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The influence of stratocumulus clouds on sub-cloud stability during the nocturnal cycle of a severe, cool-season QLCS event

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Goals

a) Investigate the role of Sc clouds in maintaining CAPE during the nocturnal period of this regional severe weather outbreak on 15 March 2024.

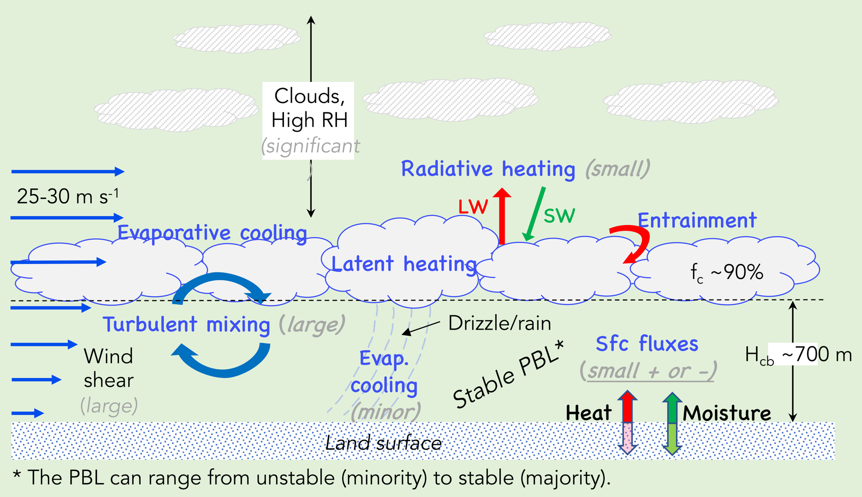
b) Utilize ground-based remote sensing (GBRS) to evaluate cloud properties and sub-cloud stability (beneath stratocumulus (Sc) clouds)

c) Basic hypothesis: *Sc clouds modulate the diurnal variation in sub-cloud T (and stability), maintaining warmer T at night. Current generation models may produce excessive nocturnal cooling and stability if Sc clouds are not well-replicated.*

Background

- Cool season Sc clouds (Knupp et al. 2024) may play a role in supporting nocturnal QLCSs and tornadoes that frequently occur during the SEUS cool season.
- For high-wind cases where shear production of turbulence is dominant, BL turbulence also plays a role in reducing surface cooling (and maintaining CAPE).

Conceptual model of cool-season, warm-sector Sc



* The PBL can range from unstable (minority) to stable (majority).

- Bold blue text represents physical processes
- Vertical shear is strong within the (sub)cloud layer
- Thin text depicts atmospheric parameters and conditions
- Shear production of turbulence is significant
- * The PBL can range from unstable (minority) to weakly/moderately stable (majority)
- Shear generation dominates buoyant generation of TKE
- Sub-cloud layer is generally stable → promotes high shear
- Evaporative cooling from drizzle/rain, and negative heat flux (cold surface) exert a stabilizing influence.

