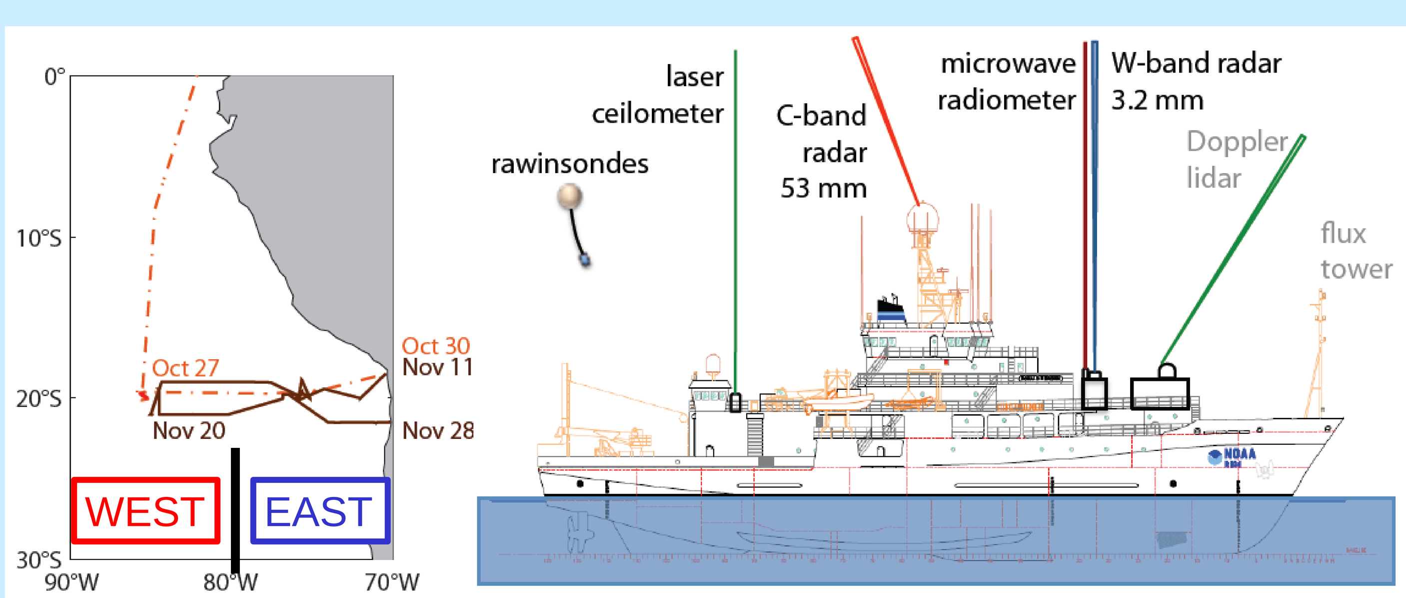
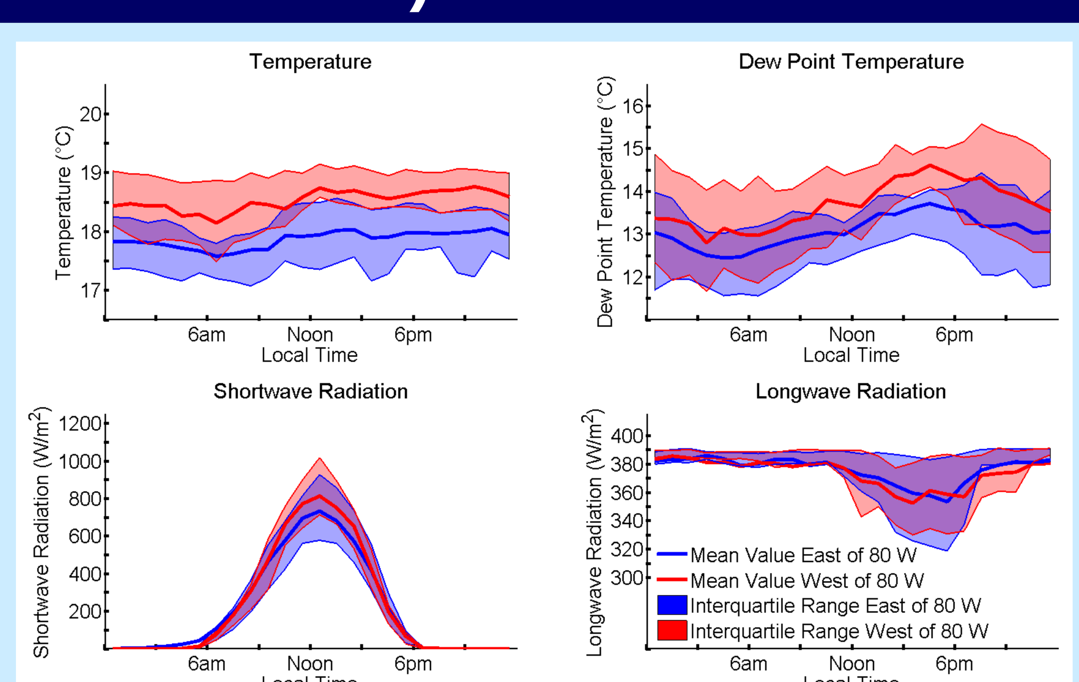


