Microphysical and Dynamical Properties of Drizzling Marine Boundary Layer Stratocumulus Clouds, Part II: Mean Conditions and Impact on Turbulence

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Motivation and Approach

Boundary layer stratocumulus (Sc) 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 these clouds have a significant impact on the Earth's radiation budget and need to be accurately represented in Global Climate Model (GCM) simulations aimed at predicting the future climate. These clouds are intimately coupled to the turbulence within the boundary layer that is maintained by the radiative cooling at the cloud top, surface heating and moistening, and entrainment. However drizzle is ubiquitous in these clouds and the falling drizzle below cloud base evaporates, cooling the sub-cloud layer and impacting turbulence. The GCM simulations made using coupled microphysical-turbulence schemes (Zheng et al. 2017) showed spurious cloudy oscillations and called for observational studies on the coupling between precipitation and turbulence.

In part-I of this study we implemented the technique by O'Connor et al. (2005) to the data collected at the Atmospheric Radiation Measurement (ARM)'s Eastern North Atlantic (ENA) site during stratocumulus cloud conditions to retrieve cloud and drizzle microphysical properties. Here we explore the impact of drizzle evaporation on sub-cloud layer turbulence.

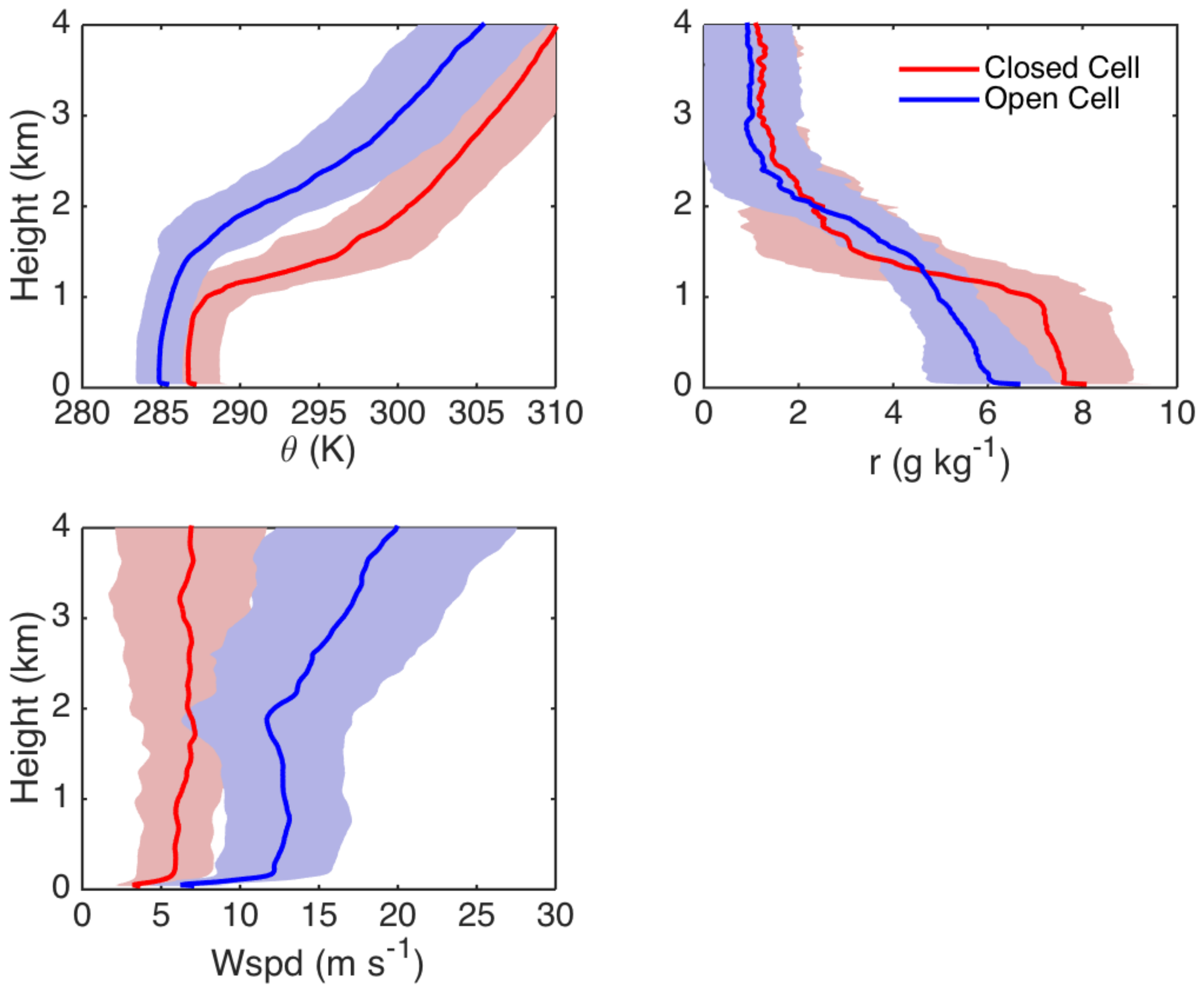

Figure 1: Profiles of potential temperature (θ), water vapor mixing ratio (r) and wind speed as reported by the radiosondes during closed cellular (red) and open cellular (blue) organizations. The lines denote mean value and the shades denote one standard deviation from the mean value. The open cellular Sc were associated with colder and deeper boundary layers with higher wind speeds than the closed cellular Sc. The closed cellular cases had higher lower tropospheric stability and stronger boundary layer inversion.

