Turbulence Profiles and Cloud-Surface Coupling in Arctic Stratiform Clouds

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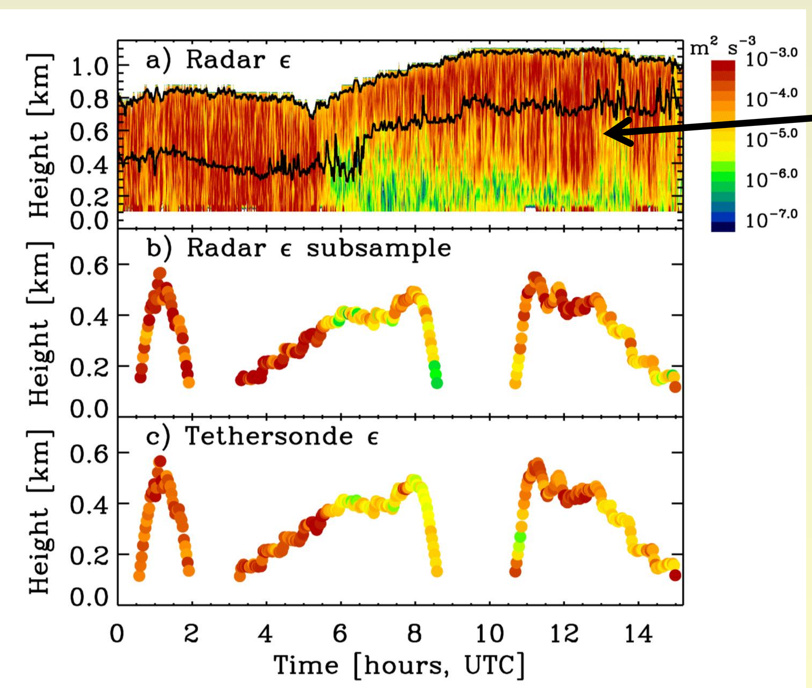
Turbulent Dissipation Rate Retrieval



Measurements and Retrieval Method

Turbulent dissipation rate (ε) is derived from the temporal variance of the vertically-pointing, 35-GHz MMCR radar mean Doppler velocity measurements.

$$\varepsilon = 2\pi\left(\frac{2\sigma_{vm}^2}{3A\left(L_l^{2/3} - L_s^{2/3}\right)}\right)^{3/2}.$$

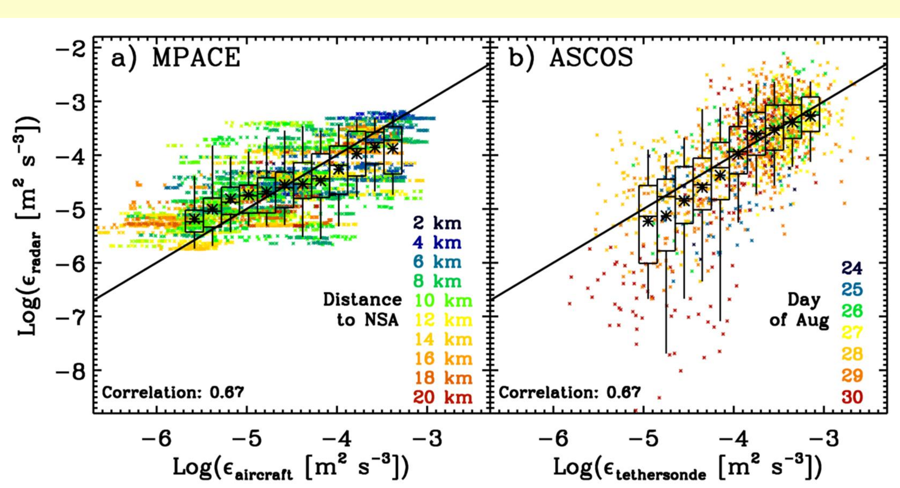
σ^2_{vm} = MDV variance over ~60 seconds
L_l=U t + 2 R sin (θ/2) = length scale for given sample time (Two time scales are 1 and 60 sec)
A = Kolmogorov constant
U = horizontal wind speed (radiosonde)
θ = radar beam width

