Thermodynamic and Synoptic-Dynamic Modulations of Freezing Rain Event Duration

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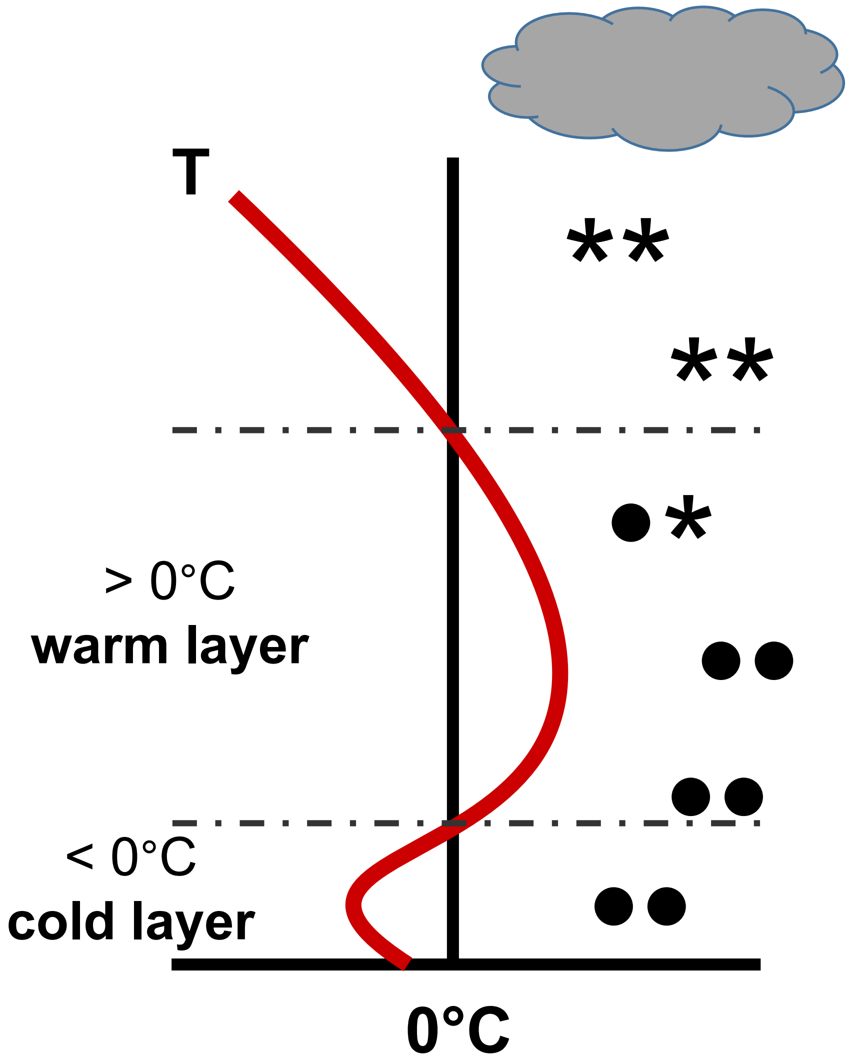
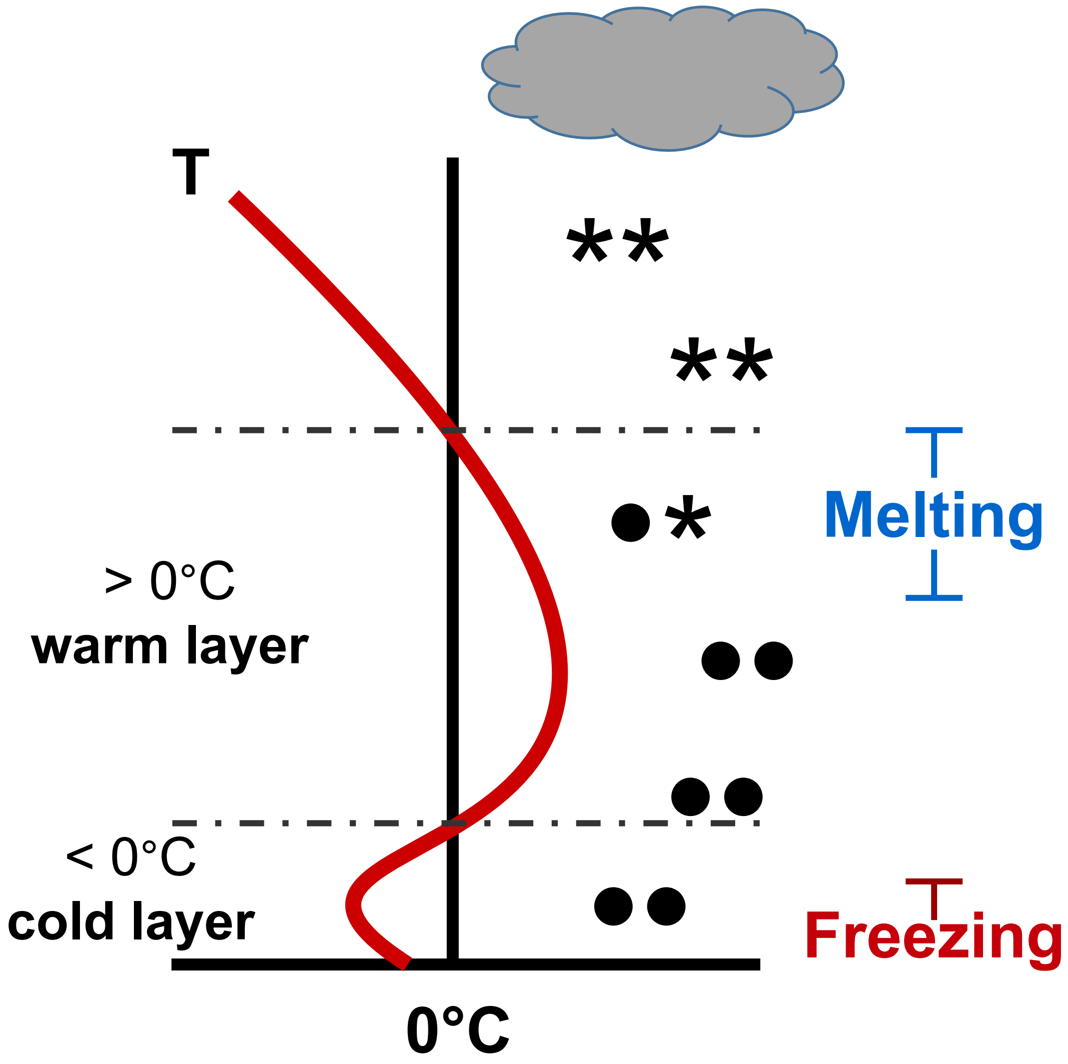
Freezing rain events remain a major forecast challenge



- They require a sufficiently warm **warm layer** aloft to completely melt snowflakes
- They also require **surface temperatures <0°C**
- Only **11%** of FZRA events last longer than 4 h (Cortinas et al. 2004)
  - **Duration** is a key factor in event severity

Diabatic effects mean freezing rain events are ***self-limiting*** (Stewart et al. 1985, Lackmann et al. 2001)



- Latent heat of fusion is...
  - **Extracted** when snowflakes melt in warm layer (cooling the warm layer)
  - **Released** when rain freezes at the surface (warming the cold layer)
- For event persistence, compensatory mechanisms are necessary:
  - At the surface…
    - Particularly **cold, dry onset conditions** OR **advection of cold, dry air**
  - In the warm layer
    - Particularly **warm onset conditions** OR **warm-air advection**

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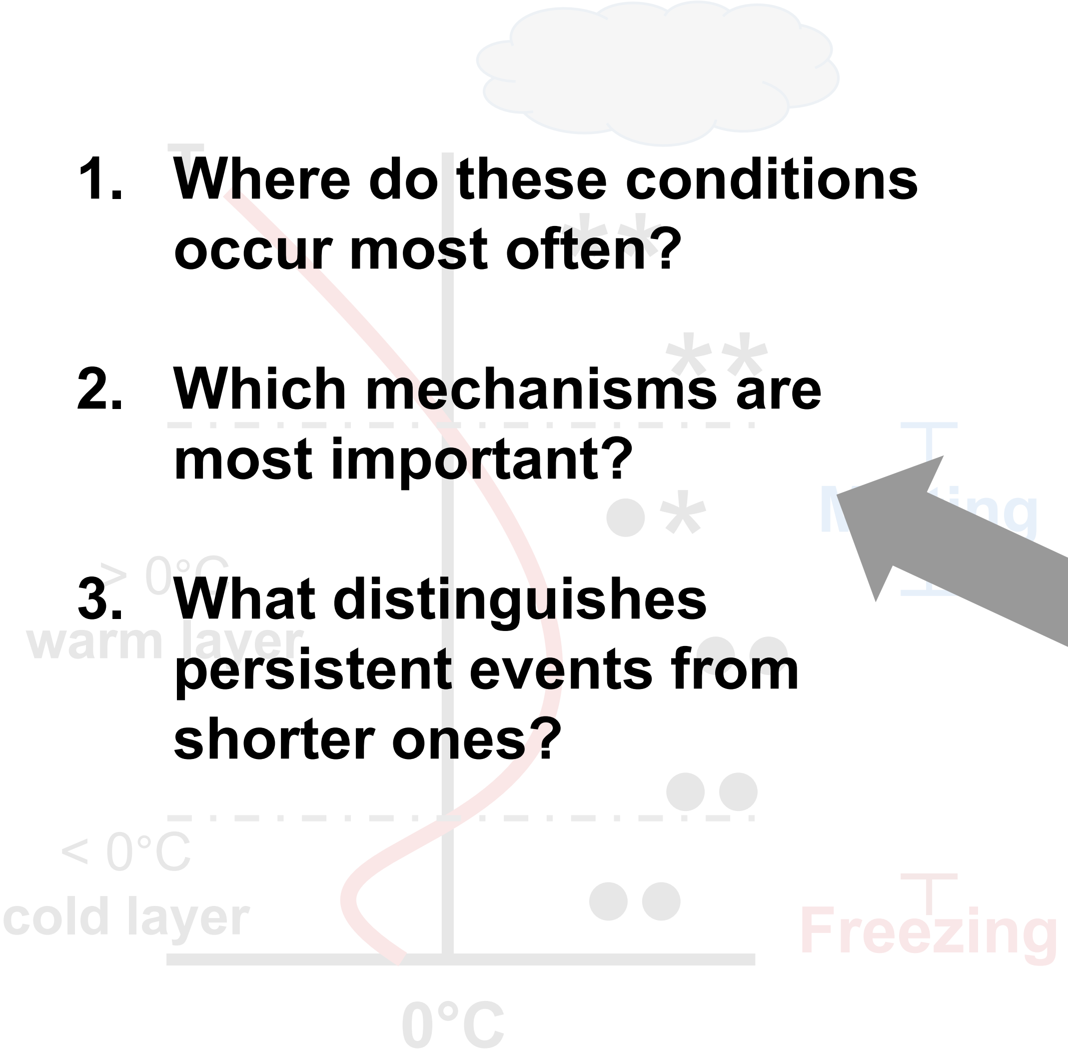

