Long-Duration Freezing Rain Events over North America:

Regional Climatology and Maintenance Mechanisms

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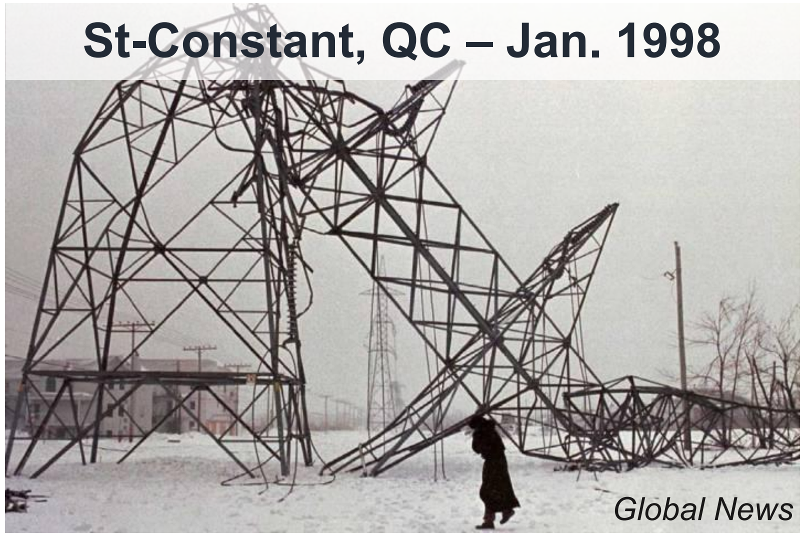
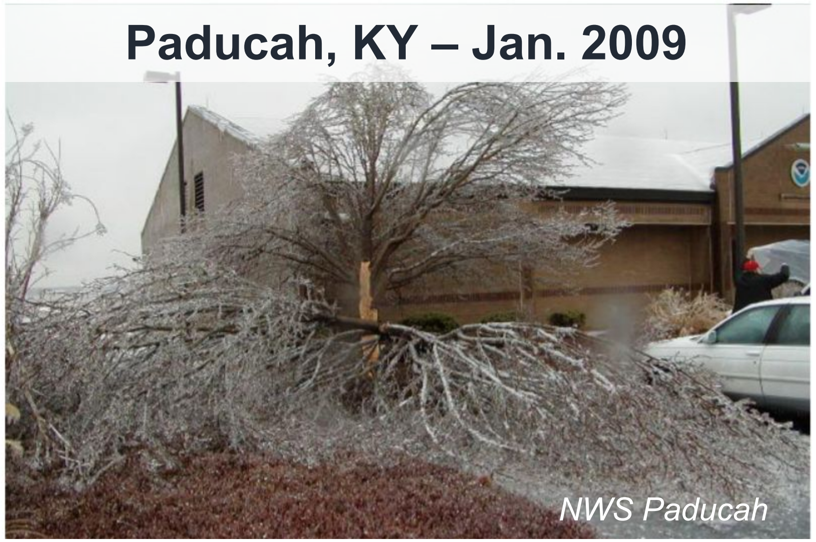
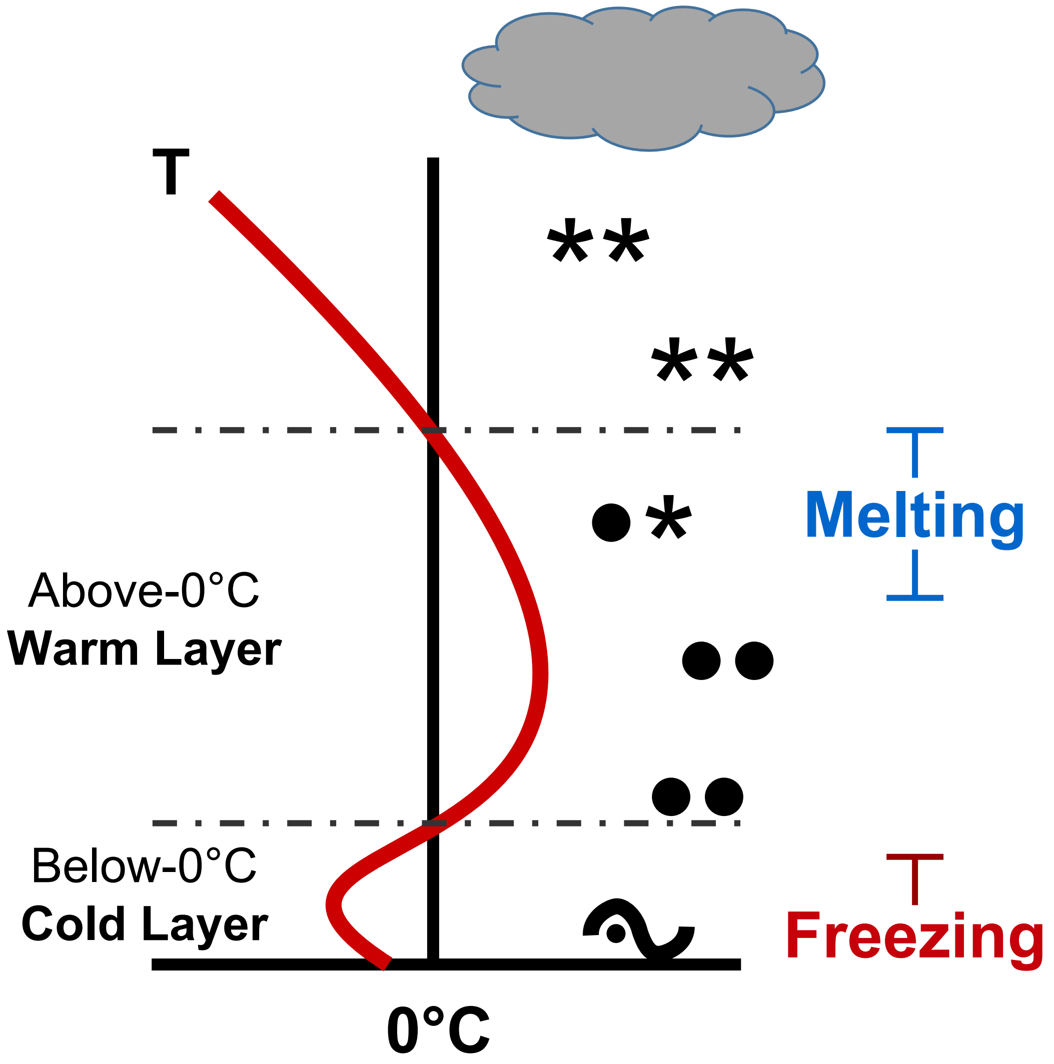
Freezing rain (FZRA) can produce severe impacts





Freezing rain events are a forecast challenge, in part because they are *self-limiting* (Stewart et al. 1985)



- Only **11%** of FZRA events last longer than 4 h (Cortinas et al. 2004)
- Diabatic cooling from melting, warming from freezing (latent heat of fusion) can destroy warm/cold layers within a few hours
  (e.g., Kain et al. 2000, Lackmann et al. 2001)
- For events to persist for many hours, compensatory mechanisms needed, e.g.,
  - Warm-air advection (WAA) in warm layer
  - Cold-air advection (CAA) in cold layer
- **Goal**: improve understanding of conditions allowing FZRA to persist for many hours

