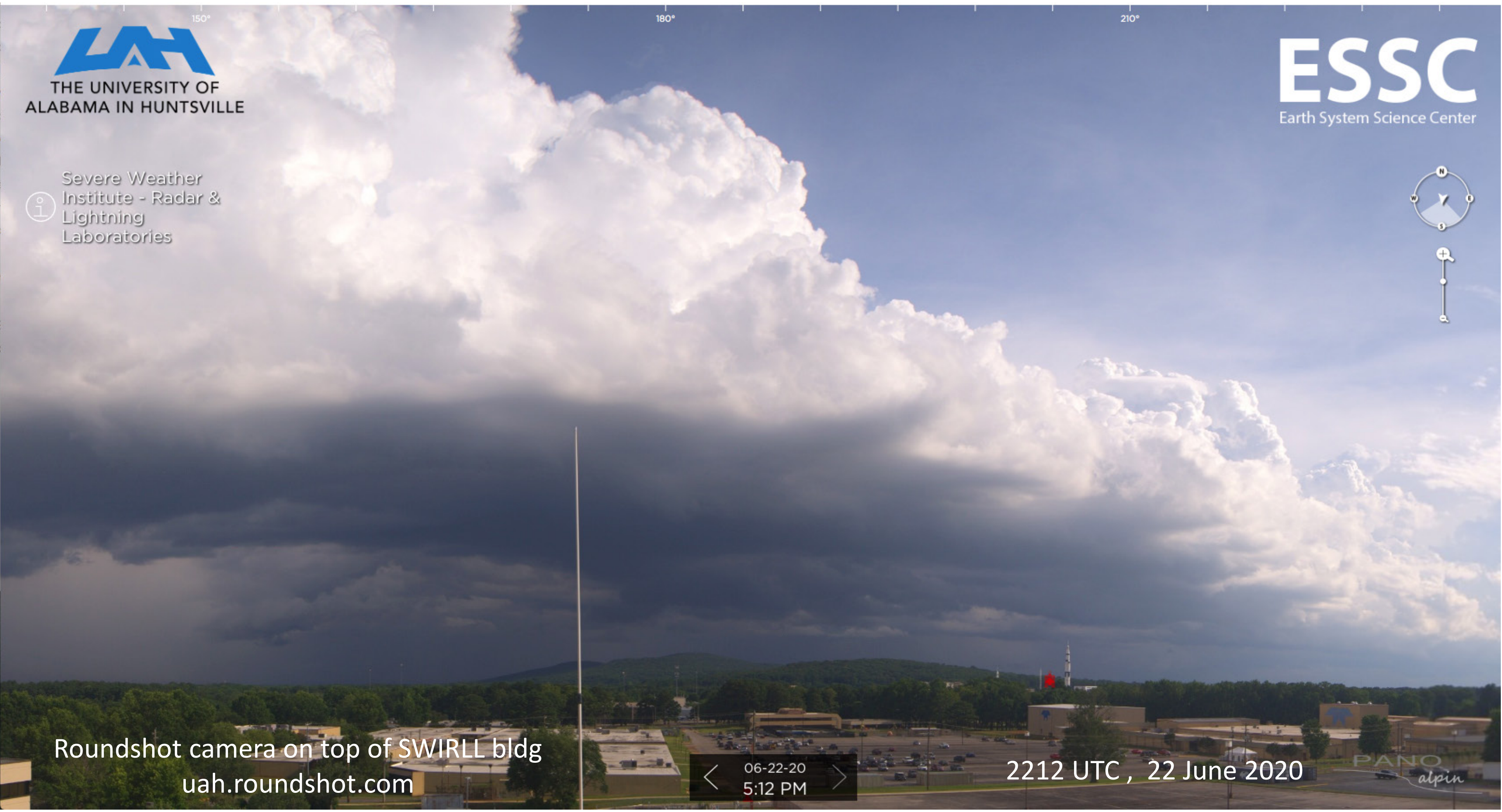
Boundary layer heterogeneity and deep convection

(relevance to AMF3 SEUS)



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Background statement

- This presentation summarizes methodologies and related science objectives in current research designed to understand the interaction between deep convection and spatial/temporal variability within the PBL (BL). The domain is our back yard, northern Alabama.
- VORTEX-SE campaigns, 2016-current

Overview

1. Network design challenges
   – Define the scientific objectives, then . . .
   – arrange radar/profiler resources to best satisfy the scientific requirements
   – within the constraints produced by obstacles (trees, orography) which limit the number of sites
2. Science: Understand BL heterogeneity and evolution
   – How it impacts Convective Initiation and QLCS evolution
   – How it modulates deep convection

General goal: Obtain both storm-scale and BL flow over (part of) the same mesoscale domain

