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Observed Low-Level Cloud and Related Boundary Layer Characteristics Preceding Severe Cold-Season QLCSs over Northern Alabama

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Brief Background and Motivation

1. NWP within the SE cool-season environment has been challenging (Cohen et al. 2015)

- High-Shear, Low CAPE (HSLC): Marginal CAPE, Large wind shear
- Rapid environmental changes, boundary layer in particular (King et al. 2017)
- Incomplete knowledge of boundary layer processes and structure, HSLC in particular

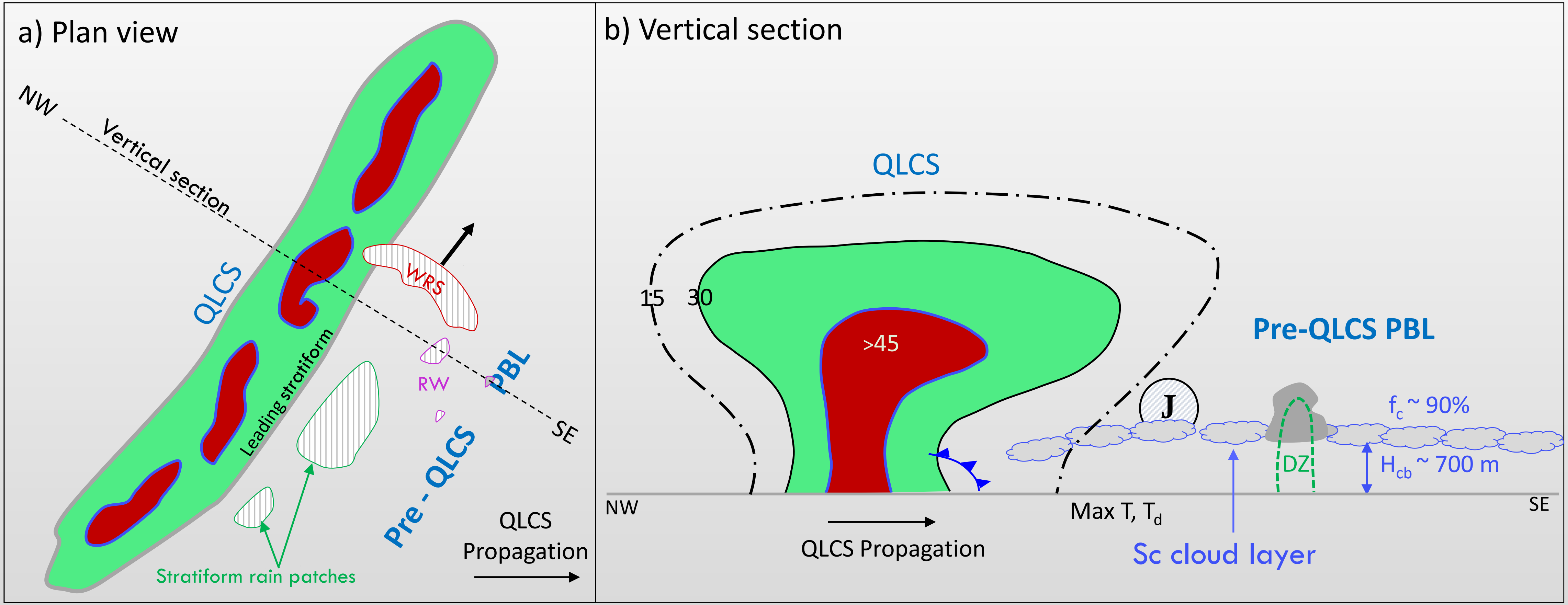
2. Characteristics of Sc clouds and associated PBL in HSLC environments have not been fully explored

- Premise: Sc clouds play an important role in, and provide insights on, BL processes.
  → The diurnal cycle of near-surface temperature (θ_e) variation is diminished.
- Premise: The PBL within cool-season HSLC environments is typically statically stable ($\frac{\partial\theta}{\partial z} > 0$), even during daytime. As a result, vertical wind shear is greater than that observed in traditional mixed layers ($\frac{\partial\theta}{\partial z} \approx 0$), since buoyant production would serve as a sink in production of TKE.

3. This study is one of the basic components of our work on PBL temporal and spatial variability.

- New research thrust on the Rain-Induced Transition (RIT, Matthew Starke), with similar physics to the AET.

Features of interest within the Pre-QLCS PBL



Features of interest include:

1. Precipitation ahead of the QLCS

- Leading stratiform
- Stratiform patches
- Showers (RW) and Wave Reflectivity Segments (WRS)

2. Sc cloud layer

- Cloud fraction (f_c) – mean value is ~90%
- Cloud base height (H_{cb}) – mean value is ~700 m AGL
- Mesoscale variability in both f_c and H_{cb}

Primary objectives

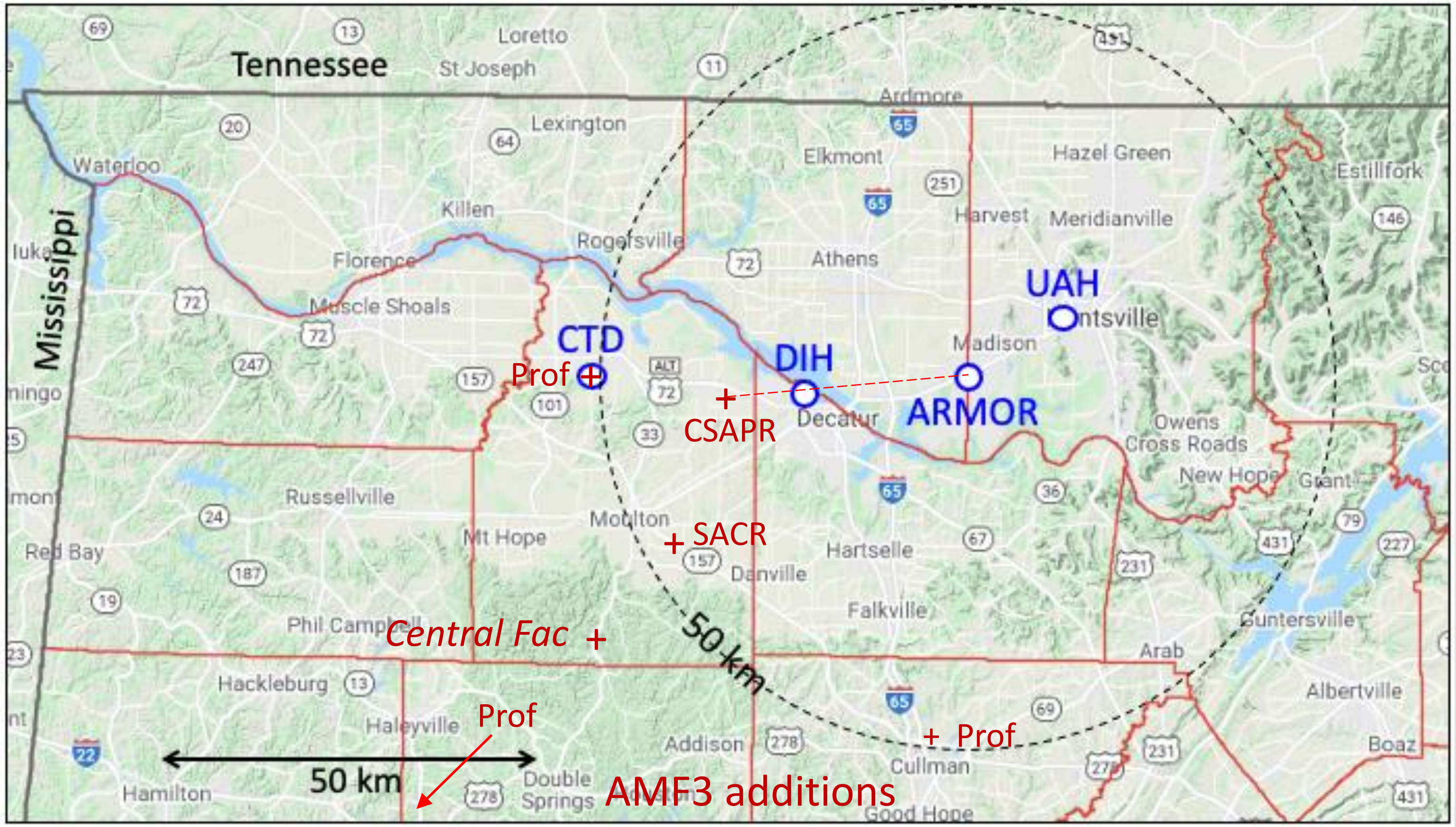
1) Define the characteristics of stratocumulus (Sc) clouds in the HSLC environment
    a) Cloud fraction
    b) Cloud base height
2) Characterize the boundary layer properties preceding cool-season QLCS's
    a) BL depth
    b) BL stability
    c) Rapid evolution and spatial heterogeneity
    d) Relation to Sc cloud characteristics