Research questions

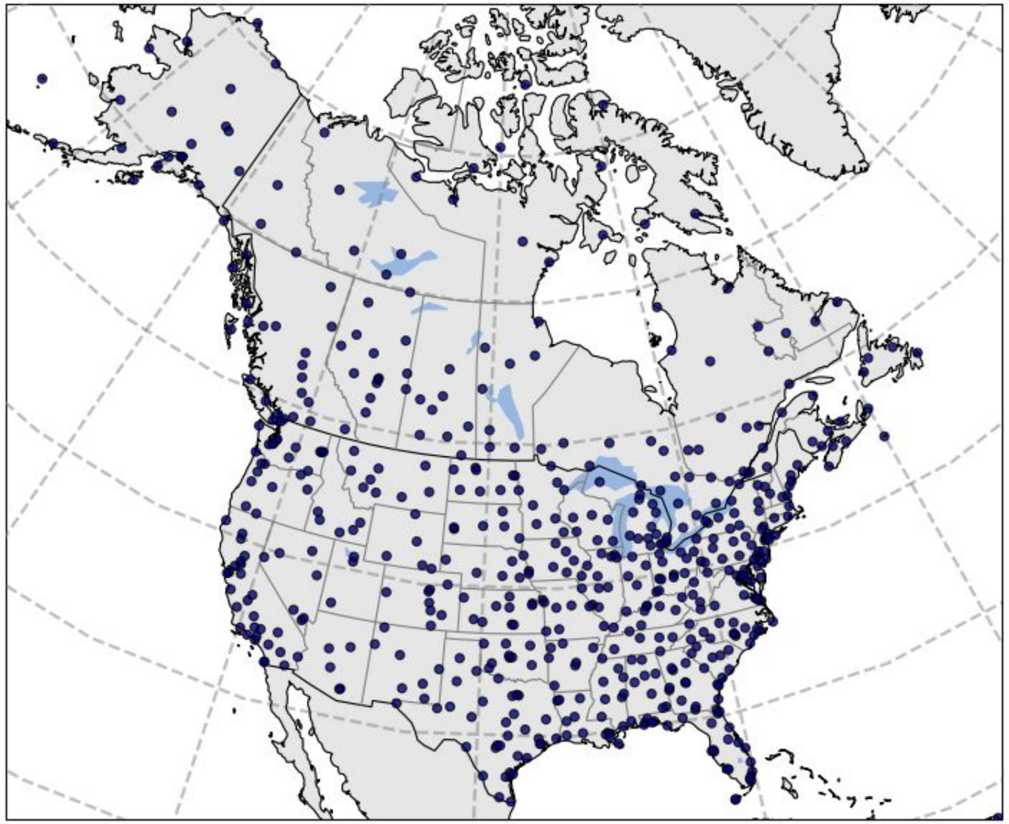
1. **Where do long-duration (6 or more hours) freezing rain events occur most frequently?**

