Observing Mixed-Phase Cloud Microphysical-Dynamical Processes

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Observational Methods

Analysis involves observations of single-layer, stratiform, mixed-phase clouds over the Arctic sea-ice by ground-based millimeter cloud radar, dual-channel 23- and 31-GHz microwave radiometer, 60-GHz profiling microwave radiometer, ceilometer, 449-MHz wind profiler, and radiosondes.

Cloud Boundaries –Cloud top identified using radar, cloud base identified using ceilometer.

Phase Classification – Uses phase-specific signatures from radar, ceilometer, microwave radiometer, and radiosonde measurements (Shupe, GRL 2007).

Ice Microphysics (IWC and IWP) – Empirical radar reflectivity power law relationship and assumed particle size dist'n and mass-size relationship (Shupe et al., JAM 2005).

Liquid Microphysics (LWC and LWP) – Adiabatic liquid water profile using cloud boundaries and temperature profiles, scaled using a liquid water path derived from microwave radiometer measurements.

Vertical Velocity (W) – From cloud radar Doppler spectra, assuming liquid water droplets are tracers for air motions (Shupe et al., JTECH 2008).

Skewness – Based on ½ hour of 4-sec. vertical velocity measurements. Positive skewness indicates stronger, narrower updrafts, and visa versa.

Turbulent Dissipation Rate (ε) – From time-variance of radar mean Doppler velocity measurements (e.g., Shupe et al., JTECH 2008).

Richardson Number (Ri) – From 449-MHz wind profiler measurements and radiosonde-constrained, 60-GHz radiometer temperature profiles. High values indicate stable stratification while lower values indicate neutral to unstable stratification.

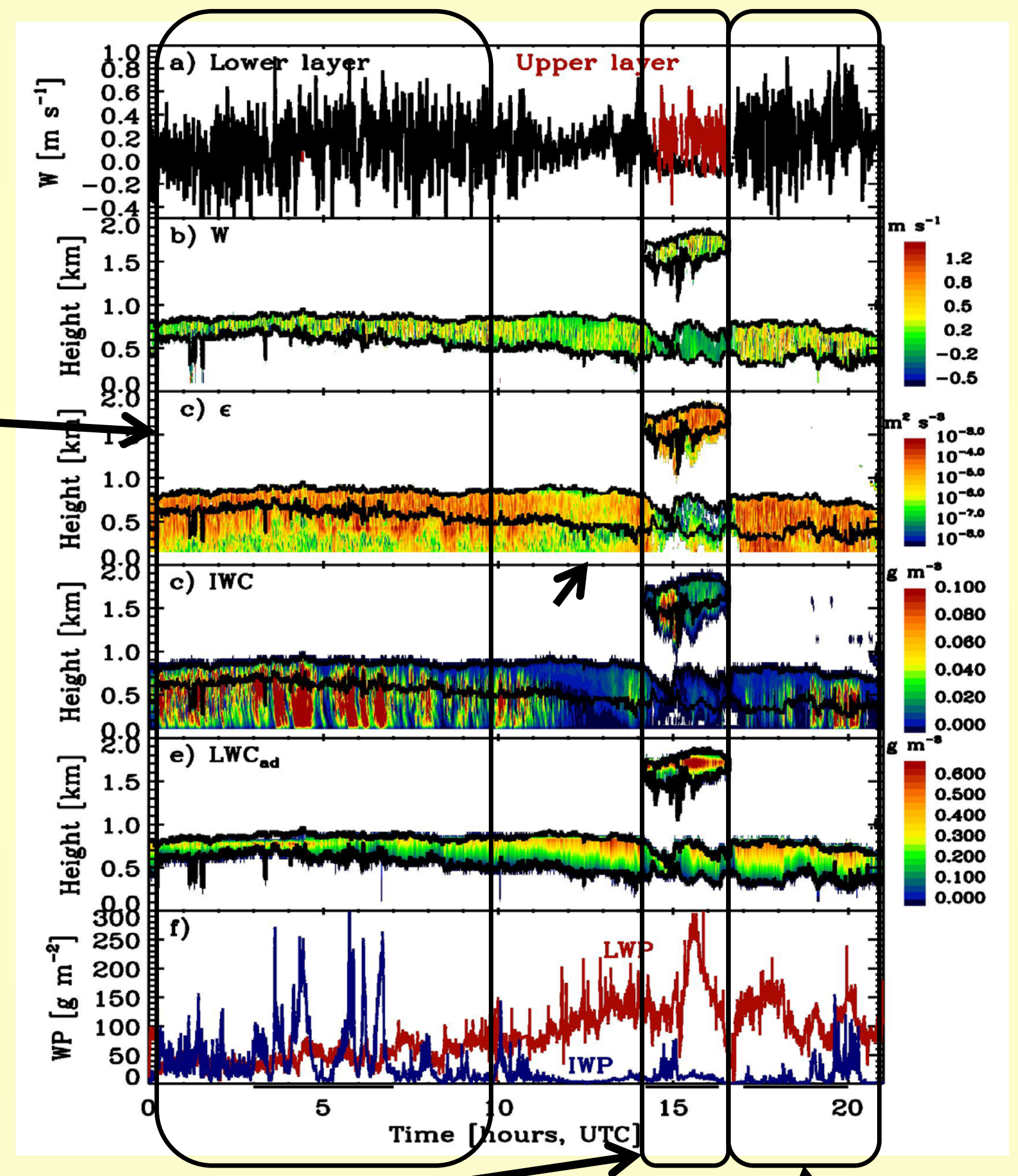
Updraft potential (Up) – Derived from Ri analysis. Temperature perturbation (warming) needed at the surface for a parcel to rise to a given height.