- Serves as on starting point for characterization and improved understanding of BL spatial and temporal variability in this complex, marginal, but yet sometimes very potent, environment.

Data sources and locations

Location: Northern Alabama
- UAH – primary location
- CTD, DIH – supplemental locations

Data sources:
- Lidar Ceilometer (Vaisala CL51) ✓
- Doppler lidar (Halo Streamline) ✓
- Balloon soundings (iMet-4, Windsond) ✓
- ARMOR C-band radar ✓
- 915 MHz wind profiler
- Microwave radiometer
- Surface data (T at 0.5, 1, 2, and 10 m; wind at 10 m) ✓
- Photos (IPhone 12, Roundshot) ✓



Total number of cases: 53 (2005-2022), Nov – mid-March
→ full spectrum: null cases to regional tornado outbreaks

MIPS – Mobile Integrated Profiling System
RaDAPS – Rapidly Deployable Atmospheric Profiling System
MoDLS – Mobile Doppler Lidar and Sounding system
MAX – Mobile Alabama X-band dual polarization radar

mAPNet
Mobile Atmospheric Profiling Network

Primary cases (selected from 53, based on comprehensive data available). Listed in chronological order

#	Date	Time UTC	f_c %	H_{cb} m	t[1] h	T/T_d °F	SLS[2] °F	V_{10} m s^{-1}	V_{1km} m s^{-1}	CAPE J kg^{-1}	SRH m^2 s^{-2}	SVR[3]	Comments
S	3/1/17 supp.	1920	84	880	14.5	74/62	-0.49	6.1	24	unk	unk	WH	Long lifetime, steady Hcb, sndg from SM; good pics
1	11/6/18	0730	100	620	12	74/68	0.57	6.3	32	200	420	WT	Warm adv., leading stratiform
2	2/12/19	1200	100	600	>6	65/61	0.60	4.0	24	200	200	none	Suppressed TKE, DWL
3	2/12/20	2330[c]	20[c]	480[c]	unk	69/65[c]	0.05	8.5[c]	34[c]	150[c]	520[c]	WT	Strong adv., stable BL; DWL
4	3/27/21	0900	95	650	4	73/66	0.08	5.7	28	760	370	W	Nocturnal appearance; DWL
5	12/11/21	1300	60	670	12	72/64	0.40	7.3	31	500	430	WT	Breaks in line, 2nd cloud layer
6	3/7/22	1545	75	740	7	71/63	-0.02	7.5	26	150	210	none	Weak synoptic forcing, 2nd, 3rd cloud layers

Footnotes:

[1] Time of Sc appearance prior to QLCS arrival. [2] Surface Layer Stability, SLS = $T_{10m} - T_{1m}$. [3] SVR - Severe reports: W – wind, T – tornado

[c] Observations from Courtland Airport (CTD), otherwise from UAH

Case 1: 6 November 2018 (Meso18/19)

Abundant tornado reports within the region

Long period of Sc (>12 h) observations

f_c = 100%, H_{cb} = 620 m

Stable (0.57), middle of nocturnal period

0-1 km bulk shear = 26 m s^{-1}, SRH = 420 m^2 s^{-2}, CAPE = 200

Case 4: 27 March 2021

Wind damage reports, unconfirmed tornadoes

Short period (4 h) of Sc observations, nocturnal formation

f_c = 95%, H_{cb} = 650 m

Weakly stable (0.08), middle of nocturnal period

0-1 km bulk shear = 22 m s^{-1}, SRH = 370 m^2 s^{-2}, CAPE = 760

Sc cloud appearance (3 cases)

a) Case with low f_c (~20%), highly sheared. Unusual case with low f_c.
b) Nocturnal formation of Sc layer.
c) Sc clouds revealing mesoscale structure.