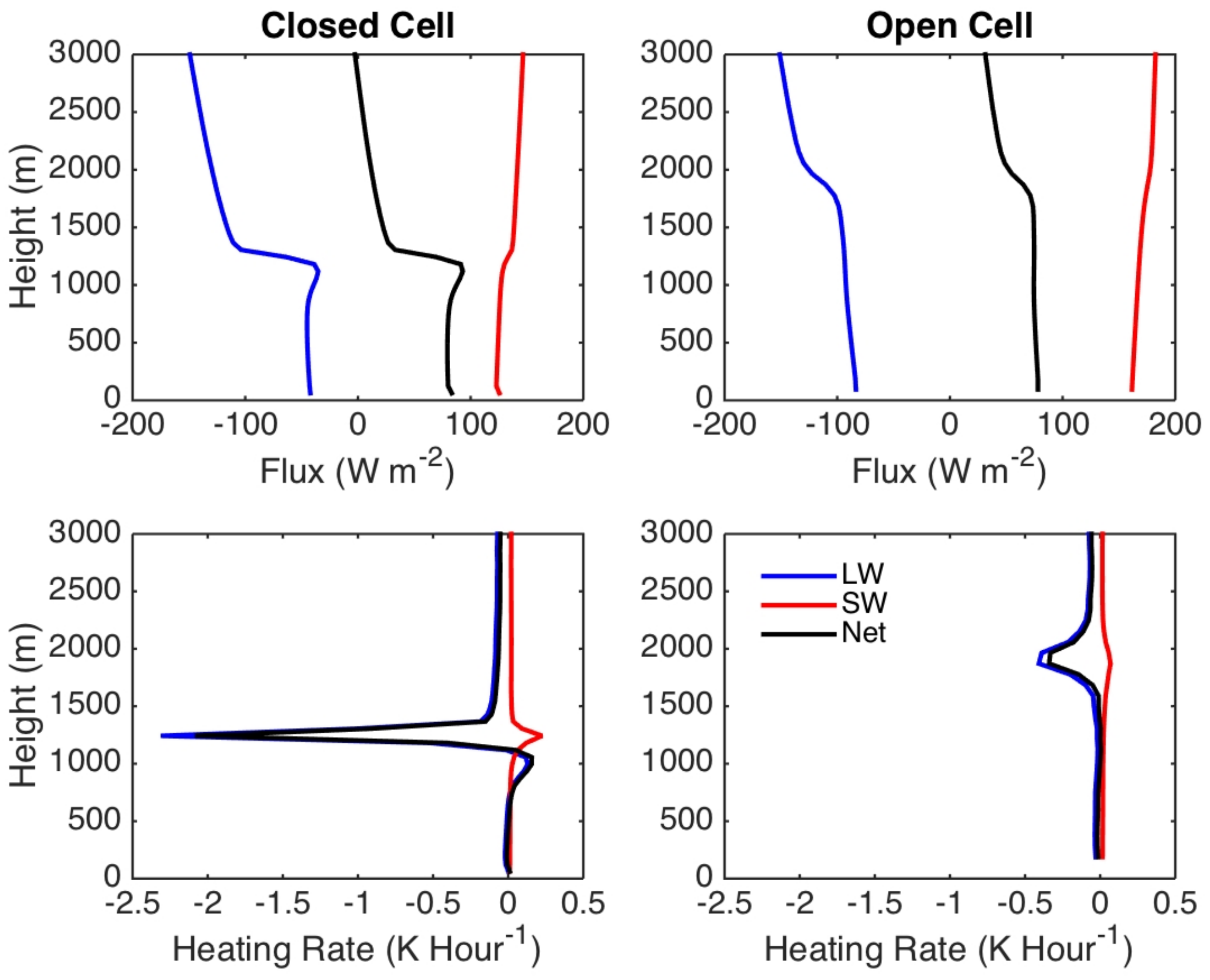

Figure 2: The microphysical and thermodynamic retrievals were used as an input to the Rapid Radiative Transfer Model (RRTM) to simulate profiles of radiative fluxes and heating rates. The averaged profiles of radiative fluxes (top) and heating rates (bottom) for closed cell (left) and open cell (right) organization are shown above. Due to lower cloud cover, the radiative cooling at the cloud top for open cell cases was lower than that for cases with closed cell organization.