Downdraft potential (Down) – Derived from Ri analysis. Number of higher layers that would descend to a given vertical location when cooled by 0.5 degrees.

Summary

- **❖ Multi-sensor measurements can reveal a wealth of information on cloud dynamical-microphysical interactions.**
- **❖ Distinct signatures in vertical velocity, velocity skewness, turbulence, and Richardson number describe the dynamical interactions between cloud and surface.**
- **❖ Cloud top radiative cooling plays a key role in some transitions in the low-level stability.**
- **❖ Observations indicate good correlation between vertical velocity and condensed cloud water and ice in some cases, but a lack of correlation in others. Aerosol concentrations may contribute to these differences.**

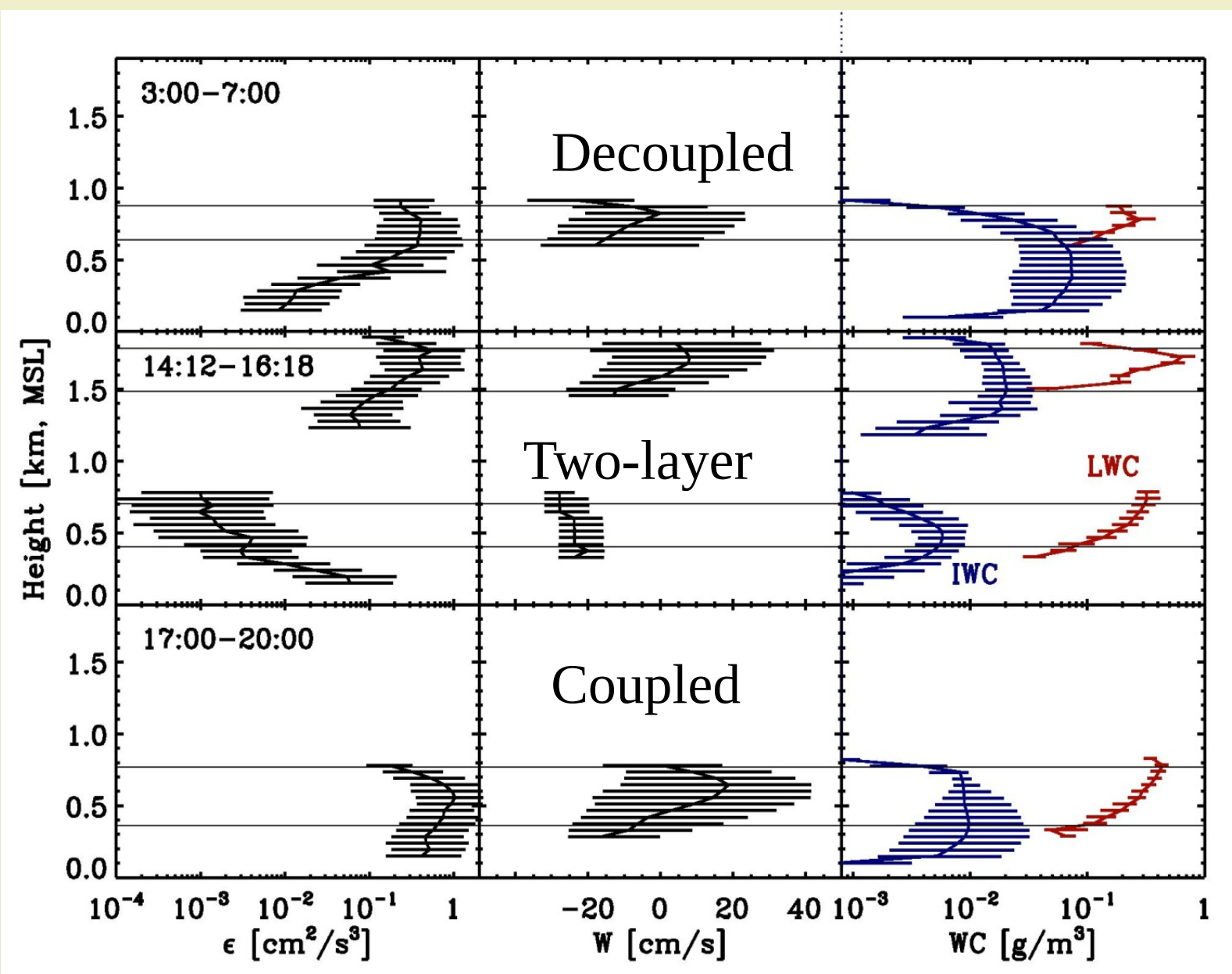
CASE 1

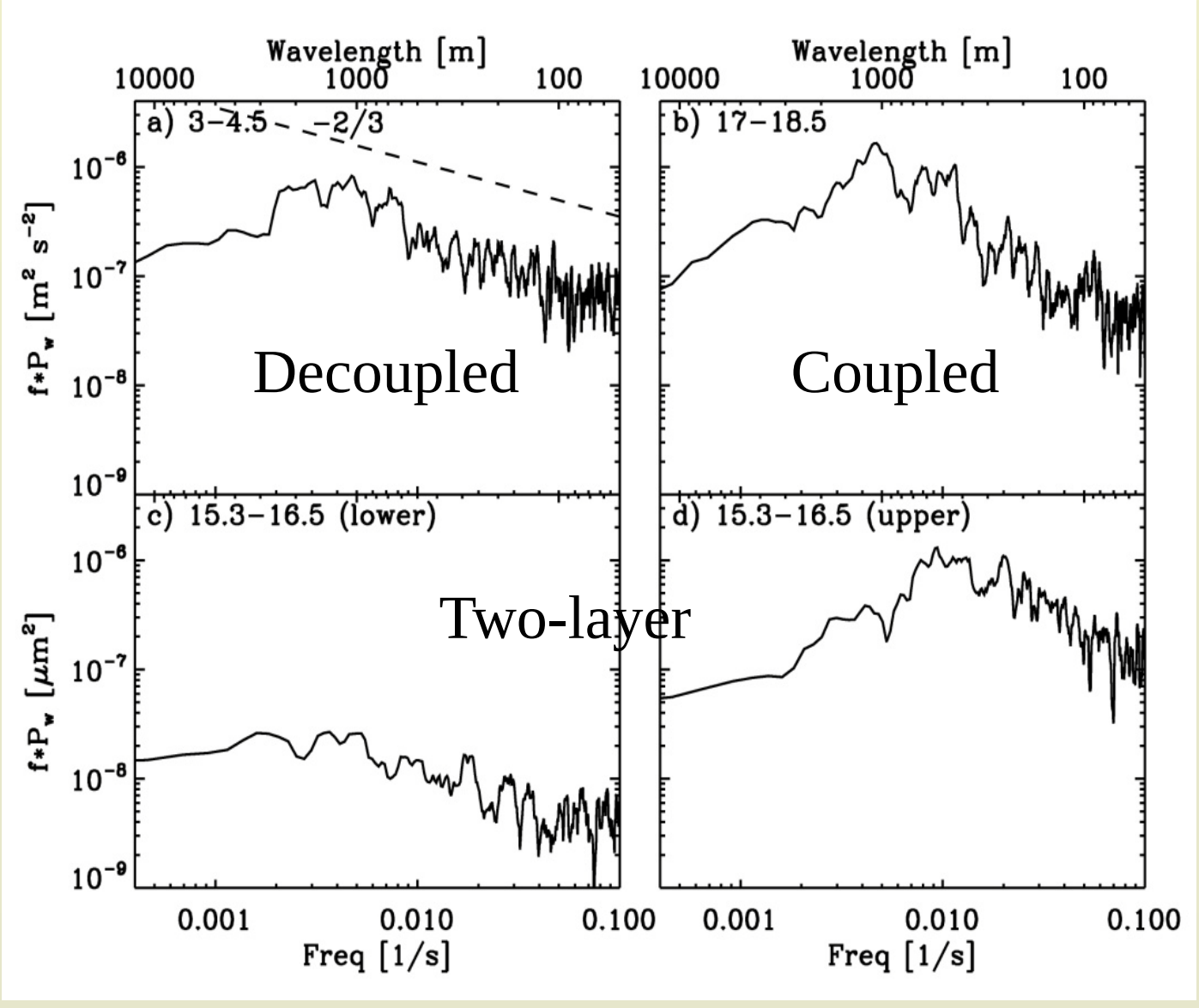


00:00-10:00 DECOUPLED:
Cloud decoupled from surface.
- Turbulent dissipation rate is a maximum within the cloud and decreases below towards the surface.
- Most prominent scales-of-motion at 0.5-3 km scales
- Periodic production of high IWP.

14:00-17:00 MULTI-LAYERED:
Two layers with radiative shading.
- Upper cloud layer shades the lower cloud layer, decreasing the lower cloud's ability to radiatively cool.
- Turbulence decreases in the lower layer, with a related decrease in liquid and ice production. This shows the importance of cloud top radiative cooling for buoyancy production.
- Turbulence in the lower layer is driven primarily from surface, dissipation rate decreases with height.
- Turbulence in upper layer is maximum within the cloud layer indicating radiative cooling.
- Predominant scales-of-motion in upper cloud 0.2-0.8 km.

17:00-21:00 COUPLED:
Cloud dynamically coupled with surface.
- Well mixed layer grows vertically from surface, meeting the cloud-mixed layer
- Turbulent dissipation rate approximately constant from cloud layer down to surface.
- LWP increase may be associated with the dynamical coupling which starts around 12:00.
- Predominant scales-of-motion 0.4-2 km