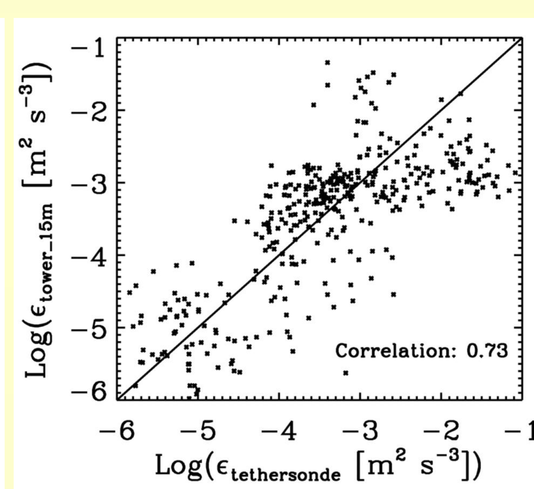
Evaluation Data Sets (Barrow and Arctic Ocean)

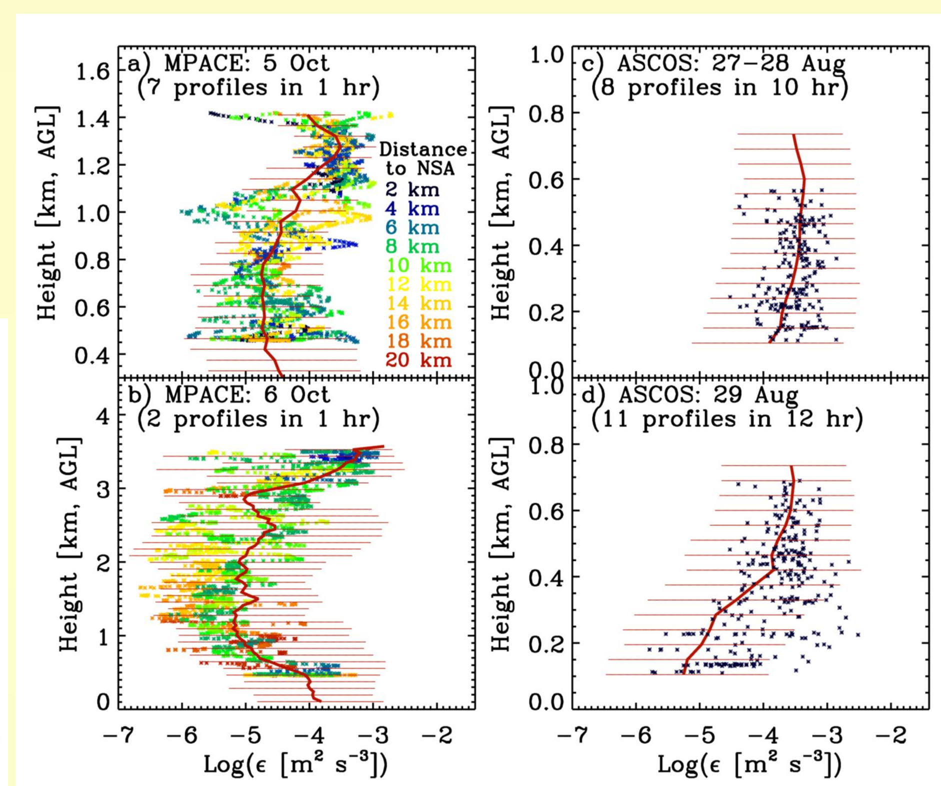
1) NSA evaluation is done using dissipation rates derived from in situ pitot tube measurements from the University of North Dakota Citation aircraft during MPACE.
2) ASCOS evaluation is done using dissipation rates derived from a sonic anemometer hanging from a tethered balloon.
3) ASCOS tethersonde measurements are compared to similar sonic anemometer measurements from a nearby tower (i.e., identical measurement & dissipation rate derivation)

Methods of Comparison

1) *Point-to-point*: Retrieved values sampled at same time and height as in situ measurements w/ variable spatial distance
2) *Profiles*: Retrieval mean and 5-95th-% range over the times of in situ measurements
3) *Histograms*: Include all comparison points (time-height match)
4) *Statistics*: All values in the table below are computed based on the $\log_{10}$ of the dissipation rates due to their variation over 4 orders of magnitude.