Background: Seasonal variation of SE deep convection

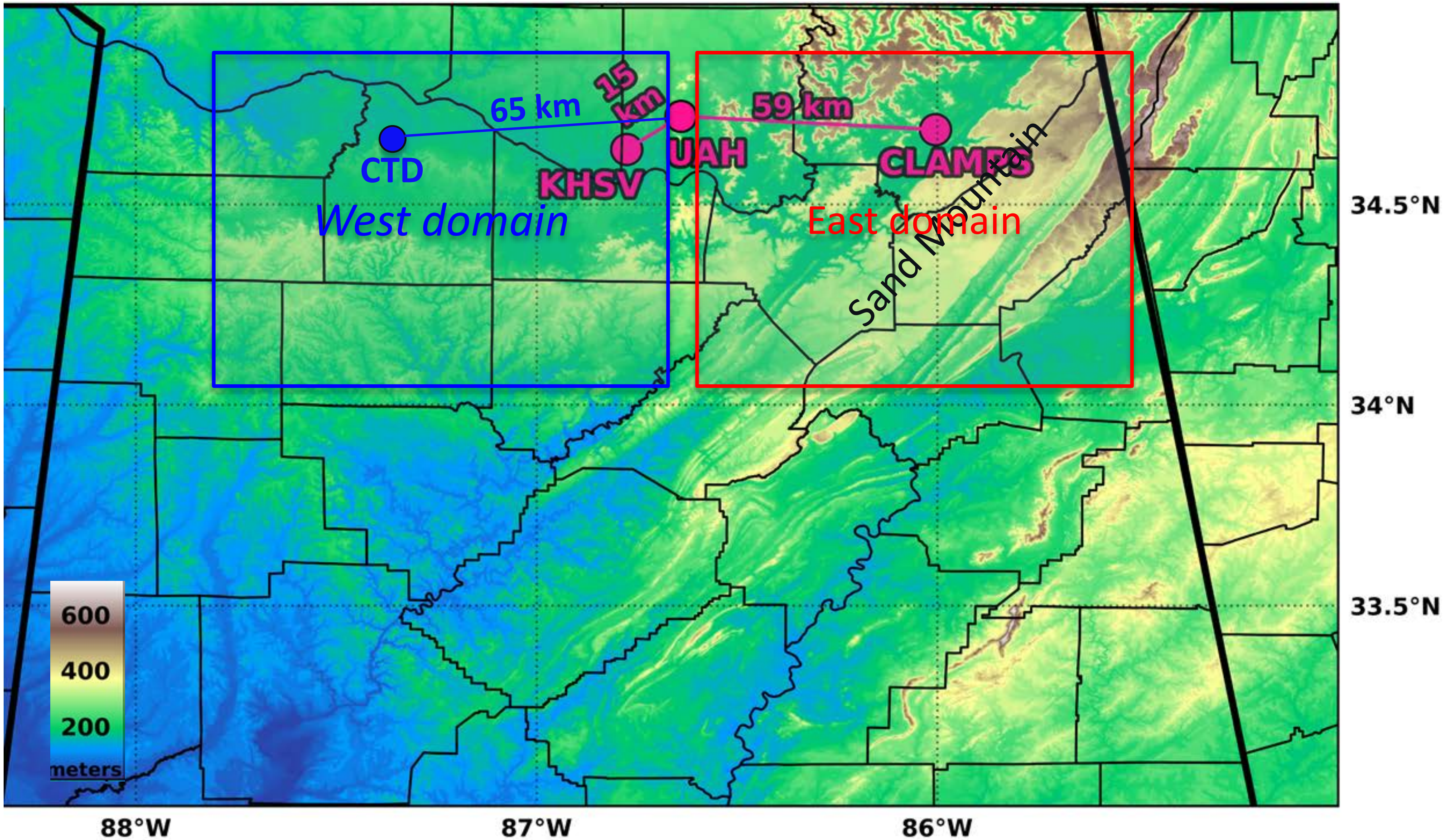
- Core warm season (Jun-Aug)
  - Diurnal dominance, afternoon maximum
  - Low shear, high CAPE (Convective Available Potential Energy)
  - Transient convective cells, occasional upscale growth to MCS (refer to title slide)
- Core cold season (Dec-Feb)
  - Strong synoptic-scale forcing (cyclone passages)
  - Organized convection within cyclone warm sector: Quasi-linear Convective System (QLCS, long-lived) is the dominant convective mode
    - High shear low CAPE
  - (Non-convective) stratiform precipitation in regions of greater stability (e.g., north of the cyclone)
- Spring and Autumn seasons (Mar-May, Sep-Nov)
  - Mix of warm/cold season, but QLCS will prevail
  - Tropical cyclones occasionally affect the SE (June-November)

1. Deployment challenges

- Trees and orography present deployment challenges for any system requiring good view of the horizon.
  - Notable examples:
    - Scanning remote sensing platforms: radars, lidars
    - Photography
    - Balloon soundings – not as restrictive
  - Considerable time may be invested in “scouting out” potential locations
  - Any radar site that has limited blockage below about 1.5 deg elevation angle is considered very good for Northern AL
  - Excellent example of a good site: Courtland AP (3 slides down)

- Road network – applies to mobile operations and design of adaptable networks of profiling systems for a specific IOP (science objective)