1. **Where do these conditions occur most often?**

2. **Which mechanisms are most important?**

3. **What distinguishes persistent events from shorter ones?**

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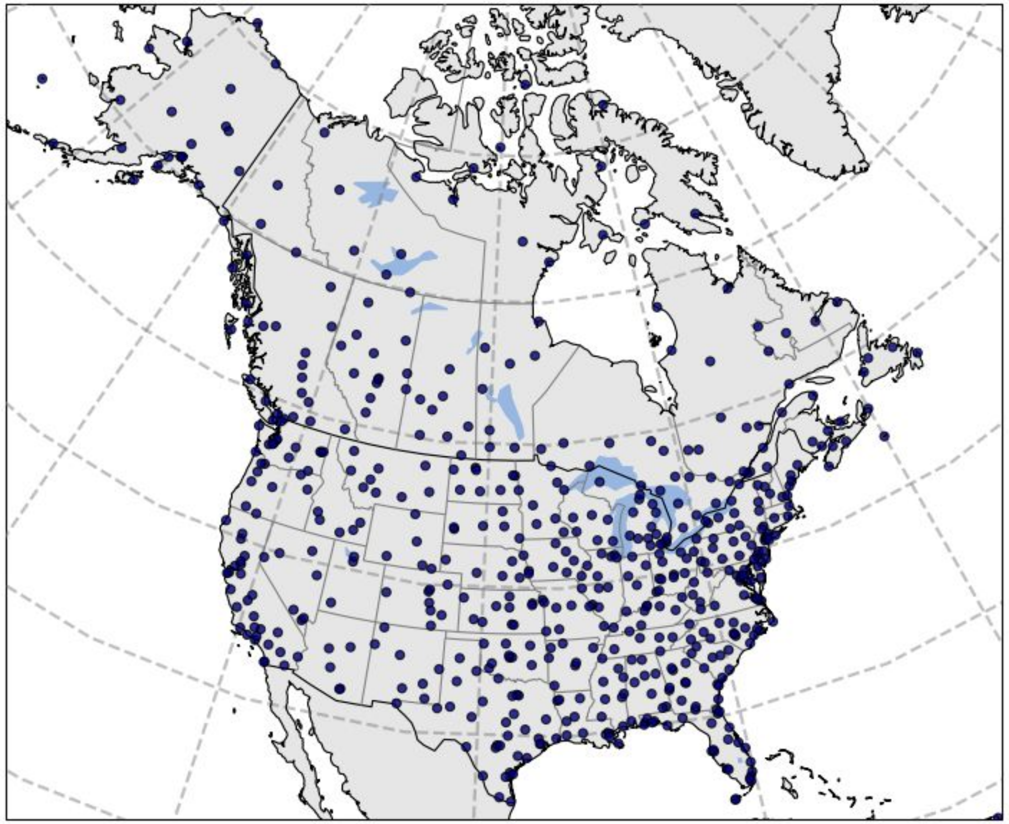
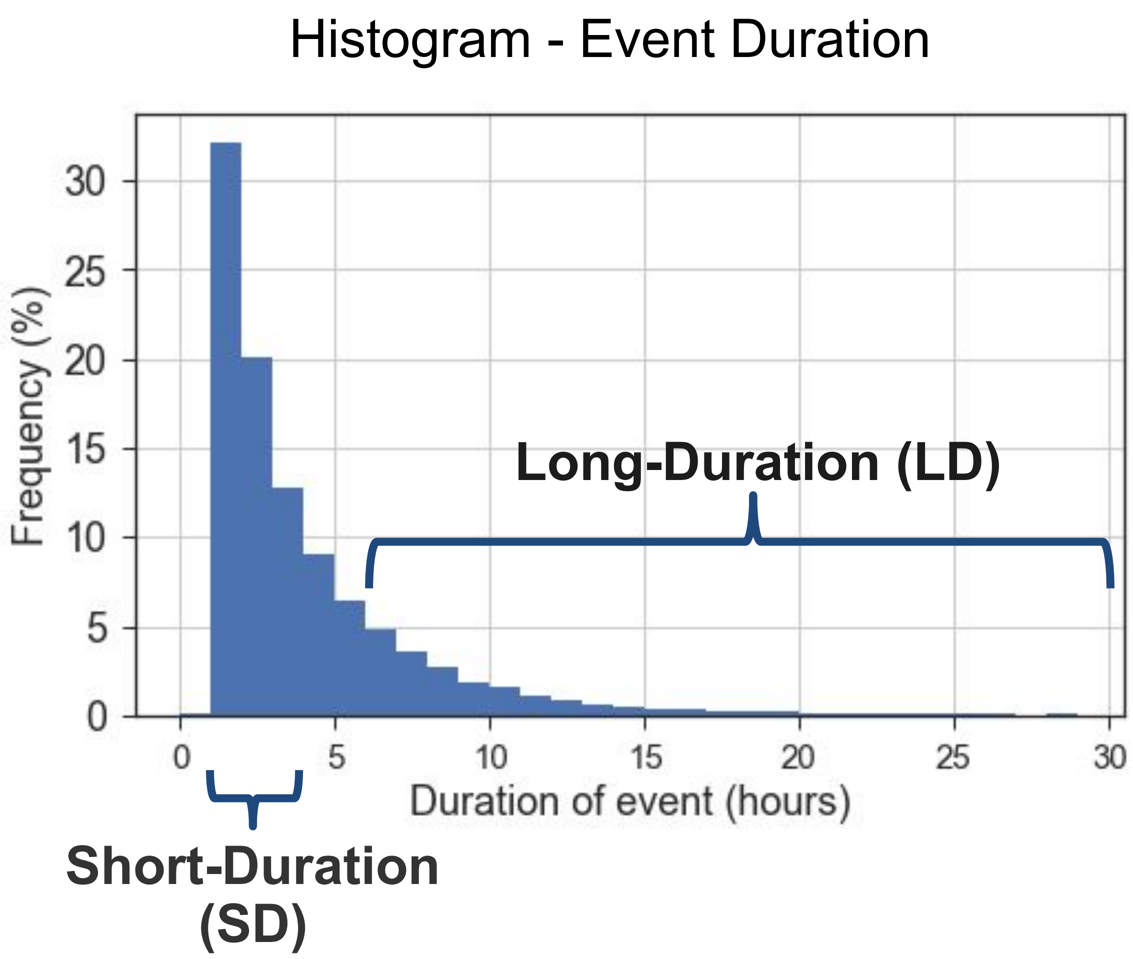
Data and methods

579 surface stations used in dataset



- **Surface Observations:**
  - NOAA Integrated Surface Database
  - 1979-2016, U.S. and Canada
- **Upper-air data:** U. Wyoming archive
- **NCEP CFSR Reanalysis**
  - 0.5°x0.5° grid, 6-hourly, 1979-present

Data and methods



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- **NCEP CFSR Reanalysis**
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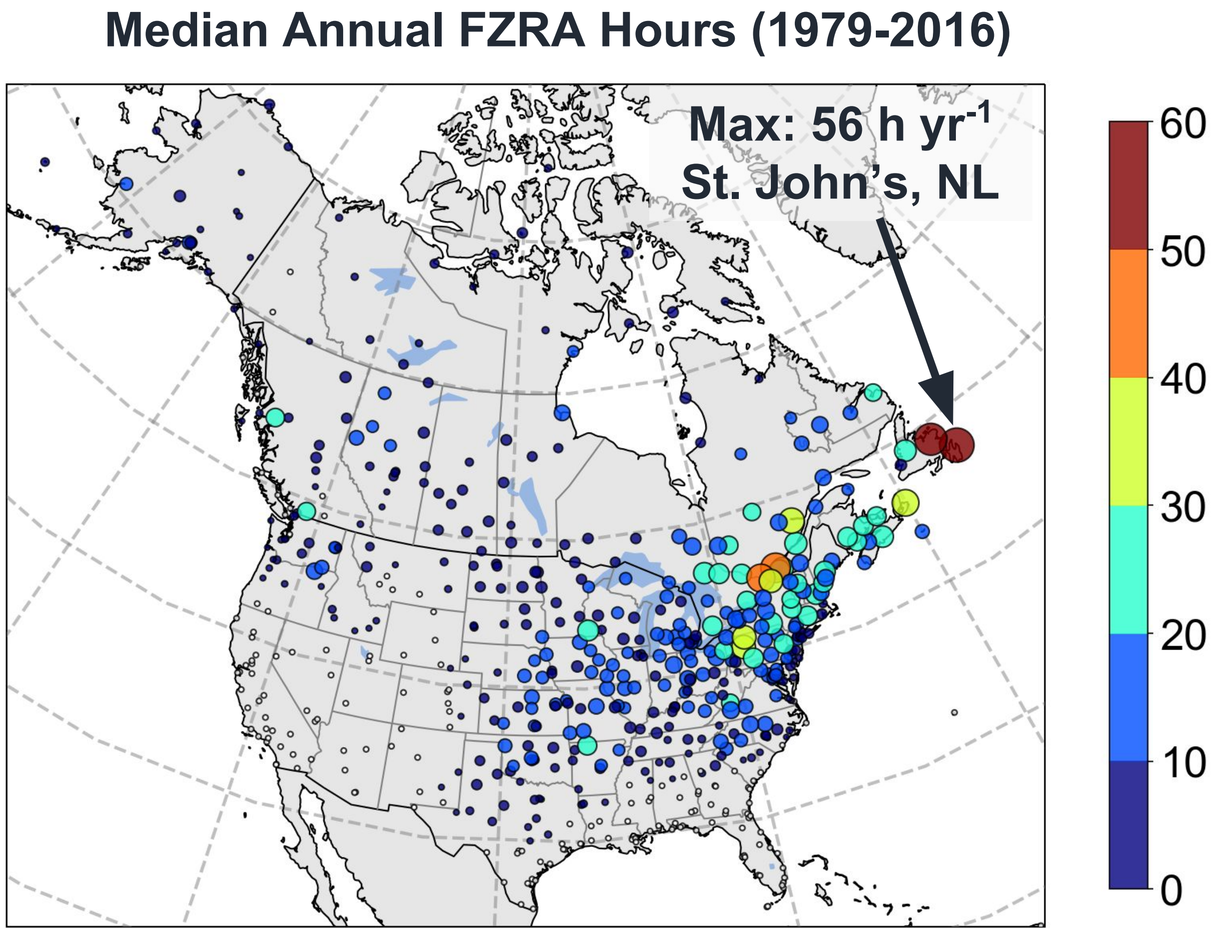
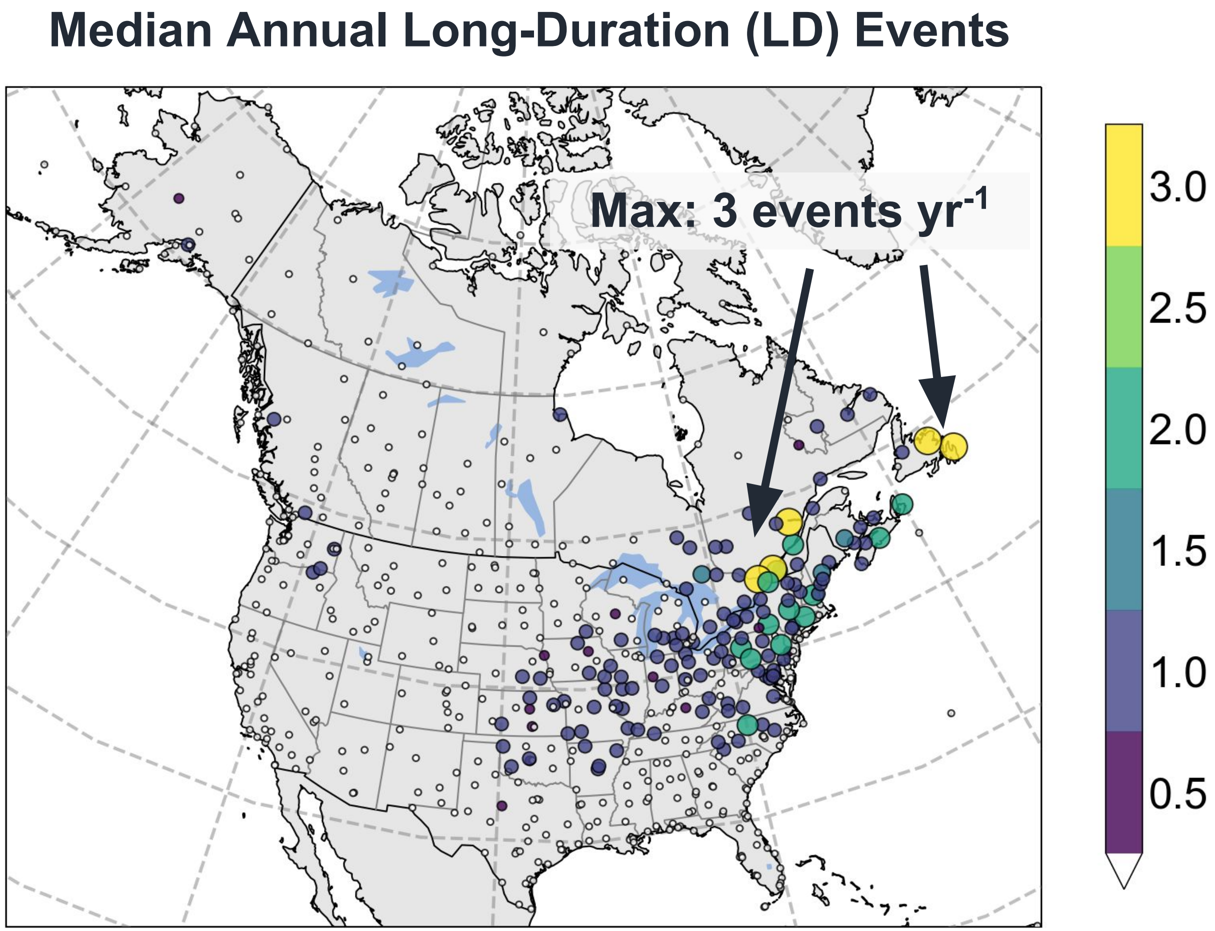
- **Freezing Rain Event Duration:**
  - Count consecutive hours of FZRA, then combine events with <24 h between them
- **Long-Duration (LD) Event:**
  - FZRA event with **6+ h of FZRA**
  - ~20% of all events
  - Longest: 61 h (Montréal, 1998 Ice Storm)
- **Short-Duration (SD) Event:**
  - FZRA event with **≤ 3 h of FZRA**