2. **What thermodynamic conditions support the persistence of these events?**

3. What synoptic-dynamic conditions support the persistence of these events?

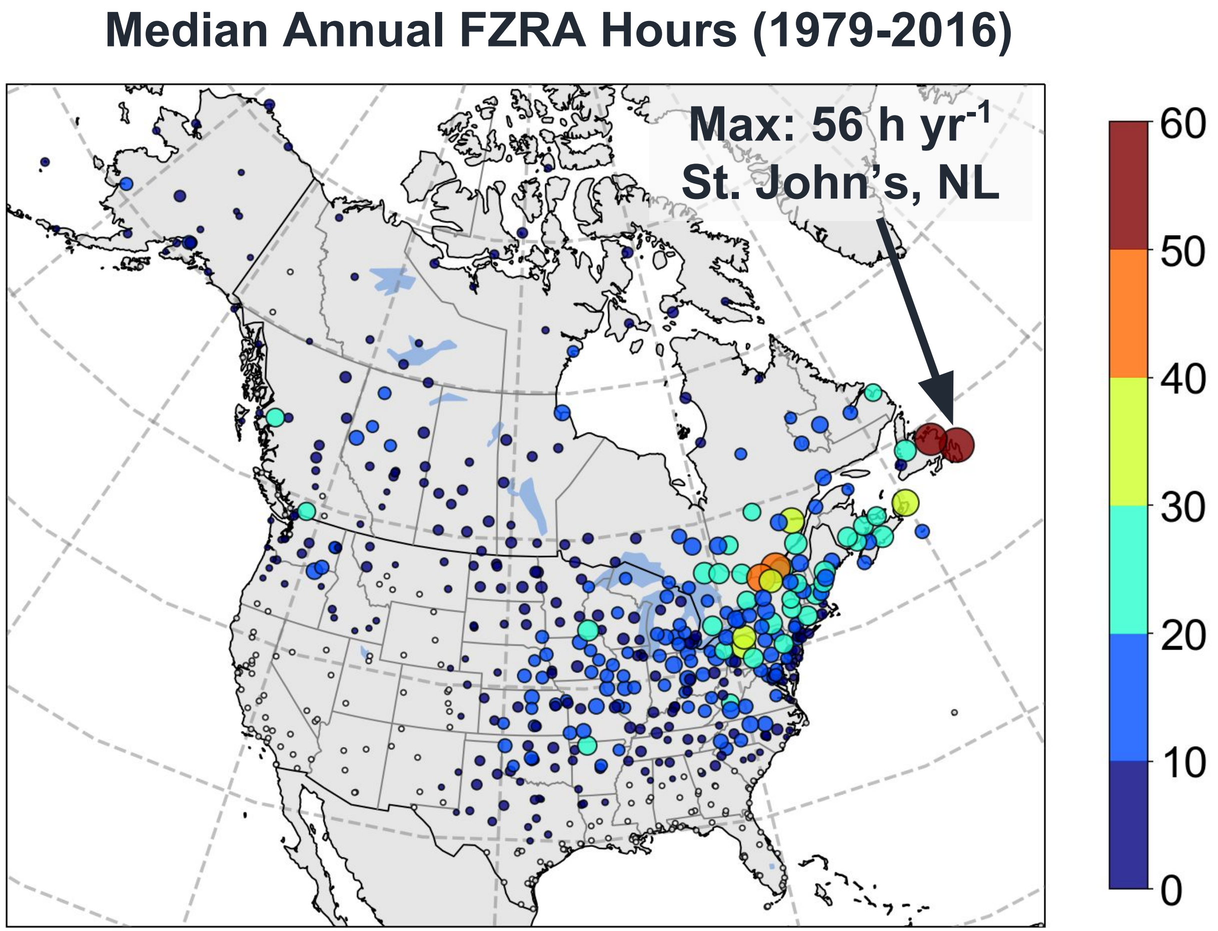
Data and methods

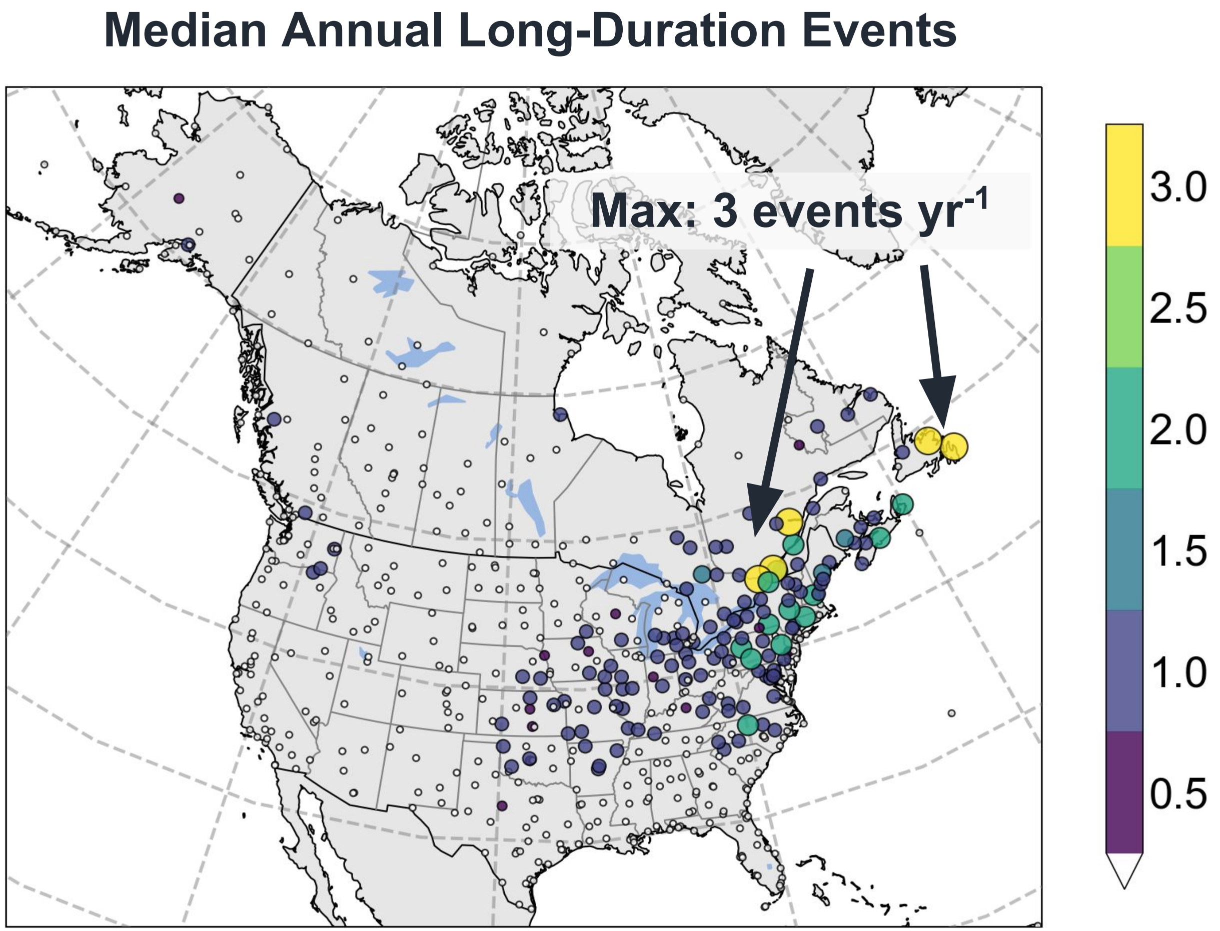
579 stations used in dataset



- **Surface Observations:**
  - NOAA Integrated Surface Database
  - 1979-2016, U.S. and Canada
- **Upper-air data:** U. Wyoming archive
- **NCEP CFSR**
  - 0.5°x0.5° grid, 6-hourly, 1979-present
- **Freezing Rain Event Duration:**
  - Count consecutive hours of FZRA, then combine events with <24 h between them
- **Long-Duration (LD) Event:**
  - FZRA event with 6+ h of FZRA
  - ~20% of all events
- **Short-Duration (SD) Event:**
  - FZRA event with ≤ 3 h of FZRA

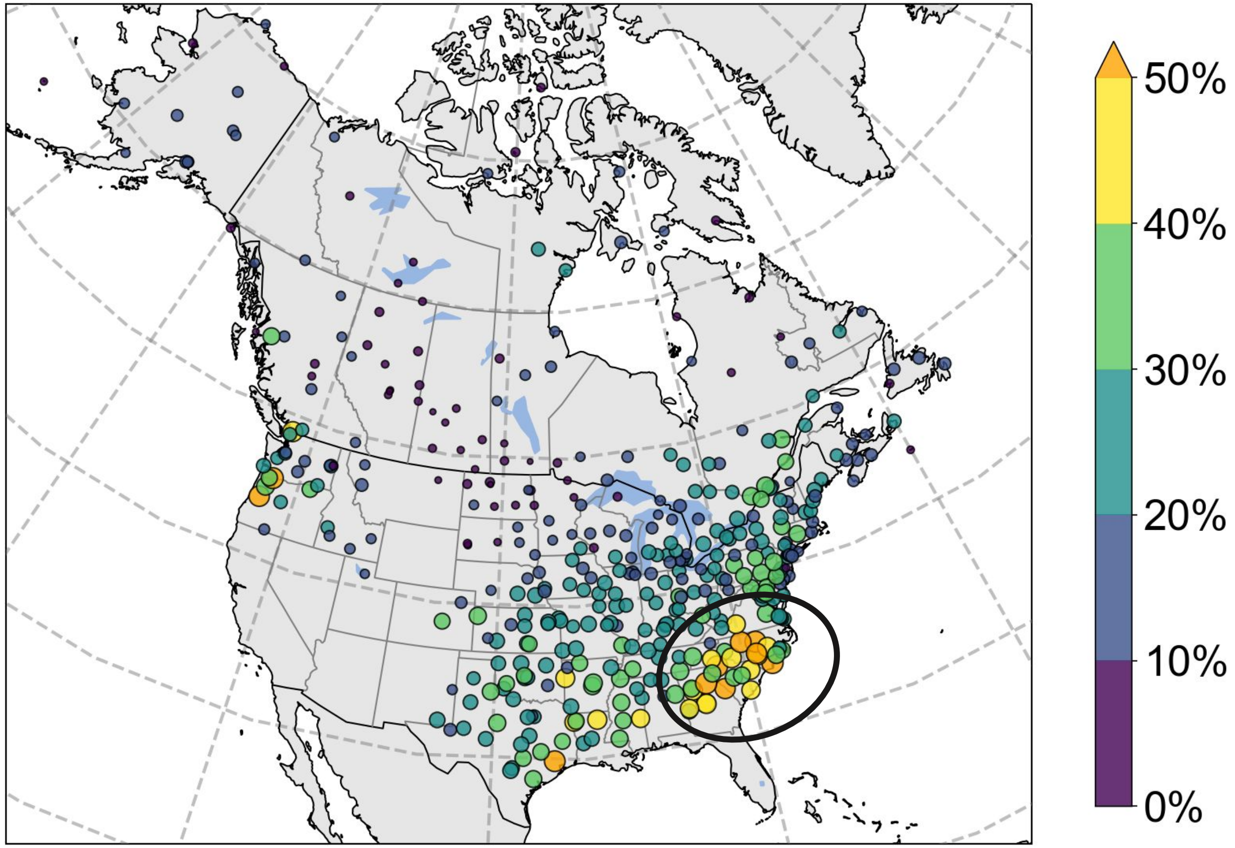
Q1: FZRA, LD events occur most often over the northeastern U.S. and southeastern Canada…



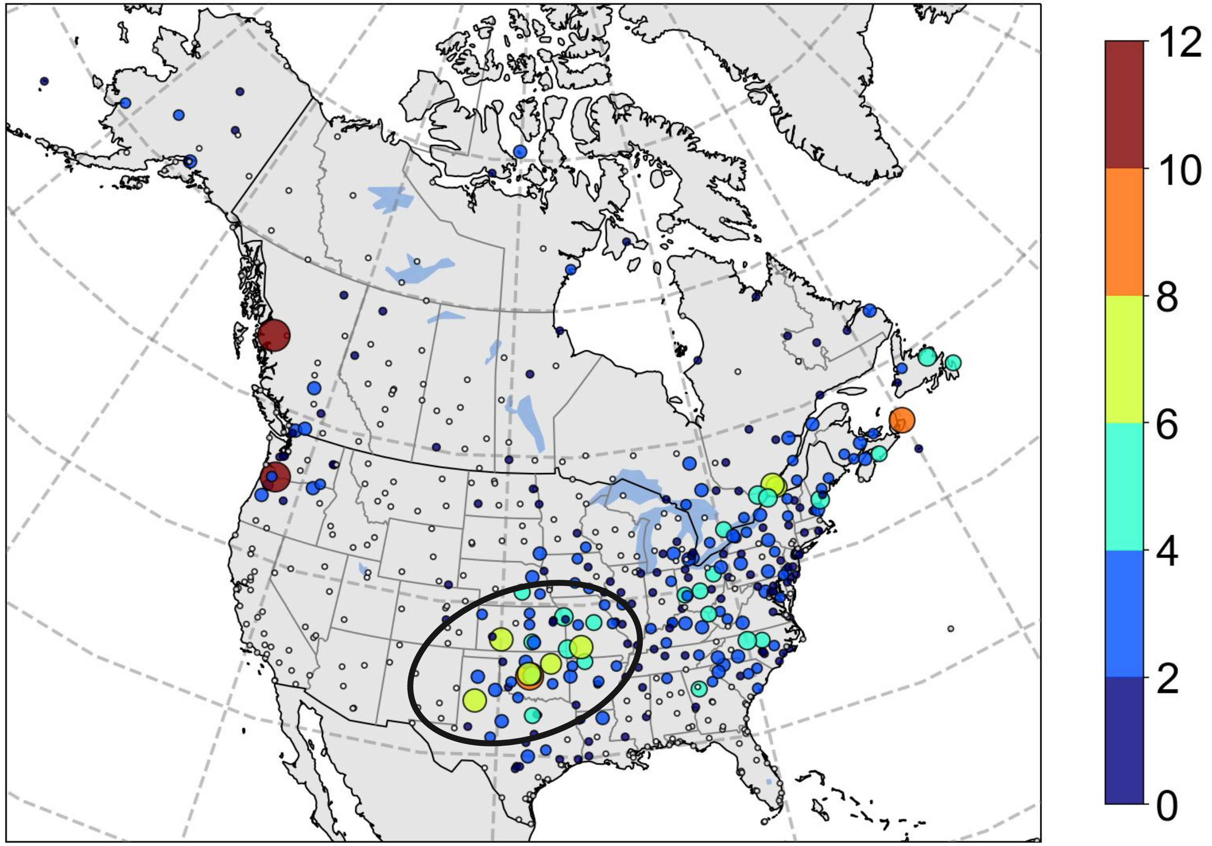


…but when FZRA occurs in the Southeast and South Central U.S., it tends to be persistent