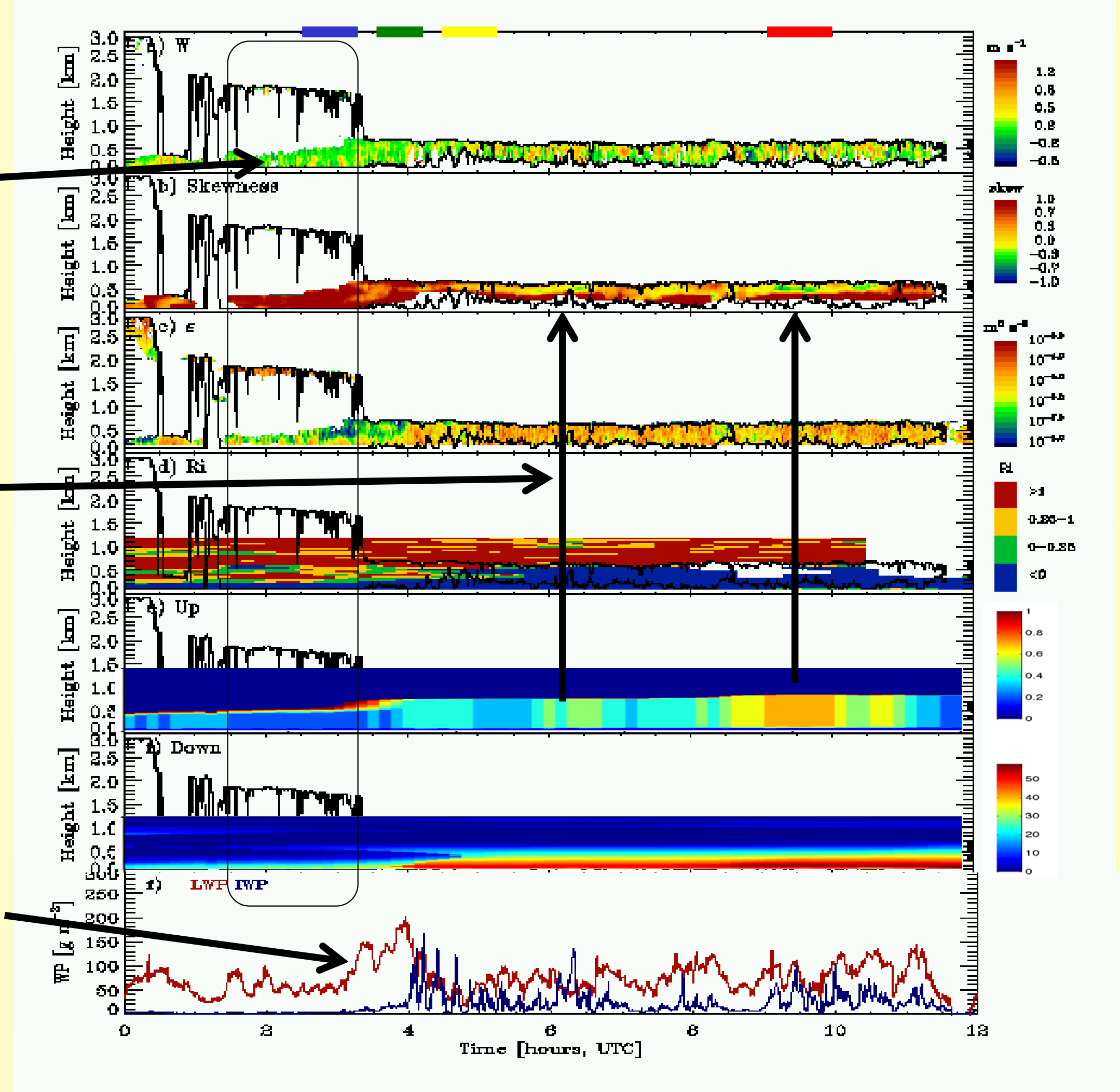


CASE 2

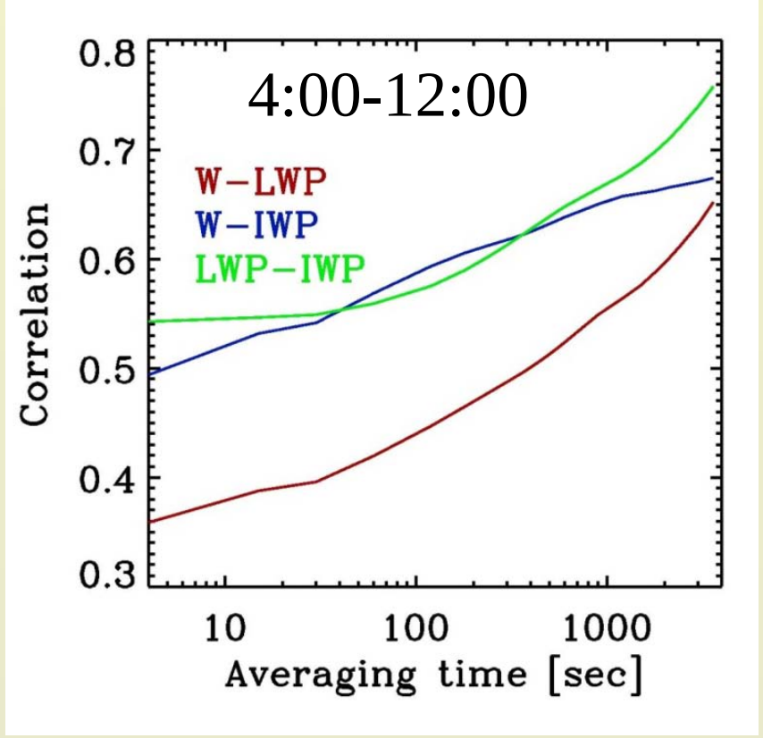
Surface-driven thermal plumes occur when lower cloud is shaded by upper cloud.