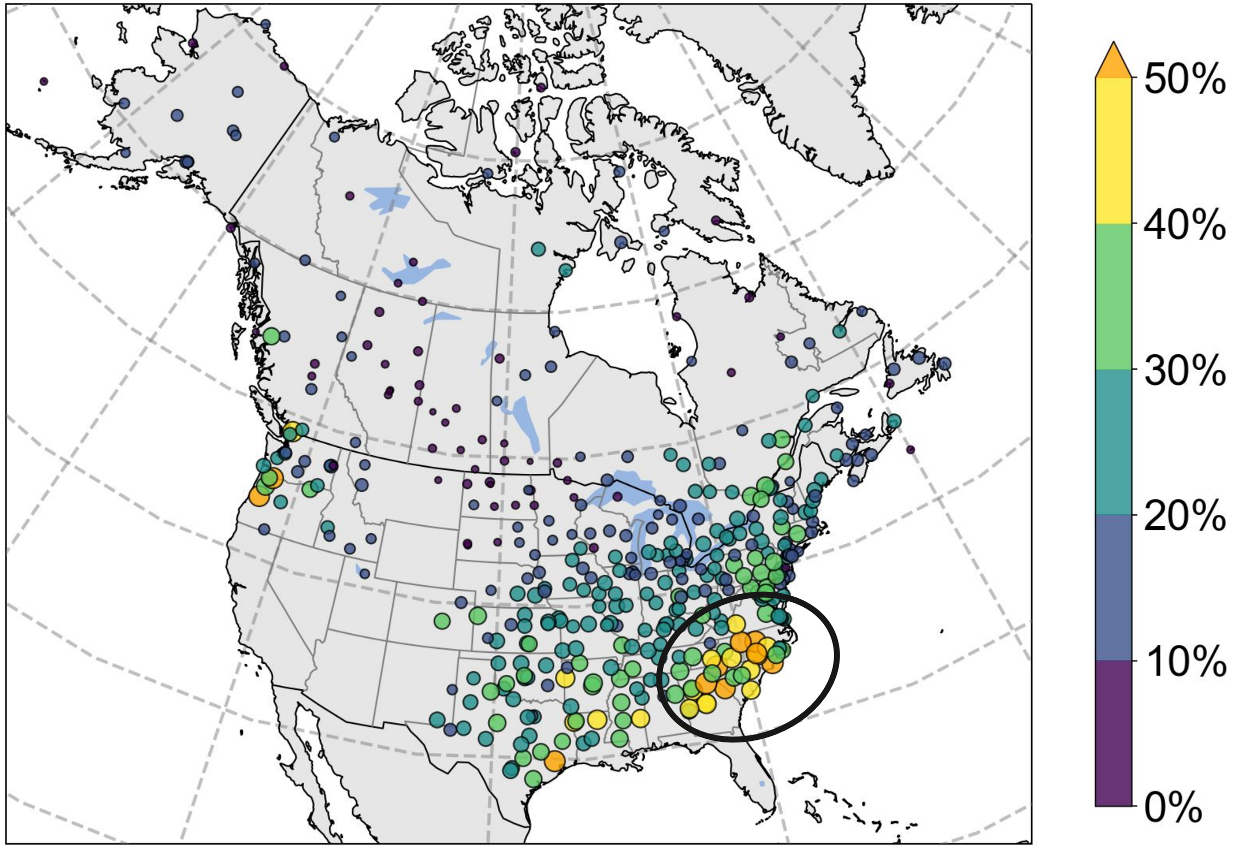
Freezing rain, LD events occur most often in the northeastern U.S. and southeastern Canada…



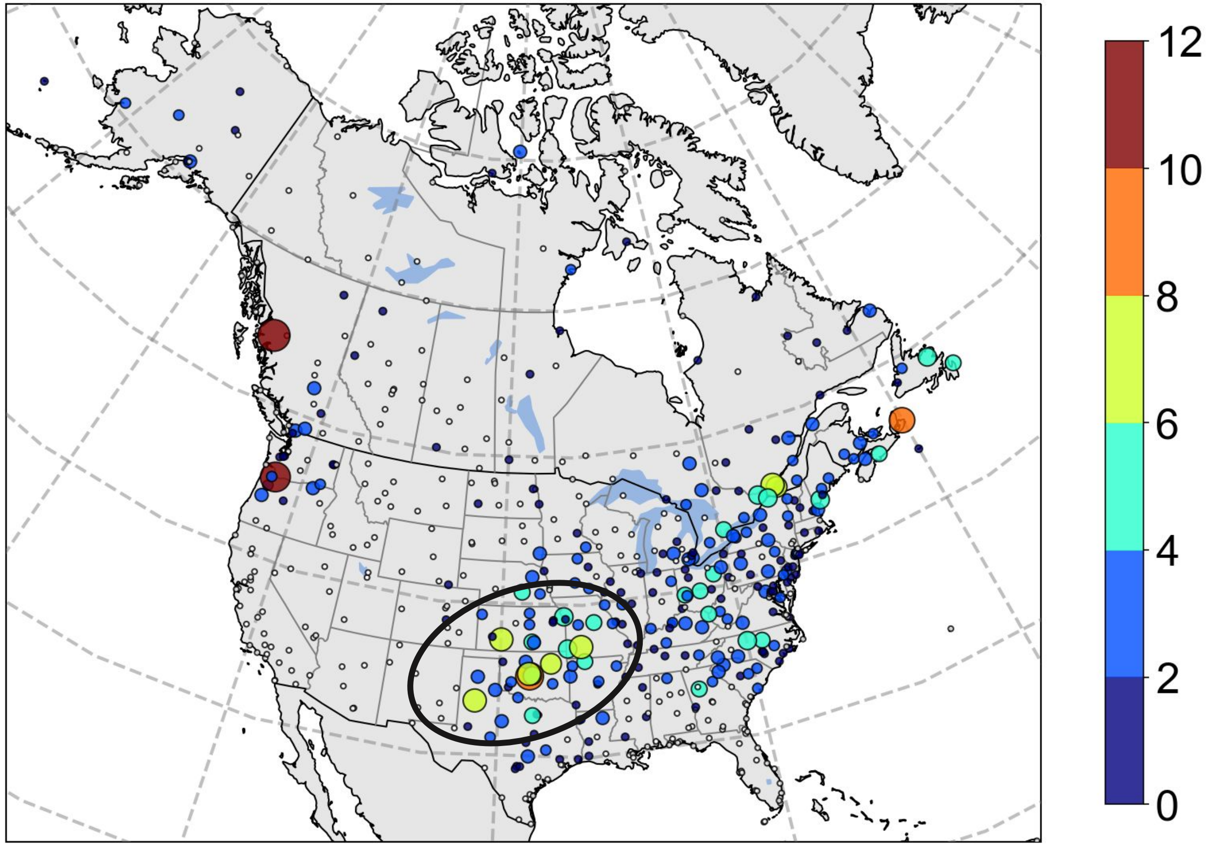


…but when freezing rain occurs in the Southeast and South Central U.S., it tends to be persistent

