Arctic Cloud-Driven Mixed Layers and Surface Coupling State

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Objective

Understand the dynamical interactions among Arctic stratiform clouds, atmospheric thermodynamic structure, and the sea-ice surface; and their impacts on cloud structure, cloud-surface coupling state, and the vertical distribution of aerosols.

Context

Arctic mixed-phase stratiform clouds are persistent and have profound impacts on surface energy budgets. Their resilience is due to a balance of influences from long-range advection, in-cloud processes, and local forcing. Sources of aerosols and moisture can critically impact the lifetime of these clouds.

Analysis: Detailed observations of stratiform, mixed-phase clouds and atmospheric structure over the Arctic sea-ice during the Arctic Summer Cloud Ocean Study (ASCOS, 2008).
Instruments: Ground-based cloud radar, dual-channel microwave radiometer, profiling microwave radiometer, ceilometer, met tower, and radiosondes.

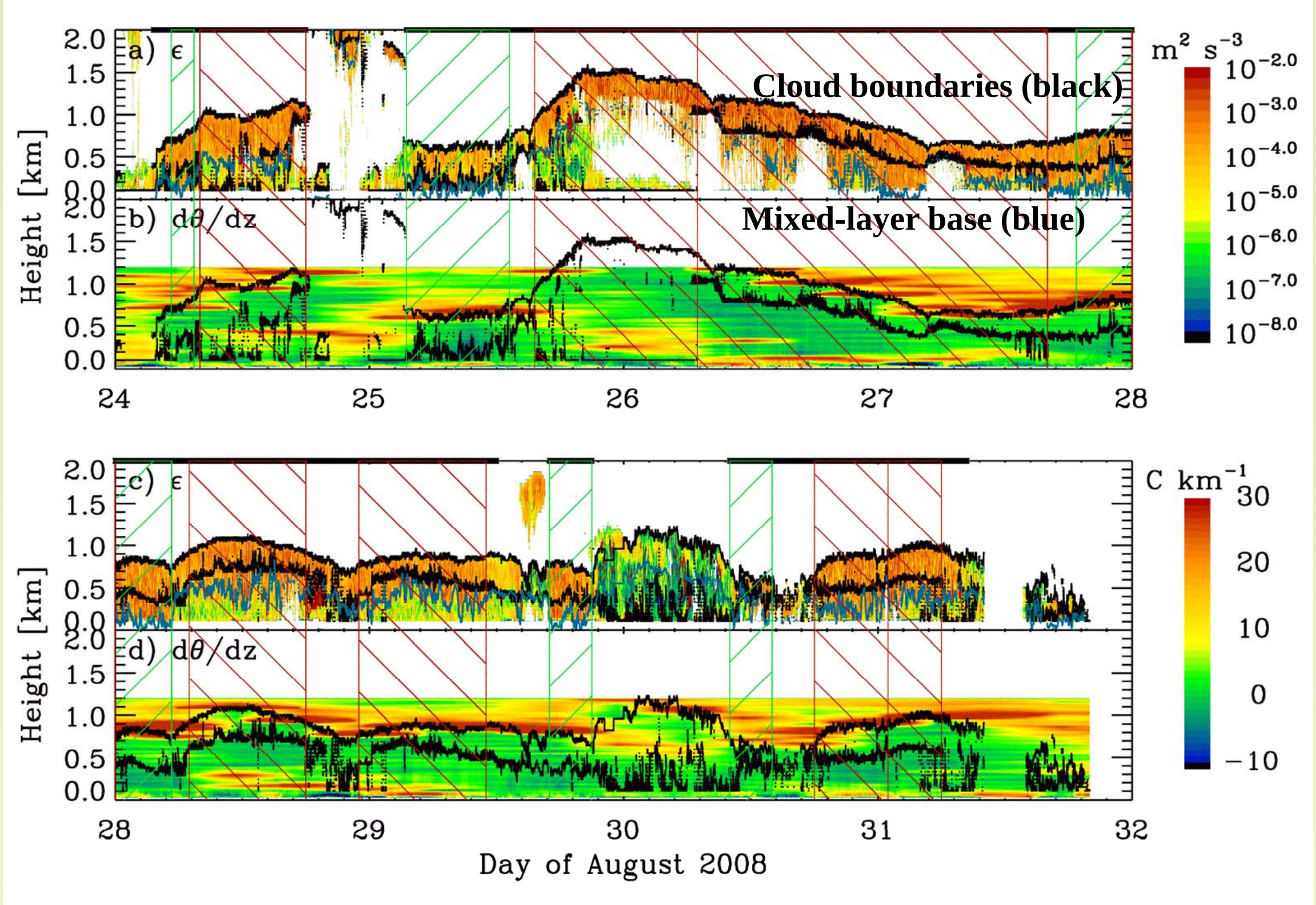
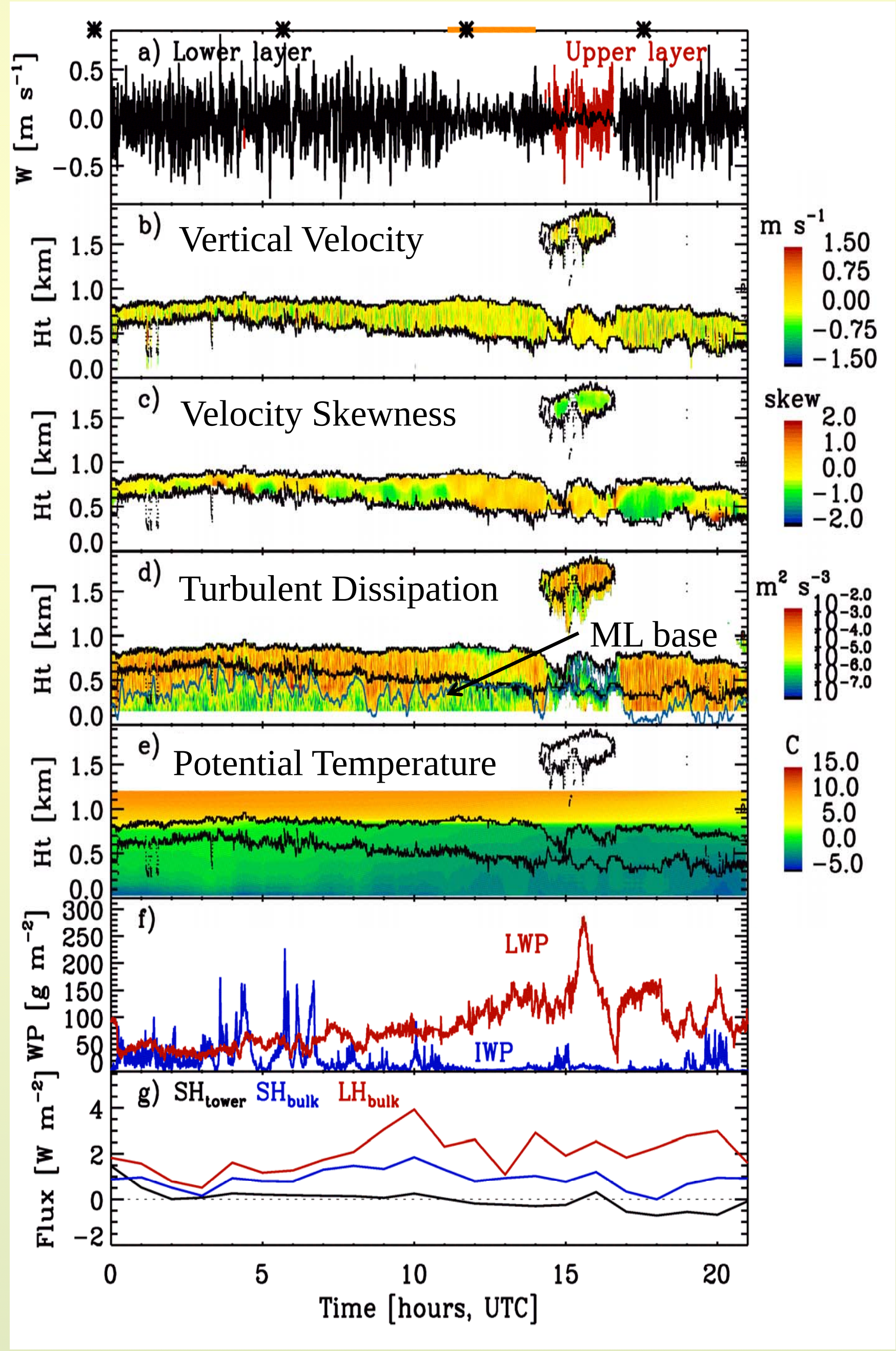