Periods of slightly more stability in the lower levels, lead to a decrease in the skewness, indicating a relatively stronger contribution from cloud top cooling towards generating buoyancy

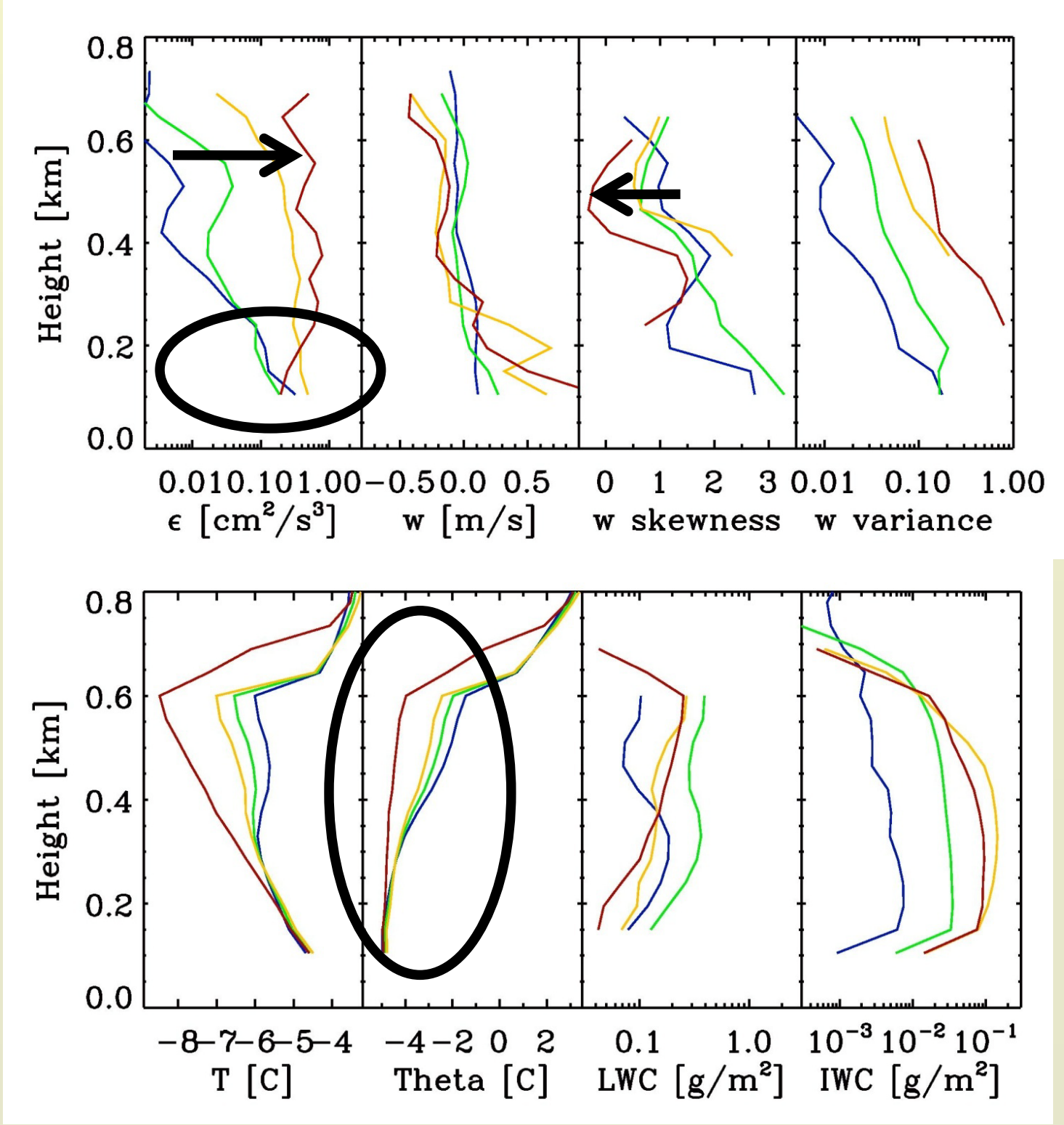
As the lower cloud becomes unshaded, there is a rapid production of liquid water, followed an hour later by increased ice production.