% of FZRA events that are long-duration



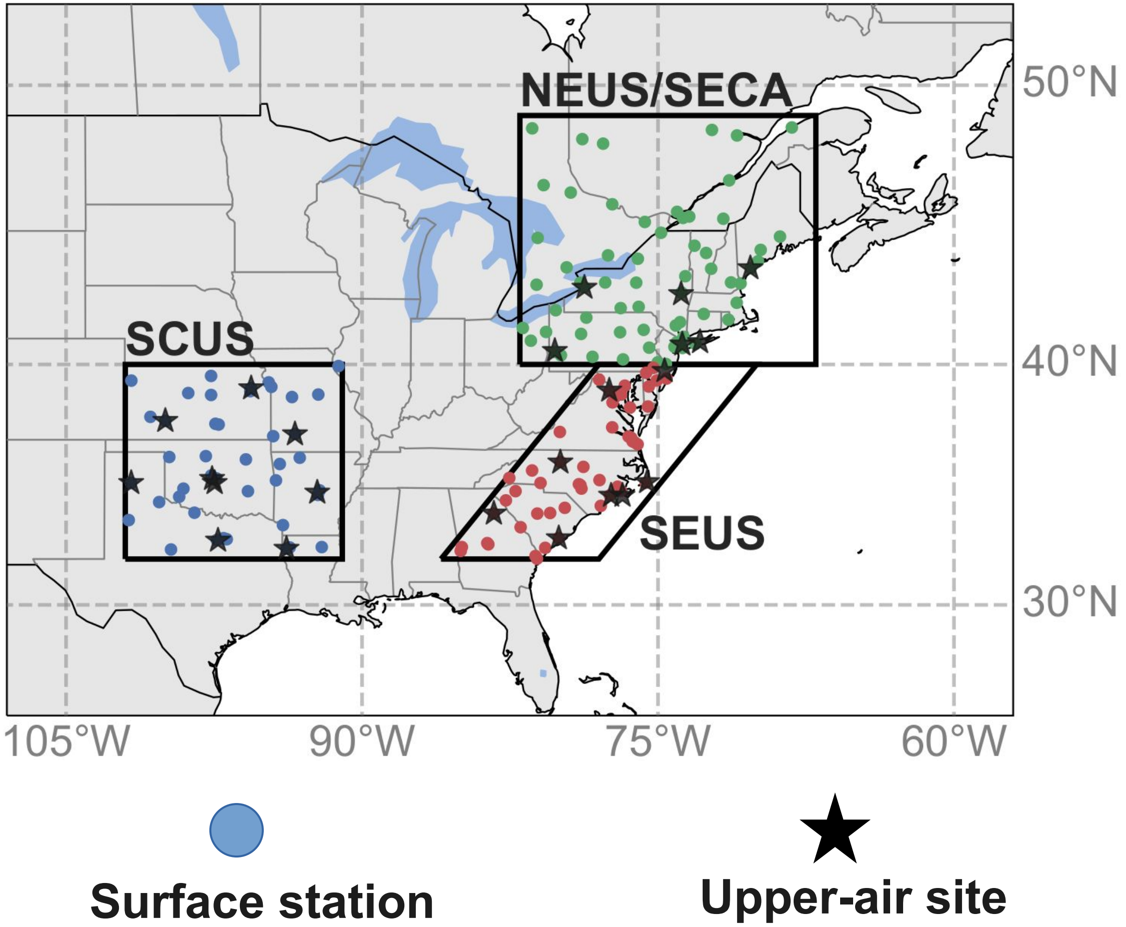
Number of 18+ h FZRA events (1979-2016)



We identify three focus regions based on this climatology and examine FZRA events in each

- Northeastern U.S./ Southeastern Canada (**NEUS/SECA**)
- South Central U.S. (**SCUS**)
- Southeastern U.S. (**SEUS**)

- Upper-air observations
  - Regional aggregation
  - Examine all soundings for events that started **within 1 h** of a radiosonde release



In McCray et al. (submitted to *Weather and Forecasting*), we identified the regional thermodynamic evolution of LD events

- We compared surface/upper-air obs taken at **LD event onset** with those at event **end**

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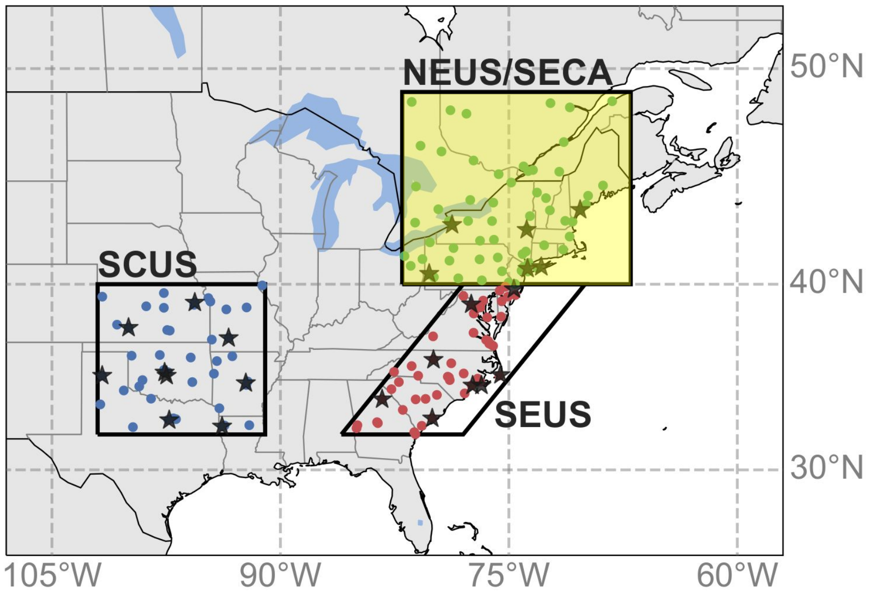
  - Cold onset surface temperature, deep cold layer
    - Weak or absent surface cold-air advection
  - Weak onset warm layer
  - Strong warm-air advection just above the surface
    - Builds warm layer, erodes cold layer
  - FZRA ends as surface temperature reaches 0°C
  - Snow/Ice Pellets → FZRA → Rain



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  - Co...
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  - We...
  - Str...
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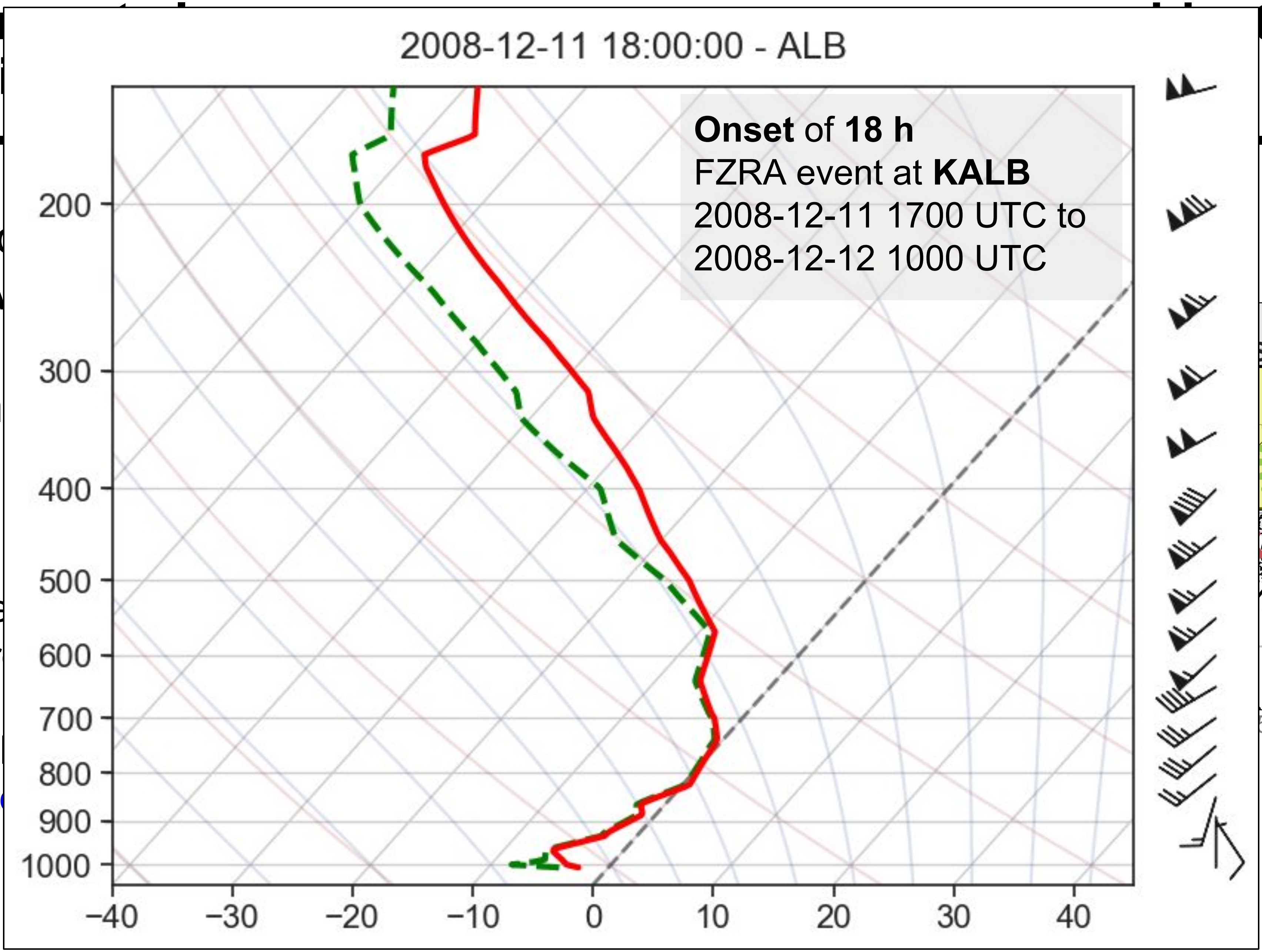
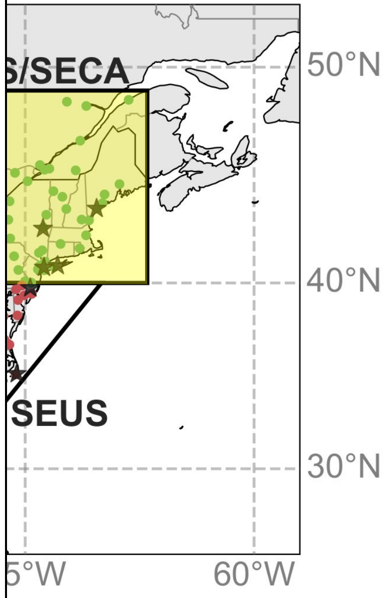
  - FZ...
  - Sn...