% of FZRA events that are long-duration

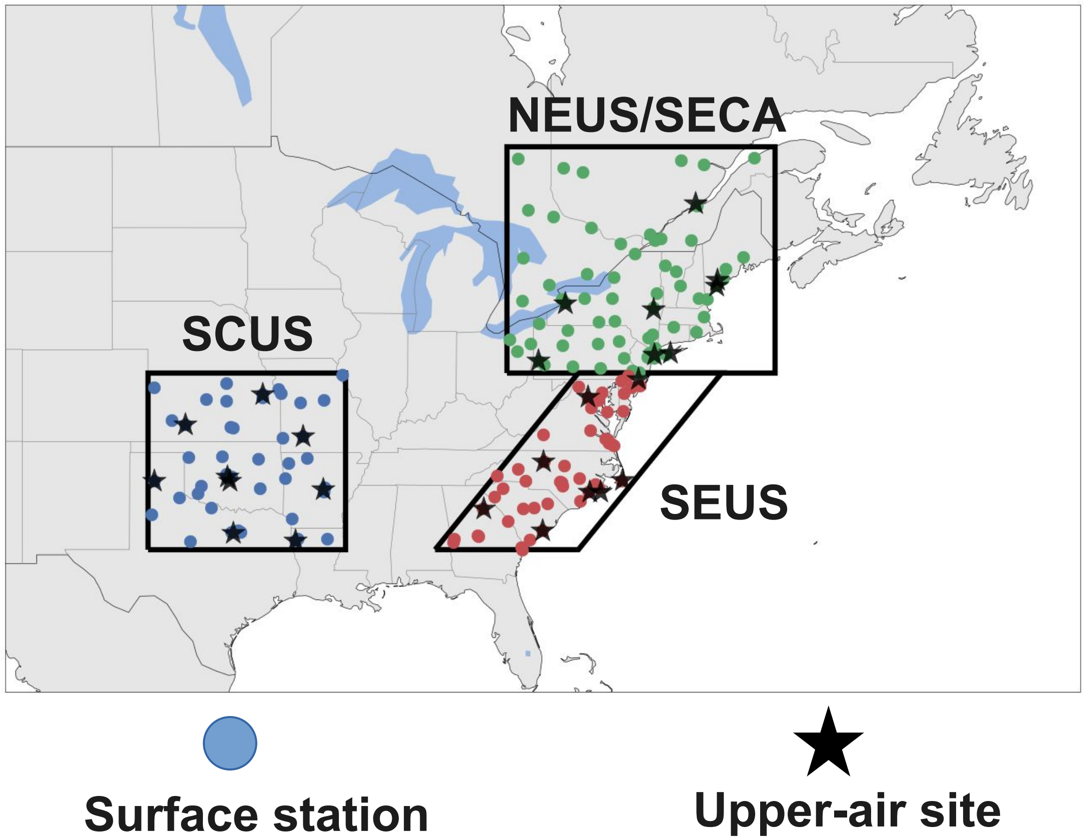


Number of 18+ h FZRA events (1979-2016)



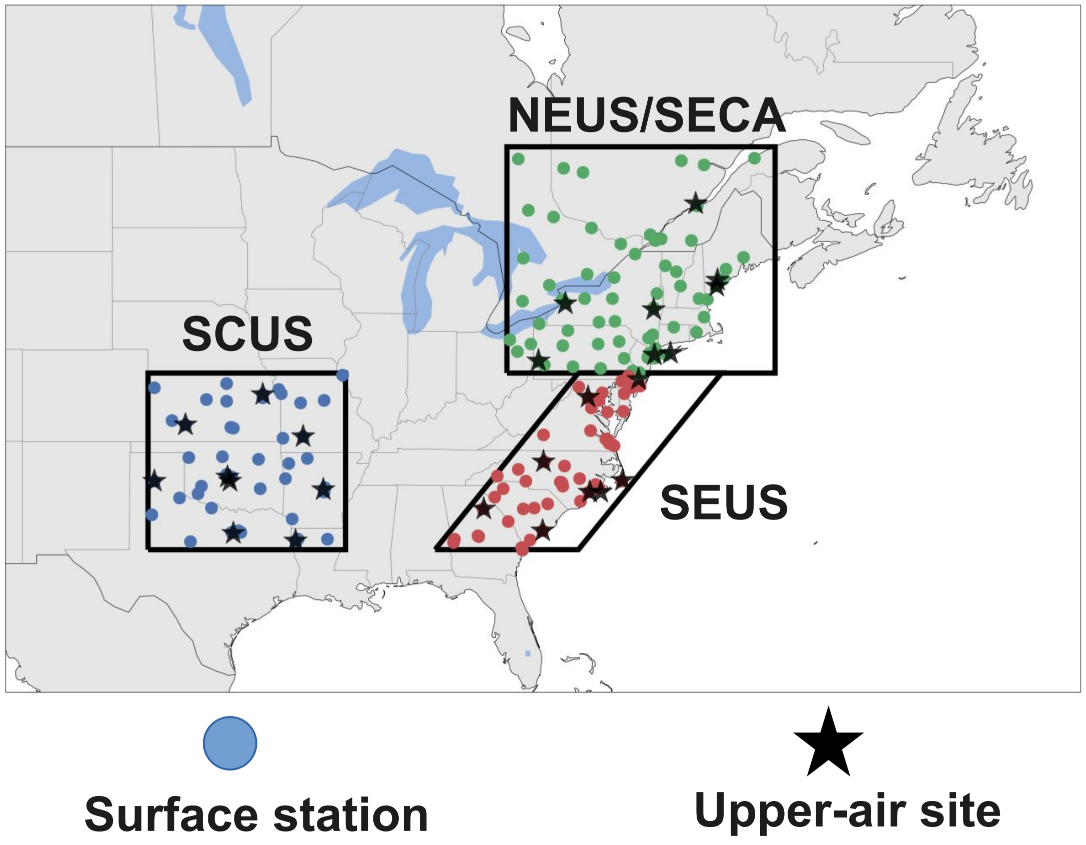
This climatology highlights several focus regions

- South Central U.S. (**SCUS**)
  - Local maximum in 99th percentile (18+ h) events
- Northeastern U.S./ Southeastern Canada (**NEUS/SECA**)
  - Observes LD events most frequently
- Southeastern U.S. (**SEUS**)
  - Observes more LD events than SD events



Q2: What thermodynamic conditions support LD event persistence?