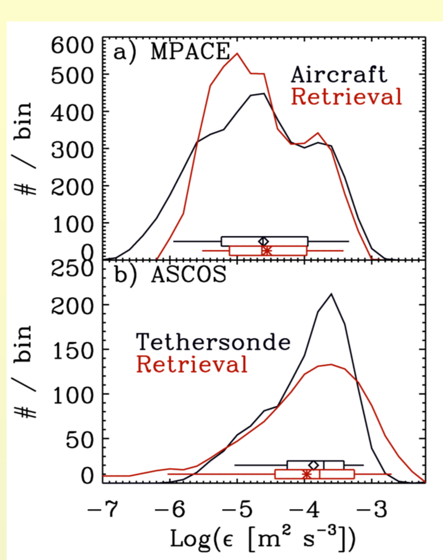


Table of Comparison Results

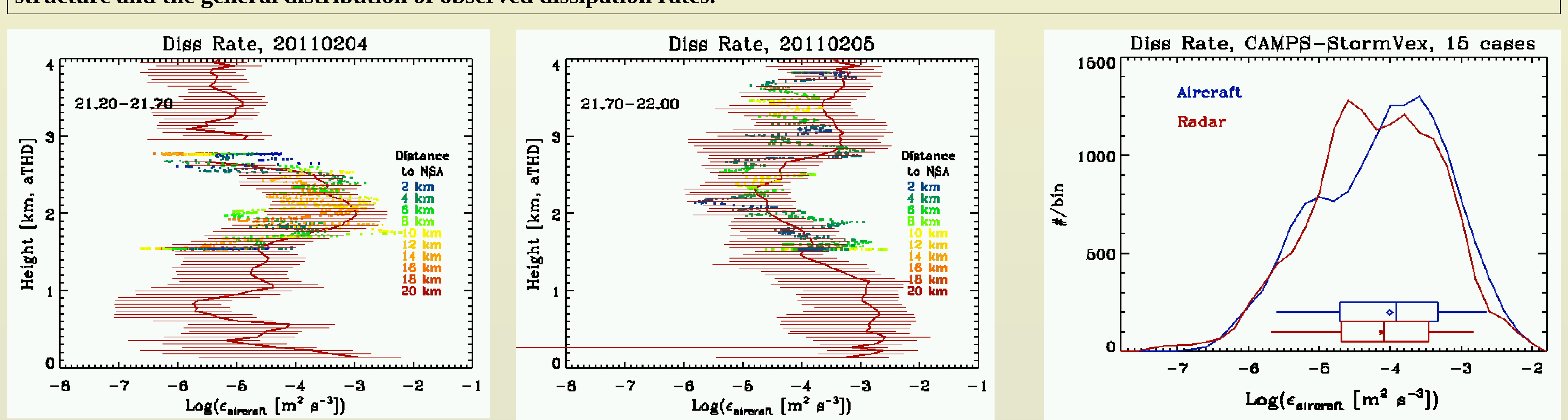
		MPACE	ASCOS	ASCOS sonic	StormVex
Root Mean Square Difference	Total	0.61	0.75	0.78	0.93
	Range	0.5-0.6	0.5-1.0	0.5-0.9	0.75-1.1
Mean Absolute Difference	Total	0.48	0.55	0.62	0.72
	Range	0.4-0.5	0.4-0.8	0.4-0.75	0.6-0.9
Bias	Total	0.01	-0.01	-0.04	-0.03
	Range	-0.10 to 0.08	-0.05 to 0.01	-0.17 to 0.09	-0.15 to 0.13

Key Results

- Radar is able to capture basic vertical structure with integrity
- Relative consistency between ASCOS and MPACE comparisons in terms of numbers but not in terms of high and low biases
- ASCOS evaluation suggests that radar-sonic comparison is as good as sonic-sonic comparison.
- RMS values are generally well within an order of magnitude
- The retrieval appears to work well in mountainous mid-latitude terrain using W-band radar as well (see below)
- *Radar is able to derive continuous profiles of the dissipation rate (when hydrometeors are present), which is a much better perspective for studying cloud processes than a single point measurement.*

Further Evaluation in Mid-Latitude, Mountainous Terrain

Similar retrievals have been applied to W-band radar measurements from the Storm Peak Cloud Properties Validation Experiment (StormVEx) in Steamboat Springs, CO. Comparisons are made in the same way as for the Arctic cases, but use in situ measurements from the University of Wyoming King Air flying over the ground-based sensors. Initial comparisons again show that the retrieval is able to capture both the vertical structure and the general distribution of observed dissipation rates.