Figure 2 – Data from multiple legs across the 20°S parallel are utilized and divided into two subsets based on longitude (W and E of 80°W). Instrumentation on the RHB that are of primary importance to this study are: the vertically-pointing W-band and scanning C-band radars, the laser ceilometer, flux tower, and rawinsondes which were launched nominally every four hours during the cruise.

III) Surface Observations



Findings

- The increase in moisture near the surface during the afternoon is likely one result of boundary layer decoupling and a shallow mixed layer.

Figure 3 – Diurnal evolution of surface thermodynamic and radiation measurements divided into eastern and western sides of the domain (see Fig. 2). Solid lines indicate the hourly mean value and shaded regions outline the area between the 25th and 75th percentiles.

IV) Cloud Observations

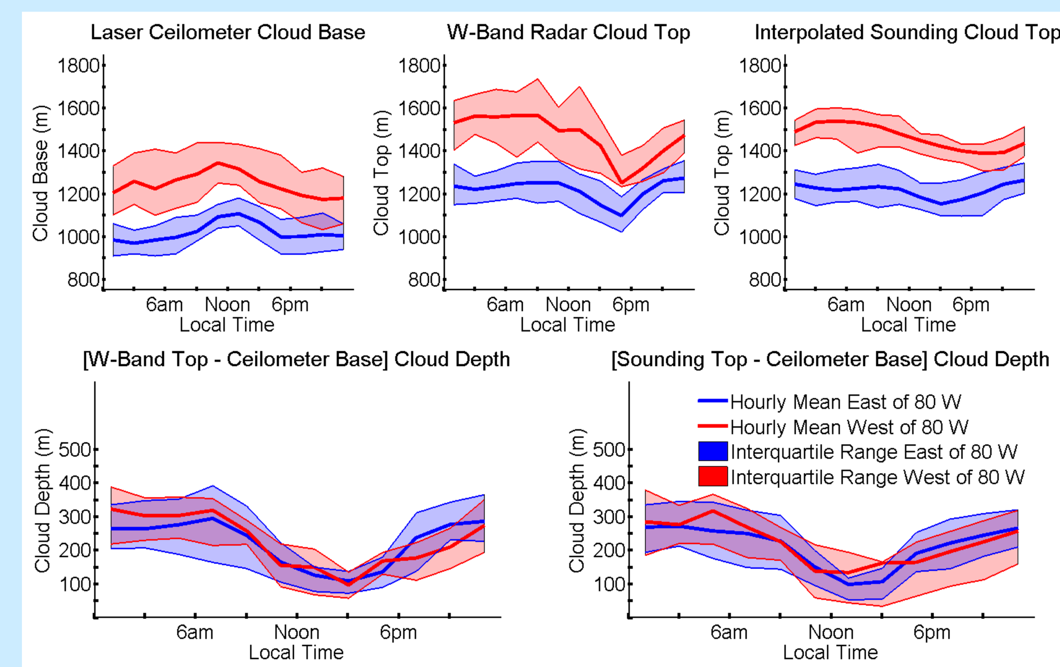


Figure 4 – Hourly average values for stratocumulus clouds over the ship of the cloud base height, top height and thickness.