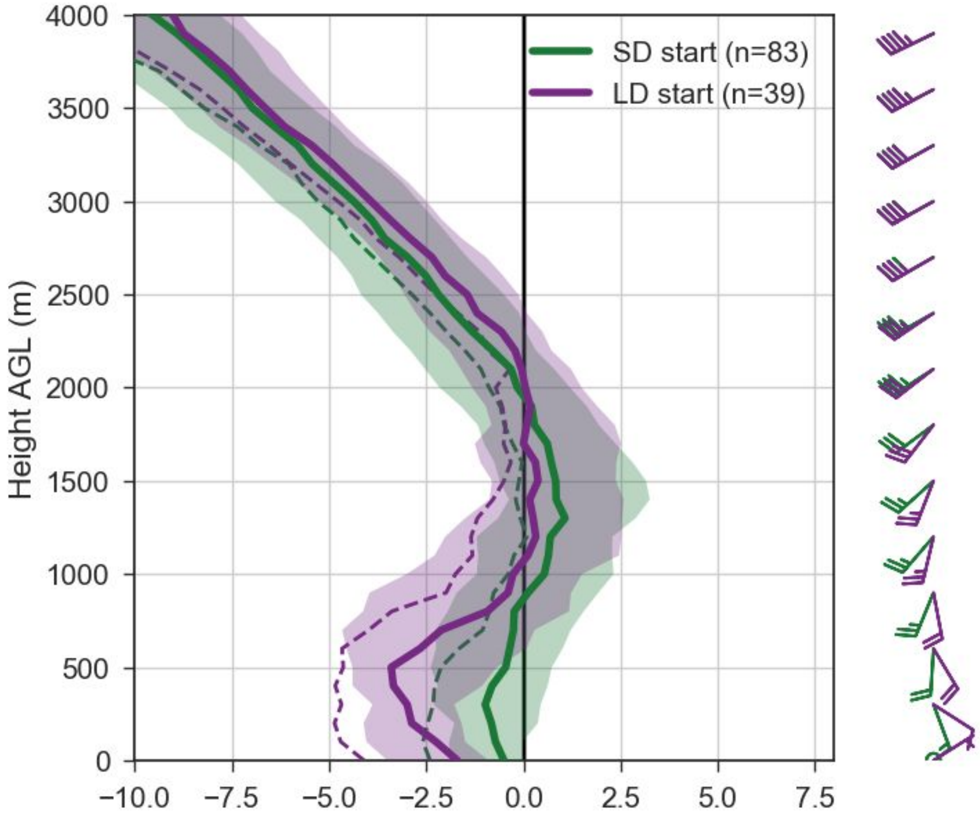
- We gather data on conditions at **LD/SD event onset**
- Within each region:
  - Composite all soundings for events that started **within 1 h** of a balloon launch
  - Typical launch times:
    - ~45 min before 00/12 UTC
- Here: only including soundings with **warm layer present**



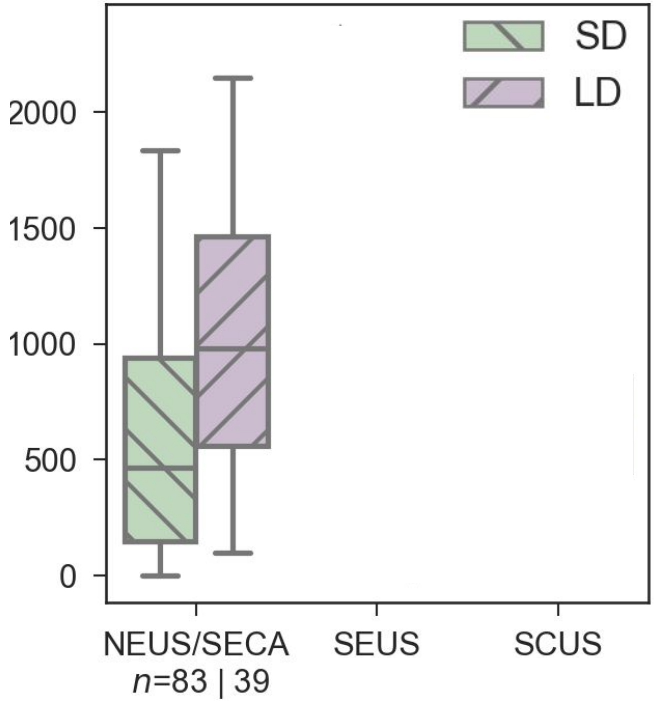
Q2: A deeper and colder cold layer supports longer duration events over the NEUS/SECA

SD and LD event onset - NEUS/SECA

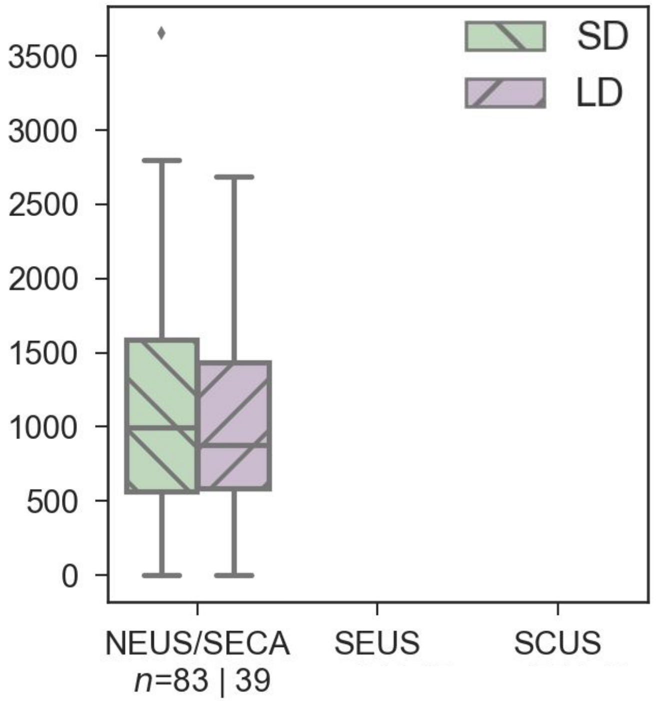
Median T (solid)/Td (dashed)
25th-75th pctile of T (shaded)



Cold Layer Depth (m)



Warm Layer Depth (m)

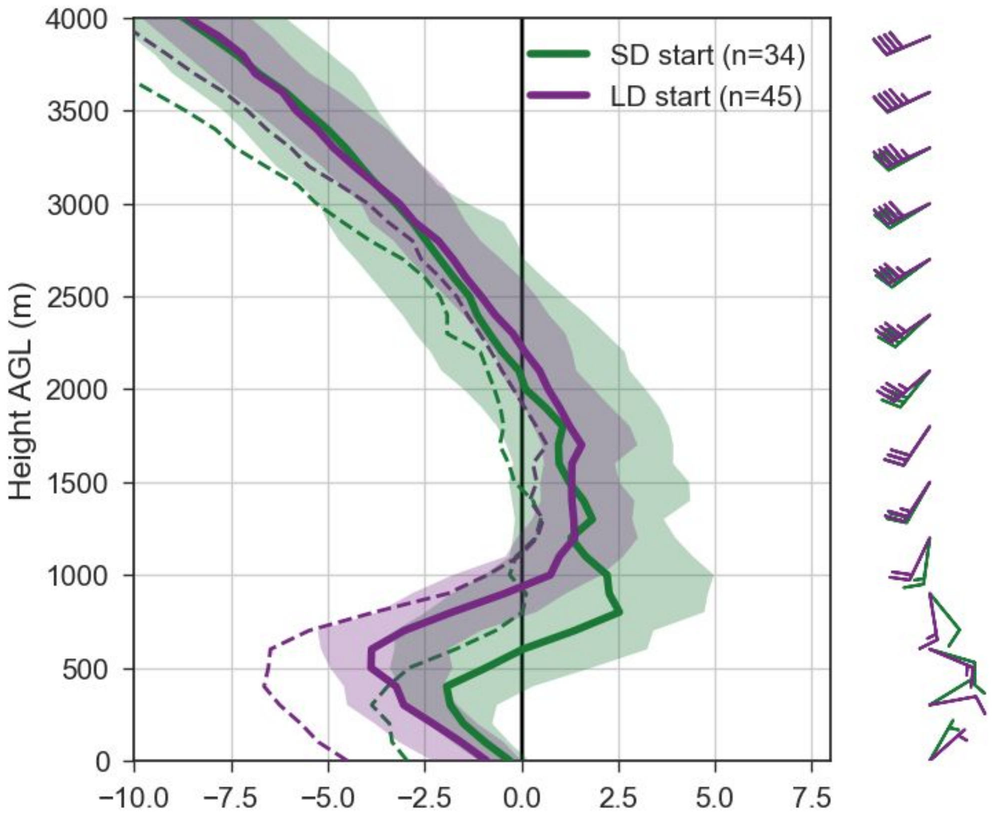


Median **cold layer** is **deeper** and **colder** for LD events (978 m, -4.8°C) than SD events (464 m, -2.4°C)
(both significant for $p<0.0001$)