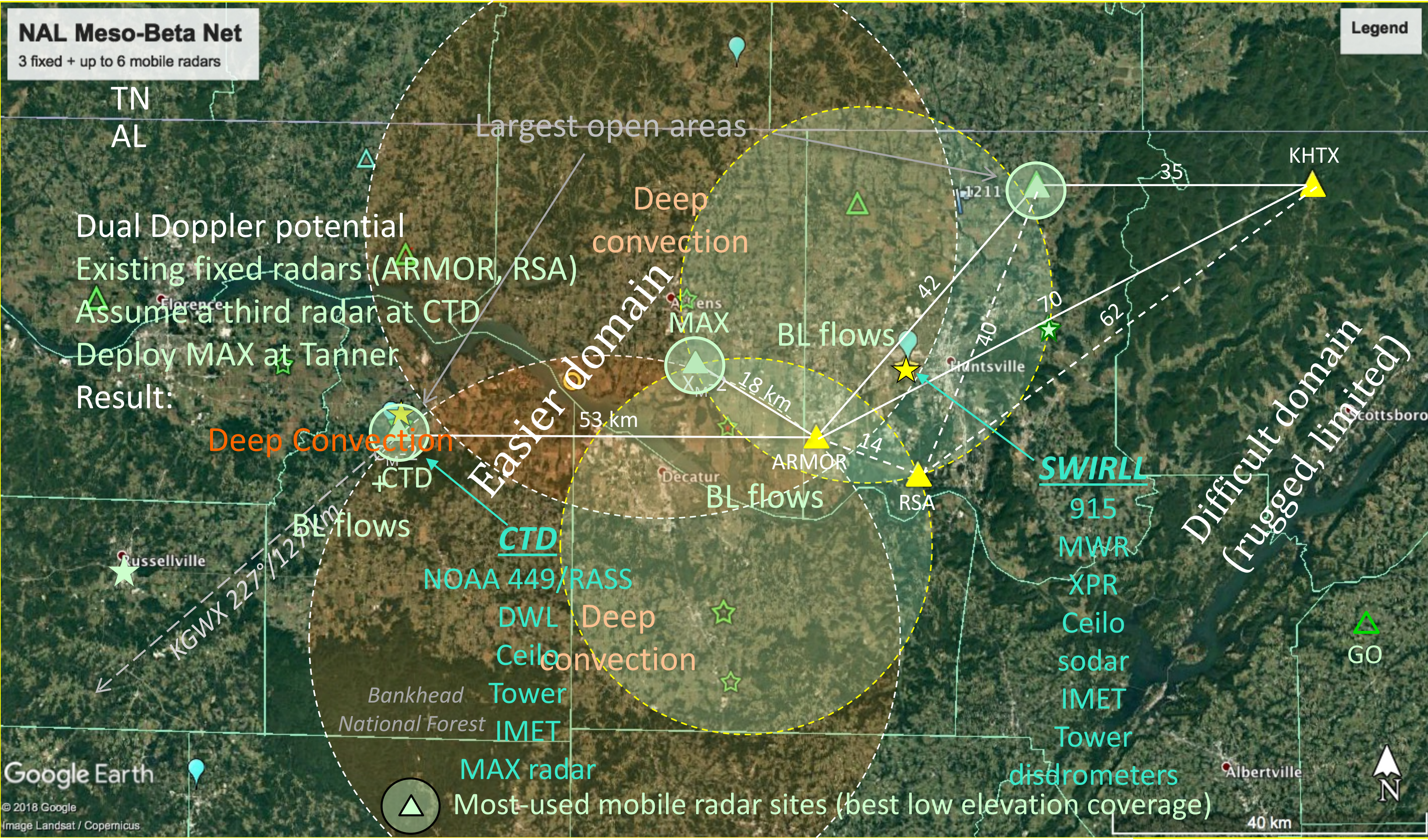
Northern Alabama domain



- Long-term profiling sites for W domain: UAH and Courtland (CTD, 2019-2020)
- Science focus on BL heterogeneity produced by variations in surface fluxes, surface roughness length, low-level wind/thermo variations

- Long-term profiling sites for E domain: UAH and CLAMPS (2017)
- Science focus: topographic influence on BL flows
- Challenging: complex flows, subpar road network, limited radar sites

Three commonly used locations for the MAX mobile radar



1. Radar sites with good view of horizon are challenging to find (3-6)
2. Short baseline is needed for retrieval of (shallow) BL flows
3. Long baseline (>30 km) favors retrieval of airflow within deep convection
4. Most ideal: short baseline nested within long baseline

△ MAX mobile radar

△ Tower-based (fixed) radar

Courtland Airport (CTD)
Instruments during 2019-2020 campaign
Legend
449/RASS
CRN
DWL
MAX
PA0
Sfc/GPS
Twr
CRN
Profiling systems
Twr
449/RASS
PA0
Sfc/GPS
DWL
1.6 km
Lockheed-Martin (DOD)
MAX radar
Courtlan
Google Earth
© 2020 Google
4000 ft
N