Data and Methods

SWIRLL

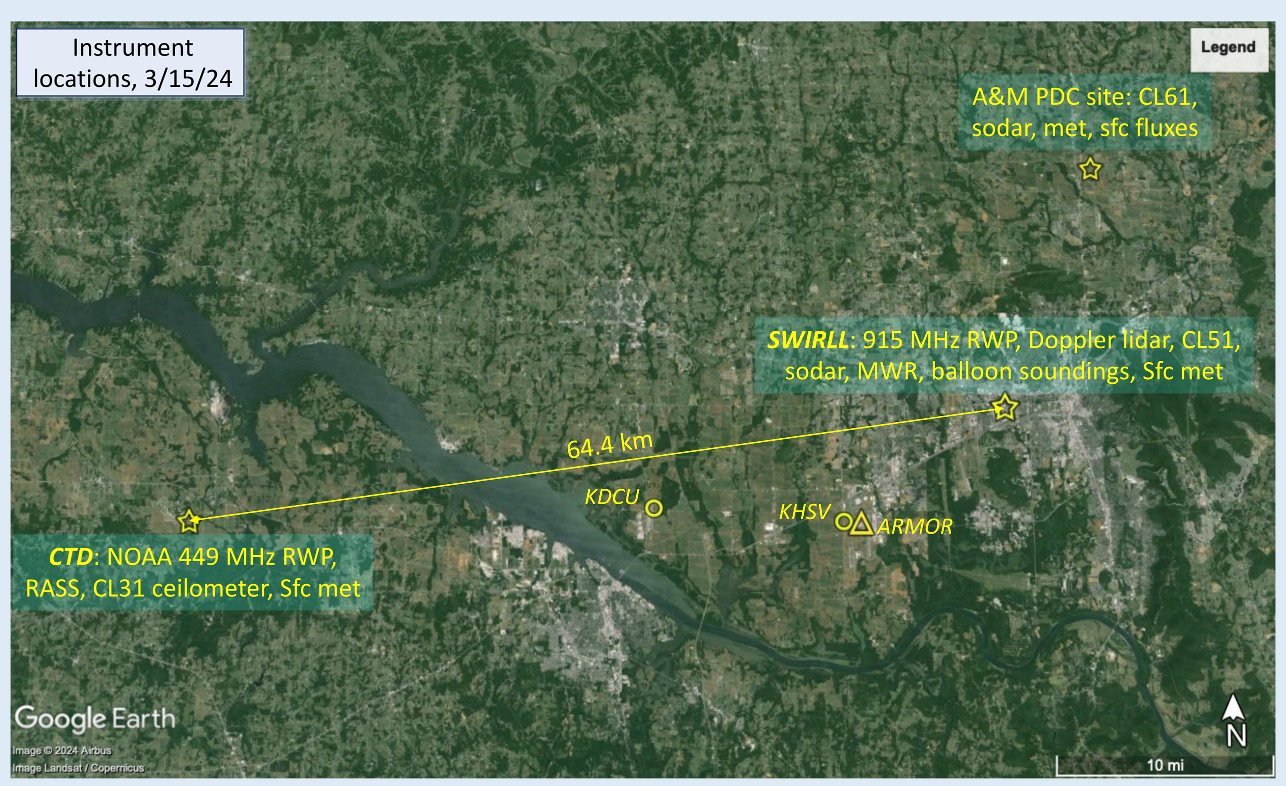
- 915 MHz RWP
- Doppler lidar
- CL51 ceilometer
- Microwave Radiometer (MWR)
- Balloon soundings
- Surface met

CTD

- 449 MHz RWP with RASS
- CL31 ceilometer
- Surface met

A&M PDC (not used here)

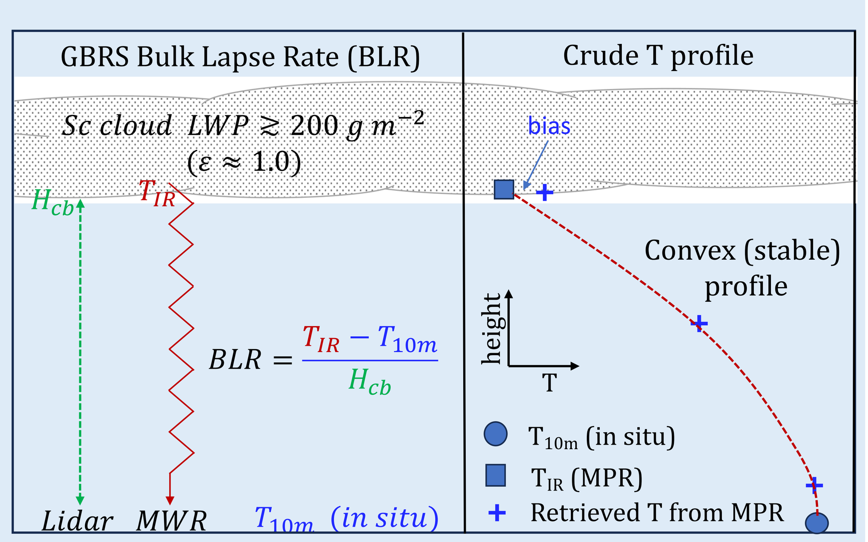
- SFAS sodar
- CL61 ceilometer
- Surface met & fluxes



Data Analysis

The lapse rate beneath cloud base is a key variable, and can be estimated from:

- Balloon sounding measurements from SWIRLL (high-resolution, limited temporal resolution, expensive)
- Microwave radiometer (MWR) profiles from SWIRLL
- RASS T_v measurements (CTD): 60-min temporal resolution, but some noise in the T_v measurement, which includes T and vapor vapor mixing ratio (r_v): $T_v = T(1+0.61r_v)$. Good approximation to static stability provided that r_v is const
- We aim utilize the "simple" ground-based remote sensing (GBRS) measurements from SWIRLL to achieve higher temporal resolution of ~2 min under favorable conditions using:
  - Infrared temperature (T_{IR}) from MWR; assume that T_{IR} represents cloud base temperature, which implies that clouds are optically thick (LWP > 200 g m⁻²)
  - Cloud base height from lidar (ceilometer)
  - Near surface *in situ* temperature, T_{10m}



Left: Schematic of the bulk lapse rate retrieval utilizing lidar and microwave radiometer (MPR). Right: Adding independent retrieved T values from the MWR produces a crude temperature profile.