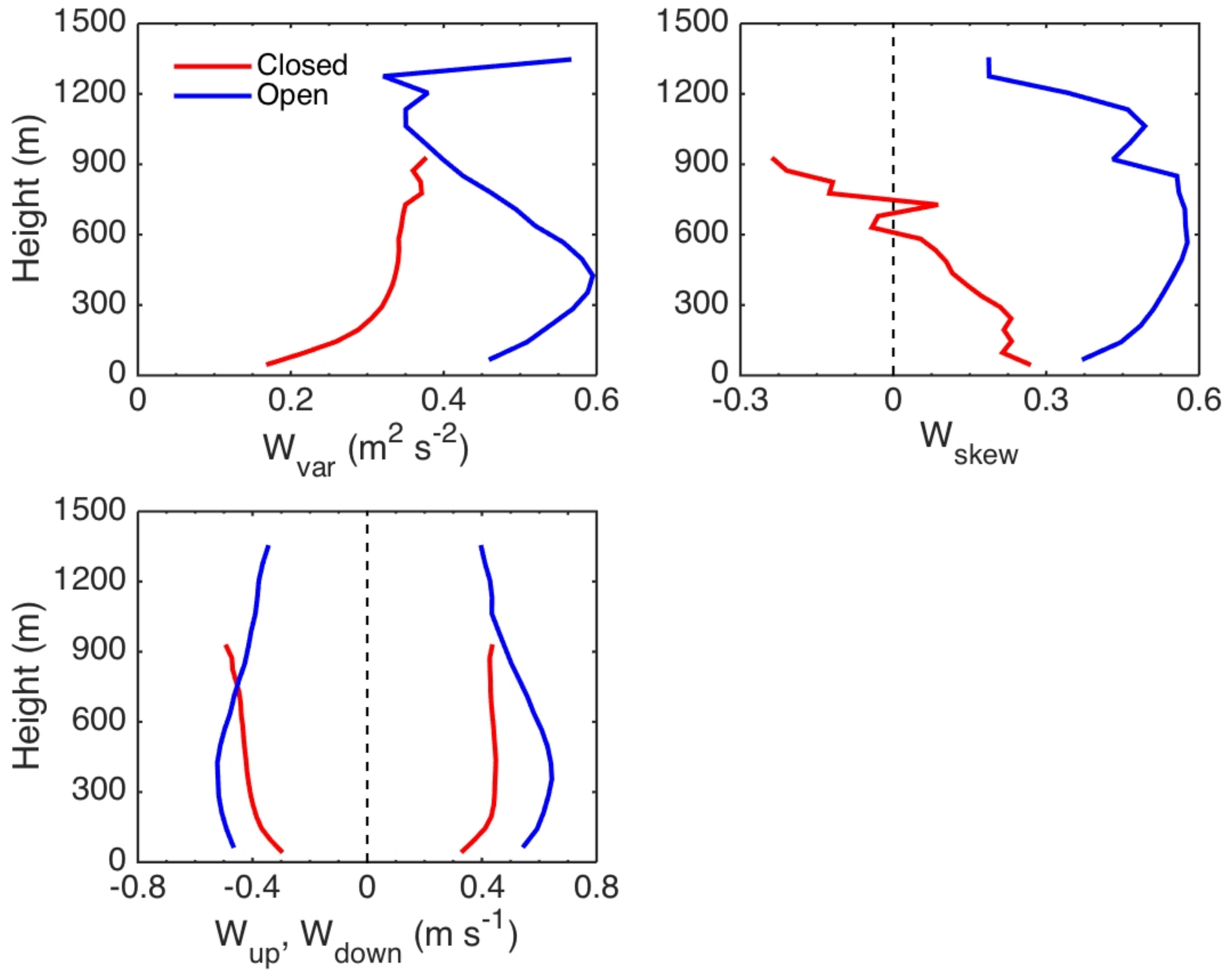

Figure 3: The data from the Doppler Lidar and KAZR was combined to retrieve the statistics of vertical air motion (W) in the sub-cloud layer. Shown above are the averaged profiles of variance of vertical velocity (W_{var}), skewness of vertical velocity (W_{skew}), and mean updraft (W_{up}) and downdraft (W_{down}) strengths for open and closed cellular Sc organization. The boundary layers associated with open cellular Sc are far more turbulent than those associated with closed cell Sc.