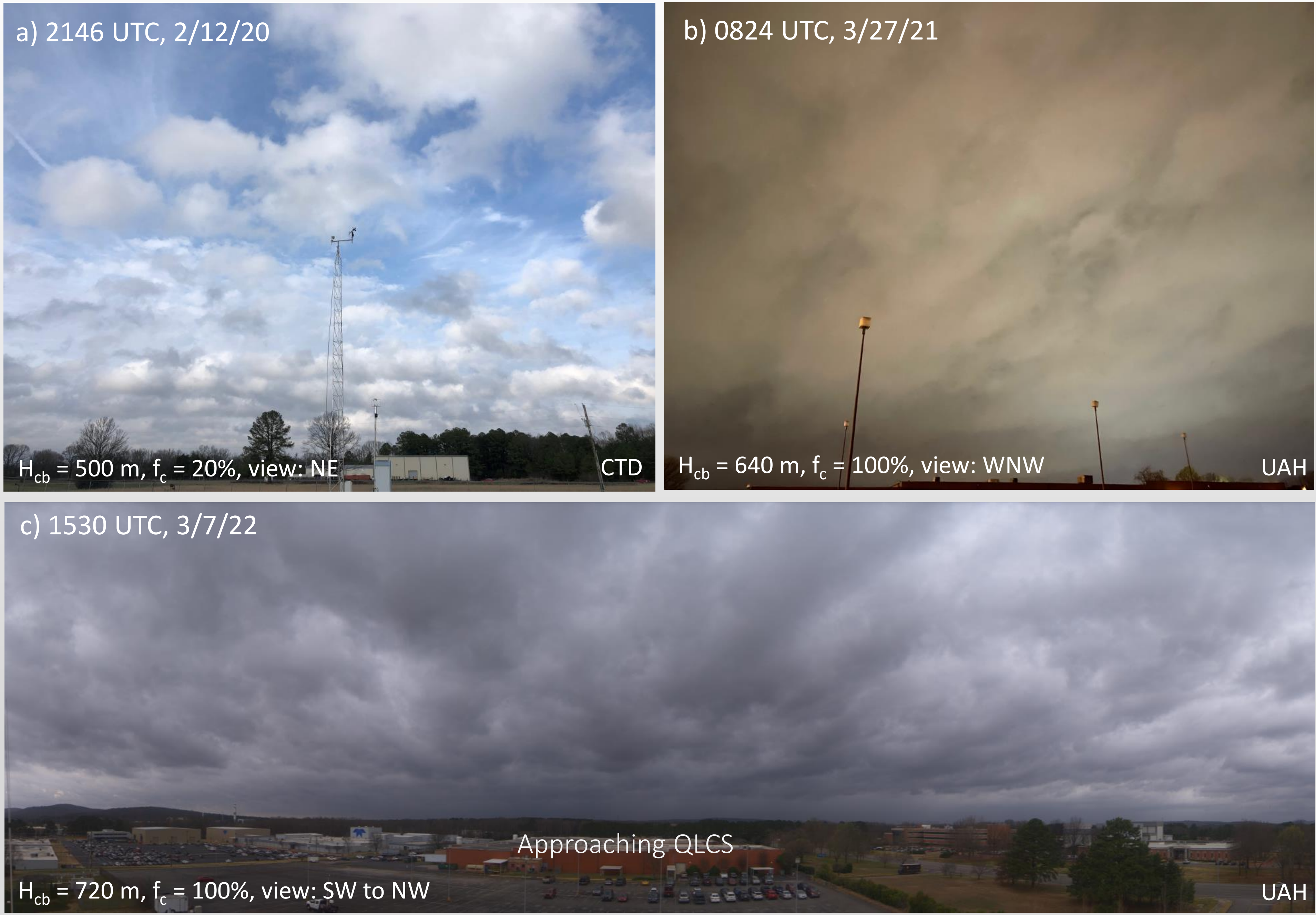
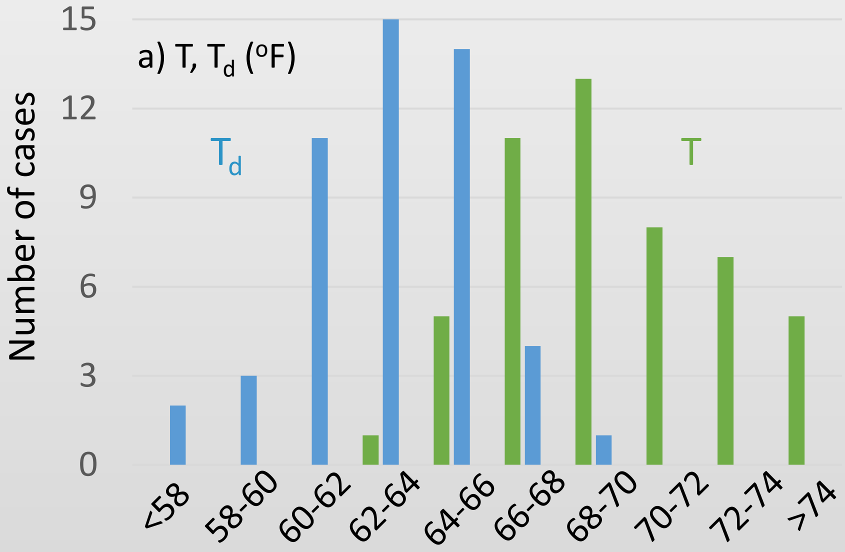


Figure 4. Photos of Sc clouds for three cases described in Section 5. The lower left-hand numbers define cloud base height (Hcb) and cloud fraction (fc). The lower right-hand characters define the location. The view directions are also annotated.

Distributions from the entire data set

→ surface properties

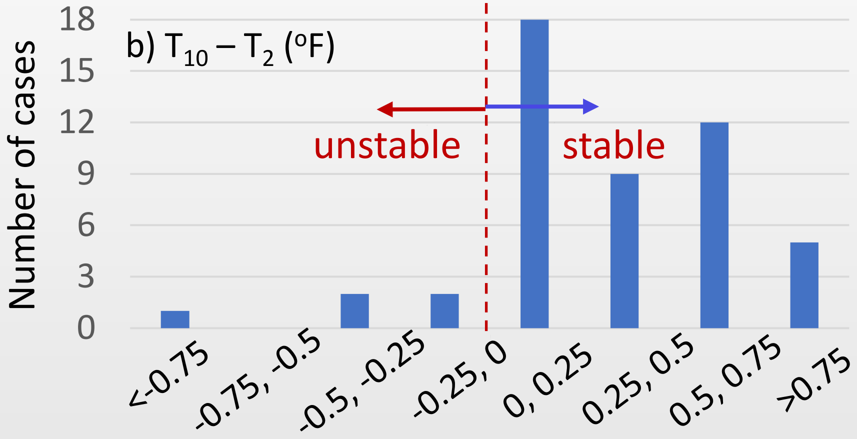
a) Temperature (T) and Dew Point Temperature (T_d) at 2 m



- Mean T = 69 F
- Mean T_d = 63 F

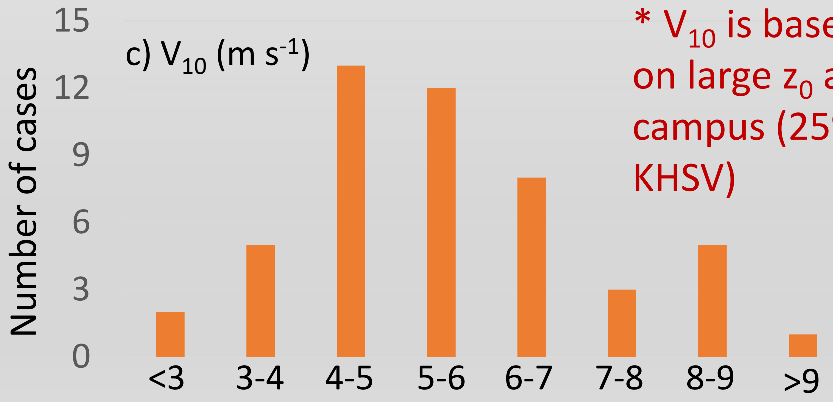
Figure 5. Statistics of surface conditions derived from the 53 case data set. (a) Temperature (T, orange) and dewpoint temperature (T_d, blue). (b) Surface layer stability, expressed as the difference between temperature at 10 and 2 m. (c) Wind speed at 10 m. All are based on 30 minute averages during the 30-60 min time interval before QLCS arrival.

b) Surface Layer Stability, $T_{10} - T_2$ (°F)