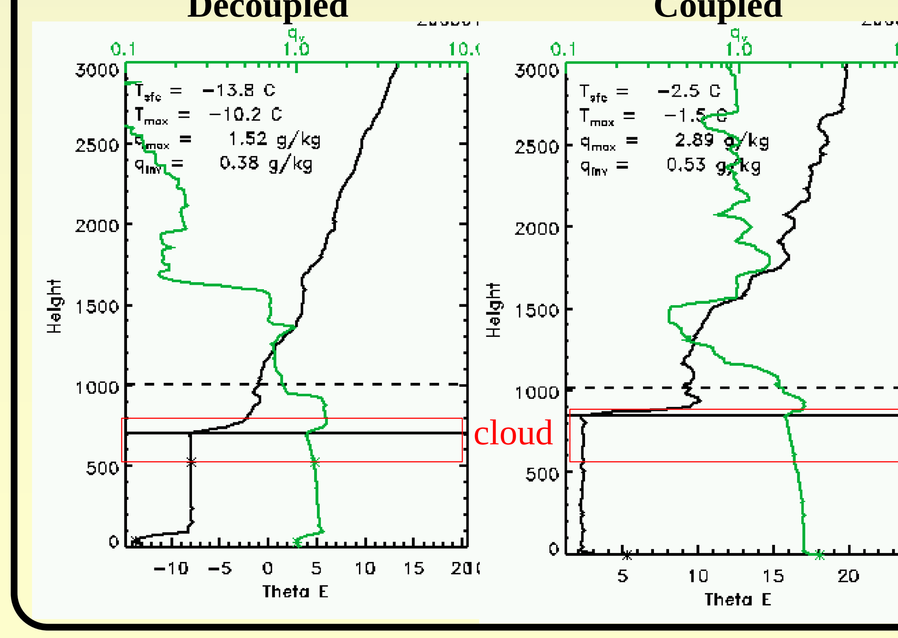
Cloud Coupling State

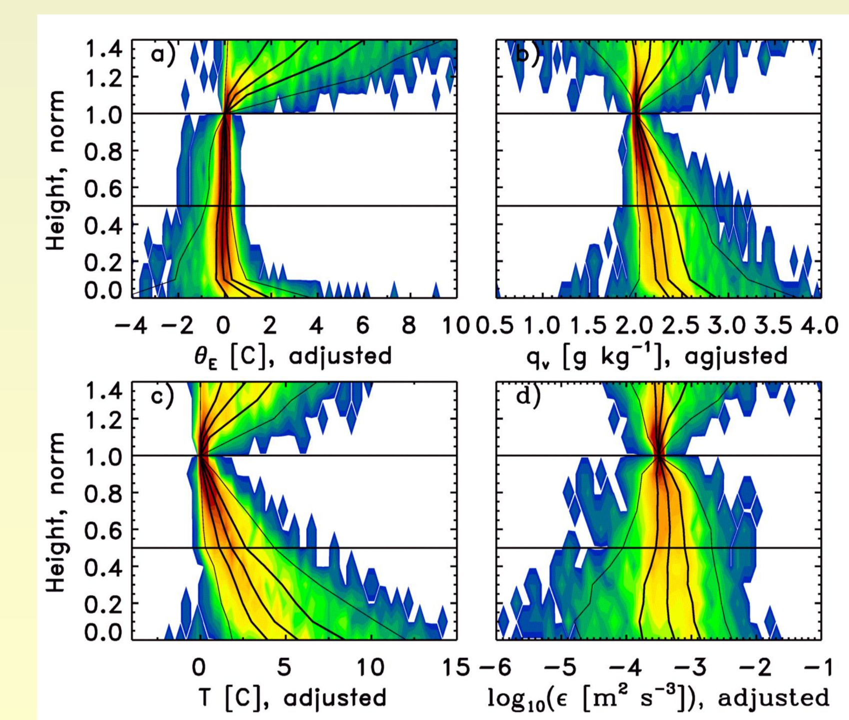
"Coupling state" refers to the interactions between a cloud layer and the surface, specifically via atmospheric mixing processes. It has implications for the cloud life cycle as it controls the energy and moisture contribution to the cloud from the surface. This panel examines the coupling state of Arctic stratiform clouds (<3 km), most of which (but not all) are mixed-phase.