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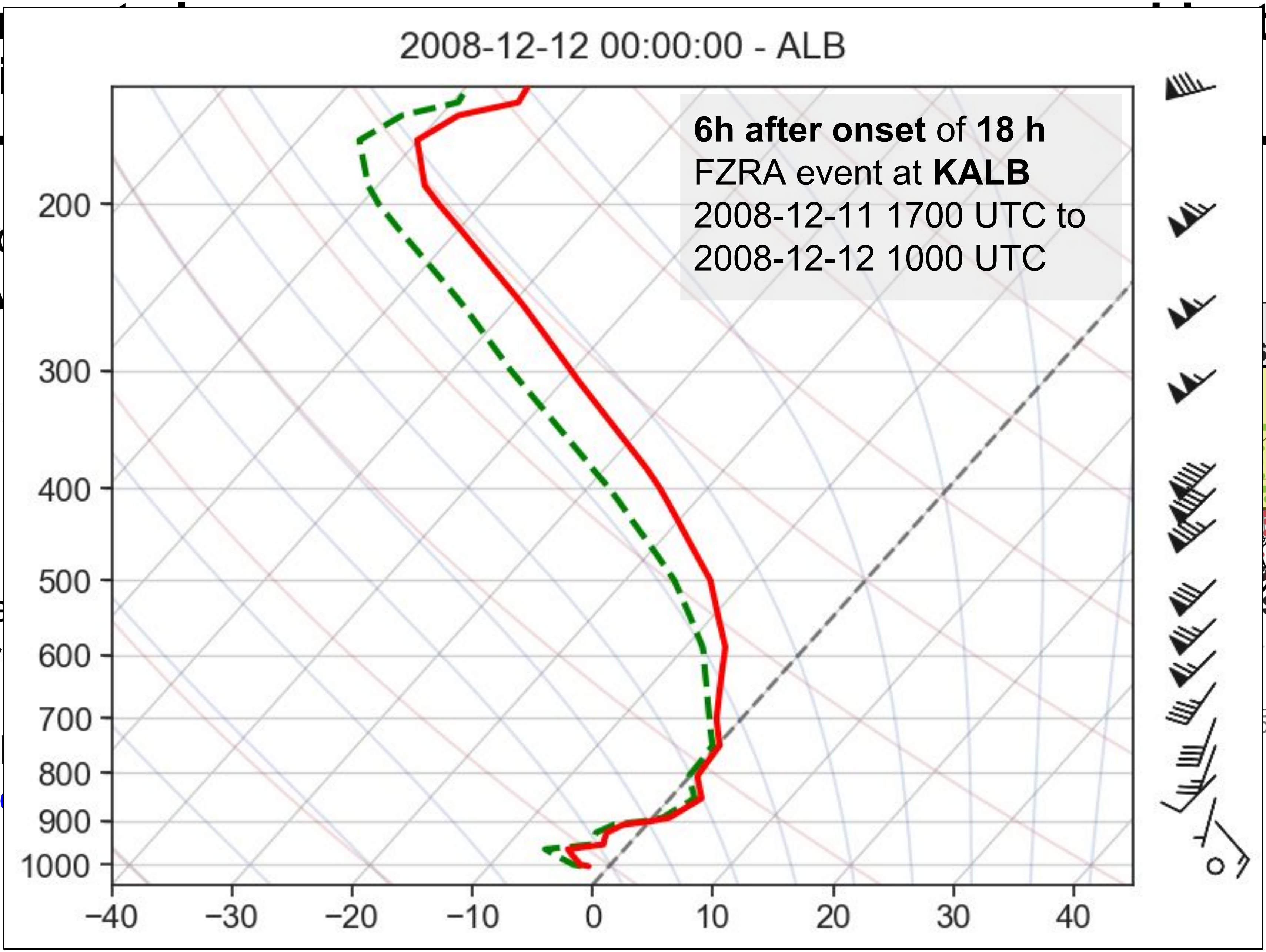

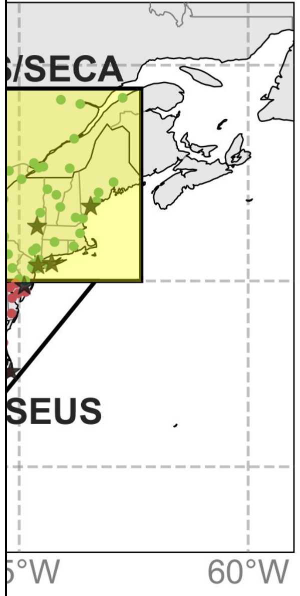

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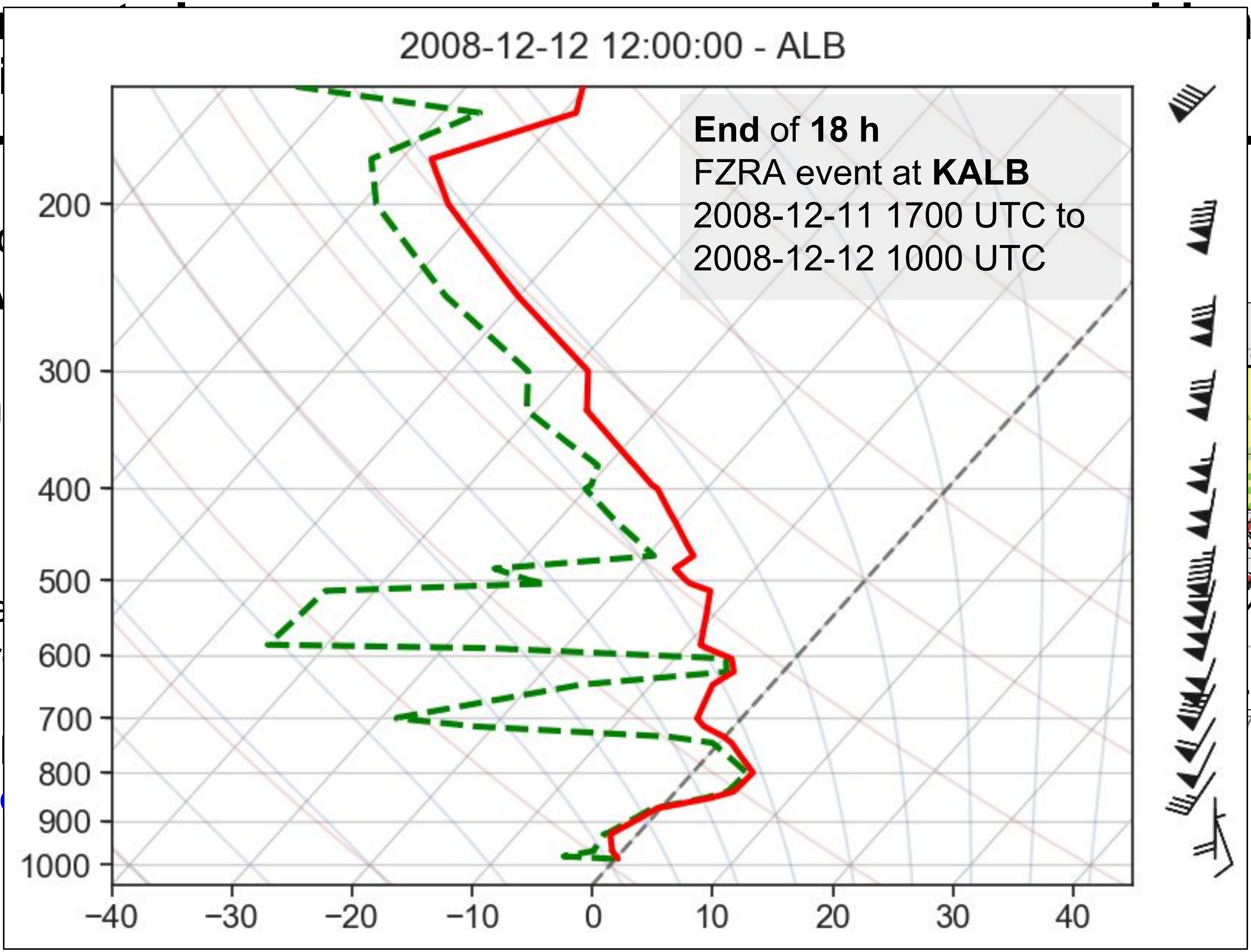

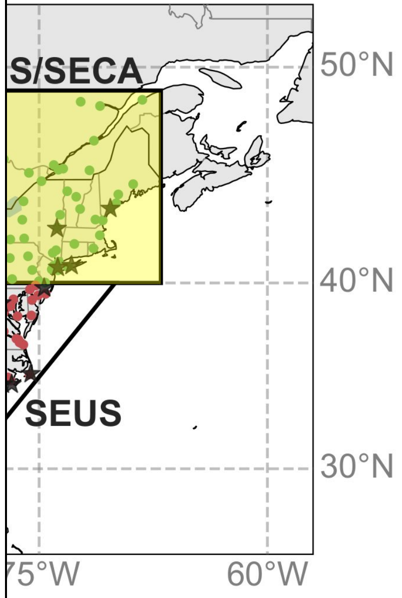

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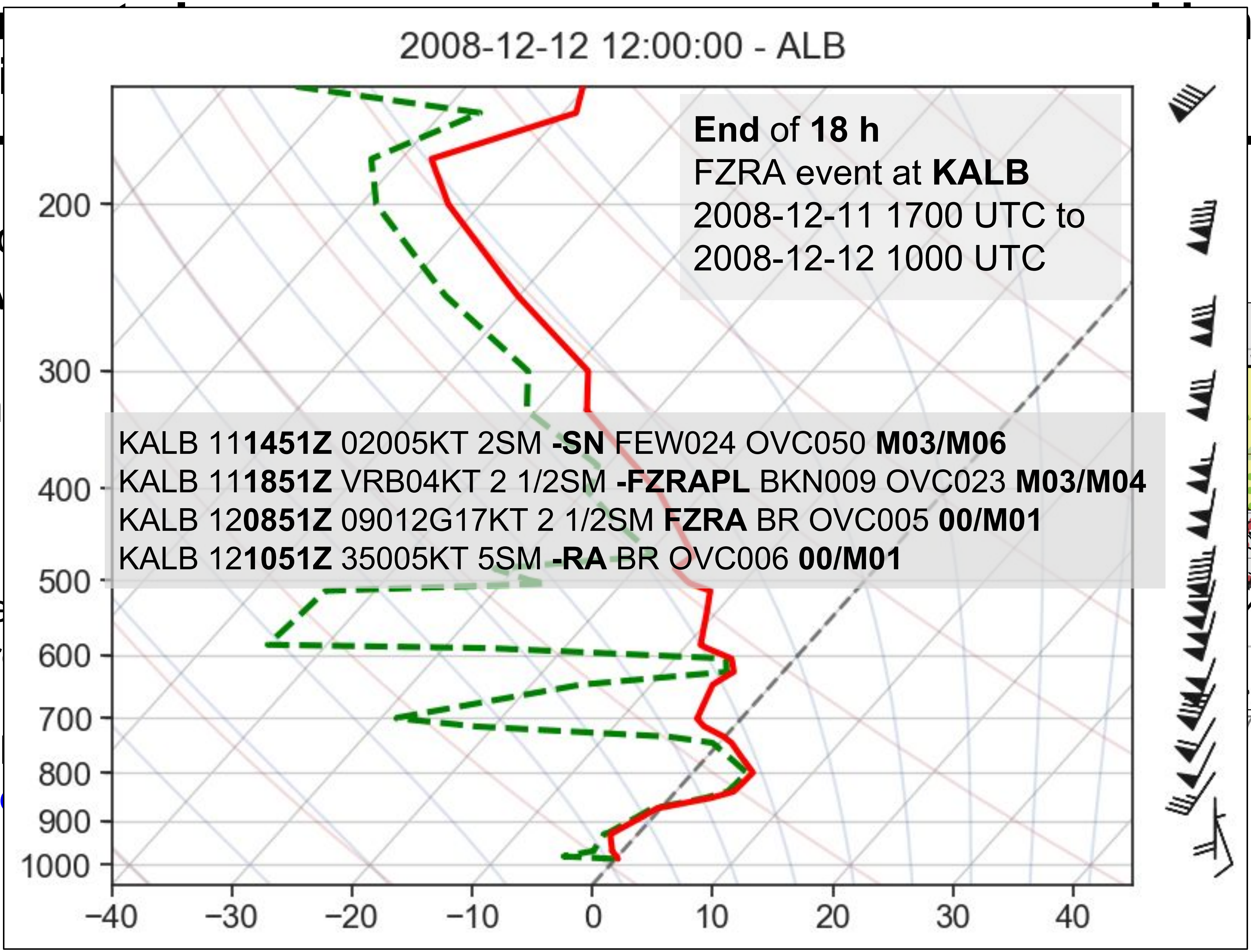