- Prevalence of stable surface layer (only 5 unstable cases)

c) Wind speed at 10 m, V_{10}*

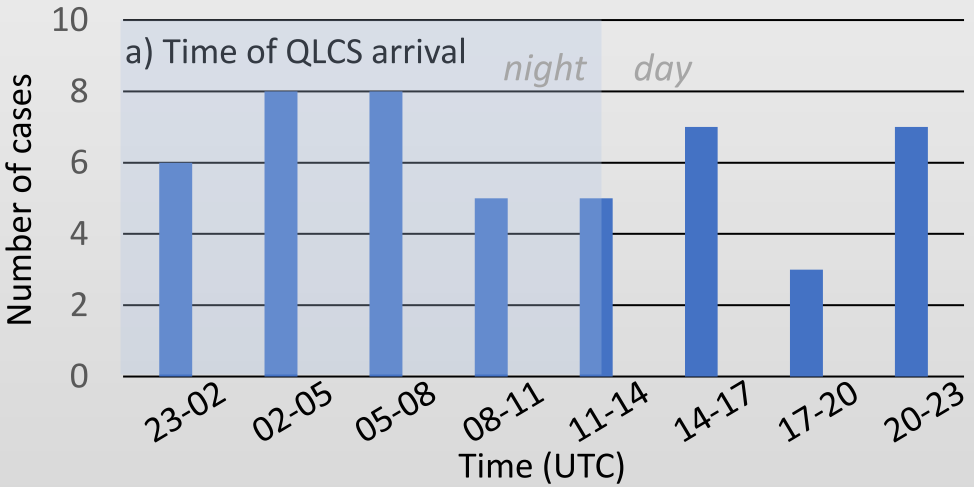


* V_{10} is based primarily on large z_0 around UAH campus (25% less than KHSV)

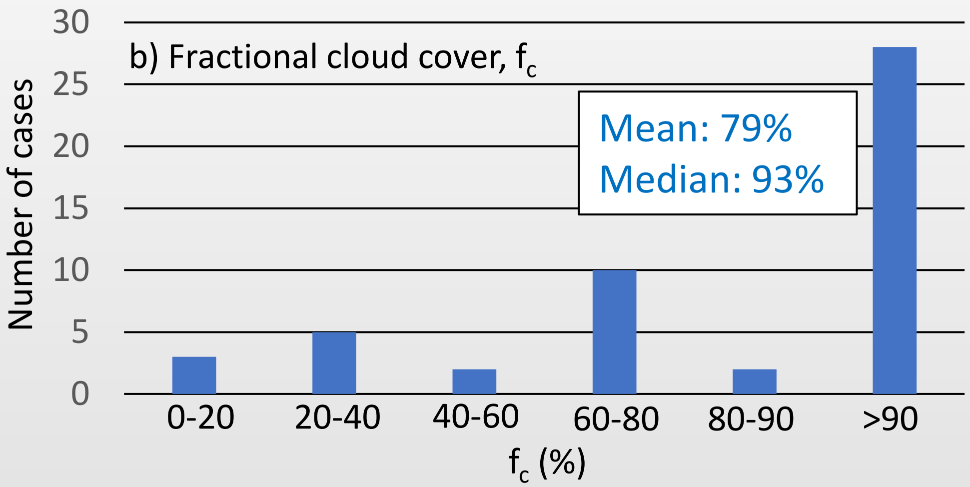
- Mean V_{10} = 5.5 m s^{-1}

Distributions from the entire data set
→ cloud properties

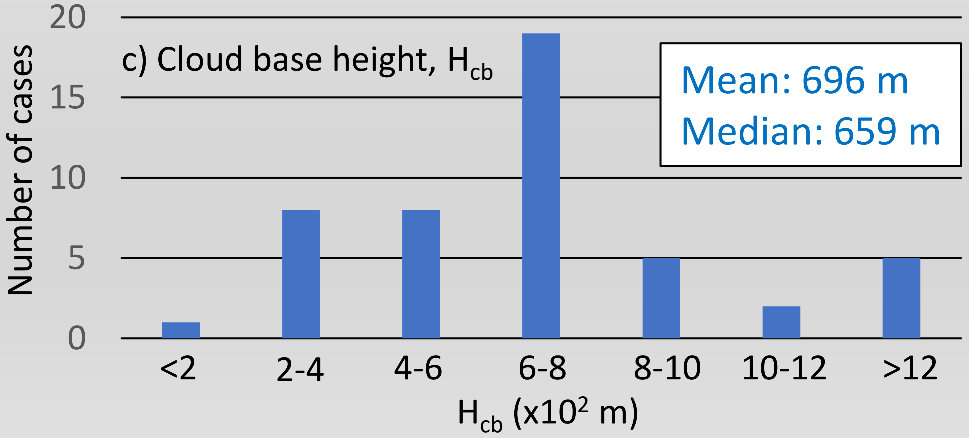
a) Time of arrival shows nearly uniform distribution, 32/49 cases occurred in dark conditions.



b) Fractional cloud cover (f_c) shows prevalence of overcast cases. Mean f_c = 79%, Median f_c = 93%



c) Cloud base height (H_{cb}) distribution is close to normal: mean = 696 m, median = 659 m



Cloud base vs. LCL (SP) height

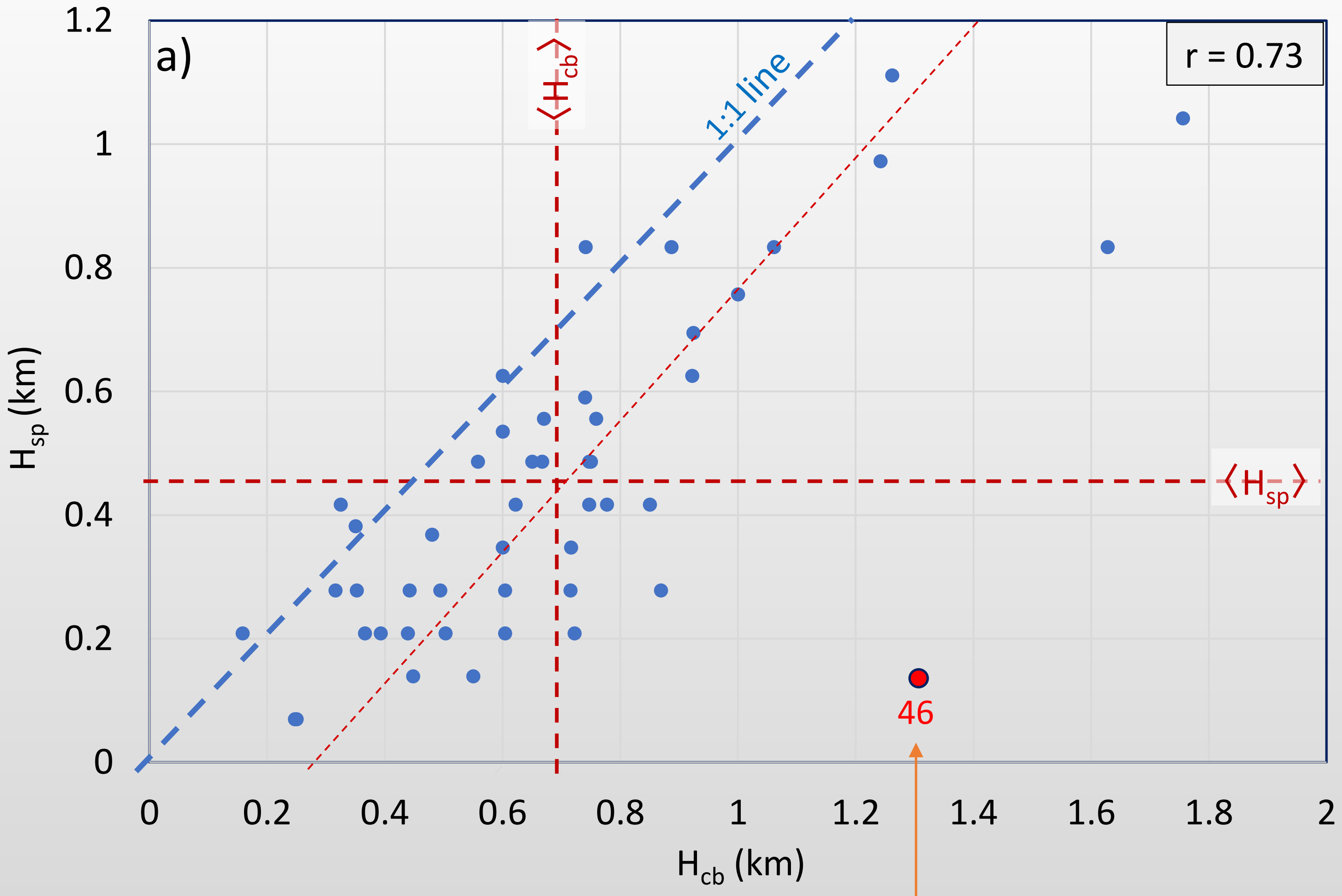
Averages for the entire data set, H_{cb} vs. H_{sp}