- Bulk Lapse Rate (BLR) is then: $BLR = \frac{T_{IR} - T_{10m}}{H_{cb}}$
- We could add MWR retrievals below ~1 km AGL, which will have ~2 independent pieces of information yielding ~4 T measurement heights between sfc and cloud base (inclusive). We will pursue this in the future.

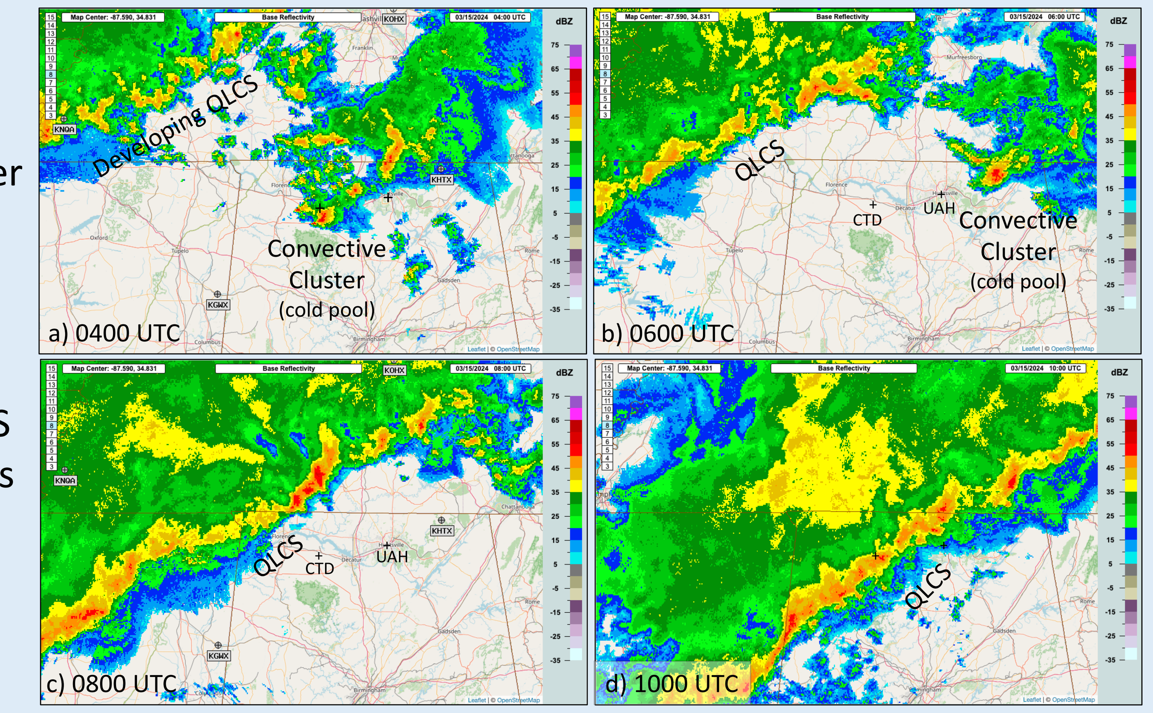
MRMS Overview of the event (4 panels)

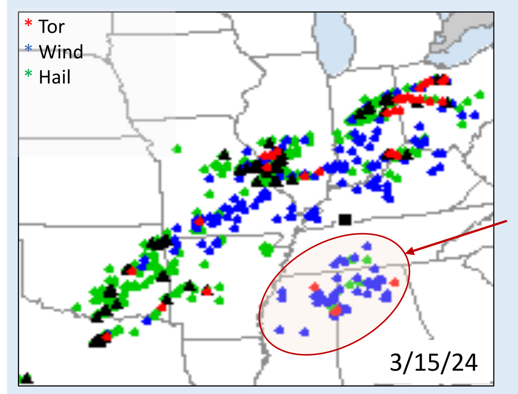
a) 04 Z: Convective cluster over N AL produces cold pool; initiated 2220, 2 W repts

b) 06 Z: Cluster retreats from region; QLCS is expanding

c) 08 Z: Intensification of QLCS

d) 10-12 Z: Severe QLCS moves over region of interest

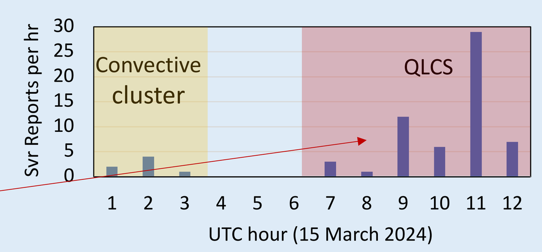




Well-defined mesoscale region of severe reports. *Why?*

→ One motivating factor for this study.

