Boundary Layer Thermodynamic Decoupling at the ARM ENA Site

Virendra P. Ghate[1], Maria P. Cadeddu[1], Michael P. Jensen[2], David B. Mechem[3], Alyssa A. Matthews[4], Francisco Reis[5] and Eduardo Azevedo[5]

1. Argonne National Laboratory; 2. Brookhaven National Laboratory; 3. University of Kansas; 4. Pacific Northwest National Laboratory; 5. University of Azores

Motivation and Approach

Marine boundary layer stratocumulus clouds cover vast areas of the Eastern subtropical oceans and reflect a greater amount of solar radiation back to space than the underlying sea surface. Hence, they are an important component of the Earth's Radiation budget. Marine stratocumulus clouds are also intimately coupled to the ocean surface and are maintained through the transfer of energy, moisture and momentum away from the surface through boundary layer turbulence. Decoupling of the cloud layer from the surface is viewed as the first signature of the broad transition from a stratocumulus cloud regime to a cumulus cloud regime. Despite its importance, the thermodynamic decoupling and its relation to dynamic decoupling has not been well-characterized. In this study, we use observations made at the ARM Eastern North Atlantic (ENA) site to characterize the annual and diurnal cycle of the Lifting Condensation Level (LCL), boundary layer depth, and boundary layer thermodynamic decoupling in the context of stratocumulus clouds.