See an evolution during this case of
1) Increased turbulent dissipation at the cloud level while the surface turbulence is approximately constant in time,
2) Potential temperature profiles showing a growth of the surface-based, well-mixed layer
3) Skewness within the cloud decreasing from strongly positive (surface-forced) to near zero (both cloud radiative cooling and surface fluxes responsible for circulations).



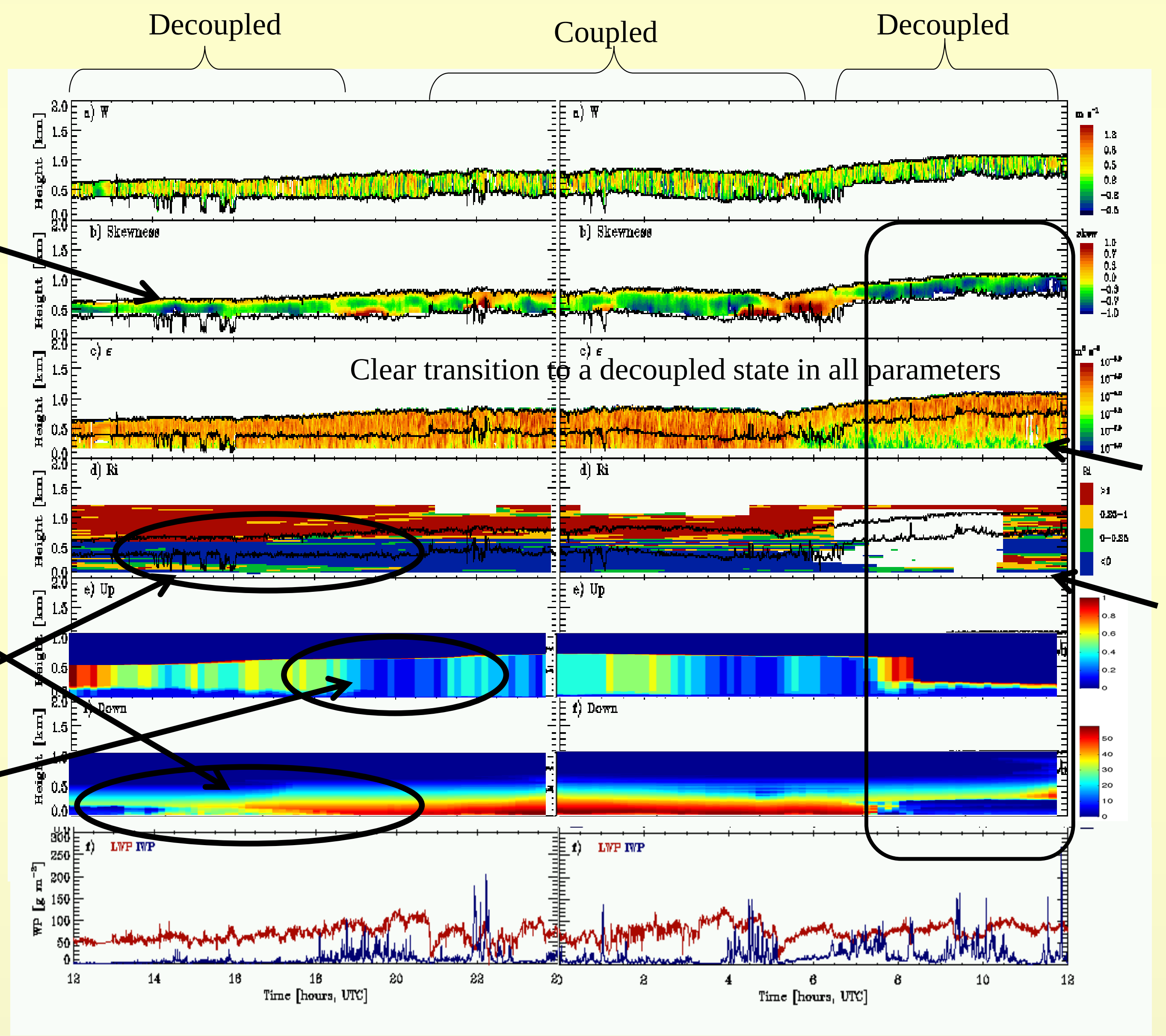
Reasonable correlation among liquid, ice, and vertical velocity. Correlation increases with averaging time, indicating better correlation for larger-scale features.