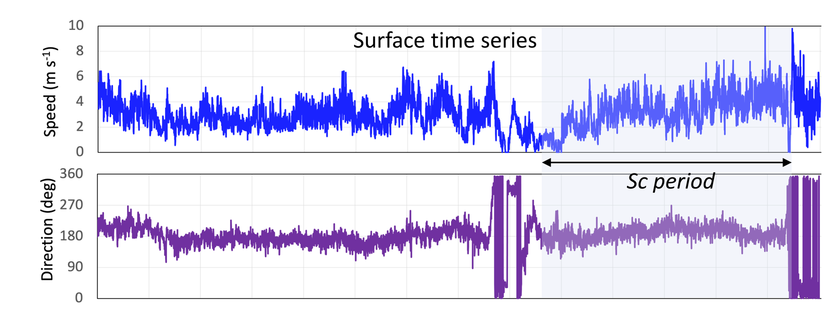
→ Significant increase in severe reports occurred well into the nocturnal period, 09-12 UTC (right). *Why?*

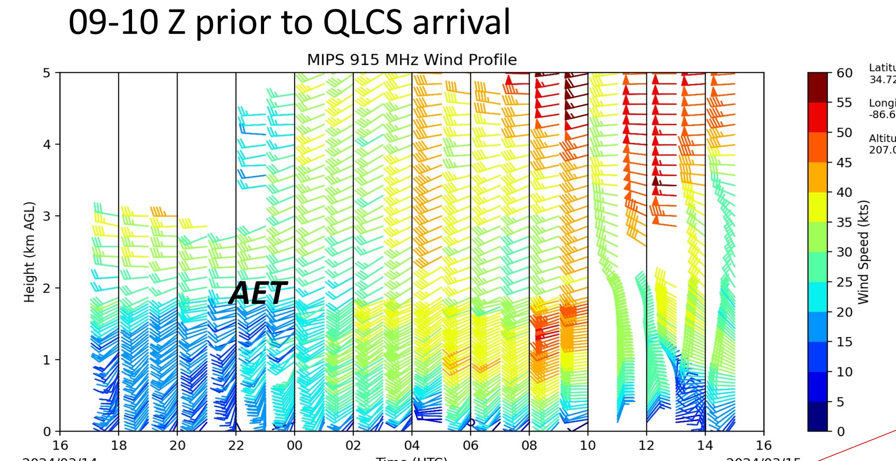


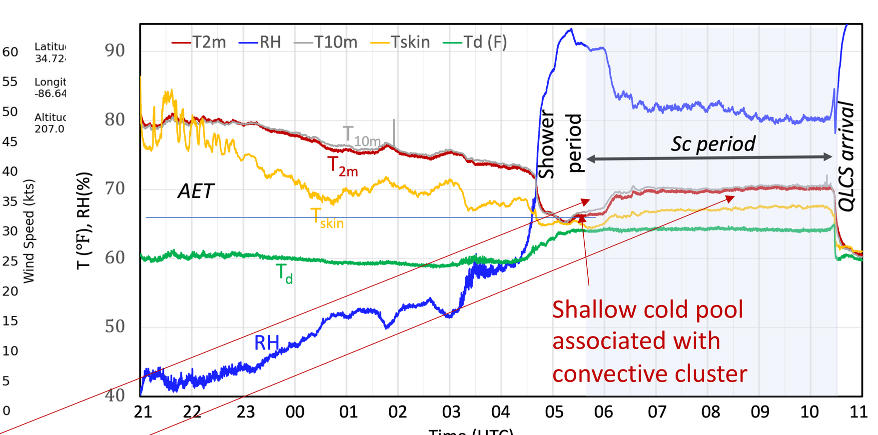
Observations at SWIRLL

Evolution from convective to nocturnal boundary layer during the Afternoon to Evening Transition (AET)