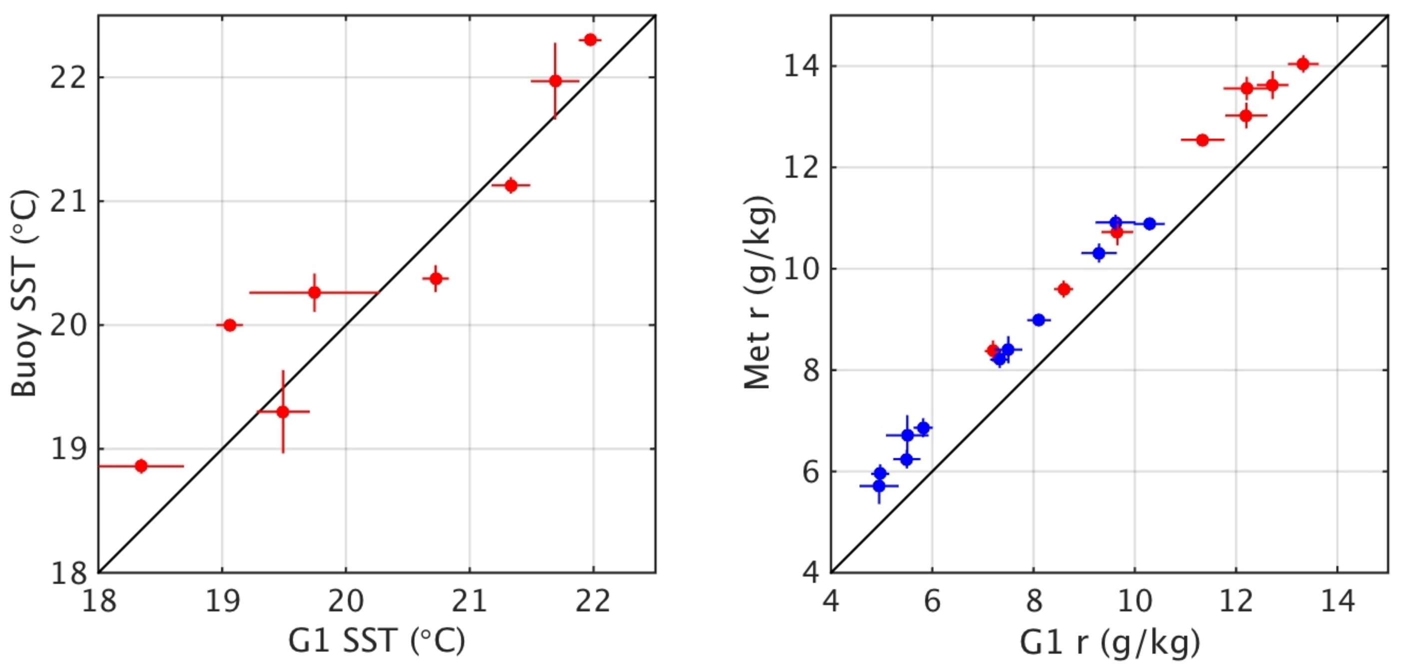

Figure 1: Scatter plot between buoy measured and G1-measured SST (left), and met station measured and G1-measured water vapor mixing ratio (right) during the ACE-ENA field campaign research flights. Blue dots indicate IOP-1 and red dots indicate IOP-2. RMSD for SST was 0.47 K and for mixing ratio was 1.64 g/kg.

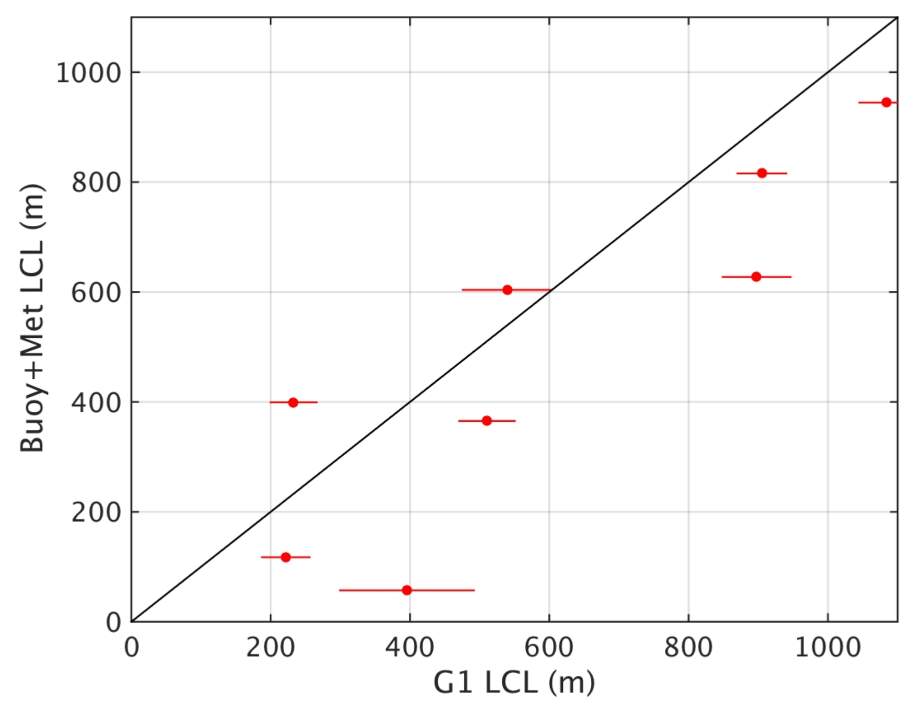

Figure 2: Scatter plot between LCL derived from instruments onboard G1 and those at the ENA site during ACE-ENA IOP-1. The RMSD was 150.79 m