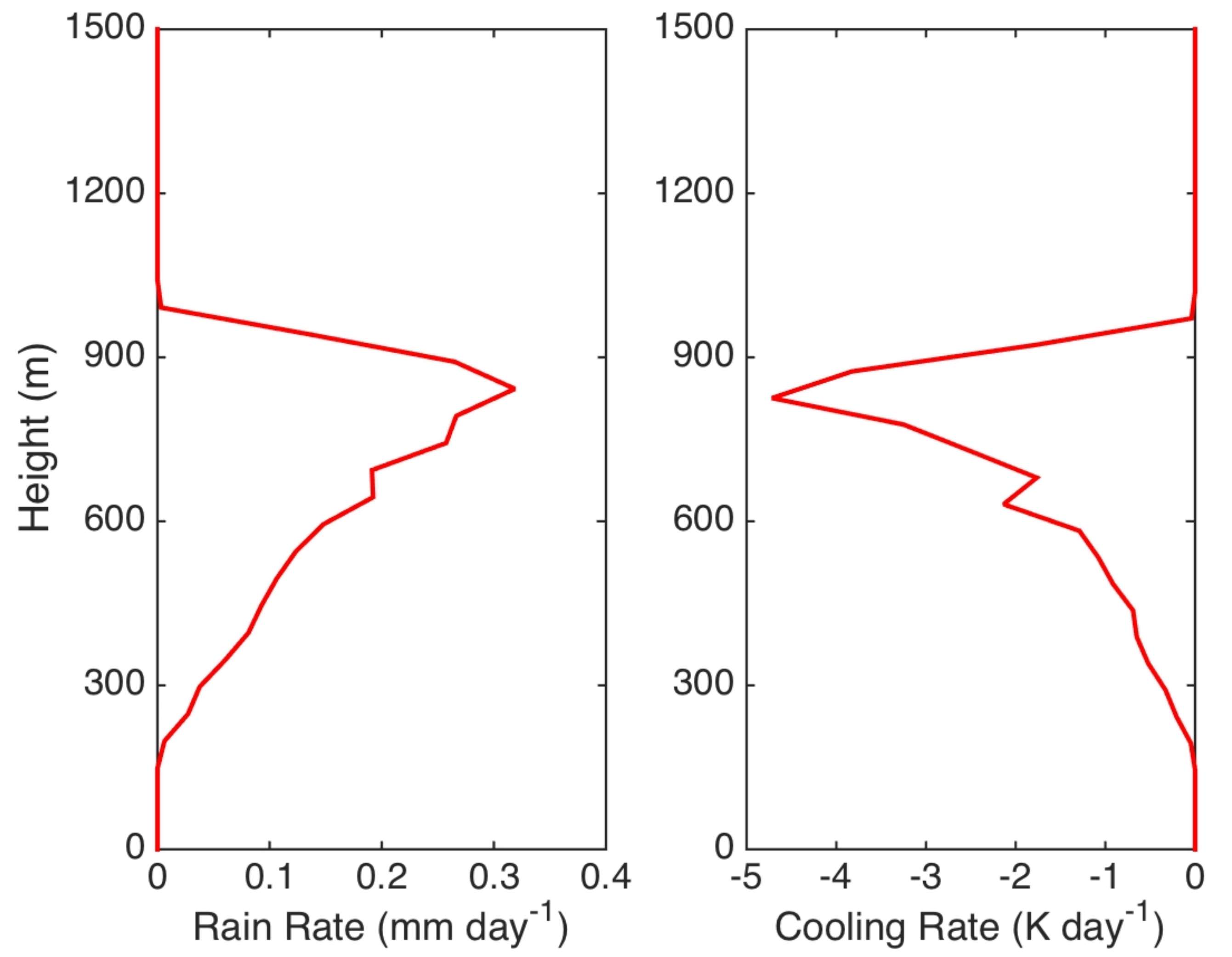

Figure 4: The retrieved microphysical properties were used to calculate profiles of rain rates, drizzle flux, and the cooling associated with drizzle evaporation. Shown above are the averaged profiles of sub-cloud layer rain rate (left) and cooling rate due to drizzle evaporation (right) for closed cellular Sc. The retrievals made at 20 m and 1 minute resolution were averaged to hourly timescales. Much of the drizzle evaporates before reaching the surface.