Figure1: Turbulent dissipation rate and vertical potential temperature gradient for 8 days. Periods of predominant cloud-surface decoupling are given as red hatches while those of intermittent coupling are in green hatches.

Detailed Case Study

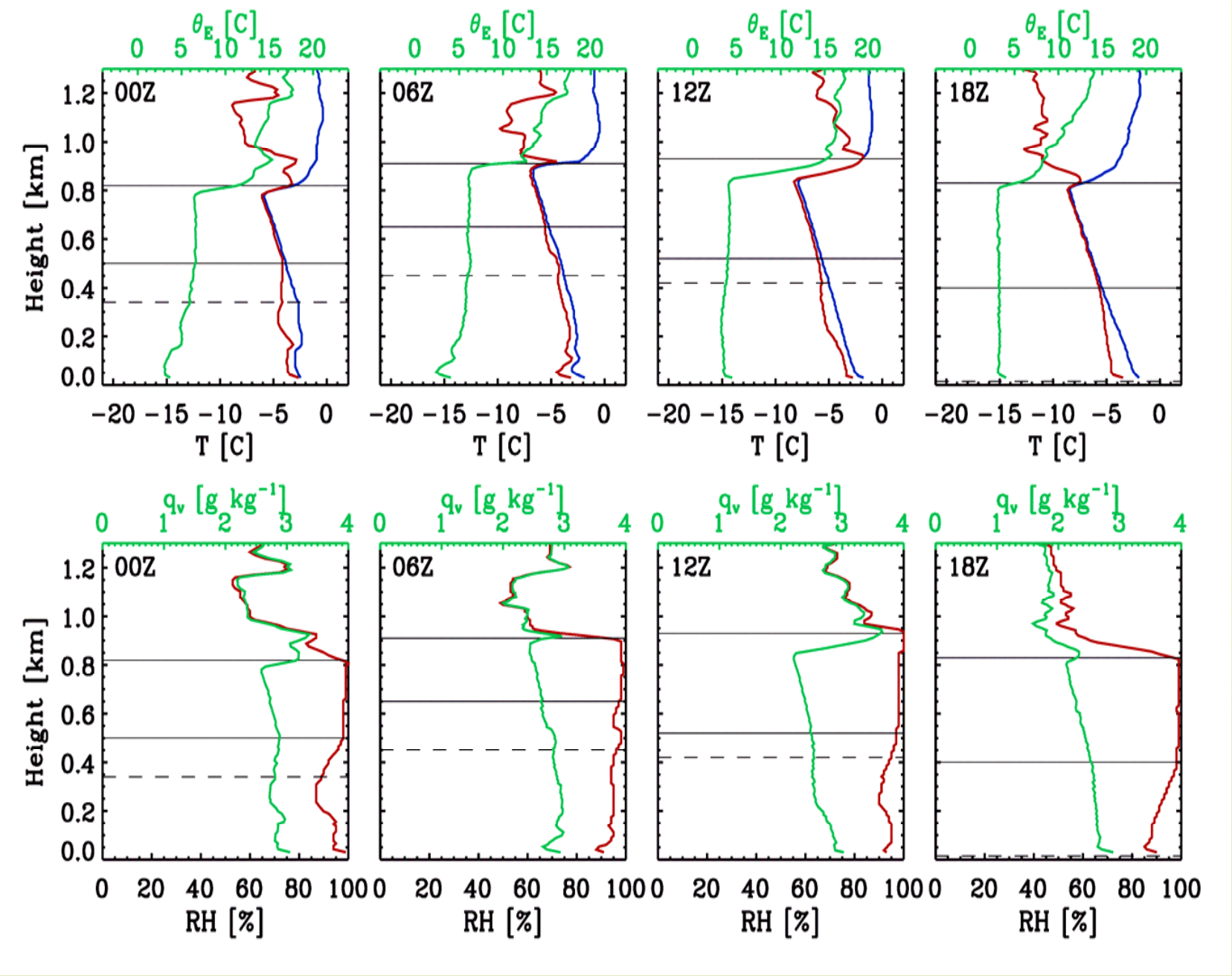
Decoupled ⟶ Coupled



Remote sensor retrieved data

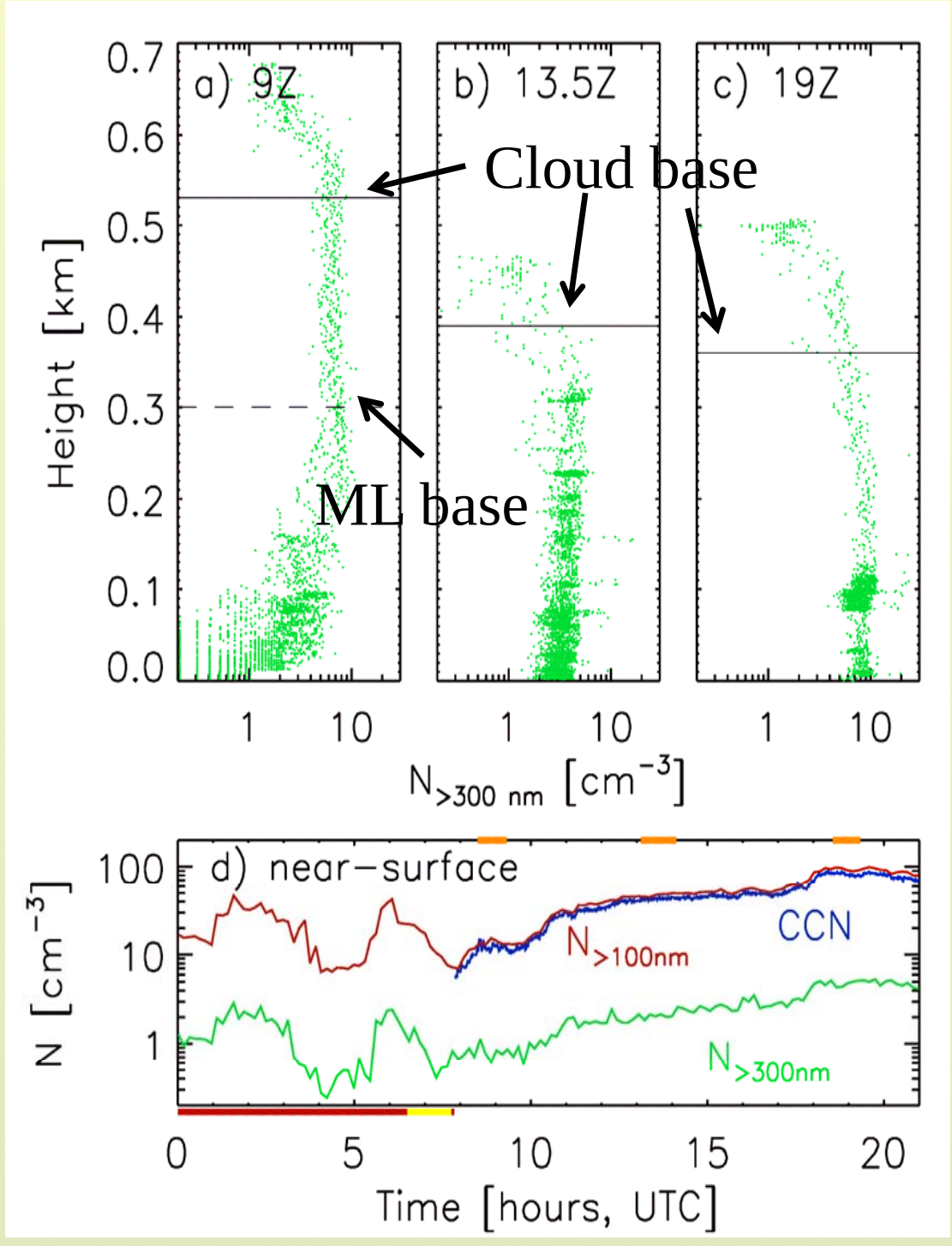
Mixed Layer: Cloud top radiative cooling leads to buoyancy-driven turbulent mixing over a layer that extends from near cloud top to some depth below cloud base. Conserved properties are approx. constant within this mixed layer.
Cloud-Surface Coupling: Proximity of the cloud-driven mixed layer to the surface determines the cloud-surface coupling state, which itself determines the extent to which cloud and surface interact.
The Transition: During this case, the low-level stratocumulus transitions from a decoupled state to a surface-coupled state. Decoupled state shows high turbulence associated with a mixed layer that is above the surface. Coupled state shows high turbulence mixing all the way down to the surface.
Response of Surface: Surface fluxes are always weak, and tend to respond to the cloud-atmosphere mixing processes rather than drive them.
Aerosol Source: Higher concentrations are observe in the decoupled mixed layer relative to the surface. Surface concentrations increase as coupling occurs. This suggests that the aerosols advected into the region with the airmass aloft.