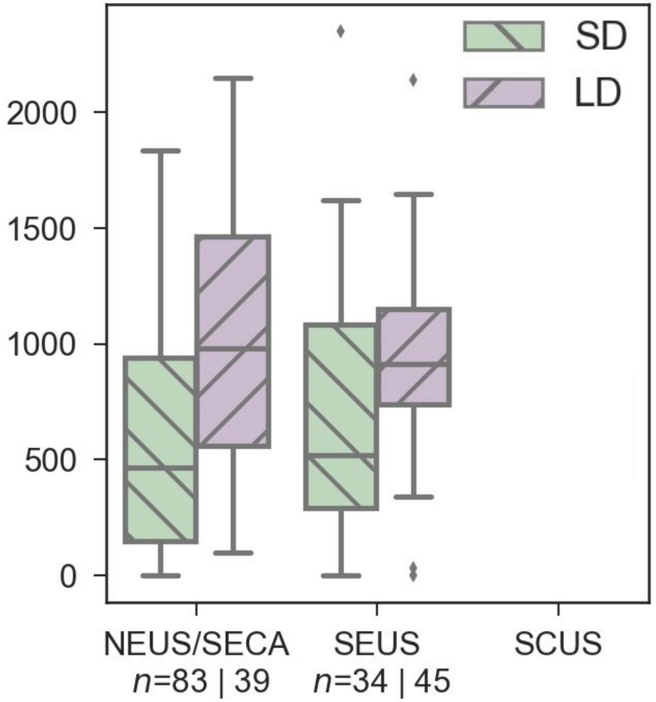
Q2: A deeper and colder cold layer also supports longer duration events over the SEUS

SD and LD event onset - SEUS

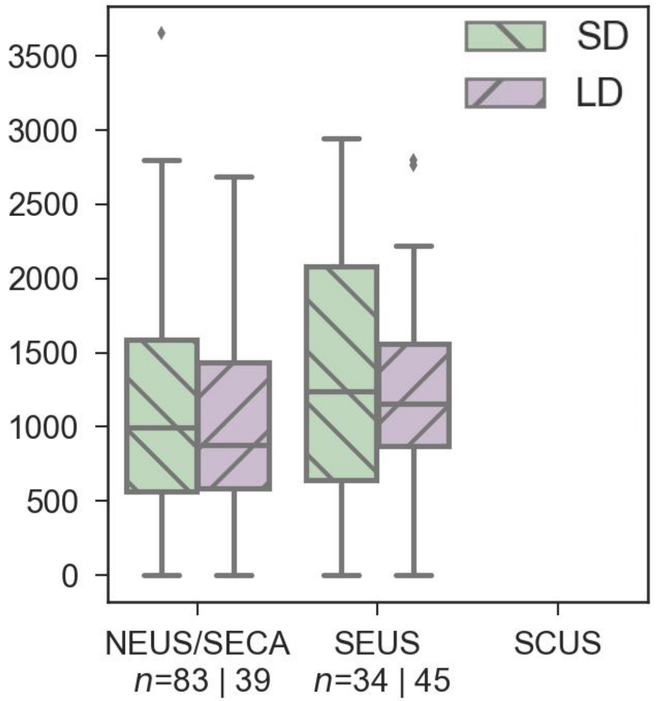
Median T (solid)/Td (dashed)
25th-75th pctile of T (shaded)



Cold Layer Depth (m)



Warm Layer Depth (m)

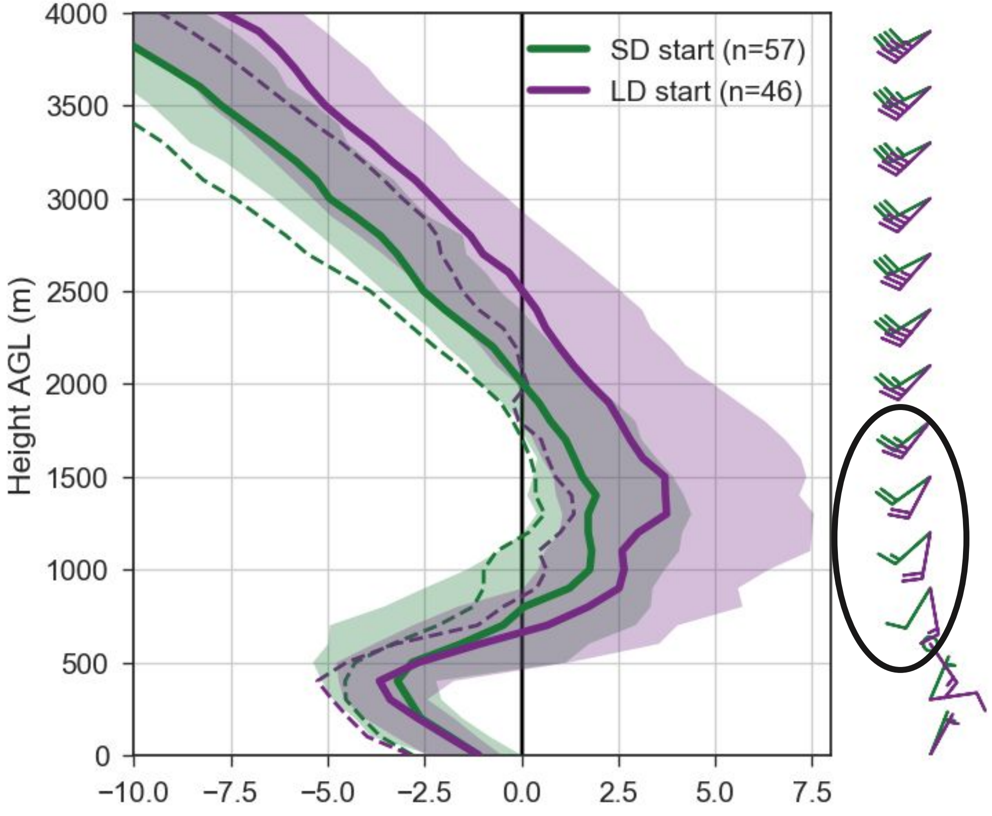


Median **cold layer** is **deeper** and **colder** for LD events (913 m, -4.4°C) than SD events (519 m, -2.4°C)
(significant for $p < 0.05$, $p < 0.01$)

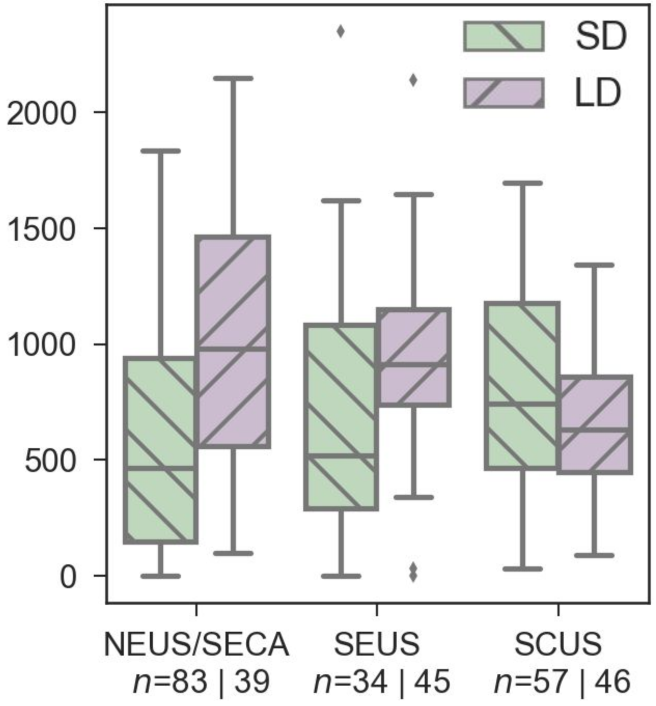
Q2: Warm layer intensity at onset is a limiting factor in event duration over the SCUS