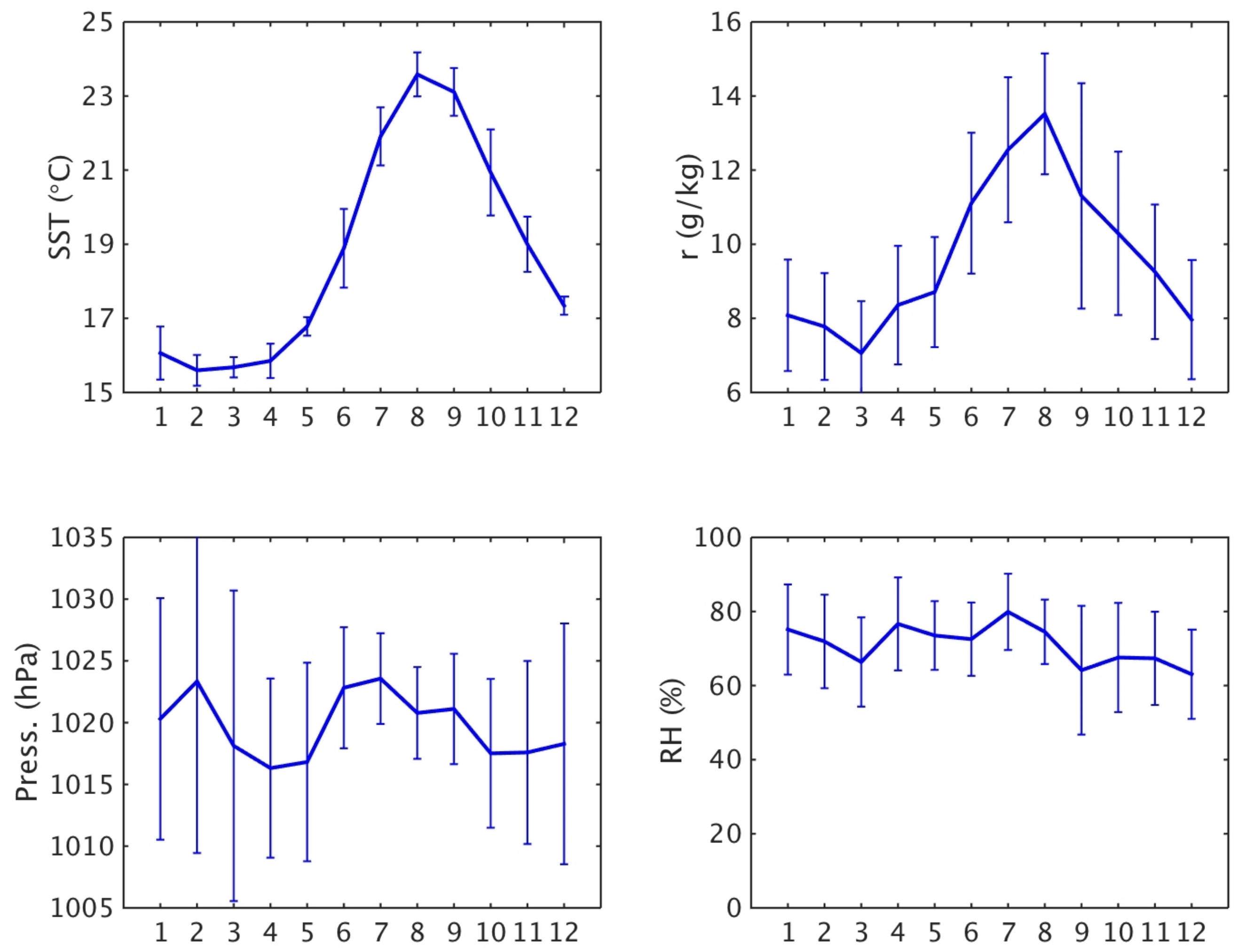

Figure 3: Averaged annual cycle of sea surface temperature (SST), and near-surface water vapor mixing ratio (r), pressure and Relative Humidity (RH) during northerly wind conditions observed between 2016-2018. Vertical bars indicate one standard deviation.