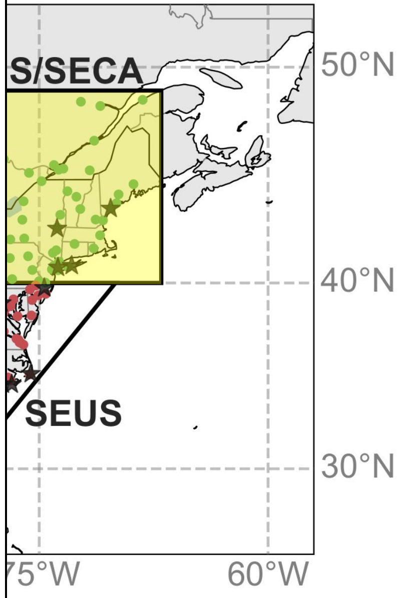

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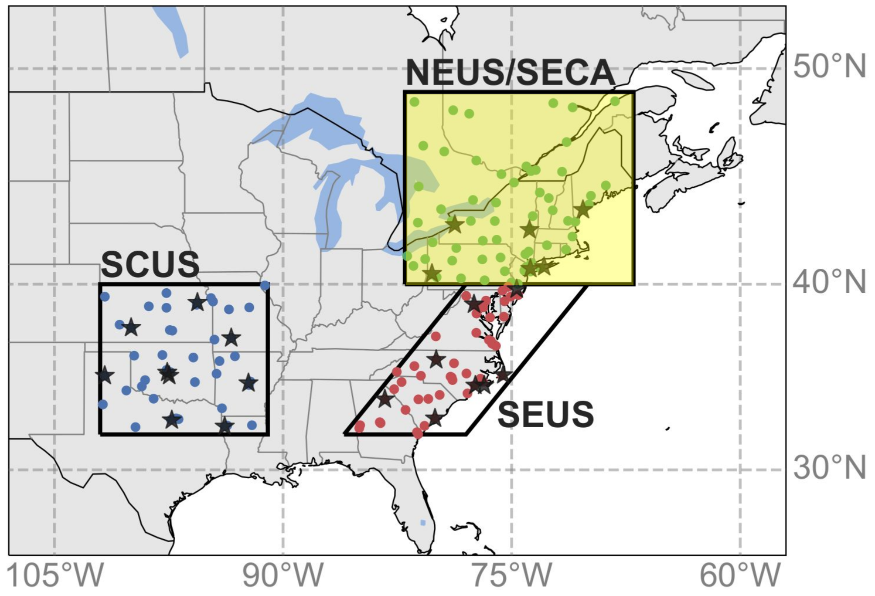
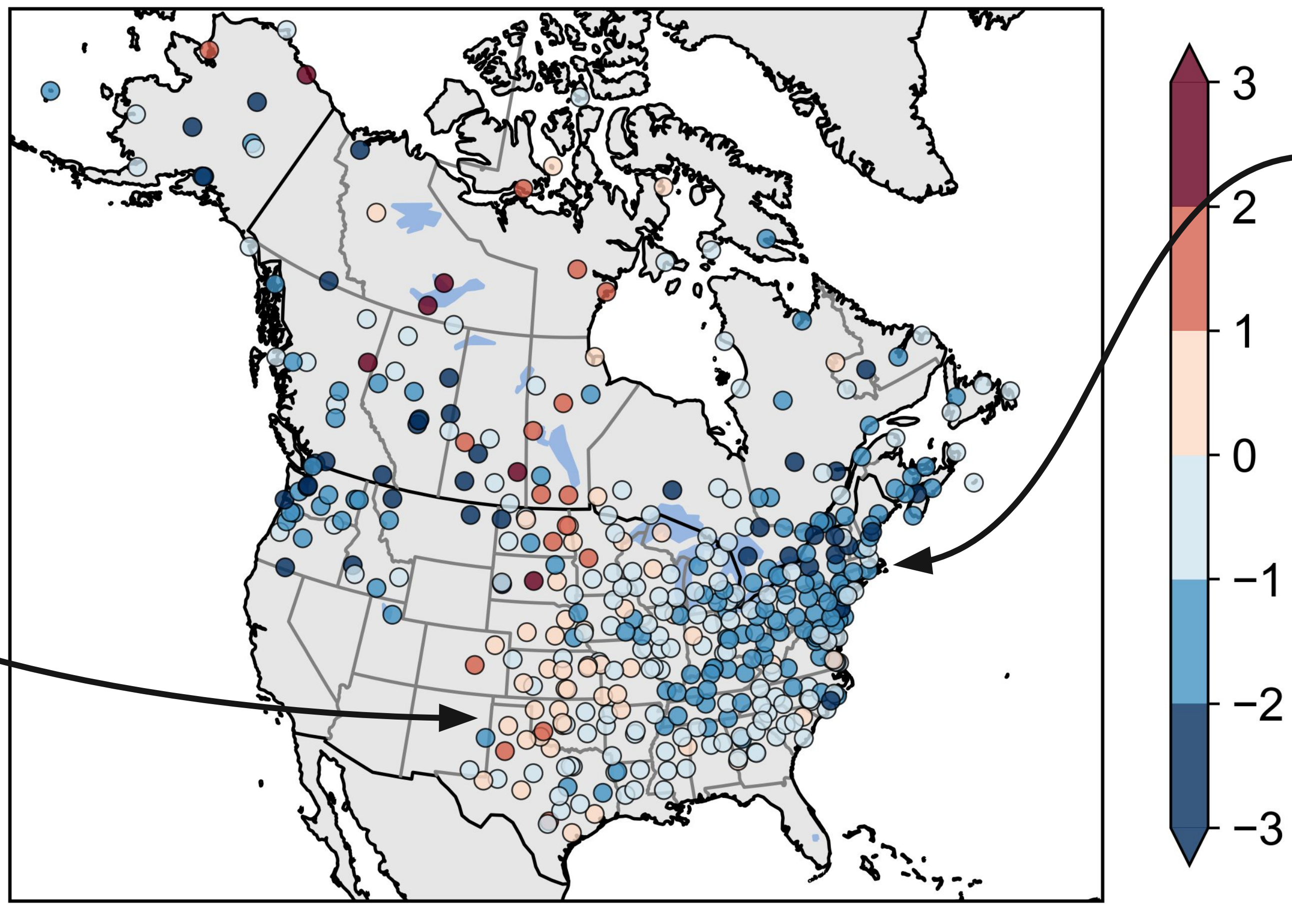


We now compare conditions at LD (long-duration) event onset with those at SD (short-duration) event onset

How do surface temperatures differ between long-duration (LD) and short-duration (SD) events?

Mean LD T_{onset} – Mean SD T_{onset} (°C)