SD and LD event onset - SCUS

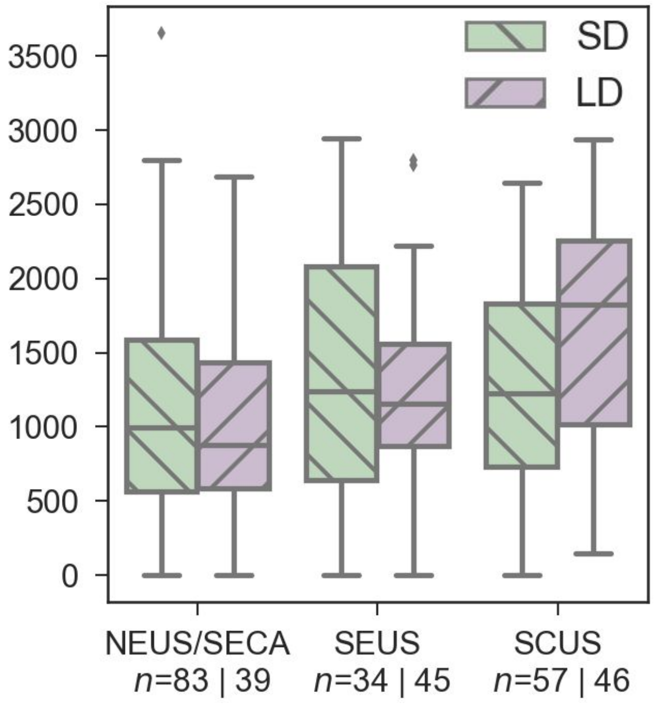
Median T (solid)/Td (dashed)
25th-75th pctile of T (shaded)



Cold Layer Depth (m)



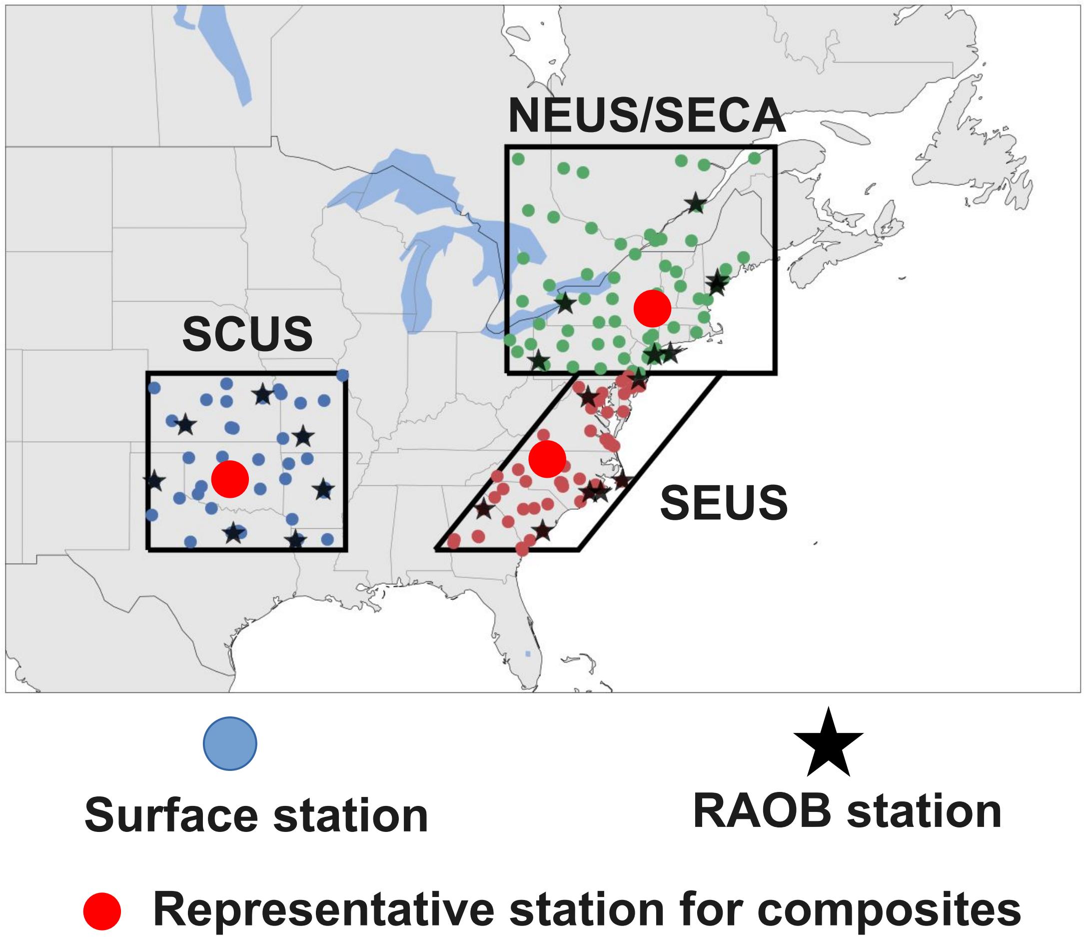
Warm Layer Depth (m)



Median **warm layer** is **deeper** and **warmer** for LD events (1826 m, 5.6°C) than SD events (1225 m, 3.5°C)
(significant for $p < 0.01$)

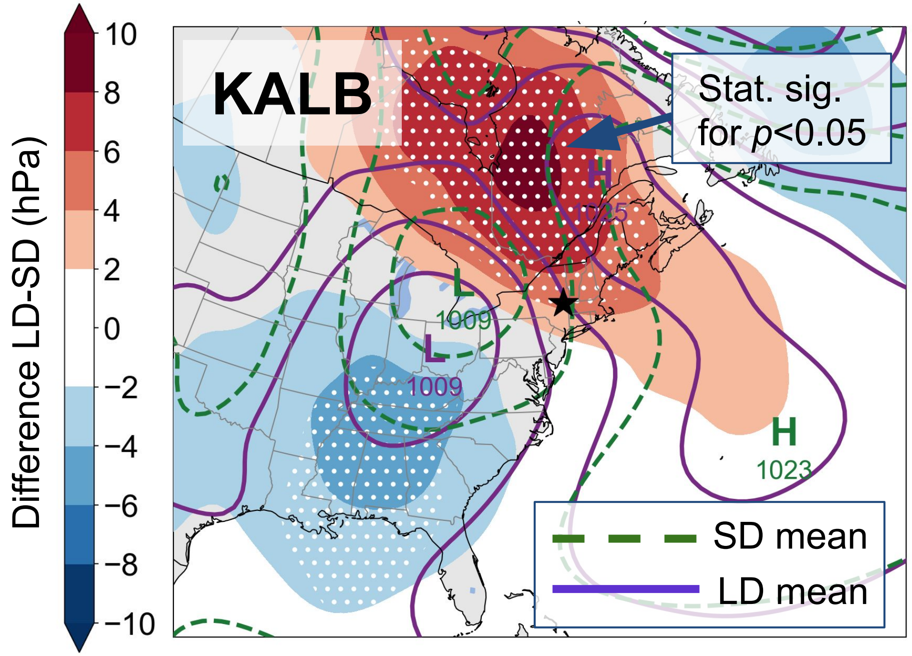
Q3: What synoptic-dynamic conditions support LD event persistence?

- Several studies have examined patterns leading to FZRA over individual regions
- Here, we **compare** composites of **LD events and SD events**
- Random sample of **30 SD, 30 LD** events at...
  - **NEUS/SECA**: KALB - Albany, NY
  - **SEUS**: KGSO - Greensboro, NC
  - **SCUS**:KOKC - Oklahoma City, OK



Q3: What synoptic-dynamic conditions support LD event persistence?

Composite SLP at event onset / Composite LD SLP - SD SLP (shaded)



- FZRA occurs north of warm front
- Warm air overruns sfc cold air ahead of front, develops warm layer