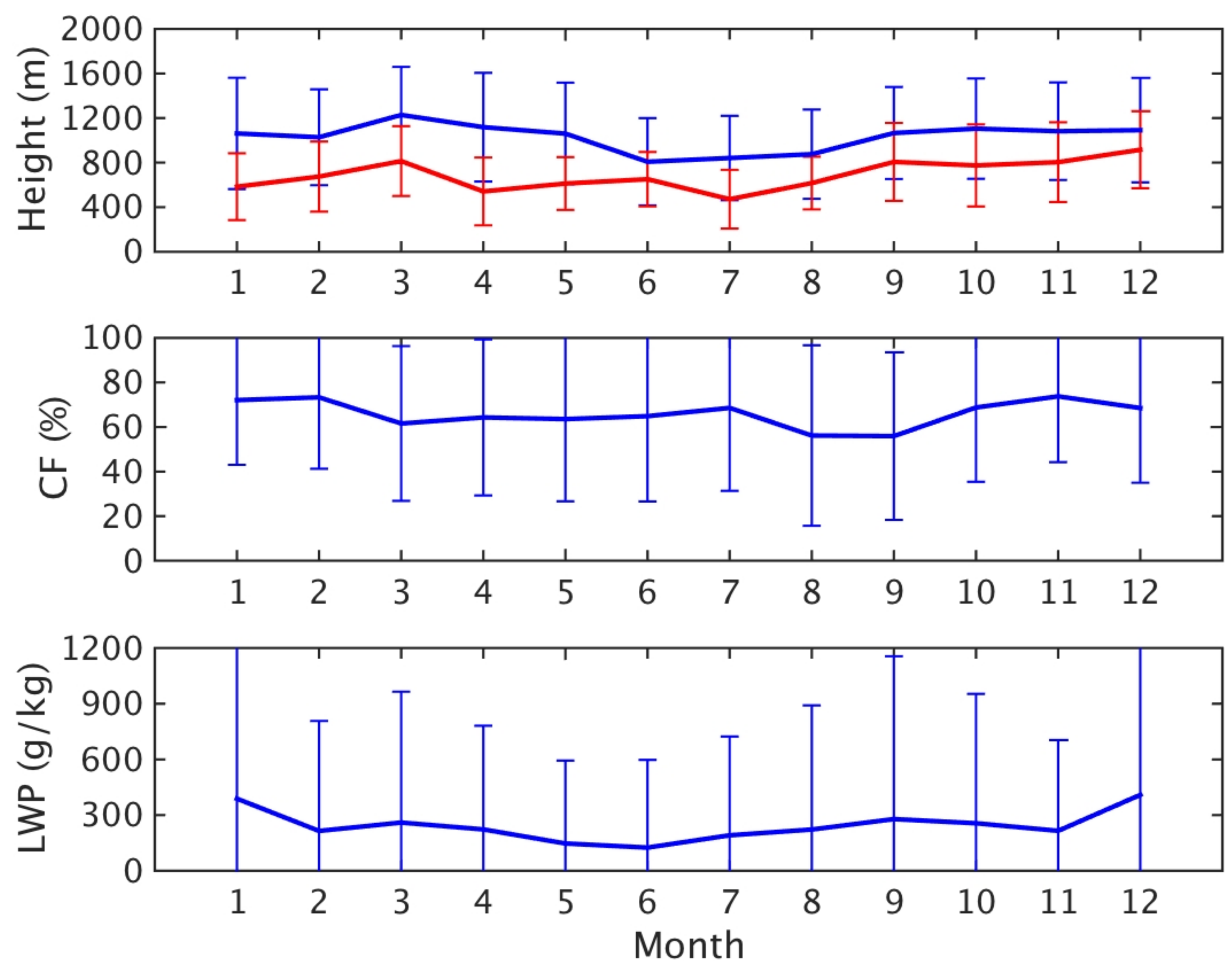

Figure 4: Averaged annual cycle of cloud base height in blue and LCL in red (Top), ceilometer reported boundary layer cloud fraction (Middle), and microwave radiometer reported Liquid Water Path (LWP) (Bottom) during northerly wind conditions observed between 2016-2018. The boundary layer was always decoupled with the distance between LCL and base lowest during the summer months. Despite prevalence of decoupled conditions the average cloud cover was ~75% with LWP of ~250 g/m2 with large variability.