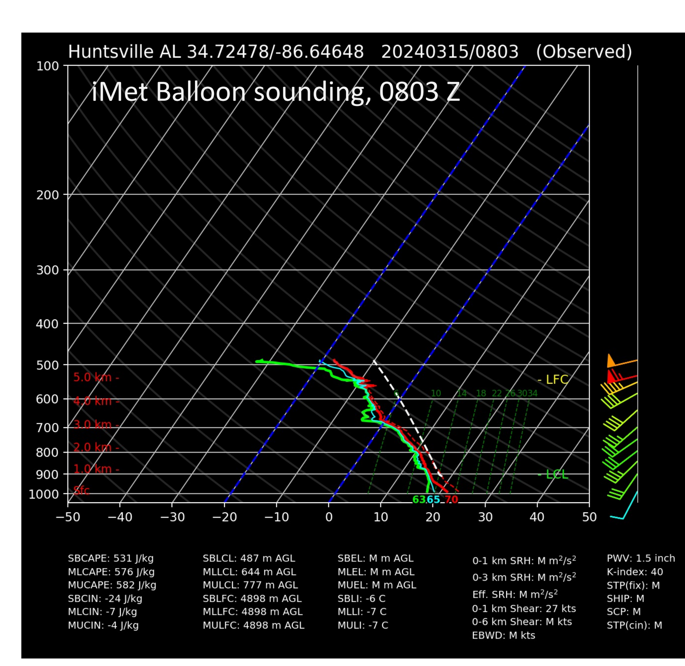
- Cooling and stabilization after 22 Z
- Increase in winds above surface layer after 22 Z
- Maximum low-level wind and wind shear during 09-10 Z prior to QLCS arrival





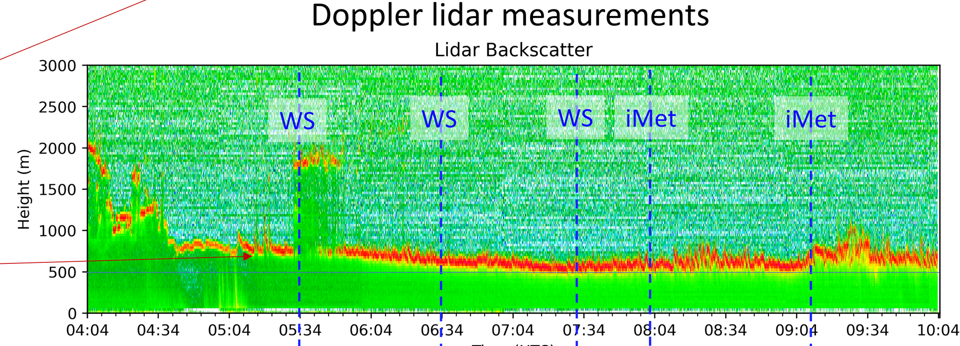


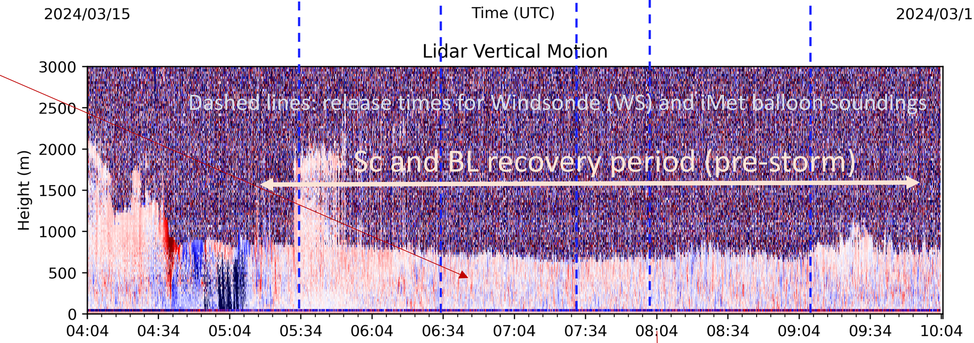
- Boundary layer recovery started ~0530 Z
- Slight surface warming occurred during the 0600-1030 Z Sc period → maintained CAPE as 0-1 SRH increased > 250 m² s⁻²
- Sc cloud development near 05 Z. Sc base down to 500 m AGL
- The sub-cloud layer exhibited weak turbulence and associated mixing



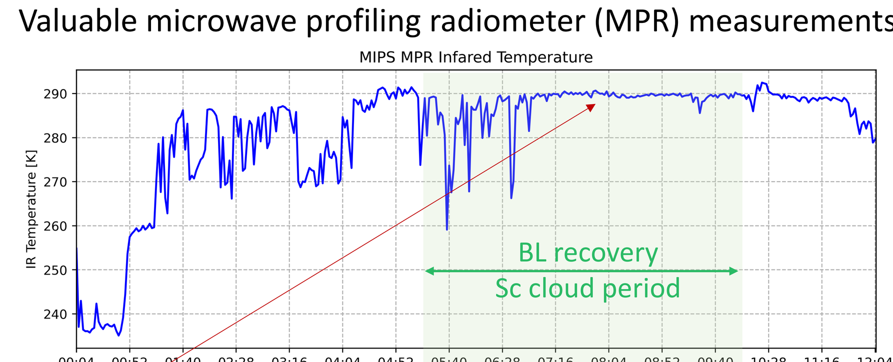
- Primary period of interest: BL recovery period during which Sc clouds maintained warm sfc T
- Sc overcast in place by 06 Z (IR temp. near 290 K)
- Sc clouds exhibited liquid water path (LWP) exceeding 200 g m⁻². The LWP also reveals appreciable temporal variability of the pre-storm environment.
- The green shading (right figures) defines the primary period of interest. Five balloon soundings (Doppler lidar figure) provide profile profile details and validate the remote sensing measurements