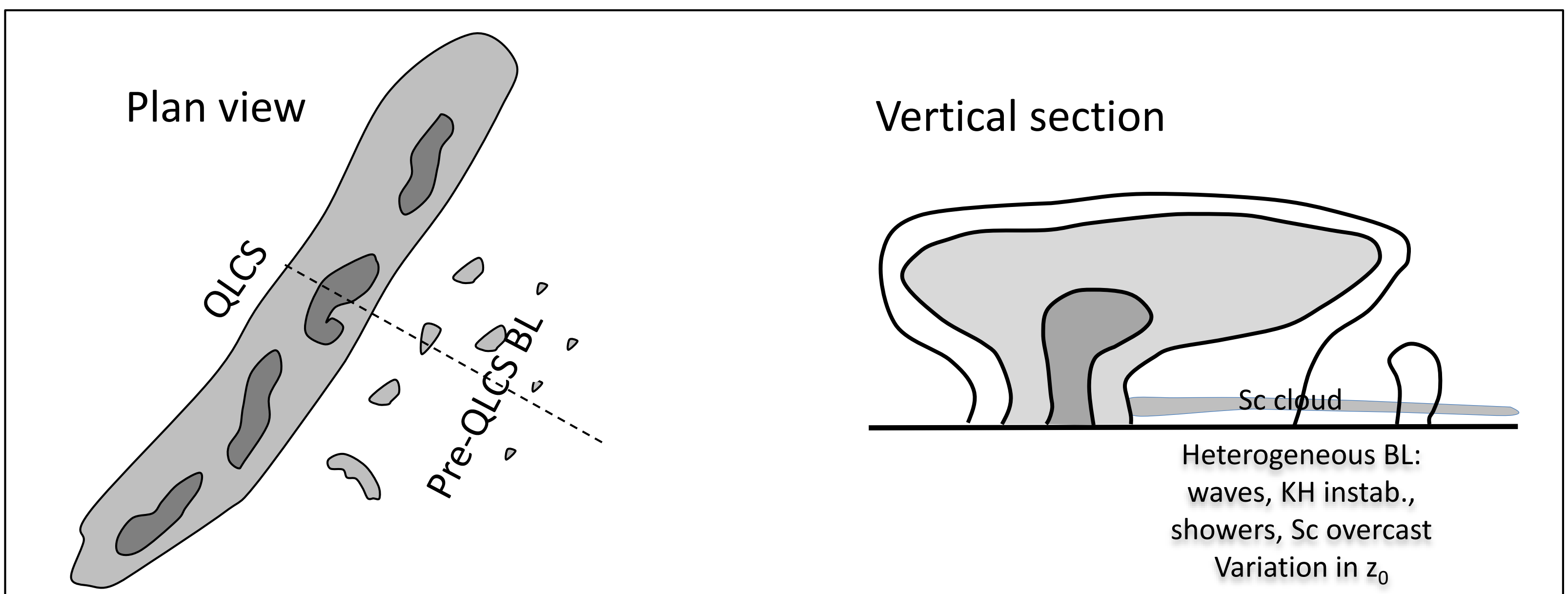
Ground-level views from the CTD site

CI over & just NE of CTD 2254 UTC, 4/23/20

Newly-formed, modest QLCS receding from CTD 2325 UTC, 4/23/20

2. Science objectives (current research)

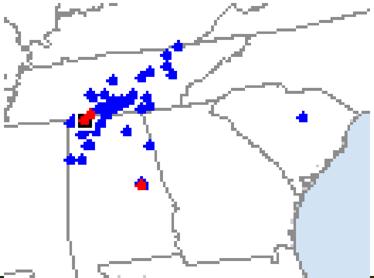
- Improve understanding of the pre-QLCS boundary layer (BL) and its variability (BLV) (primarily Nov-April)
  - Heterogeneities (large scale): significant horizontal advection
  - Heterogeneities: boundaries, evaporational cooling from stratiform rain & showers, heterogeneous surface, variations in vertical shear (z_0), shear instabilities (K-H), BL eddies/streaks
- Key question: How do variations in wind/thermo profiles in the pre-QLCS environment produce changes in QLCS internal flows?

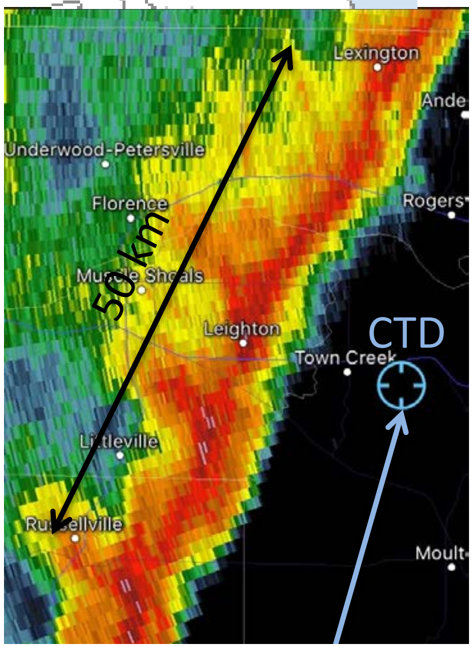


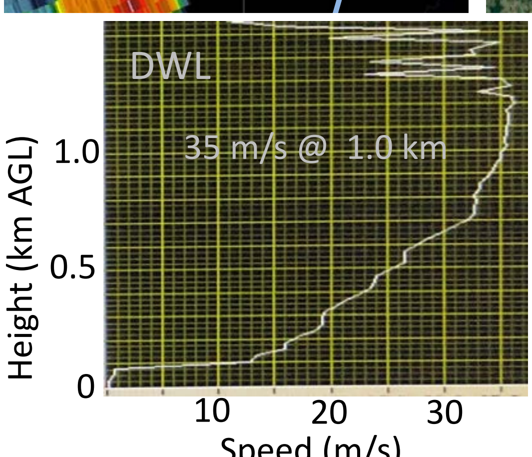
Network design example: Pre-QLCS mesoscale BL variability, E-W line of profilers + dual Doppler (BL)