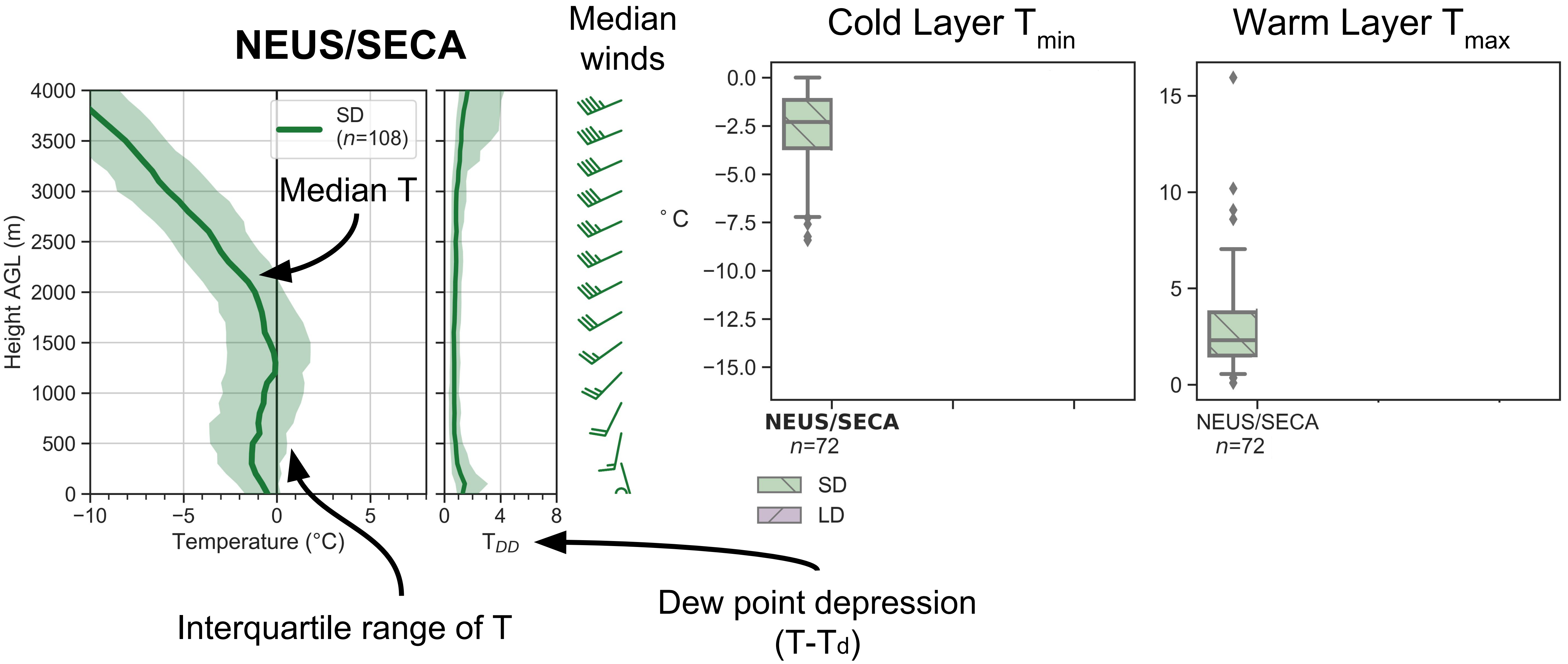


SCUS
Regional mean:
0.0°C

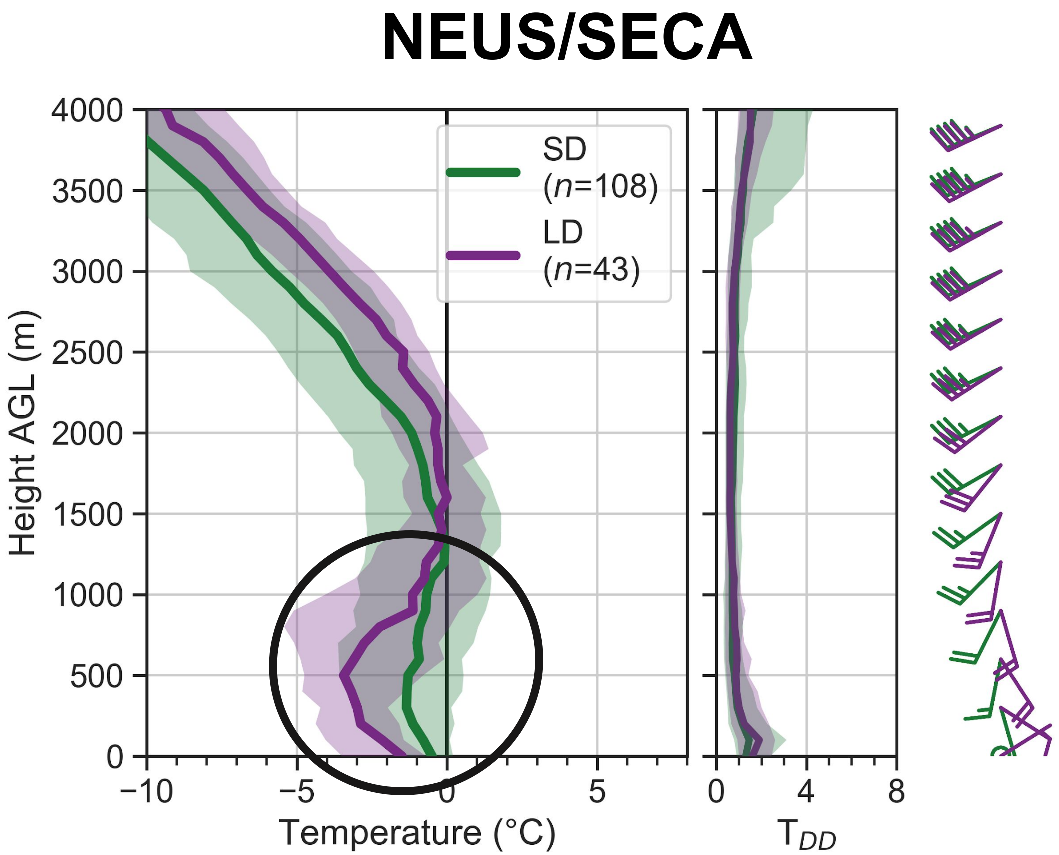
NEUS/SECA
Regional mean:
-1.6°C
(Significant for $p<0.001$)

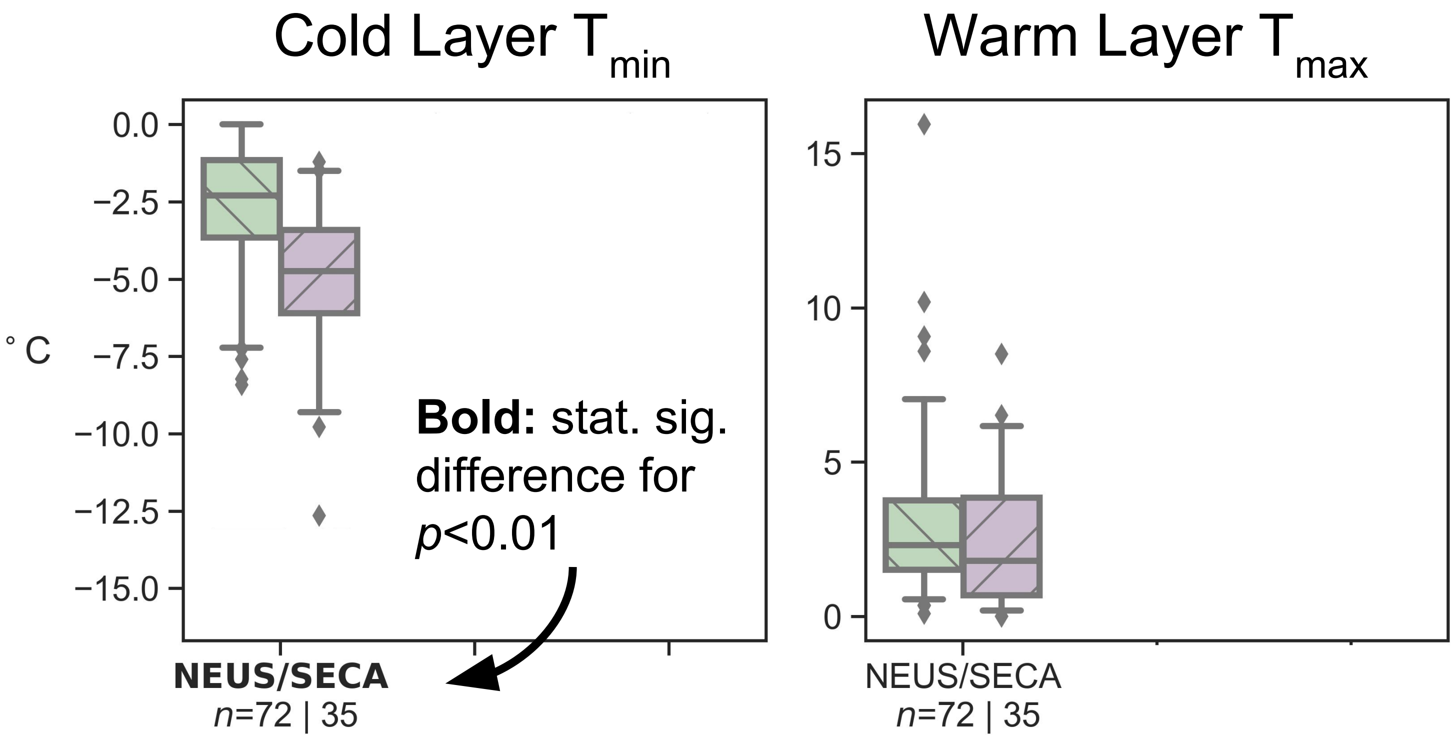
LD events start at surface temperature that are on average 1.6°C *colder* than for SD events

How do thermodynamic profiles differ between SD and LD events?



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



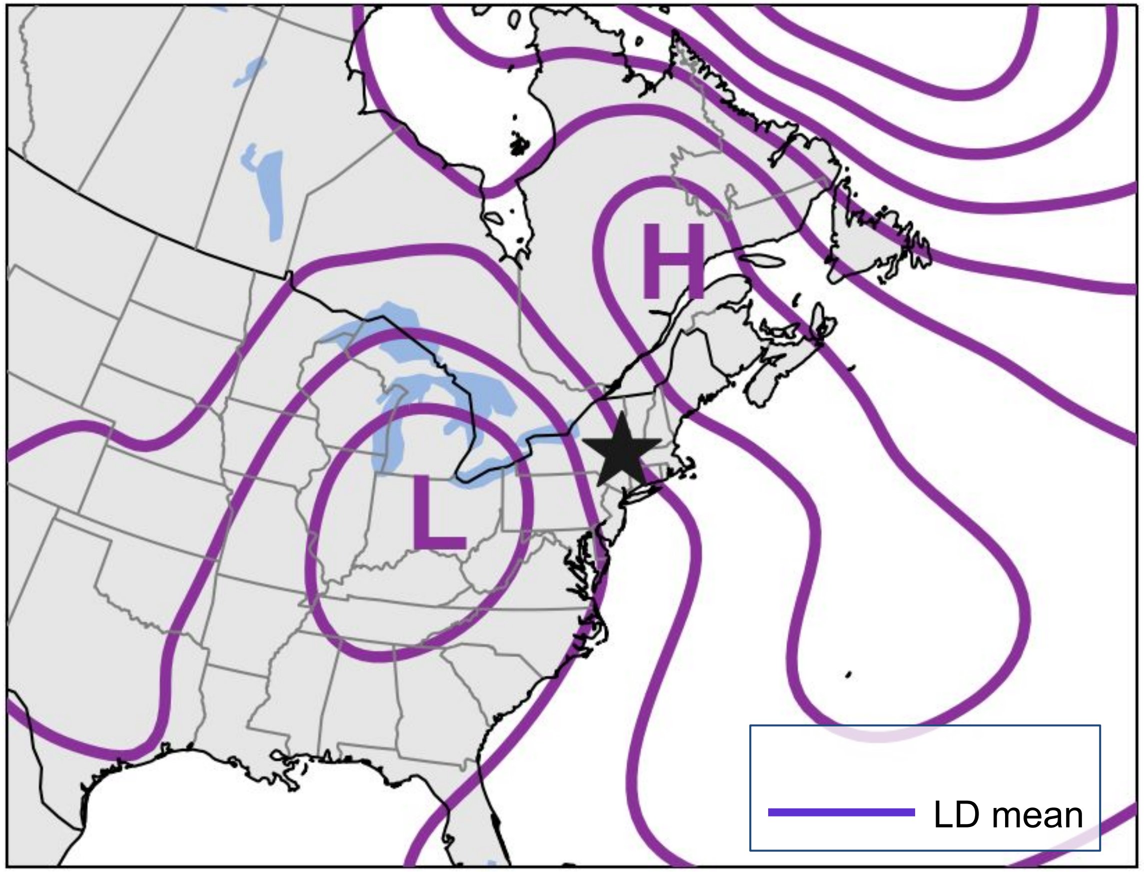


Median **cold layer** is **deeper** and **colder** at onset of LD events than SD events

➔ Allows warming from freezing + advection to persist for longer period before layer surface warms to 0°C

How do synoptic patterns differ between SD and LD events?