Decoupled ⟶ Coupled



6-hourly radiosondes

Aerosol measurements & profiles



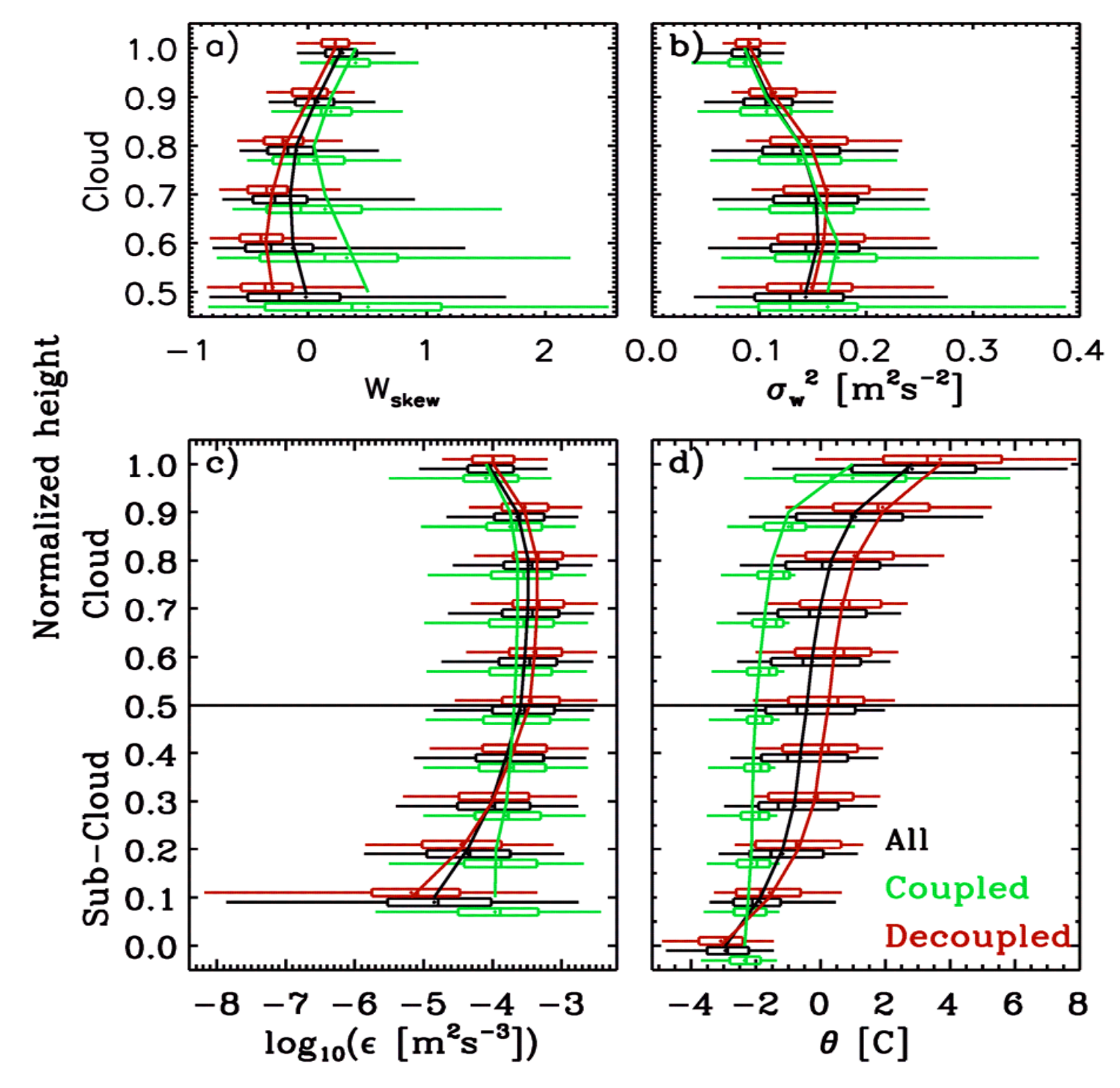
Key Findings

- ❖ Low-level, stratiform clouds are typically decoupled from the Arctic sea-ice surface due to stratification caused by warm air advection over cold sea ice and weak surface fluxes.
- ❖Decoupled clouds are still persistent, stressing the importance of in-cloud processes vs. surface forcing.
- ❖Surface coupling is determined by proximity of cloud to surface and the amount of ML cooling.
- ❖Cloud top is an important region (moisture inversion, cloud within inversion, distinct motions).
- ❖Cloud-active aerosols generally advect with air masses, rather than coming from local sources.