$$\langle H_{cb} \rangle = 670\ m$$

$$\langle H_{sp} \rangle = 450\ m\ (LCL)$$

$$Generally, H_{cb} \geq H_{sp}$$

The difference, $(\langle H_{cb} \rangle - \langle H_{sp} \rangle) \approx 220\ m$, is common for cloud-topped mixed layers – continental and maritime (Jones et al. 2012).



Outlier example: point 46 from 12/30/21 (H_{cb} = 1.3 km, H_{sp} = 0.12 km) corresponds to a case that is not surface rooted. The warm sector did not extend downward to the surface.

Surface layer and boundary layer stability

Surface layer

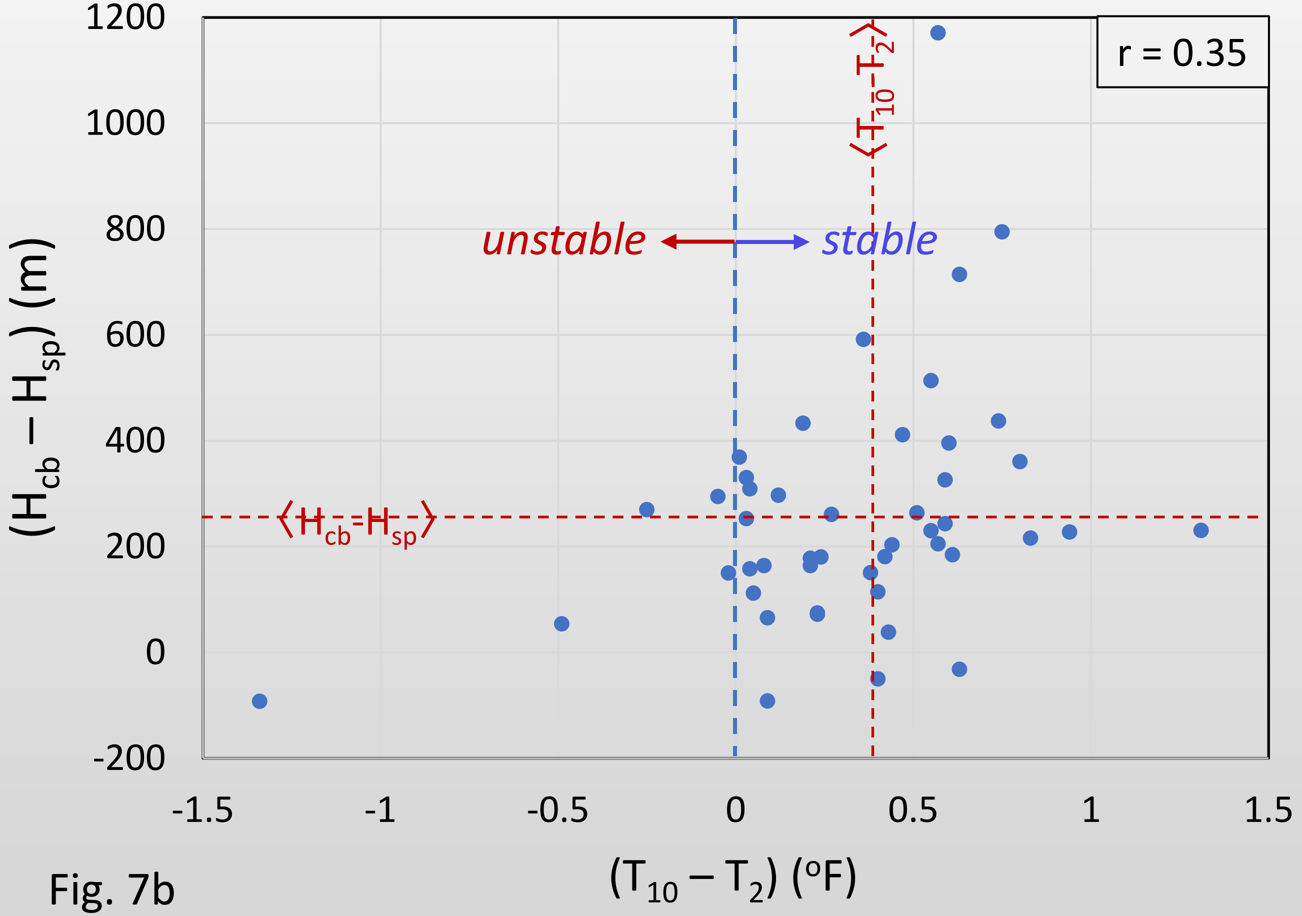


Fig. 7b

➤ Average 2-10 m temperature difference: +0.36 F.

Boundary layer

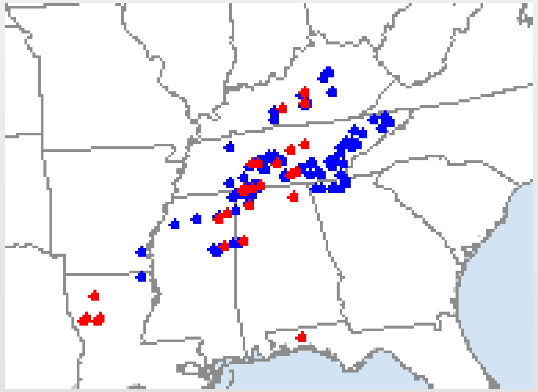
Average lapse rate, 0 - 500 m (balloon soundings)