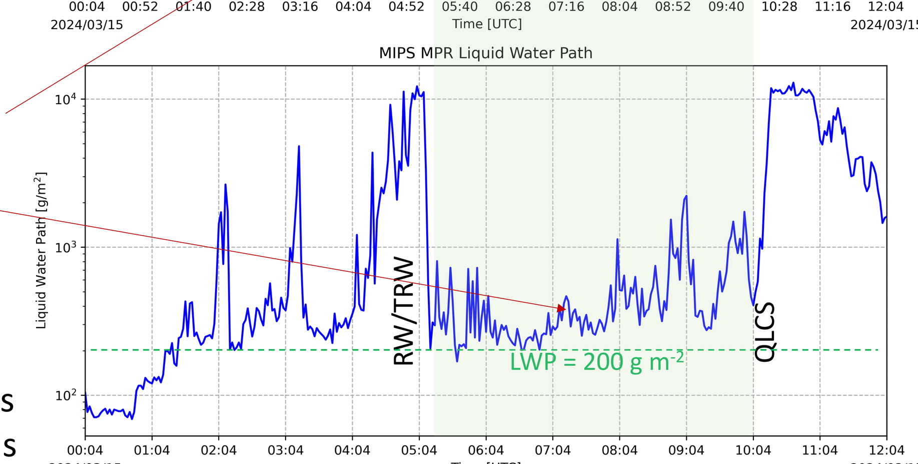
Doppler lidar measurements



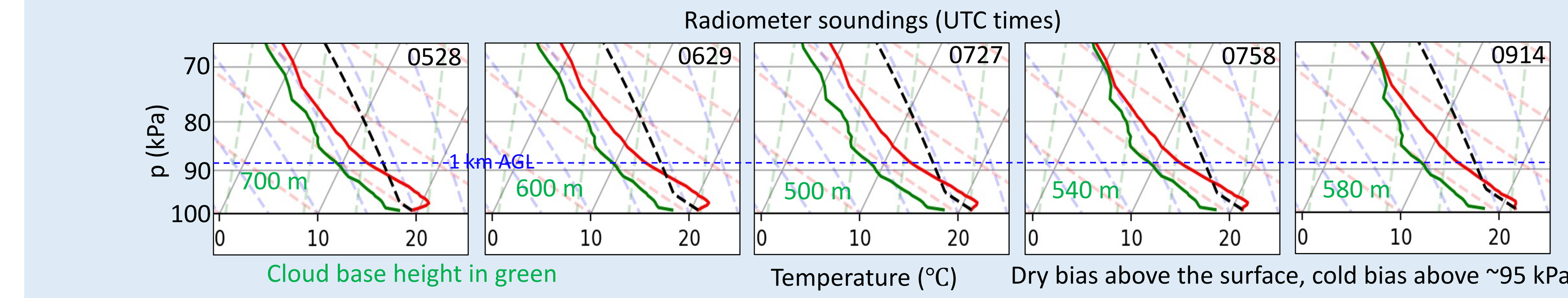


Valuable microwave profiling radiometer (MPR) measurements





Evolution of MPR T profiles from SWIRLL



Reduction in surface-based inversion; increase in near-surface T; increasing θ_e; CAPE ↑, CIN ↓