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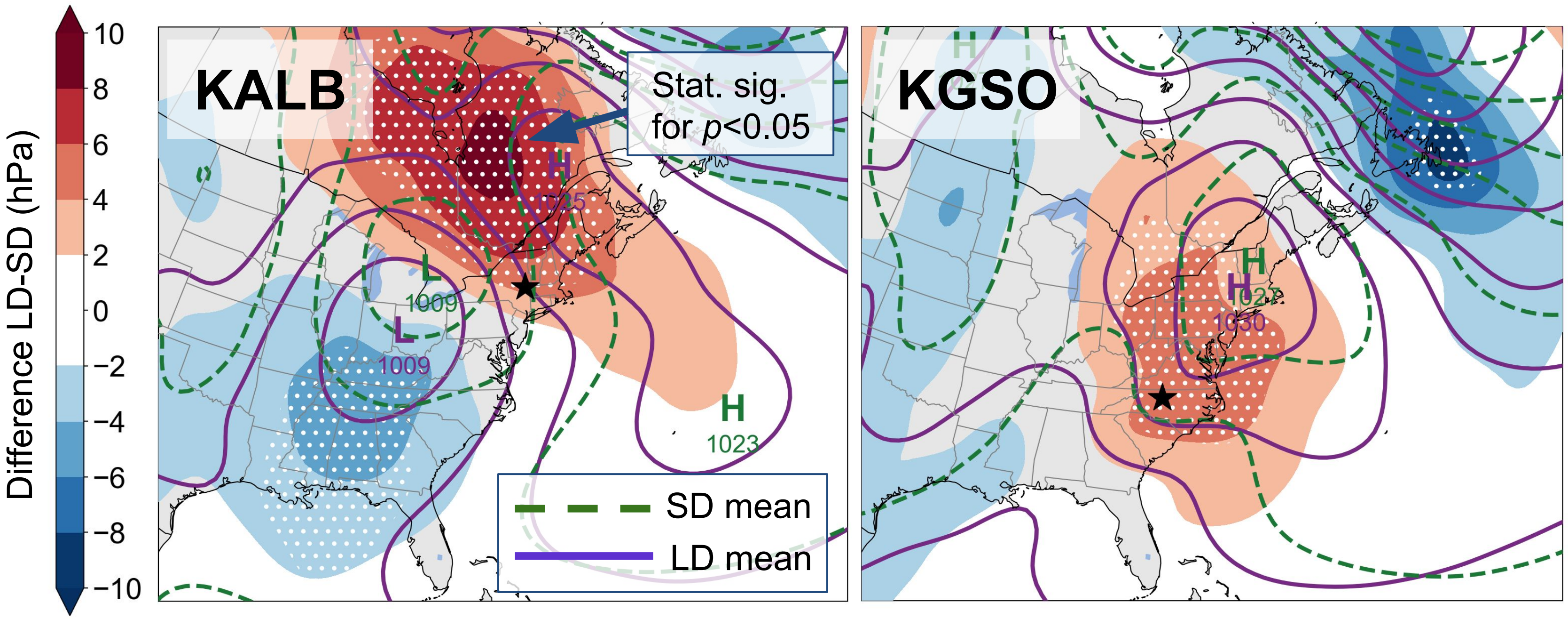

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- Appalachian CAD pattern
- Higher SLP, colder sfc T over CAD region for LD composite than for SD

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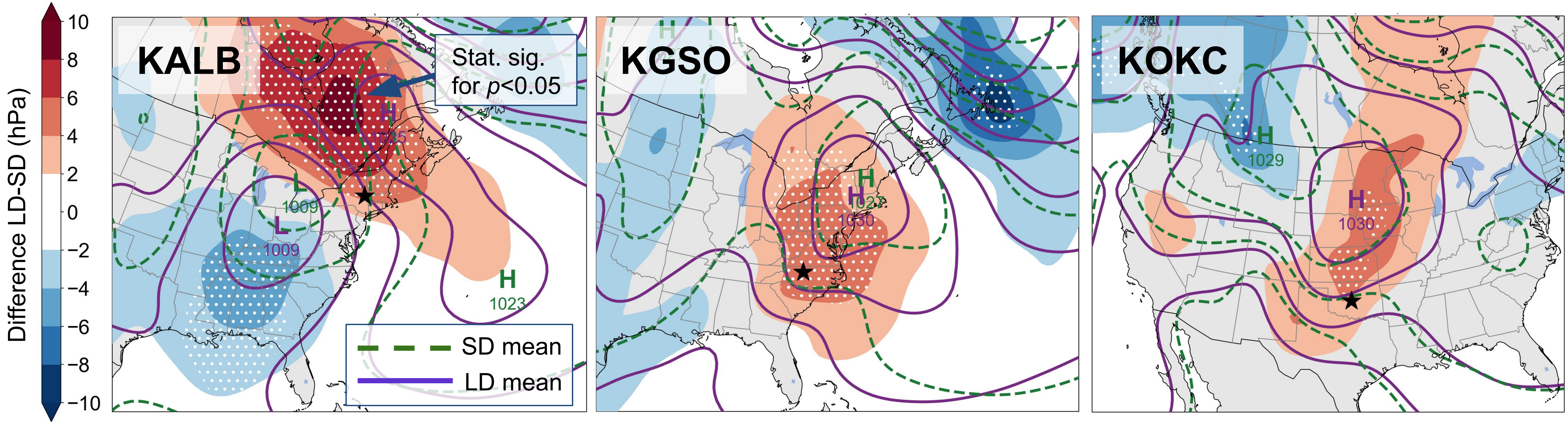

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- Warm air overruns sfc cold air ahead of front, develops warm layer

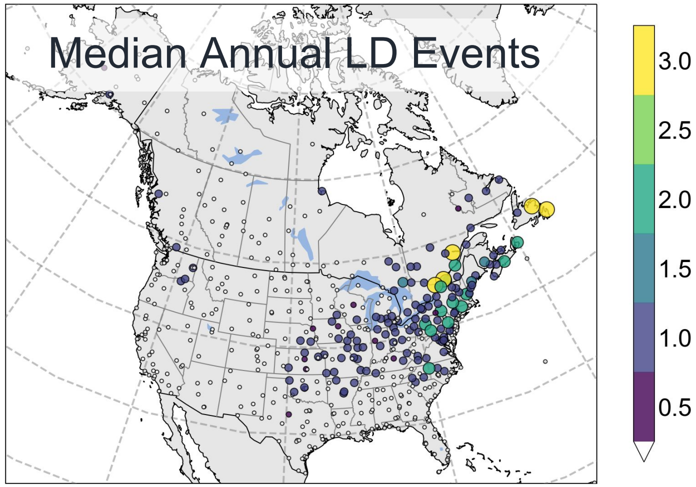
- Appalachian CAD pattern
- Higher SLP, colder sfc T over CAD region for LD composite than for SD

- FZRA occurs with Arctic anticyclone/cold front
- Cold air undercuts warmer air
- Flow off of Gulf of Mexico overruns low-level cold air

Summary

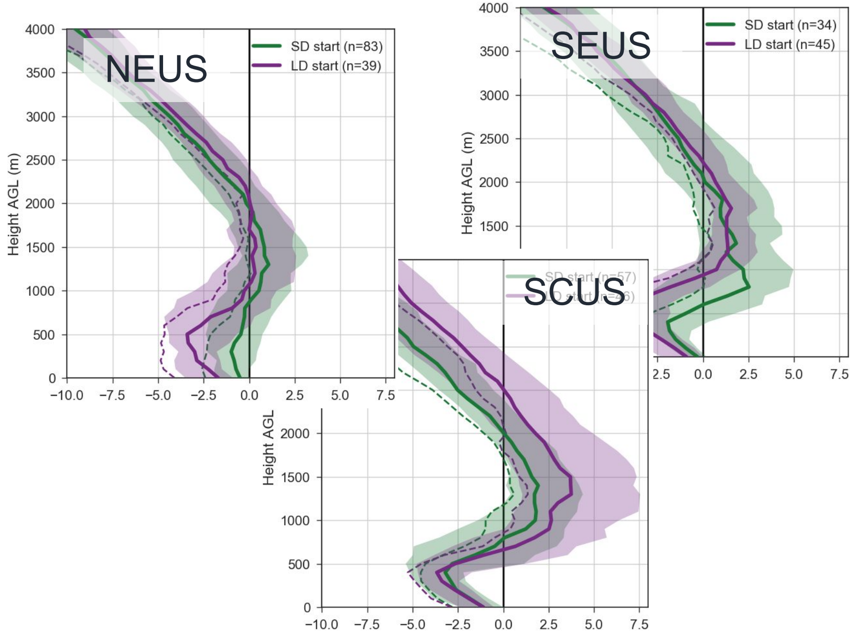
Q1: LD FZRA Climatology

- Storm track, terrain important
- LD events most common over **NEUS/SECA**
- When FZRA occurs over **SEUS**, tends to be LD
- Most extreme (18+ h) events have regional maximum over the **SCUS**



Q2: Thermodynamics

- Colder/deeper **cold layer** at event onset key for LD events over **NEUS/SECA** and **SEUS**
- Deeper/warmer **warm layer** at onset, flow from Gulf most important over **SCUS**



Q3: Synoptic-Dynamics

- **NEUS/SECA**: FZRA events occur ahead of warm front
- **SEUS**: events associated with Appalachian CAD
- **SCUS**: events occur behind cold front/Arctic anticyclone