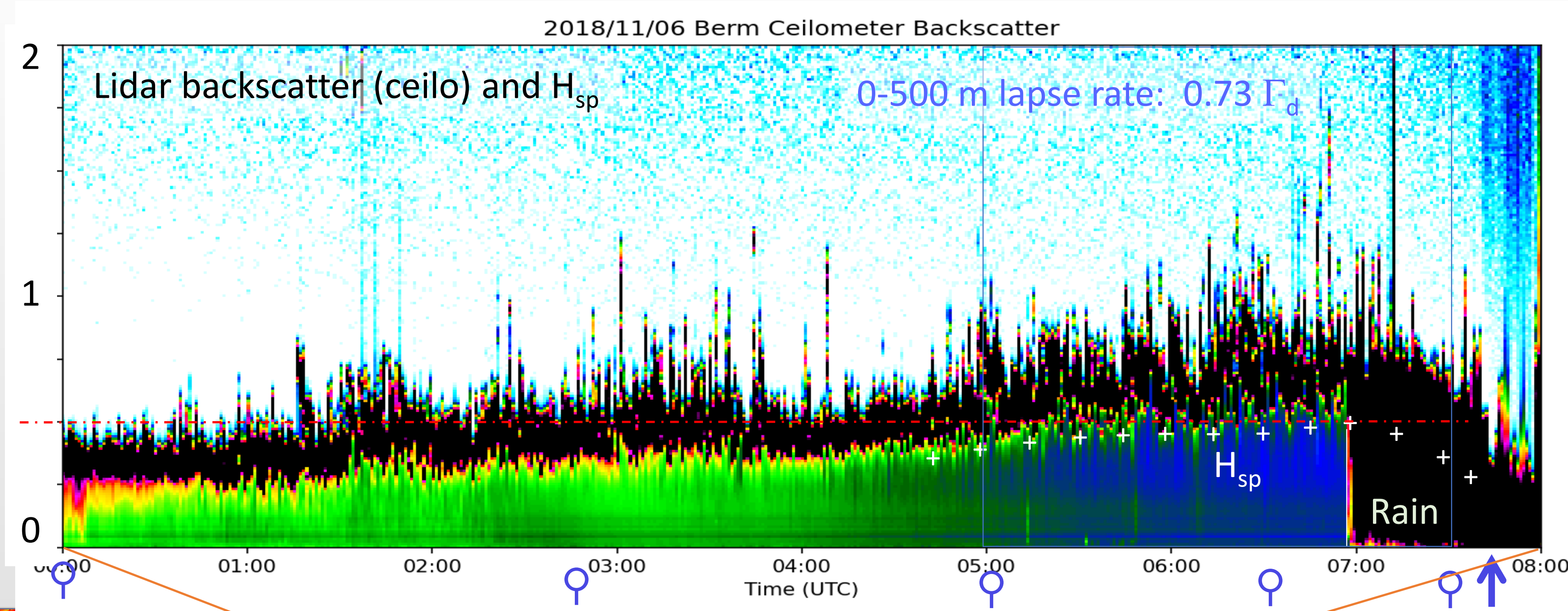
Date	Range of sounding times (UTC)	Fraction of Γ_d
11/6/2018	0500-0730	0.73
2/12/2019	1000-1130	0.68
2/12/2020	2100-2400	0.75
3/28/2021	0600-0830	0.79
12/11/2021	0730-1300	0.88
3/7/2022	1200-1540	0.87
Average		**0.78**

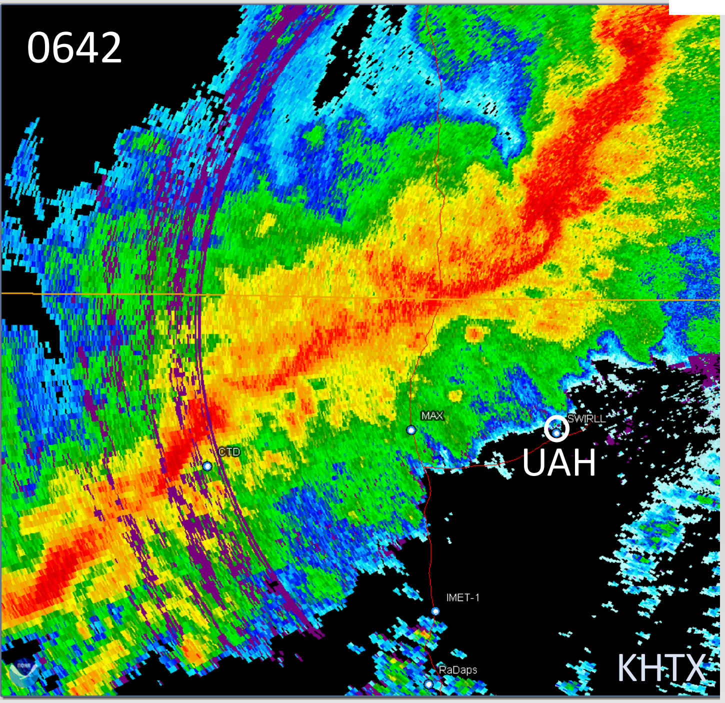
➤ Average 0-500 m lapse rate: 0.78 Γ_d

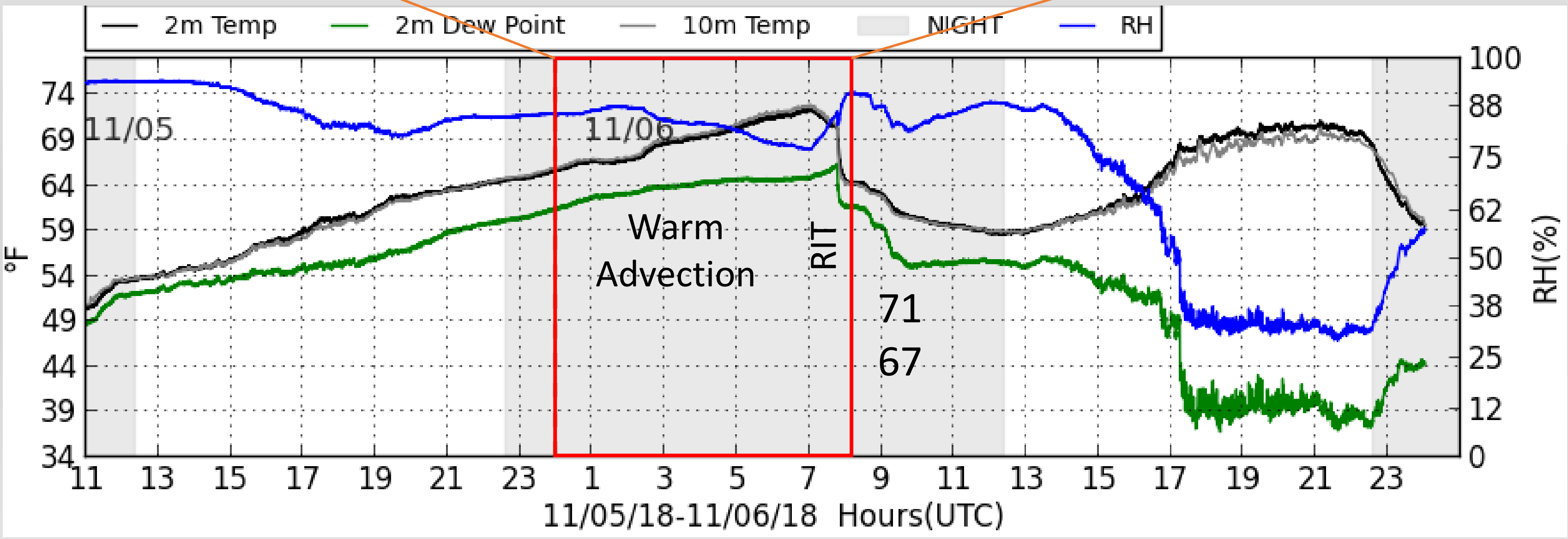
11/6/2018 (MESO)