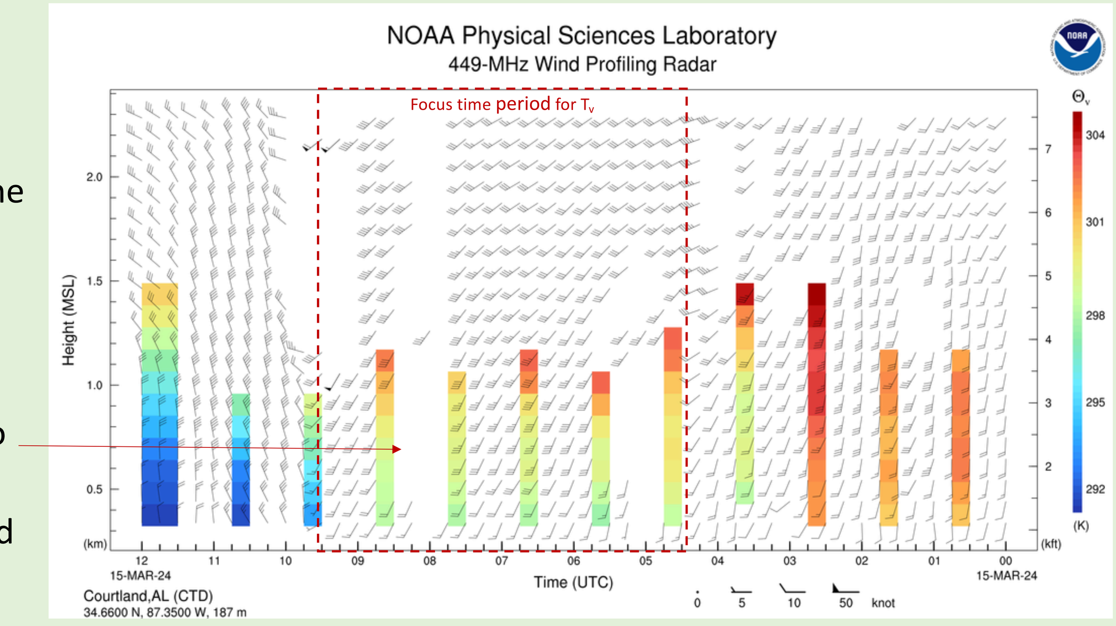
Observations at CTD

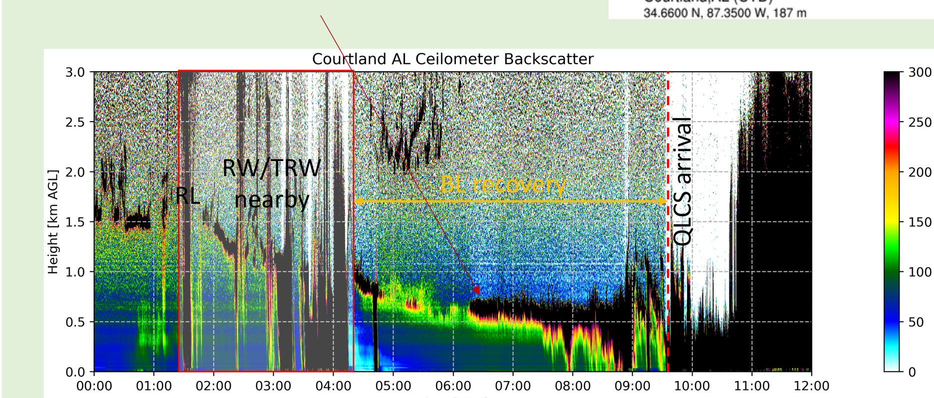
Utilization of 449 MHz radar wind profiler, RASS, and CL31 ceilometer

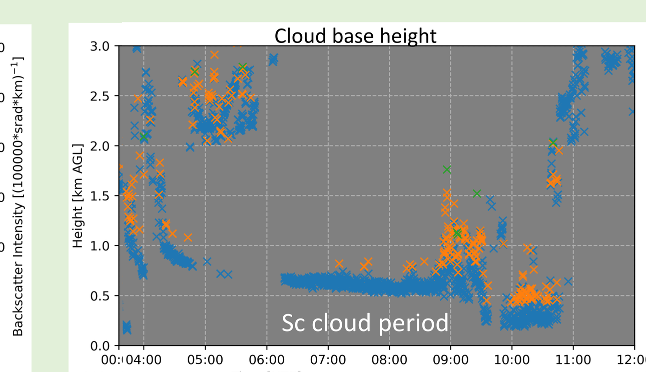
CTD was closer to the centroid of the severe weather reports

Patterns are similar to those observed at SWIRLL:

- Low-level winds and wind shear increased from the AET period to arrival time of the QLCS
- Sc developed near 05 Z, exhibited thickening and lowering 06-09 Z.