Findings

- Cloud top height decreases throughout the afternoon and begins to increase near sunset.
- Cloud thickness decreases significantly after sunrise and begins to increase again in the middle of the afternoon.
- Cloud thickness is similar both east and west of 80°W despite a deeper boundary layer in the west.

V) Precipitation Observations

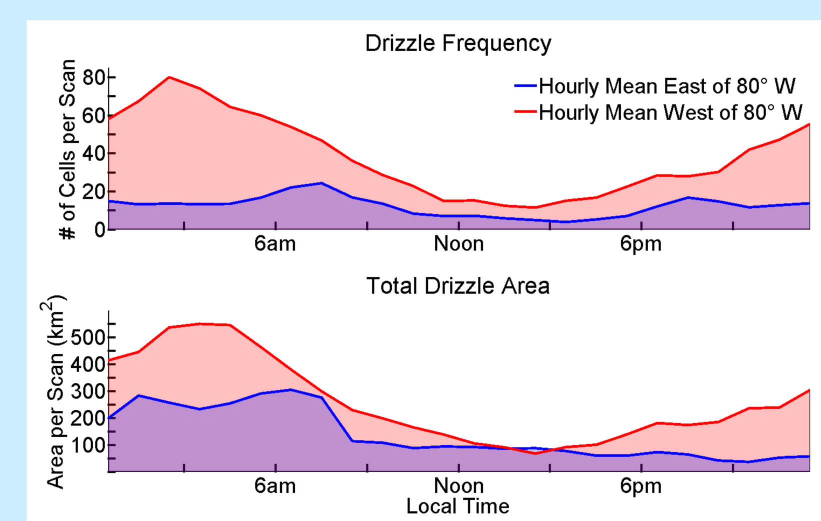


Figure 5 – Diurnal variation of drizzle cell number frequency and drizzle cell total area.

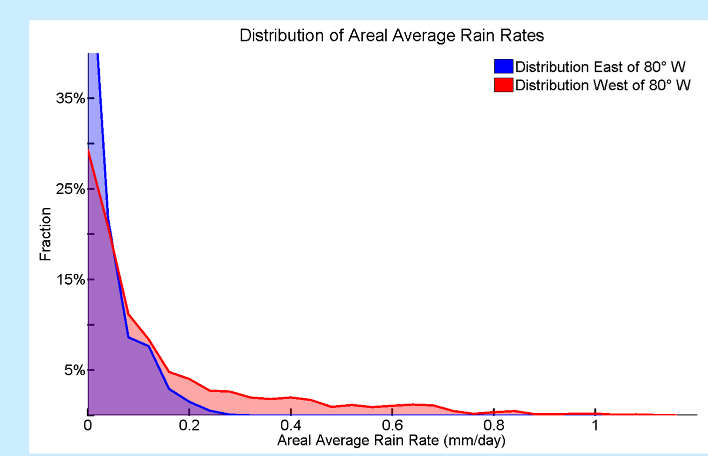


Figure 6 – Distributions of areal average rain rate for east and west portions of data set. Rain rates are a preliminary estimate based on scanning C-band radar reflectivity over more than a 9000 km^2 area.

Findings

- Drizzle increases through the late afternoon into the evening, maximizes near 3 am, and decreases sharply with sunrise. The decrease is earlier and slower in the west compared to the east.
- Daytime minimum observations of drizzle frequency and area are approximately 20% of the overnight maximum values.
- Heavy drizzle occurs more frequently in the western portion of the domain compared to the eastern portion.