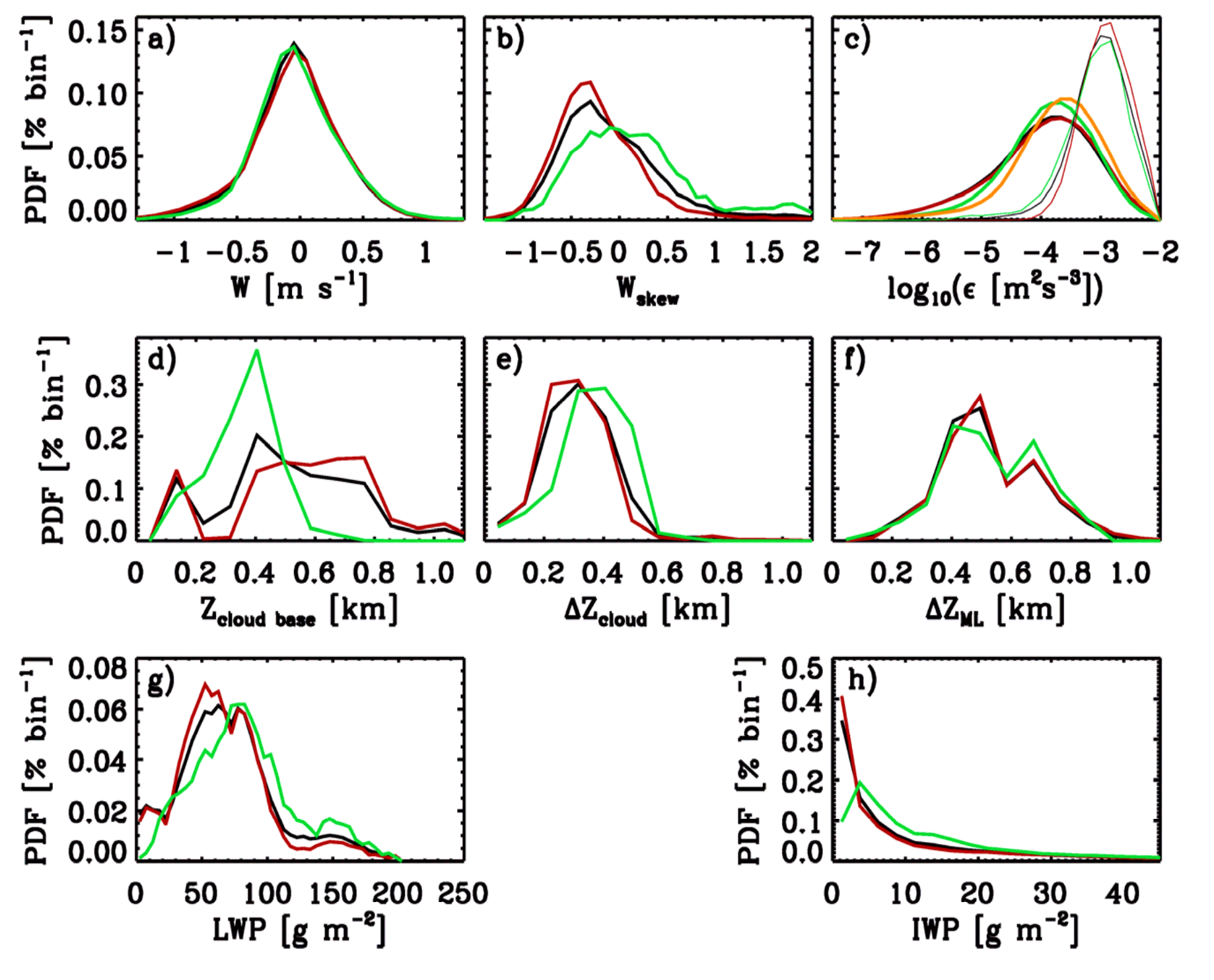
General Results

Results given here are for a week of observations. Cases are distinguished between all single-layer clouds (black), "decoupled" (red), and intermittently "coupled" (green). These periods are also shown in Fig. 1.