Characteristic Signatures

A constant equivalent potential temperature from cloud to surface indicates coupling, while a decrease indicates decoupling. Here a decrease of 0.5 C denotes decoupling. Notice also the humidity inversion at cloud top

Decoupled Coupled



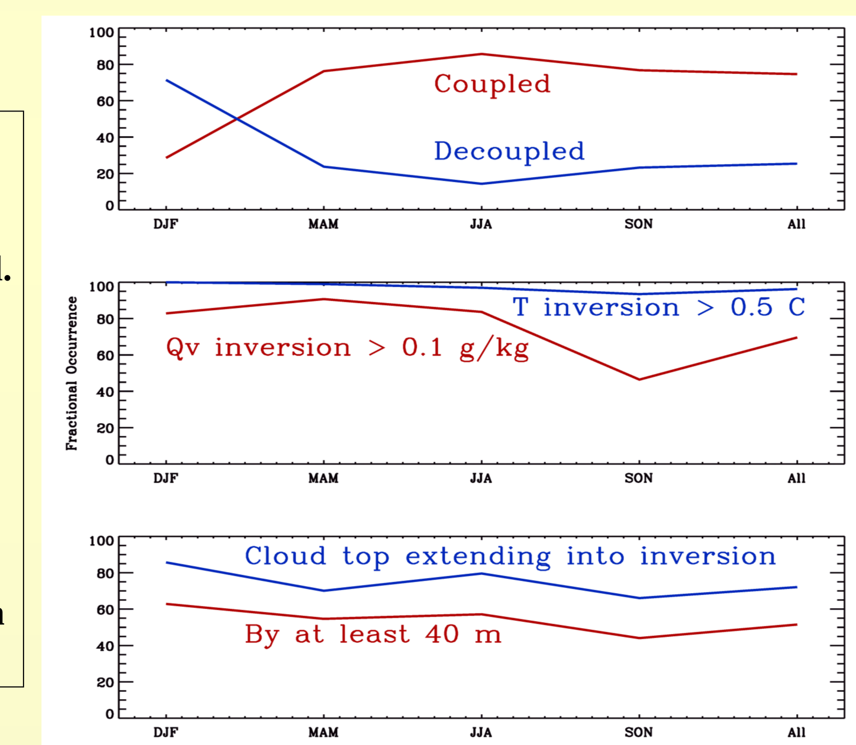


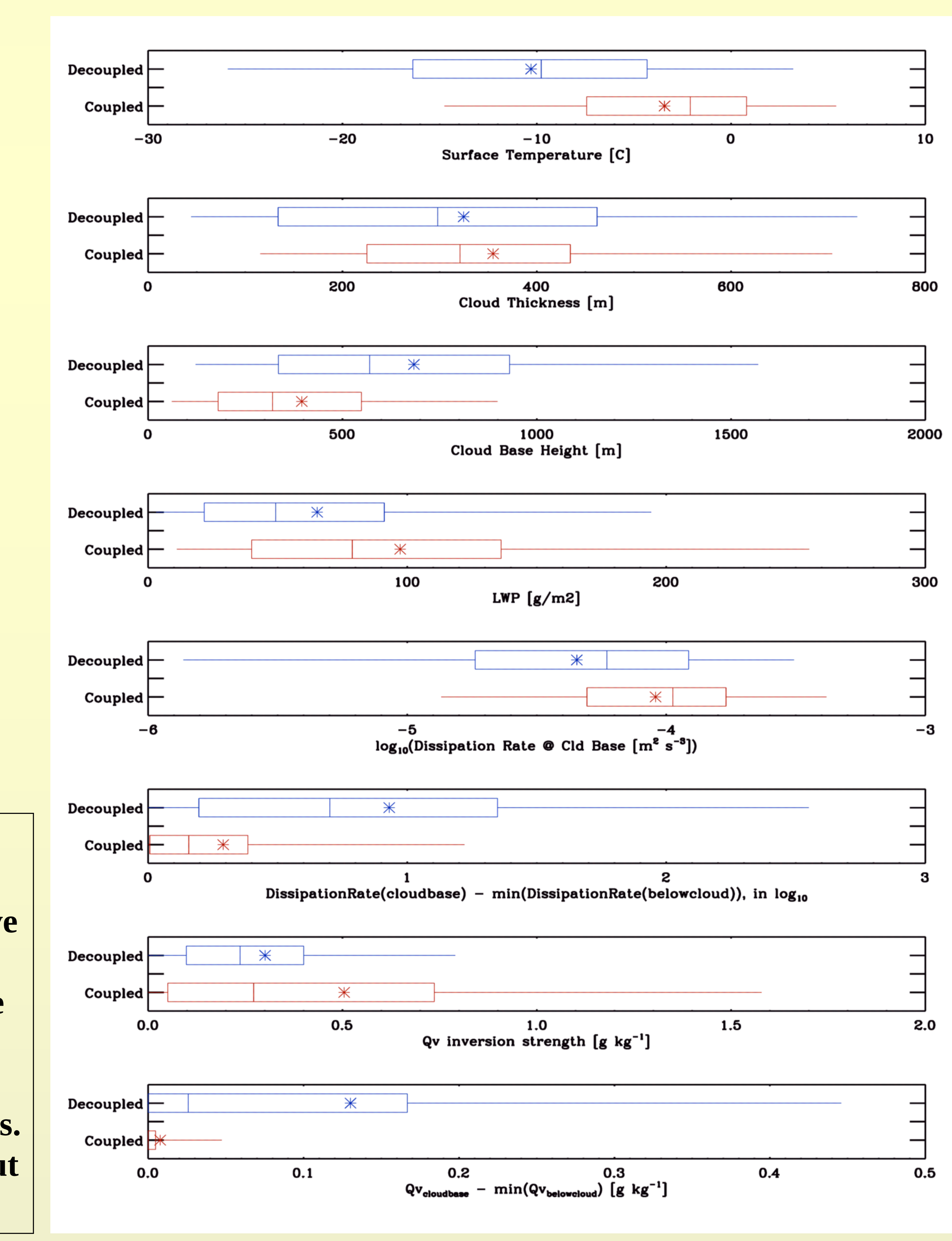
Probability Distributions

- Analysis of all stratiform clouds <3km, NSA 2002-2009
- Normalized in height (0=surface, 0.5=cloud base, 1.0=inversion base, 1.4=cloud top if extends into inversion)
- PDFs computed at each height. Black lines are 5, 25, 50, 75, 95th percentiles.
- Frequent constant θ_E in vertical with typical T inversion at cloud top.
- Frequent q_v inversion at cloud top with typical maximum q_v near surface.
- Turbulence can increase or decrease with height.

Occurrence Frequencies

- More frequent surface-coupled clouds in non-winter months, 75% total.
- 25% of clouds are decoupled from surface.
- T inversion is almost always present
- q_v inversion frequent in non-autumn months.
- Cloud top usually extends into the inversion layer.





Characteristics of the Coupling State

- Cloud-surface coupling is most frequent with warmer temperatures
- Coupled clouds are lower and maybe a little thicker physically, and generally have a higher liquid water path.
- Coupled clouds have higher turbulent dissipation rates near cloud base with little (if any) decrease in dissipation rate below cloud base, while the dissipation rate drops significantly below decoupled clouds.
- Somewhat stronger cloud top moisture inversions are observed for coupled clouds.
- Specific humidity increases below the cloud base for almost all coupled clouds, but decreases below the cloud base value for most decoupled clouds.

Summary

❖ Turbulent dissipation rate can be derived with integrity from vertically-pointing cloud radar measurements, providing important perspectives on the time-height evolution of turbulence.
❖ Turbulence profile information is consistent with radiosonde information when determining the coupling state of low-level Arctic stratiform clouds.
❖ Low-level Arctic stratiform clouds are decoupled from the surface approx. 25% of the time.
❖ Moisture inversions at cloud top are frequent and lead to cloud top extending into the inversion.