VI) Boundary Layer Coupling Observations

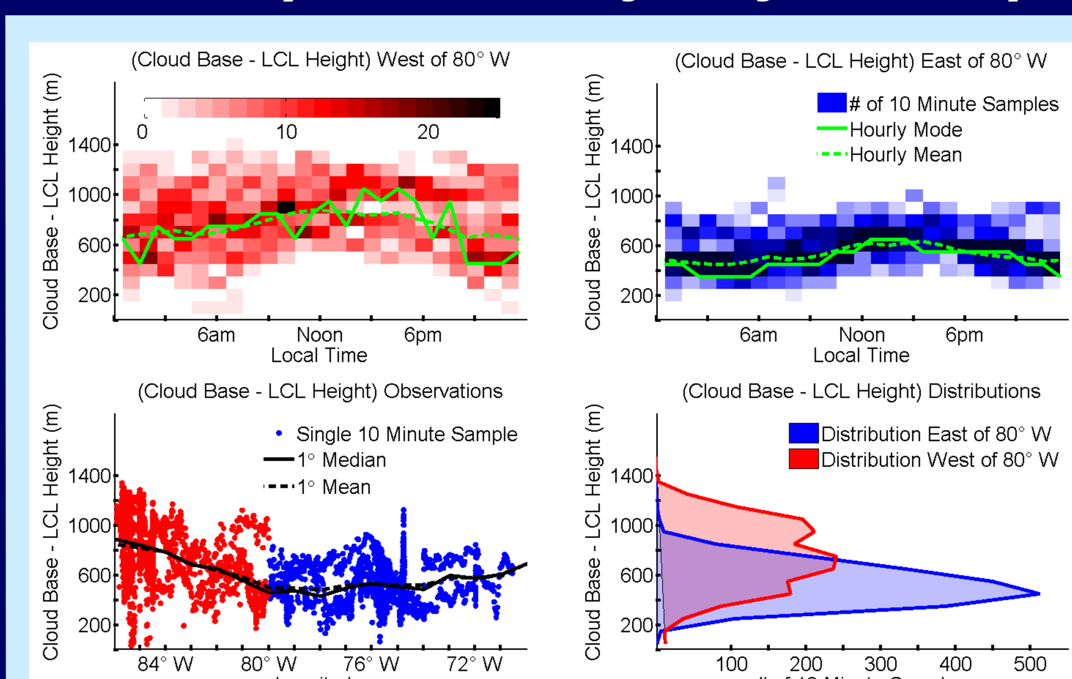


Figure 7 – Diurnal and longitudinal variation of a coupling measurement based on lifted surface parcels.

Underpinning

The difference between the cloud base and LCL of a lifted surface parcel will be smallest when the boundary layer is most coupled.

Findings

- The boundary layer is less coupled during the day and quickly couples shortly after sunset.
- Larger differences between cloud base and LCL heights are more frequent in the western portion of the domain.

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VI) Boundary Layer Coupling (continued)