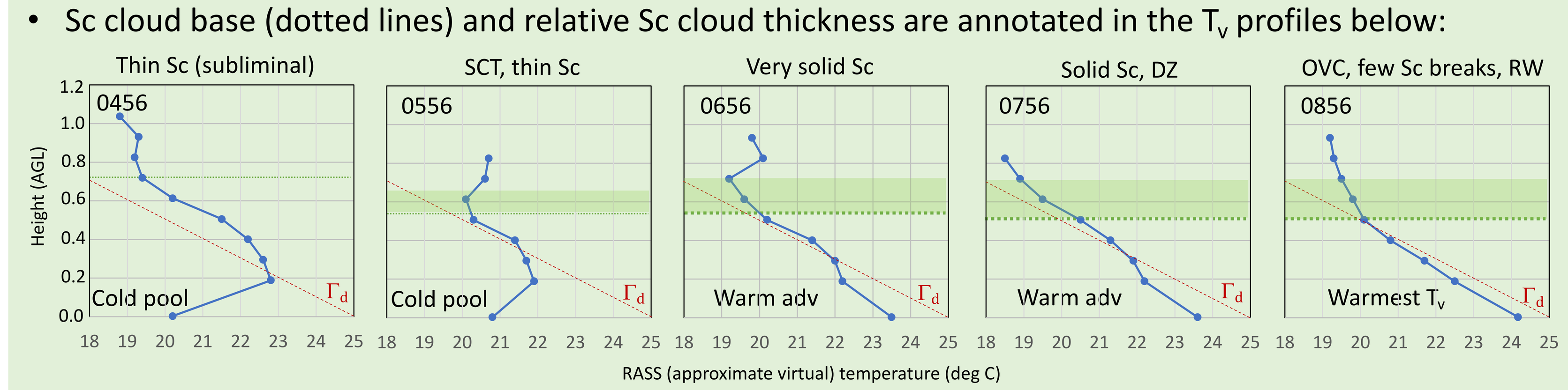




Destabilization under Sc cloud cover; rain ended 0420 UTC

T_v profile evolution at CTD

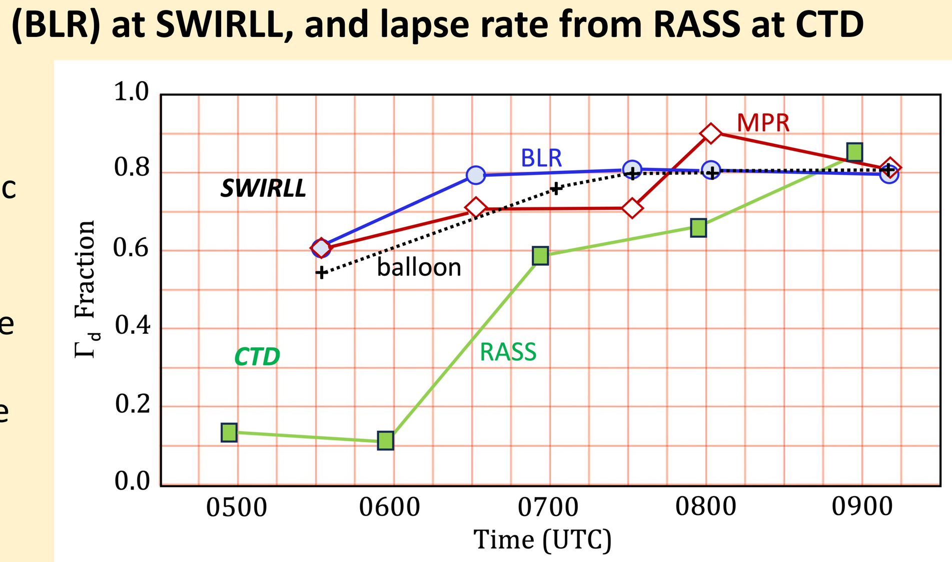
- Cold pool was more prominent than at SWIRLL, horizontal advection was more important, CIN ↓, CAPE ↑
- Sc cloud base (dotted lines) and relative Sc cloud thickness are annotated in the T_v profiles below:



Synthesis: Evolution of Bulk Lapse Rate (BLR) at SWIRLL, and lapse rate from RASS at CTD

Combined analysis

- Sub-cloud lapse rate value is plotted, and expressed as a fraction of the dry adiabatic lapse rate (Γ_d)
- The prominence of the cold pool at CTD stands out → relative recovery is therefore more significant
- The simple bulk lapse rate (BLR) technique compares very well with the profiles from the microwave radiometer and balloon soundings



Summary and Conclusions

- The simple bulk lapse rate (BLR) technique worked well, but requires sufficiently thick Sc clouds (LWP ≳ 200 g m⁻³). Ideally, such clouds should be uniform with high cloud fraction.
- Given that Sc clouds are ubiquitous in the pre-storm environment of cool-season QLCSs, the BLR technique may provide measurements that improve real-time diagnosis of trends in CIN and CAPE
- * Nocturnal Sc clouds can indeed promote sufficiently high CAPE *well into* the nocturnal period. The Sc presence maintains high surface T, and may even increase sfc T during the nocturnal period, as in this case.
- Side note: even though RASS is a relatively old technology, it provides some very unique measurements within conditions not well suited for infrared or even microwave remote sensing of thermodynamic profiles

Acknowledgements

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