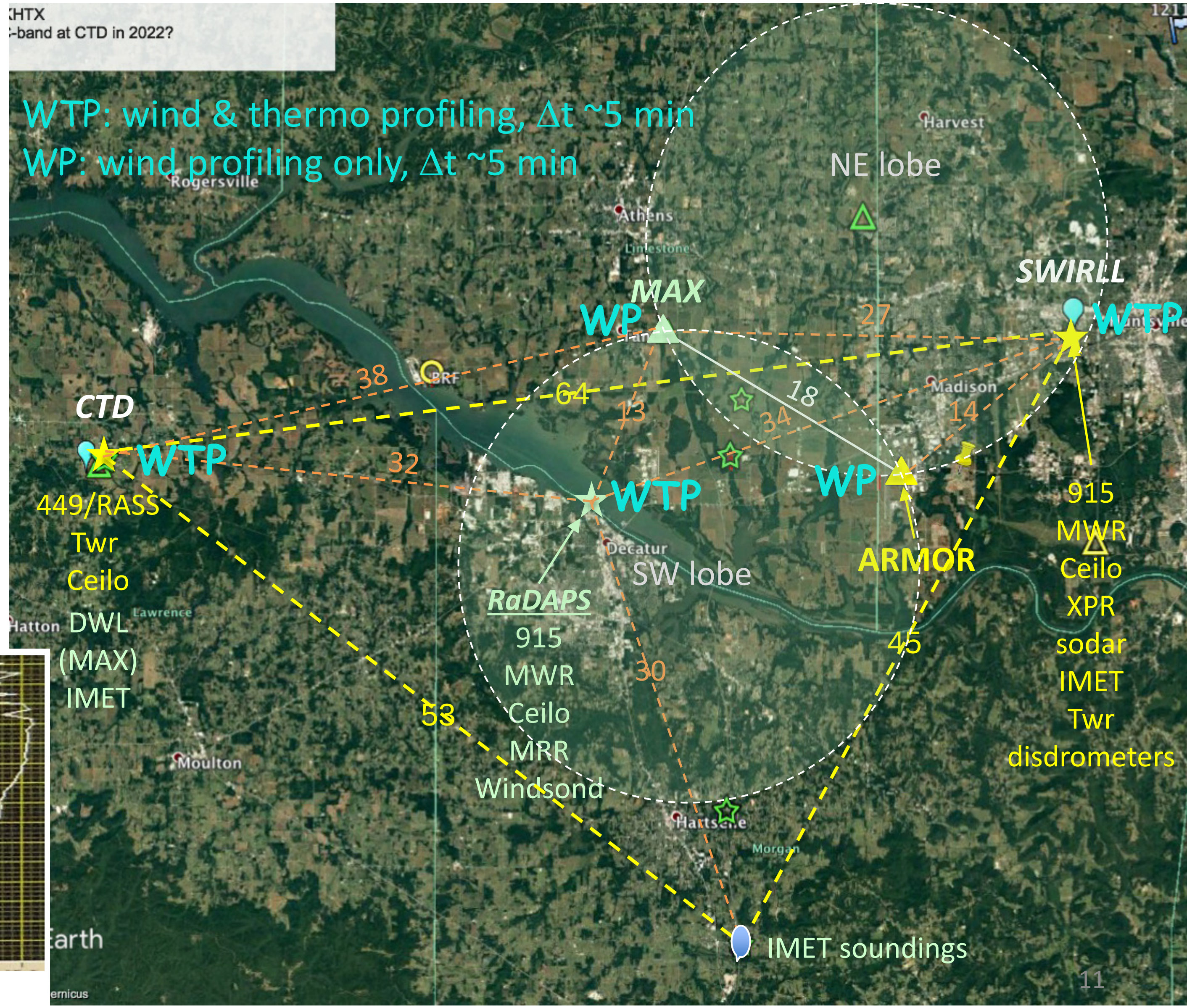
IOP5
2/12/2020

- Vigorous QLCS with low-level circulations
- Comprehensive profiling at CTD, DBL, and SWIRLL