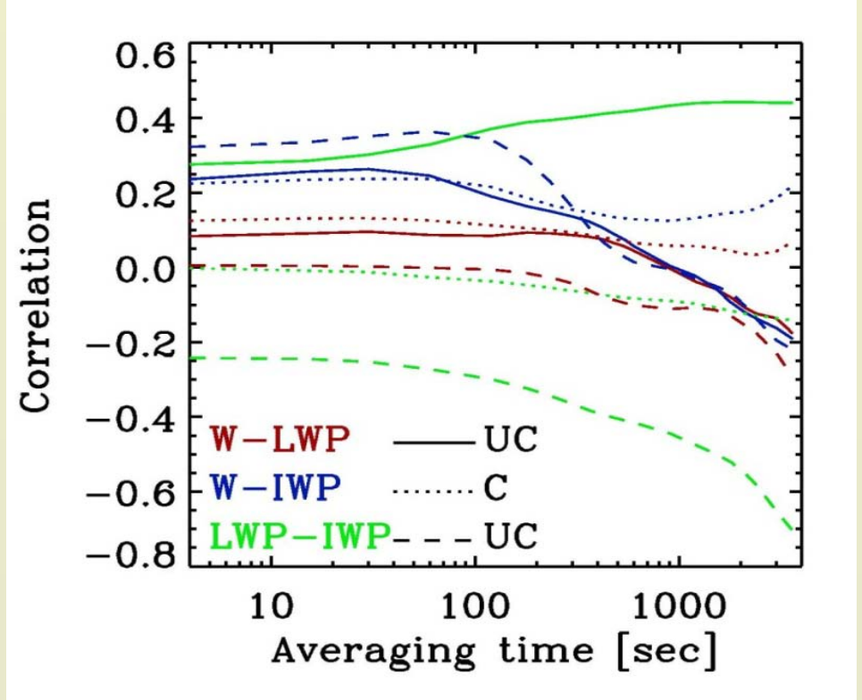
CASE 3

Slight increase in skewness at cloud top is associated with cloudiness extending above the inversion.

Cloud-driven circulations deepen, eroding the low stable layer, eventually initiating surface-forced updrafts and a coupling between surface and cloud.



Multiple transitions occur, with similar signatures to the other cases. In this case, the cloud top turbulence remains relatively constant while the near-surface turbulence changes depending on the stratification (or not) between cloud and surface. With higher turbulence near the surface, the skewness becomes more positive.



In this case, however, the microphysics are generally not well correlated with the vertical velocity from the zenith-viewing perspective