- Long period of Sc (12 h)
- Increasing trend in H_{cb}
- Rapid reduction in H_{cb} during RIT



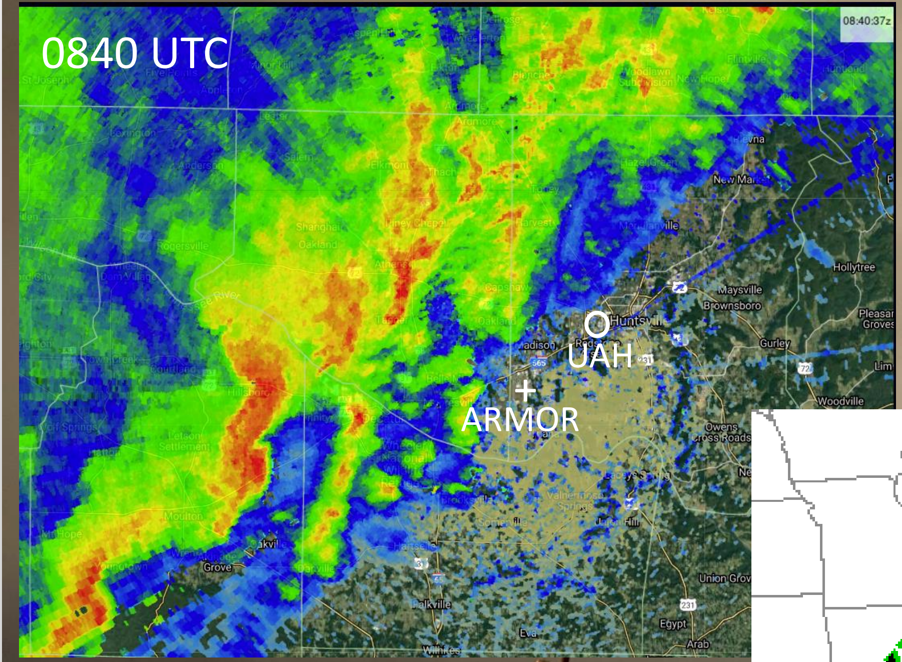


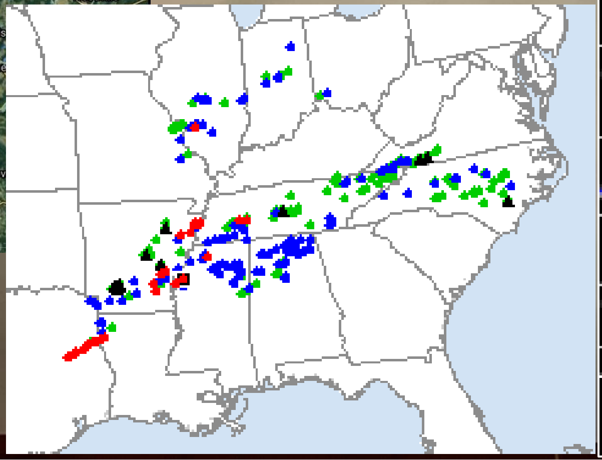


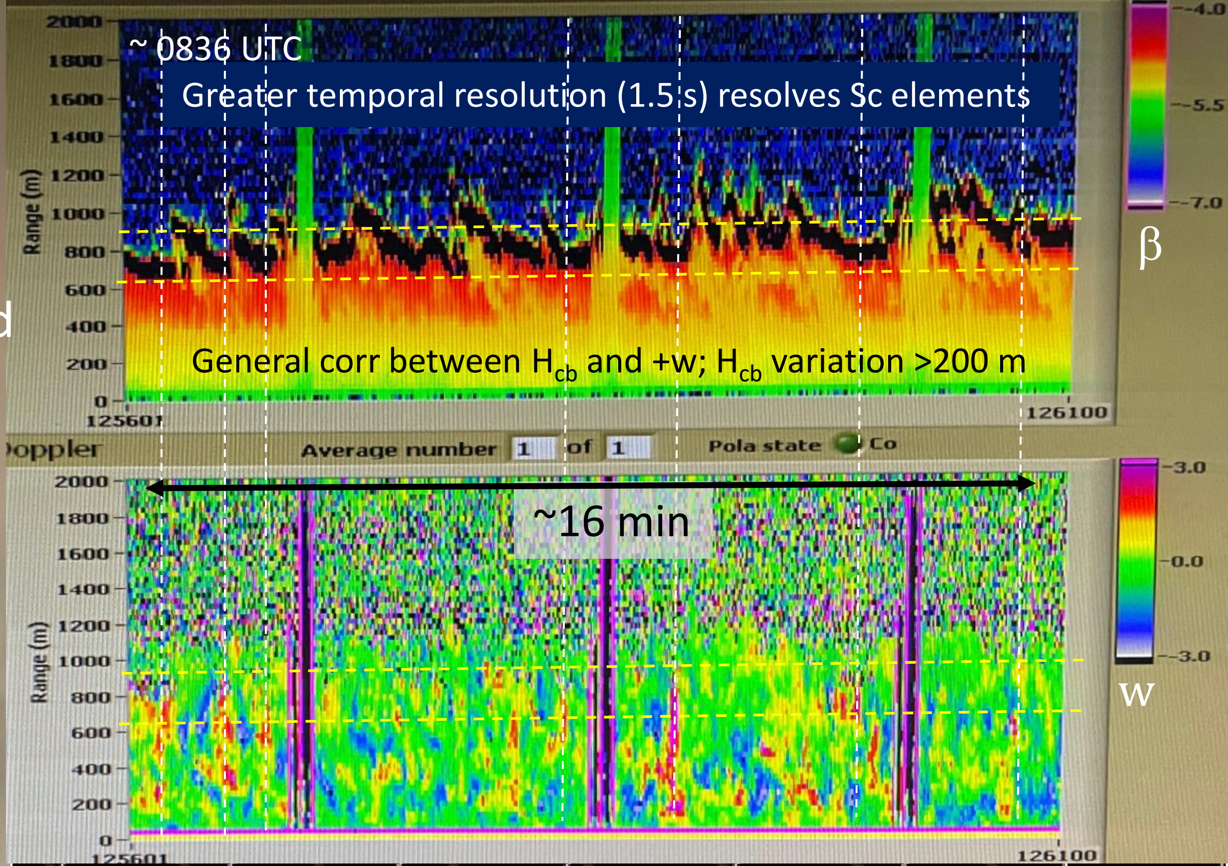


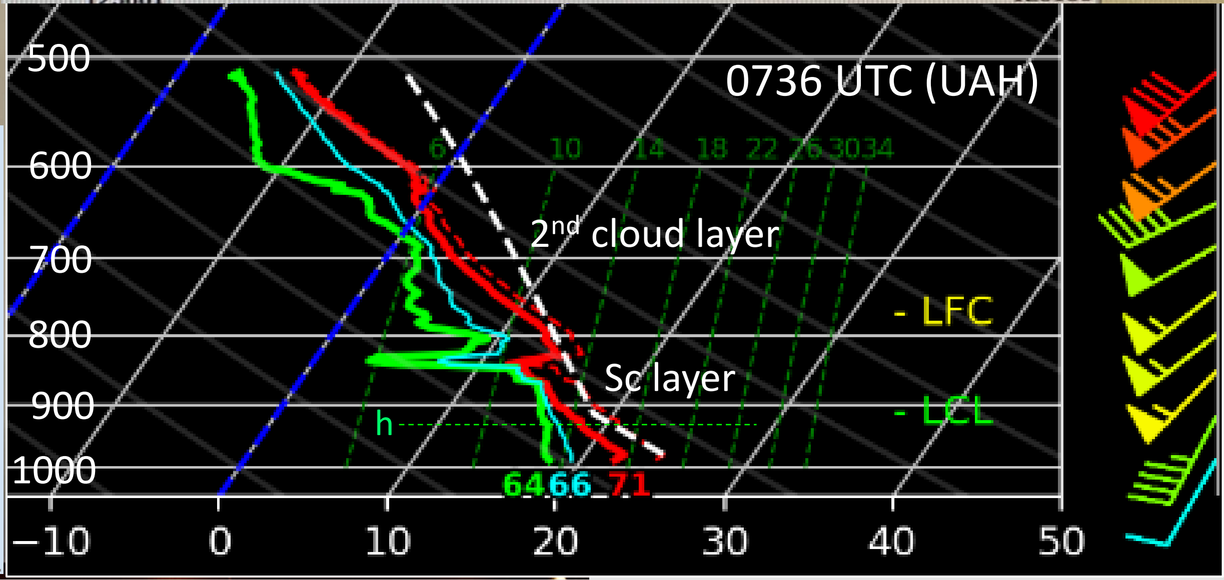
3/27/21

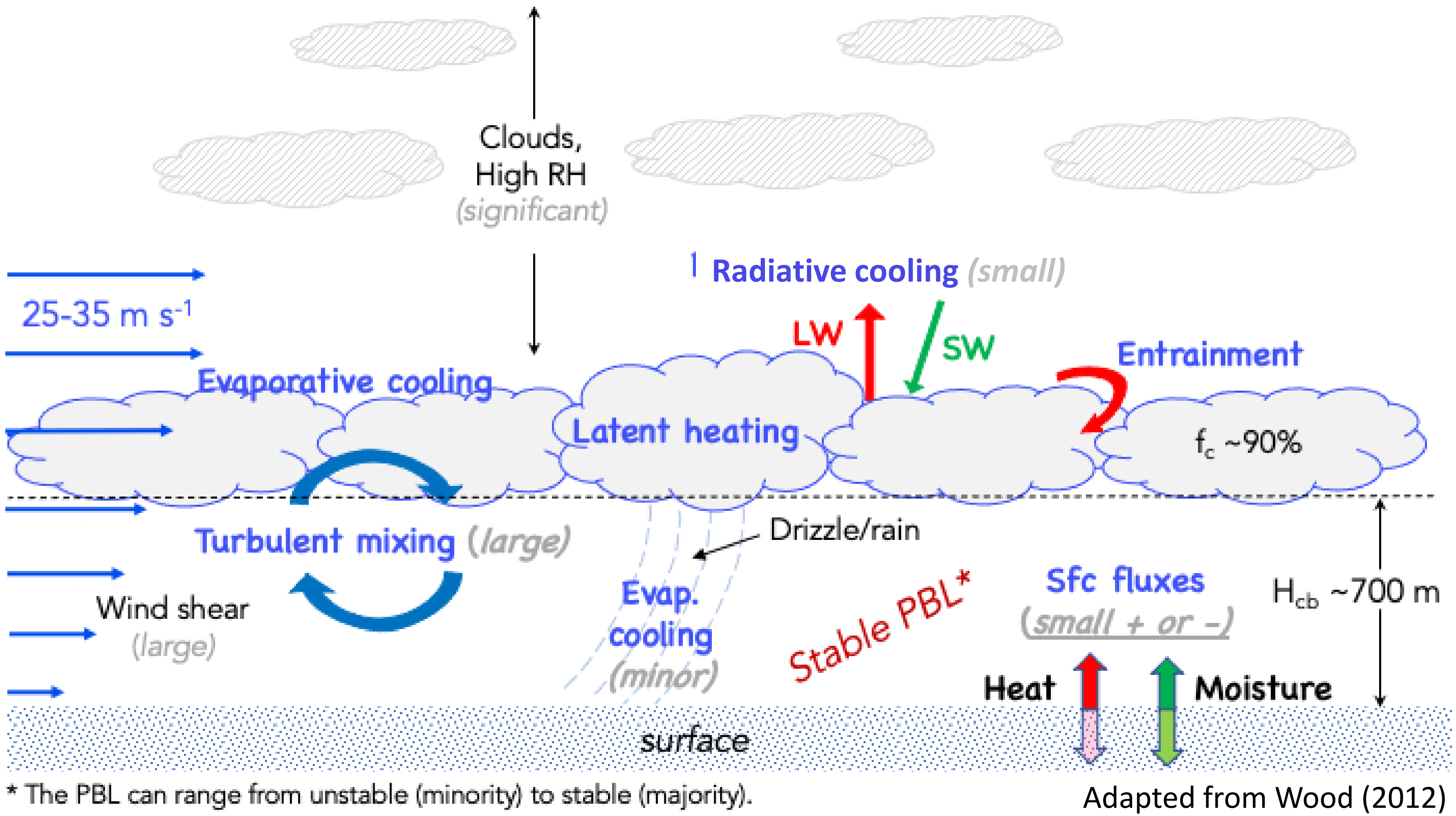
- Formation of Sc during the NBL period (0500-0900 UTC)
- Sc formed when upward-growing turbulence layer reached the SP (LCL)
- The height scale of most turbulent eddies displays limited depth (~ $\frac{1}{3}$ BL depth). Similar structure in other cases.
- Sounding displays inversion above top of Sc layer (not usual)











Conceptual model of warm sector Sc

Differences from maritime Sc under lower wind (shear) conditions:

1. Lower surface fluxes. **Heat flux is often negative.**
2. Presence of clouds and high RH above the Sc cloud layer.
   → Radiative cooling at cloud top may not be significant.
3. Greater BL wind and wind shear.
   → Shear production of turbulence is the primary source of TKE.

- Bold blue text represents physical processes.
- Thin text depicts atmospheric parameters/conditions.

- Shear production of turbulence is significant.
- Sub-cloud layer is generally stable.
- Sc clouds regulate day-night temperature variation.

Summary/Conclusions

- Sc clouds are common ahead of cool-season QLCSs

  H_{cb} ~ 670 m

  f_c ~ 90%

- Most cases display a statically stable surface layer and boundary layer, with lapse rate ~0.78 Γ_d
- Static stability favors stronger vertical shear (greater SRH)
- Sc clouds reduce the diurnal T variation → greater number of tornadoes during NBL period
- Sc cloud fields commonly exhibit mesoscale variations in depth and f_c. The background image shows this.
- Shear-induced turbulence is the main driver that maintains boundary layer turbulence and Sc clouds in these cases
- Are these "mixed" layers? Perhaps, but not the traditional mixed layer.

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