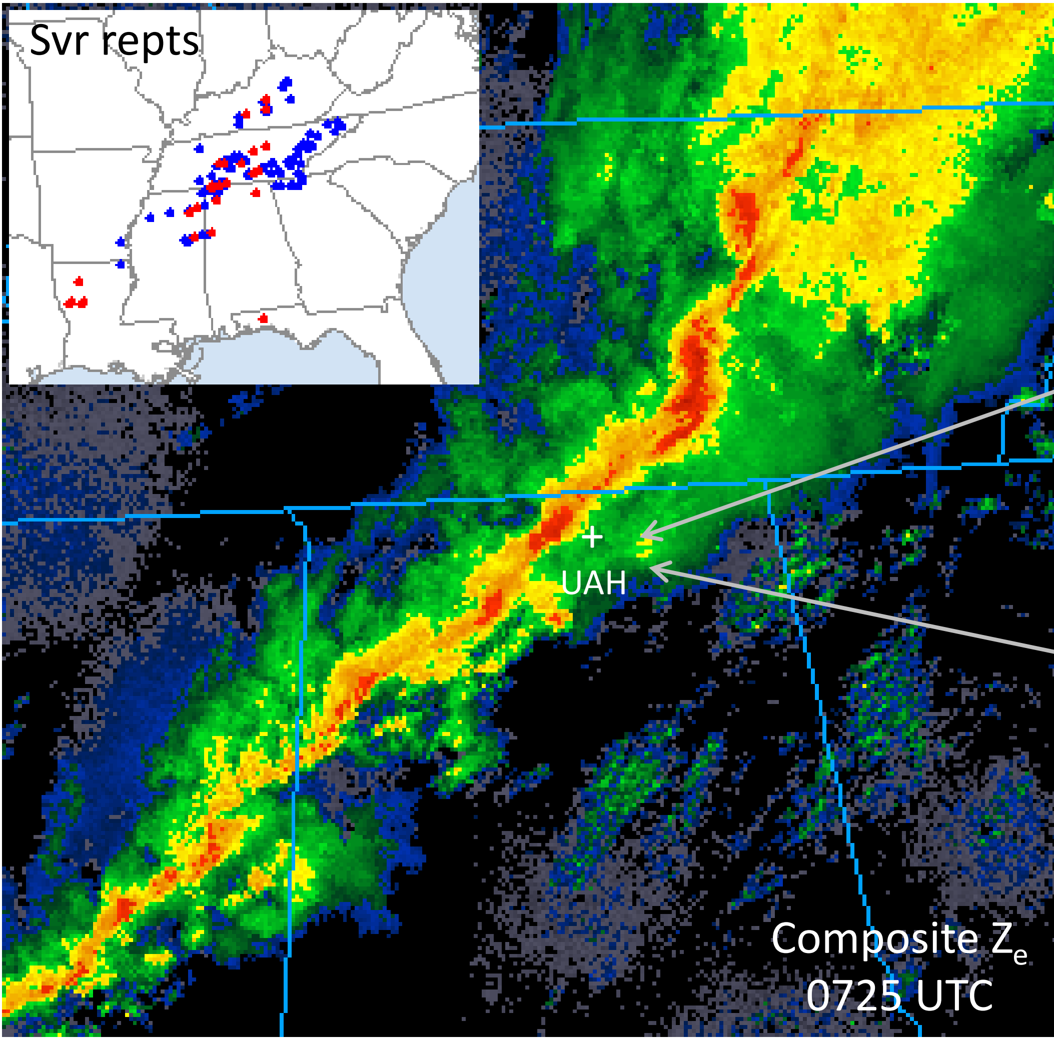




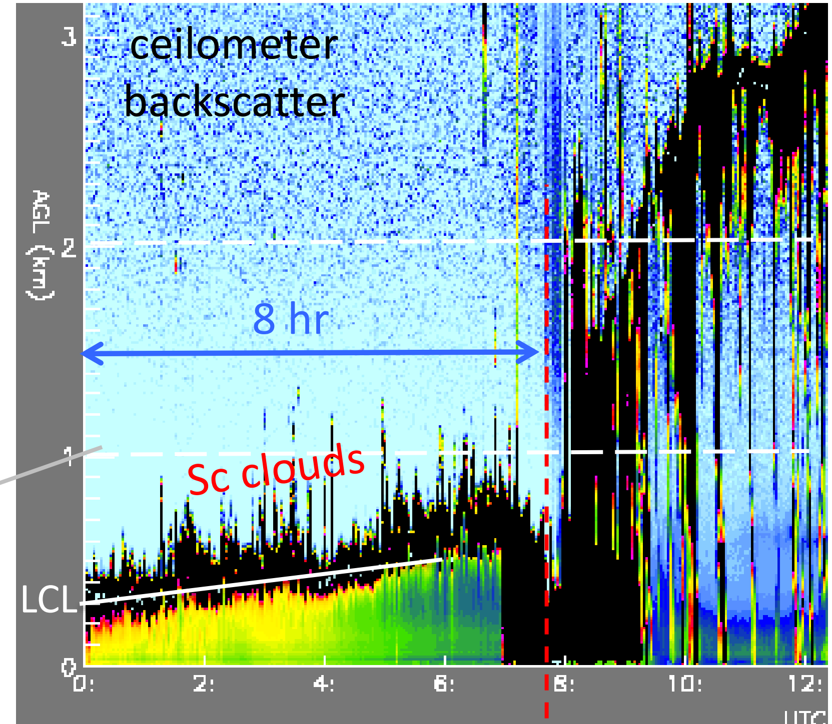


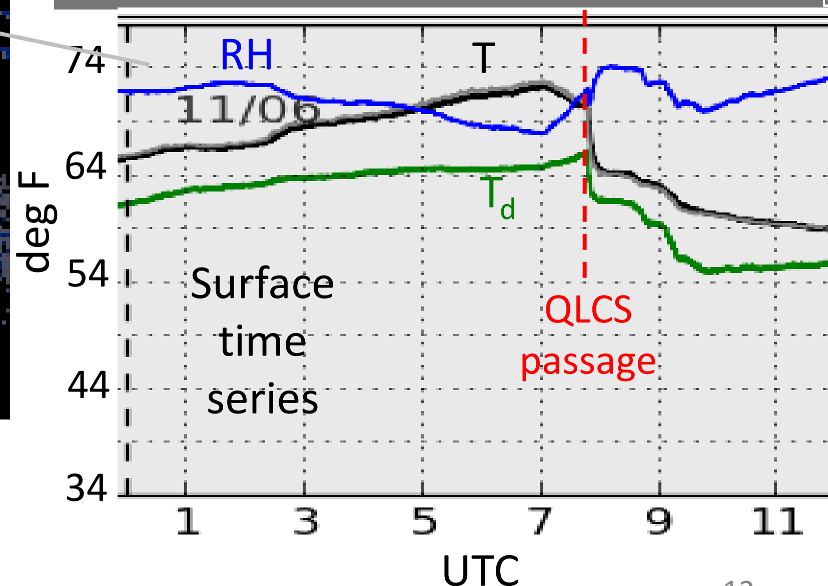
2.1 Sc clouds preceding the QLCS

Example: Severe QLCS, 6 Nov 2018



Co-located ceilometer and surface





Stratiform and convective rain preceding the QLCS may play an important role in stabilizing the BL and enhancing wind shear on ~10 km scales

Characteristics of Sc clouds preceding severe cold season QLCS's

Motivation

- Sc clouds are:
  - An important component of the BL "system"
  - Modulate subcloud static stability/shear
- Sc cloud base height and fraction may serve as a good metric for numerical simulation fidelity

Hypothesis

- Not a traditional cloud-topped mixed layer
- BL is statically stable in most cases

CAMS do not reproduce this cloud-topped PBL to sufficient detail.

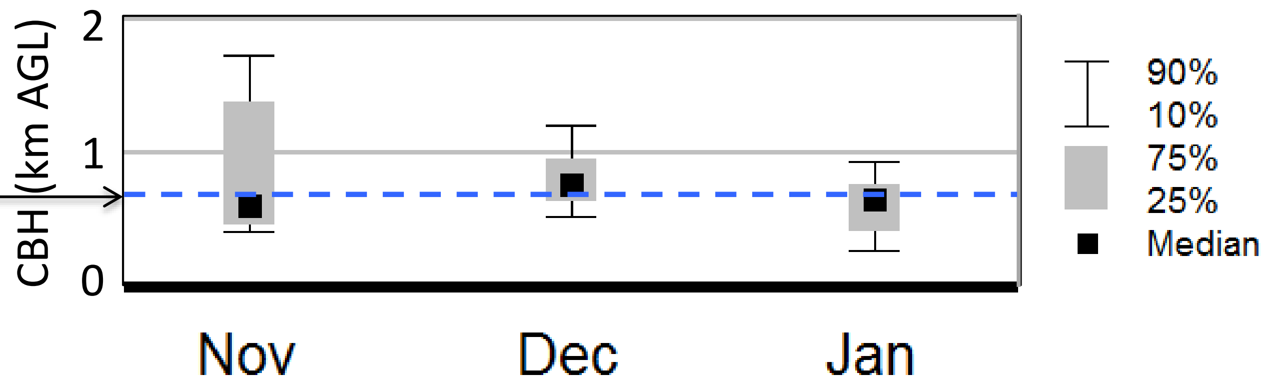
Low cloud fraction vs. month
Based on ceilometer data