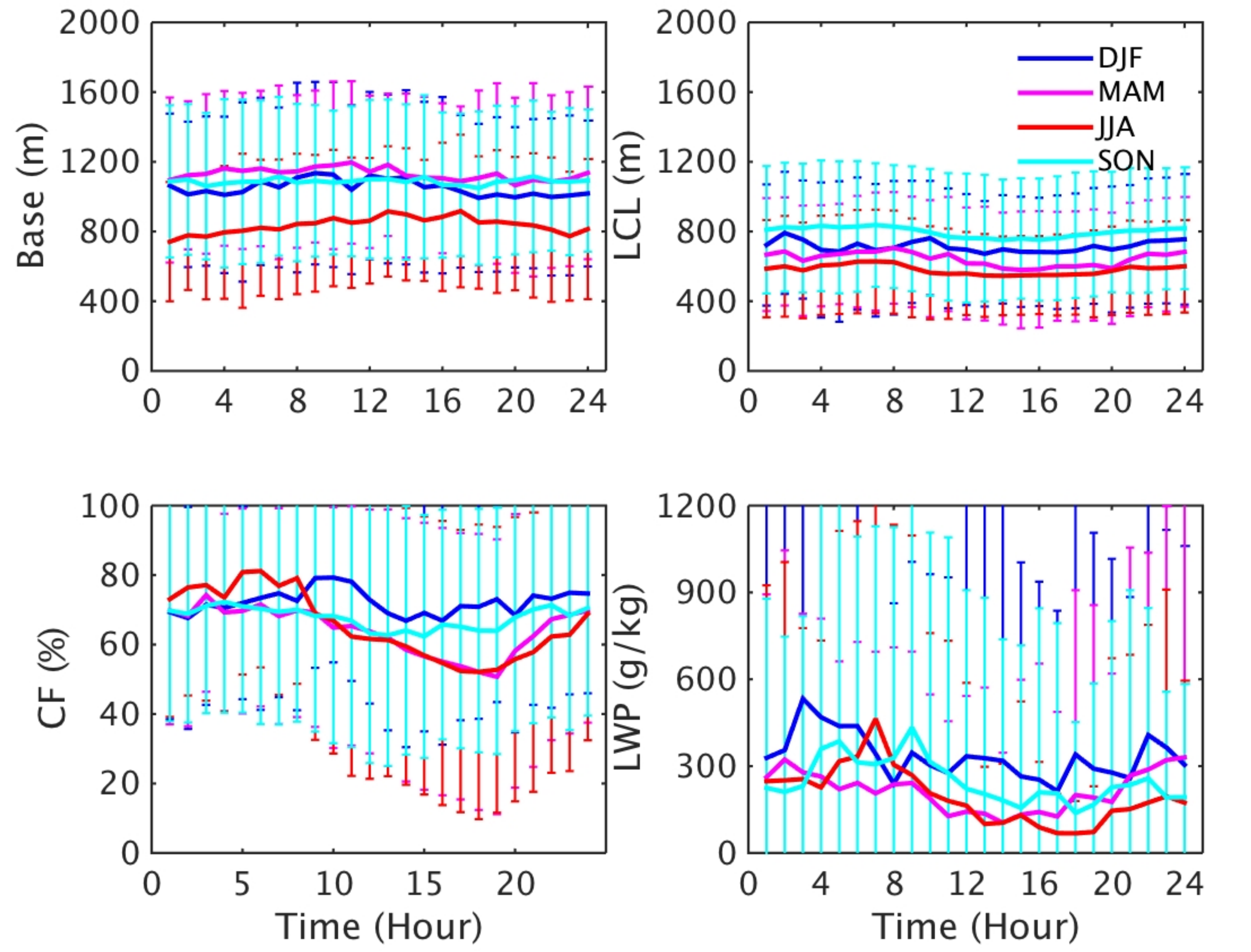

Figure 5: Average diurnal cycle of cloud base height, Lifting Condensation Level (LCL), ceilometer reported boundary layer cloud fraction (CF), and liquid water path (LWP) during northerly wind conditions observed between 2016-2018. No changes in cloud base height and LCL can be seen on diurnal timescales, with some hint of a diurnal cycle in cloud fraction and LWP during summer and spring months.