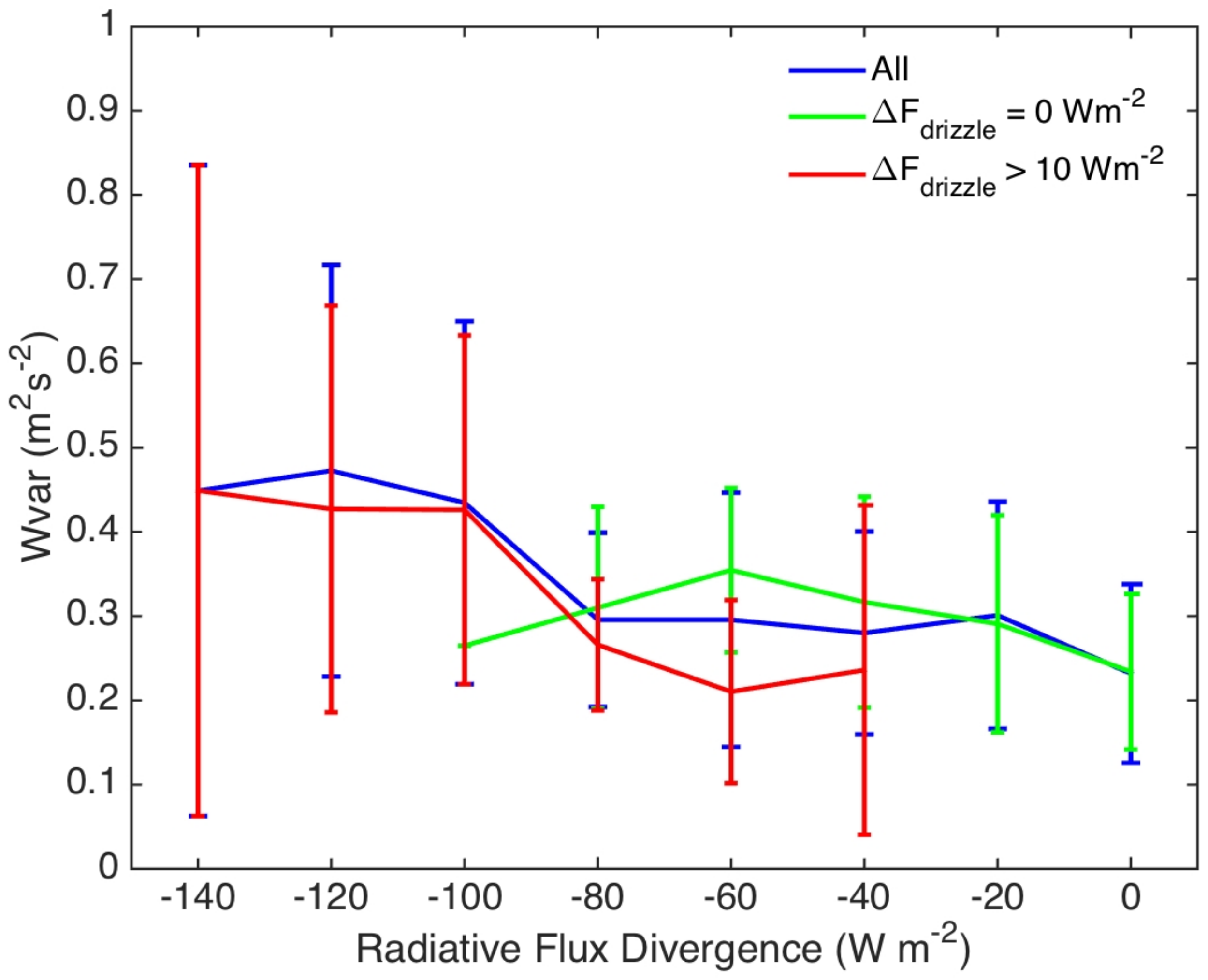

Figure 5: The radiative flux divergence within 40 m of the cloud top was calculated on hourly timescales. Shown above is the averaged sub-cloud layer variance of vertical velocity binned by radiative flux divergence near the cloud top for all hours (blue), hours with no drizzle evaporation (green) and hours with drizzle evaporation (red) conditions. During strong radiative cooling there were no hours without precipitation, and for weak radiative cooling there were no hours with precipitation.

Preliminary results and Future Work:

- Open cellular stratocumulus clouds had weaker cloud top radiative cooling but stronger turbulence than their closed cellular counterparts.
- For a radiative flux divergence of -60 Wm^{-2}, drizzle evaporation can reduce the variance of vertical velocity from 0.35 m^{2}s^{-2} to 0.21 m^{2}s^{-2}, a reduction of 40%.
- Future work will focus on extending our analysis to impact of drizzle evaporation on cell-averaged turbulence and intense updrafts associated with cold pools.

References:

O'Connor et al., 2005: Retrieving stratocumulus drizzle parameters using Doppler lidar and radar., *J. Appl. Meteorol.*, **44**, 14-27.

Zheng, X., and coauthors, 2017: A cloudy planetary boundary layer oscillation arising from the coupling of turbulence with precipitation in climate simulations. *J. Adv, Model. Earth. Syst.*, **9**, 1973-1993.