Month	cases	CBH < 2 km (%)
Nov	9	82
Dec	8	89
Jan	7	87
Feb	12	78
Total	**36**	**83**

- *Cloud fraction is high*

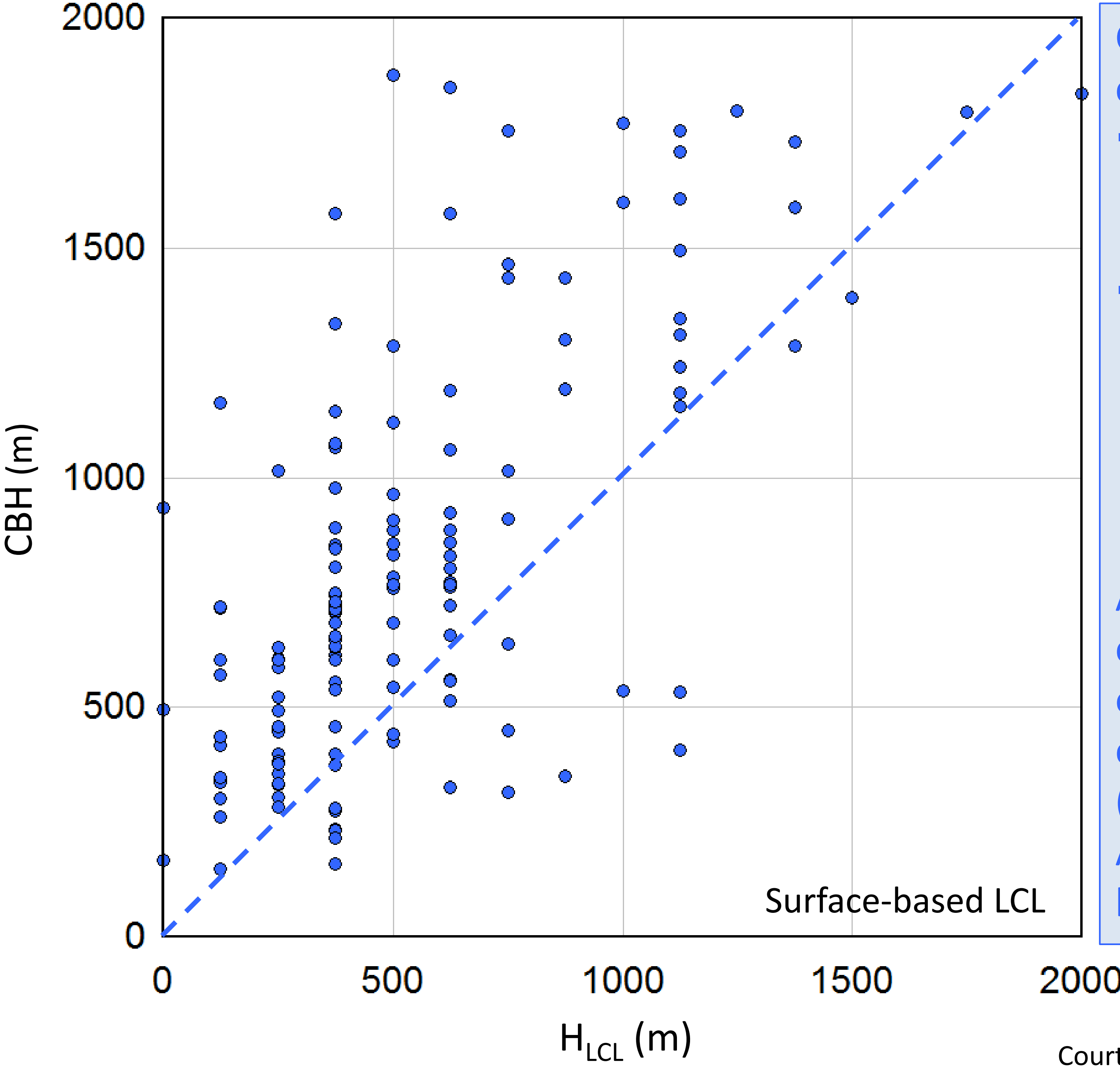
Box plot of cloud base height (CBH)

- *Median CBH is around 700 m AGL*



Results from Tim Coleman

CBH (ceilometer) vs. H_{LCL} (sfc data)



Courtesy of Tim Coleman

CBH > H_{LCL} in most cases

- ➔ BL is not mixed: It is statically stable in most cases
- ➔ Static stability moderates TKE (mixing), and promotes greater wind shear

AMF3 would provide comprehensive data on Sc cloud characteristics (cloud radars, lidars, AERI, scanning C-band radar)

A future project (planning stages) to examine AV/BLV preceding QLCSs

- ***C**haracterization of **A**tmospheric **V**ariability, **E**volution, **A**nd **T**hermodynamics preceding **Q**LCSs (CAVEAT-Q)*
- PI's: Knupp, B. Geerts (UW), M. Biggerstaff (OU) and Z. Wang (CU)
- Key platform: UW King Air with the following instruments:
  - Compact Raman Lidar (T and w.v. mixing ratio profiles)
  - Wyoming Cloud Radar (W-band, cloud depth, kinematics)
  - Ka-band zenith/nadir profiling radar (KPR) (precip distribution, kinematics)
  - In situ
- Other facilities: all UAH, two mobile SR radars from OU, maybe others
- Objectives:
  - Advance understanding of BL characteristics, spatial variability, and driving physical processes in the pre-QLCS environment
  - Understand how variations in pre-QLCS BL structure, in particular low-level shear and CAPE, affect storm-scale process within QLCSs, especially the evolution of vorticity within or near shallow convective updrafts
- Likely time period: Feb – Apr 2022 or 2023 (cold season to spring conditions)
- Domains: near Courtland (Alabama) and Mississippi delta (TBD)
- Additional objectives (e.g., aerosol) would be easy to incorporate