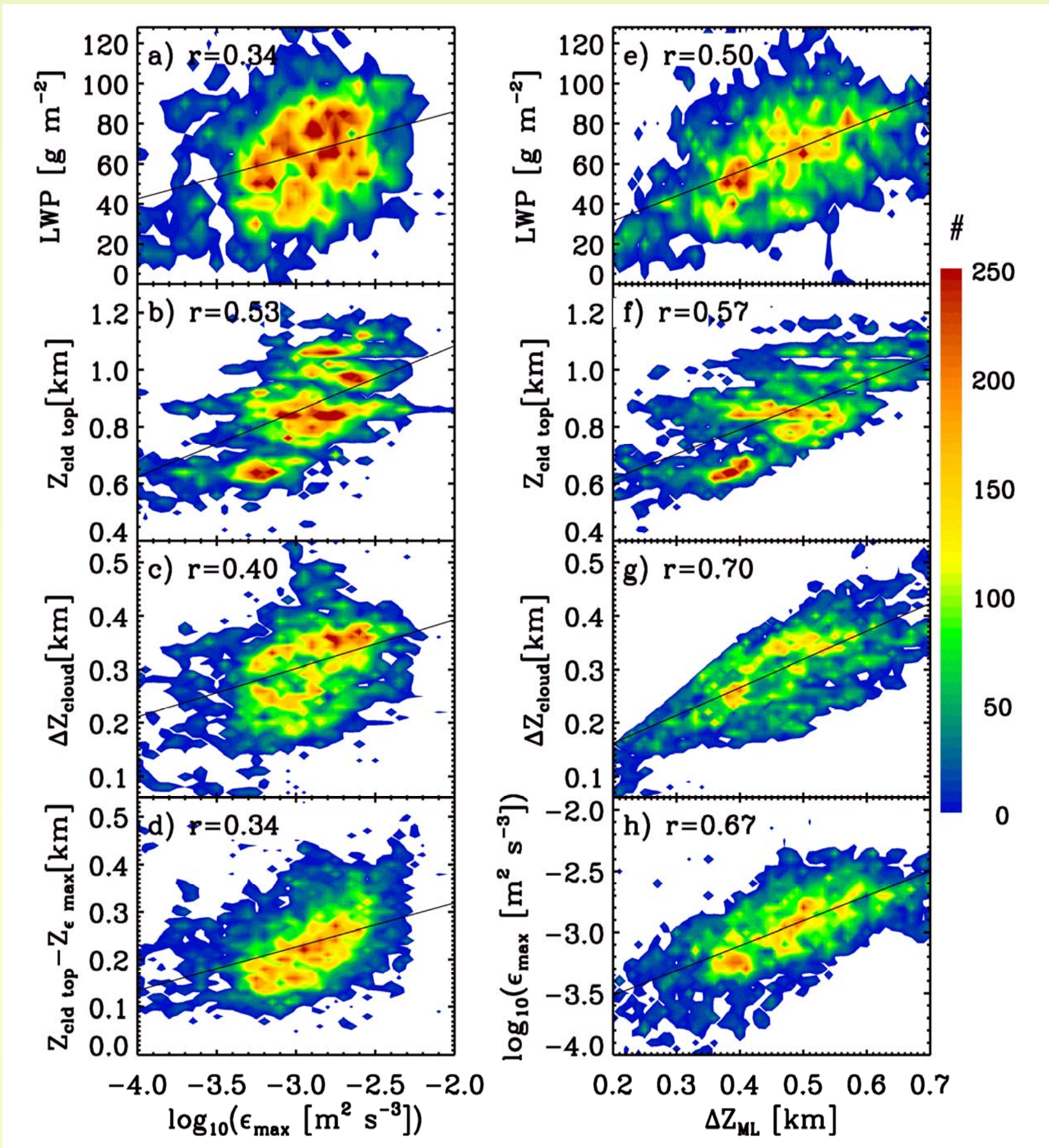
Vertically-Normalized Profiles



PDFs of Key Parameters



Multi-Parameter Relationships



- ❖ Vertical structures of turbulent dissipation rate and potential temperature show a consistent depiction of coupled vs. decoupled structure.
- ❖ Decoupled mixed layers are warmer than the temperature-regulated surface.
- ❖ W variance profile has characteristic shape for mixed-layer eddies.
- ❖ Potential temperature shows cloud extending into the inversion.
- ❖ W skewness profile increases at cloud top; motions above the inversion are on a difference scale than the eddies within the mixed layer.
- ❖ Coupled clouds often have higher LWP, are thicker, are lower, and have less negative W skewness , all perhaps related to moisture and energy sources from below.

The cloud-driven mixed layer depth is positively related to the cloud depth, LWP, cloud top height, and maximum turbulent dissipation rate in the ML.

These relationships demonstrate a healthy relationship between the presence of cloud liquid, the turbulence that is created from cloud top radiative cooling, the subsequent depth of vertical mixing, and the feedback on cloud formation.

Observational Methods

Cloud Boundaries –Cloud top identified using radar, cloud base identified using ceilometer.
Phase Classification – Combined radar, ceilometer, microwave radiometer, and radiosonde measurements (Shupe 2007).
Ice Microphysics (IWC and IWP) – Empirical radar reflectivity power law relationship (Shupe et al. 2005).
Liquid Water Path (LWP) – Derived from microwave radiometer measurements (Westwater et al. 2001).
Vertical Velocity (W) – From radar Doppler spectra, assuming liquid water droplets trace air motions (Shupe et al. 2008).
Skewness –Based on ½ hour of 4-sec. W estimates. Positive skewness indicates stronger, narrower updrafts, and visa versa.
Turbulent Dissipation Rate (ε) – From time-variance of radar mean Doppler velocity measurements (Shupe et al.2008).
Potential Temperature (θ) – Derived from scanning 60-GHz radiometer using interpolated radiosondes as initial guess.
Surface Turbulent Sensible & Latent Heat Fluxes (SH, LH) – Eddy covariance w/ met tower measurements and bulk flux method
Aerosol Concentrations – Surface and helicopeter-based particle counting instruments.