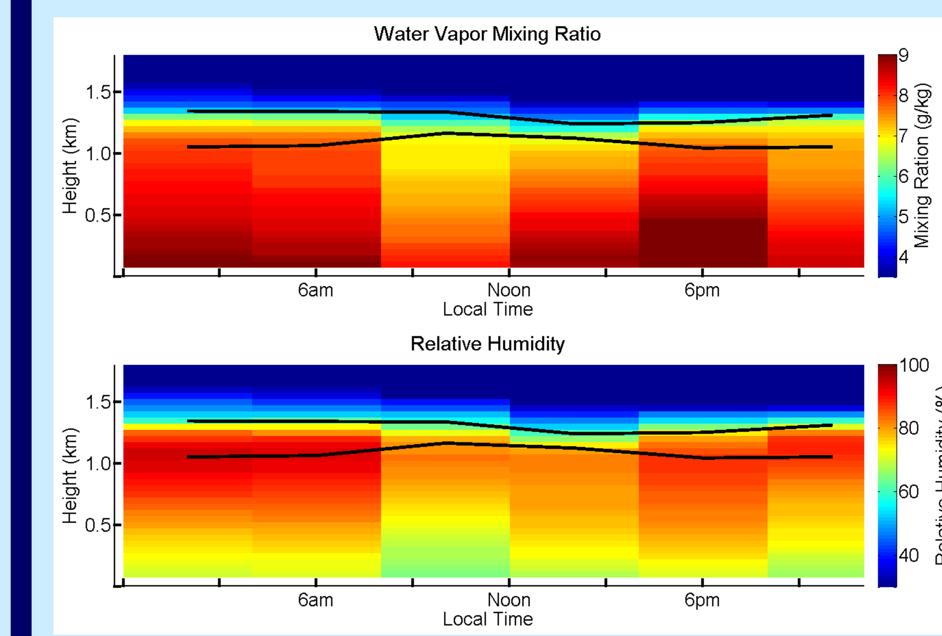

Figure 8 – Diurnal variation of the 50 m vertically averaged values of water vapor and relative humidity based on rawinsonde data. Bold lines indicate mean cloud boundaries as a function of time.

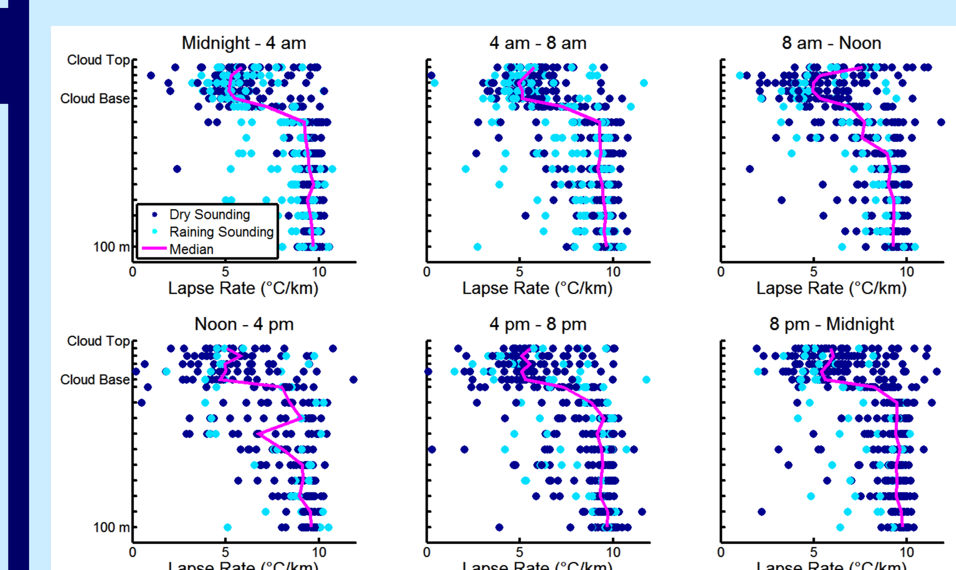

Figure 9 – Measurements of the cloud relative lapse rates. Dark blue dots indicate soundings that were likely taken in dry conditions whereas light blue observations were likely taken with significant drizzle upstream of the ship.

Findings

- Water vapor increases in the lower half of the boundary layer during the afternoon. Stronger boundary layer coupling in the evening allows some of this moisture to mix from the surface into the cloud, lowering cloud base.
- Evaporation of drizzle within downdrafts adds moisture to the lower portion of the boundary layer.
- Smaller subcloud lapse rates overnight may be evidence for the modification of the boundary layer by drizzle.
- An evaporatively cooled stable subcloud layer can develop overnight during precipitation. Such a stable layer would reduce moisture flux into the cloud and reduce precipitation (Bretherton and Wyant 1997).

VII) Conceptual Model