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Ideal example of synergism with AMF3 capabilities (wind, thermodynamic, and cloud profiling) and ARM/ASR science

Summary

- Challenges in network design
  - trees, orography
  - document both BL and cloud-scale flows
- Complex surfaces (turbulent fluxes) introduce heterogeneities on small scales that likely influence deep convection
- Mesoscale variability is important to document
  - Time-to-space conversion of time series data (profilers)
  - Scanning radar
  - Aircraft measurements if/when available

Backup slides

BL heterogeneity

- Impact on tornadic QLCSs and supercell storms
- Importance in convective initiation (CI)
- Modulation of Cu cloud fields
- Mesoscale variations in surface properties (z_0, fluxes)
- Example:
  - 4/9/13
  - Wheeler lake breeze

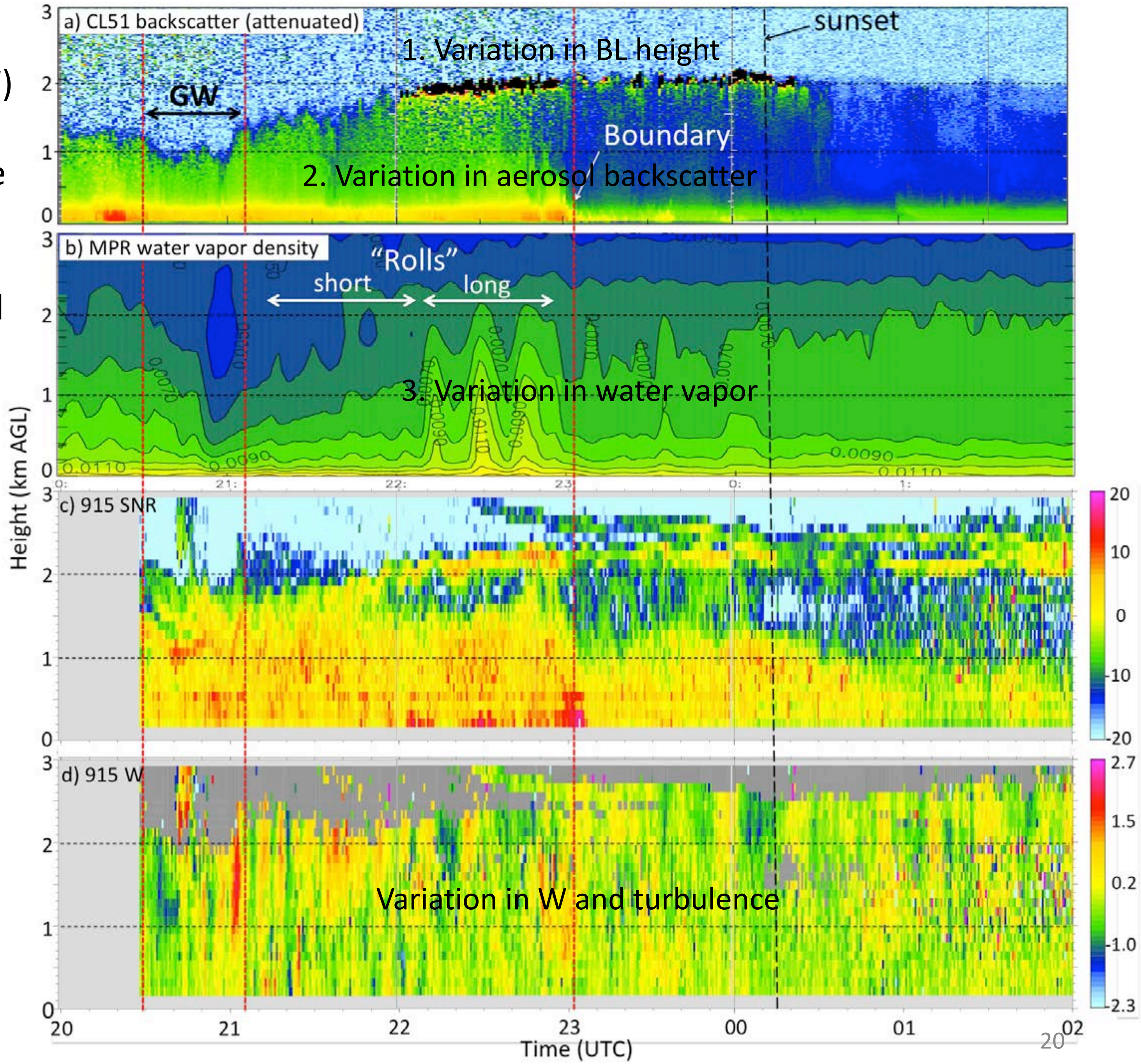
Note: Relative forcing by mesoscale heterogeneities is likely a more important regulator on deep convection during the warm season when synoptic-scale forcing is small and surface fluxes are large.

4/9/2013

MIPS observations

a) Gravity wave (GW)
b) BL rolls
c) Boundary passage

Appreciable variation in z_i, water vapor, and relative aerosol loading.



MAX Observations

2139 UTC (top): Limited region of enhanced Z_e and V_r streaks, consistent with BL rolls. Distinct difference in T & T_d between KDCU (D) and KHSV (H)

2247 UTC (bottom): Presence of boundary (not a lake breeze), superimposed within a region of bands of relatively enhanced V_r.

M: MIPS
X: MAX
D: KDCU ASOS
H: KHSV ASOS
U: UAH