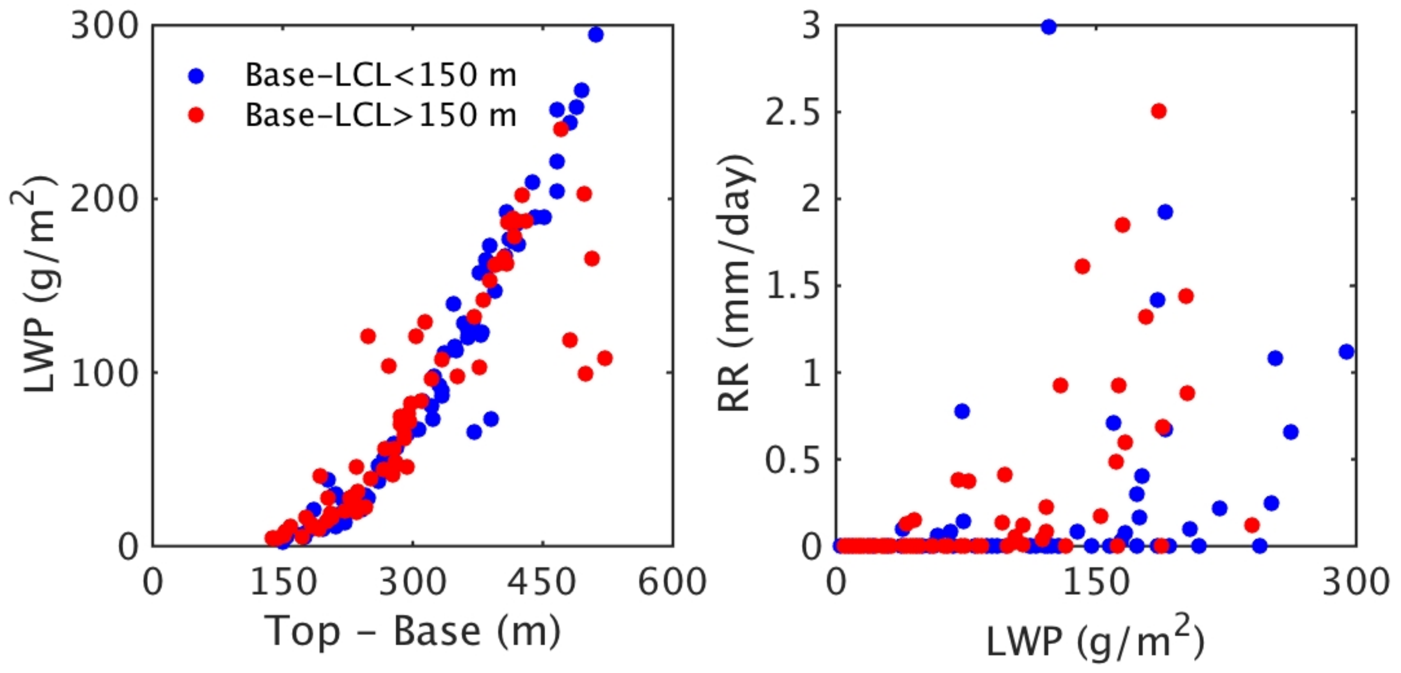

Figure 6: Scatter plot between (left) cloud thickness and LWP, and (right) LWP and cloud base rain rate during 17 cases of closed cellular stratocumulus cloud conditions at the ENA site. Each dot represents an hourly average, and the data is segregated using a threshold of 150 m for the distance between the cloud base and the LCL. The clouds were largely adiabatic and lightly precipitating.

Preliminary results and future work:

- Good agreement with the aircraft and buoy measured SST, but not water vapor mixing ratio. Hence, the LCL calculated from site instrumentation has uncertainty of ~150 m.
- Lack of distinct annual cycle in all variables except for SST and mixing ratio. Hint of a diurnal cycle in LWP and cloud cover during spring and summer months.
- Future work will focus on characterizing the changes in thermodynamic and dynamic properties between the LCL and the cloud base.

References:

Bolton, D., 1980: The Computation of Equivalent Potential Temperature. *Mon. Wea. Rev.*, **108**, 1046–1053.

Ghate, V. P., and M. P. Cadeddu, 2019: Drizzle and turbulence below closed cellular marine stratocumulus clouds. *J. Geophys. Res. Atmos.*, **124**, doi: 10.1029/2018JD030141

Jones, C. R., Bretherton, C. S., and Leon, D.: Coupled vs. decoupled boundary layers in VOCALS-REx, *Atmos. Chem. Phys.*, **11**, 7143-7153