Composite SLP at onset



KALB - Albany, NY

- We composite a random sample of **30 LD** and **30 SD** events at select locations
- At KALB, LD events involve:
  - A cyclone situated to the SW
  - An anticyclone centered to the NE

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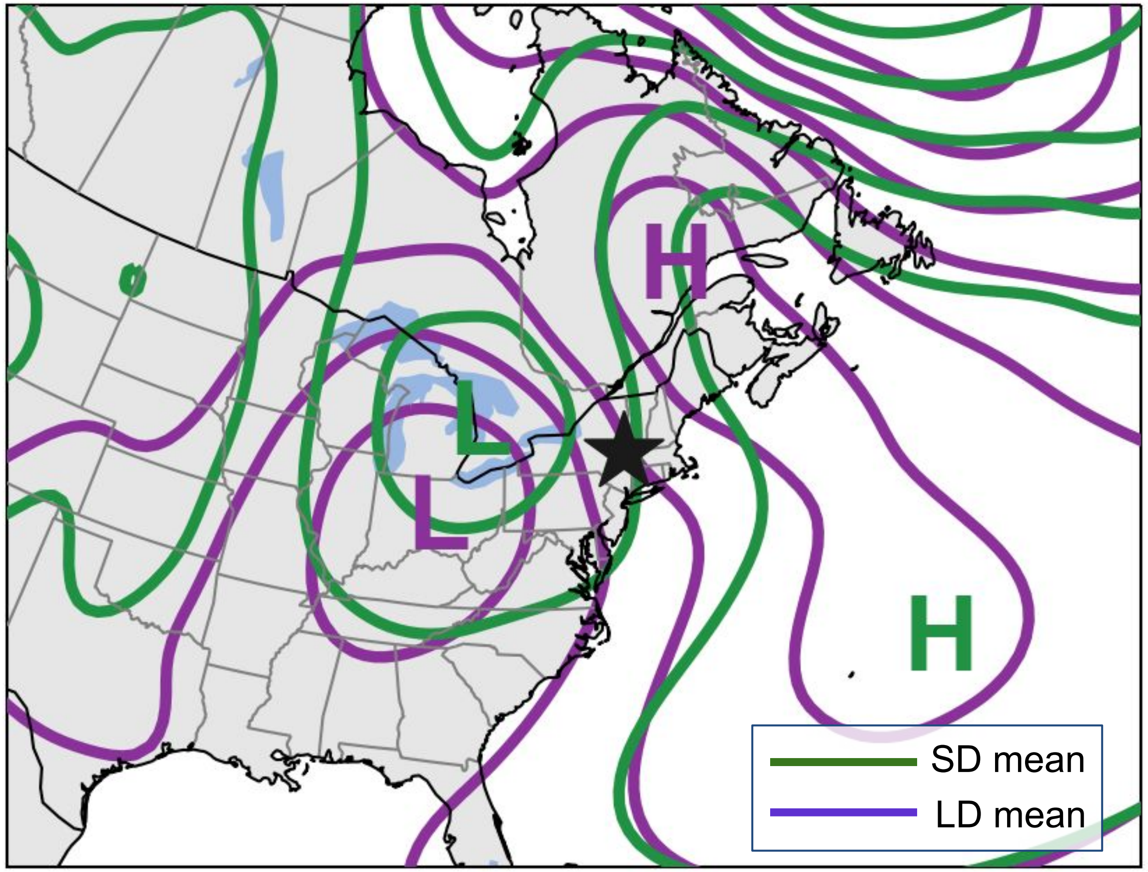

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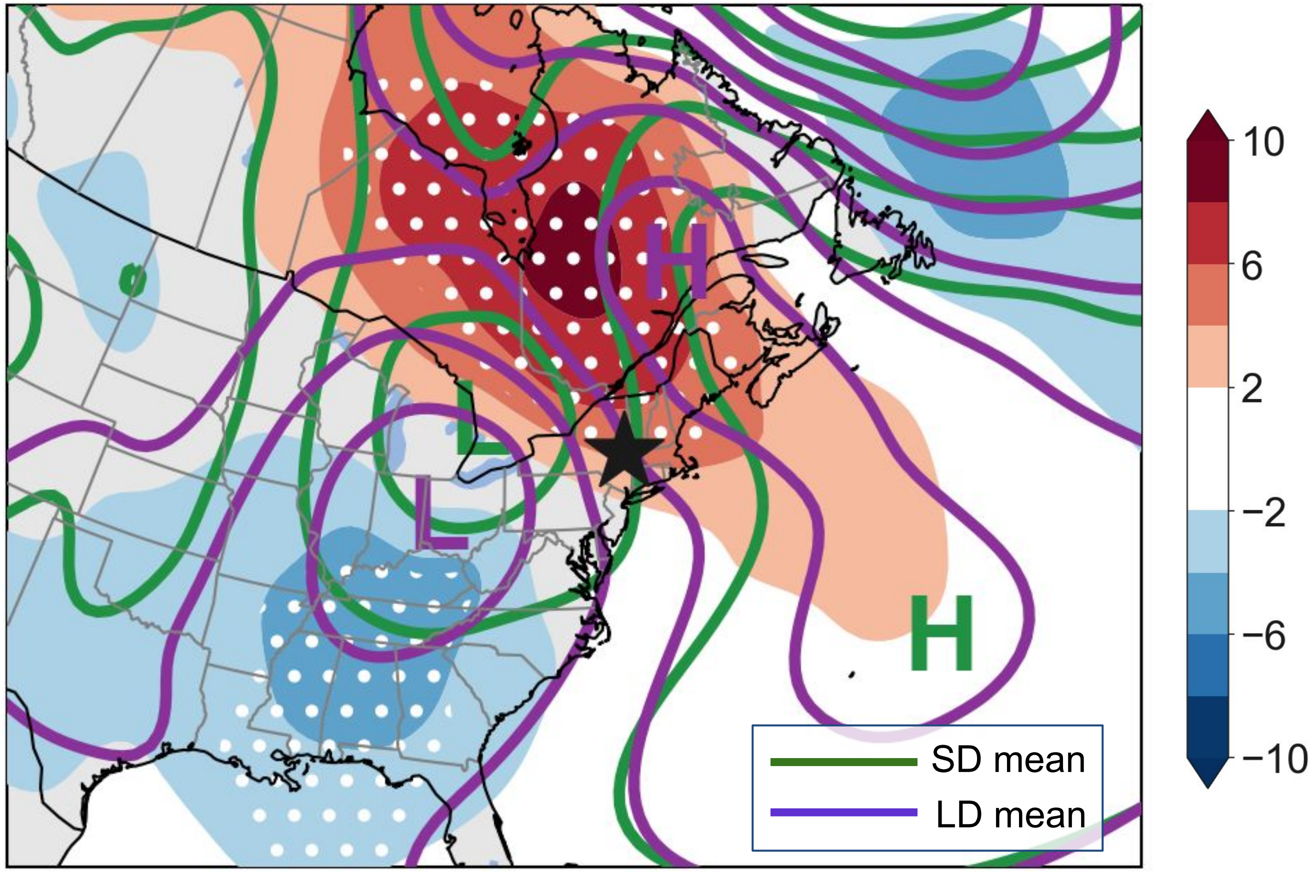
  - An anticyclone centered due E

How do synoptic patterns differ between SD and LD events?

LD mean SLP − SD mean SLP



Stippling:
Significant for $p<0.05$

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These differences are consistent within focus regions, despite terrain variations, etc.

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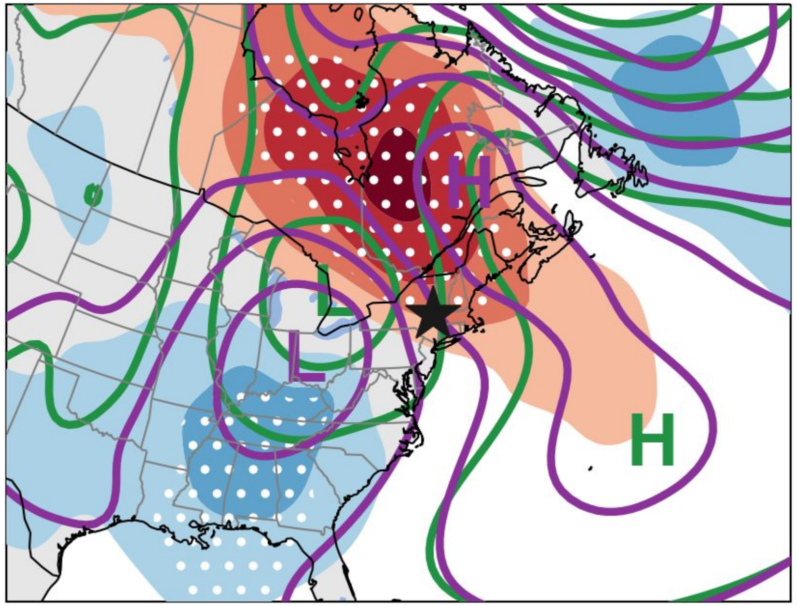
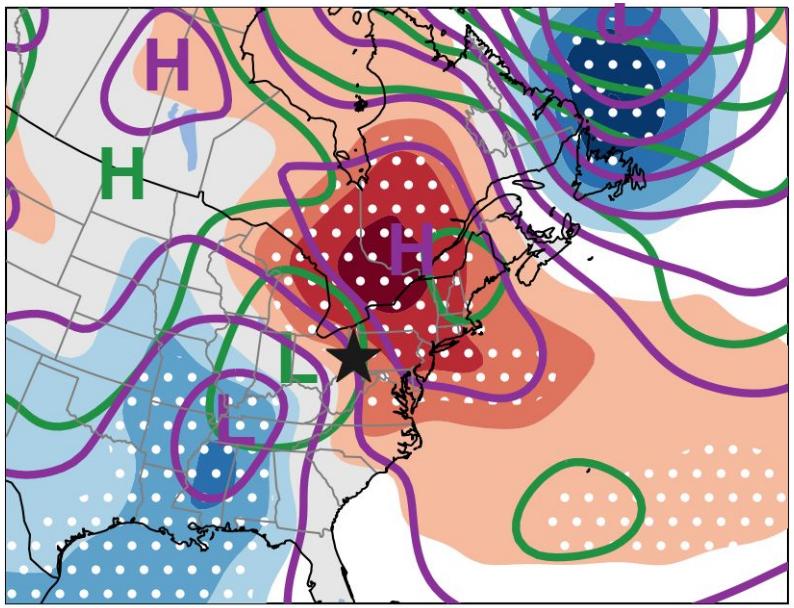
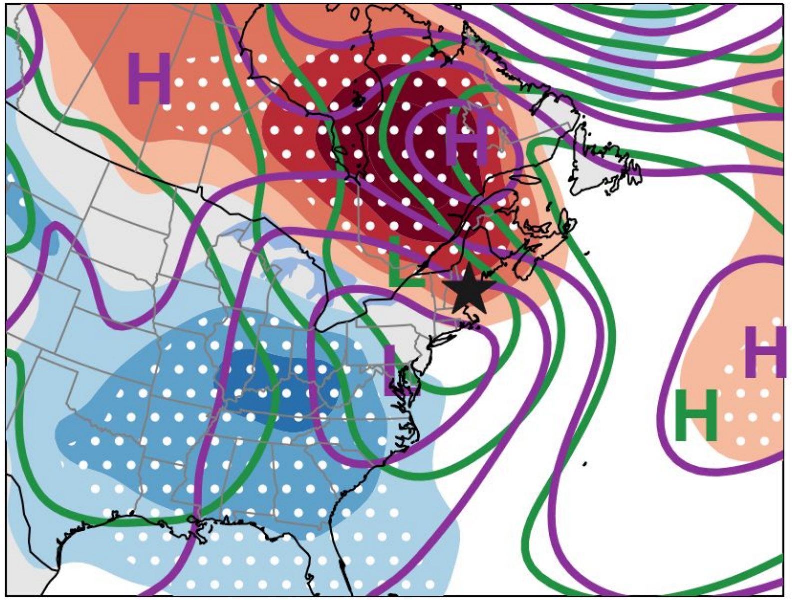


KPIT - Pittsburgh, PA



KPWM - Portland, ME



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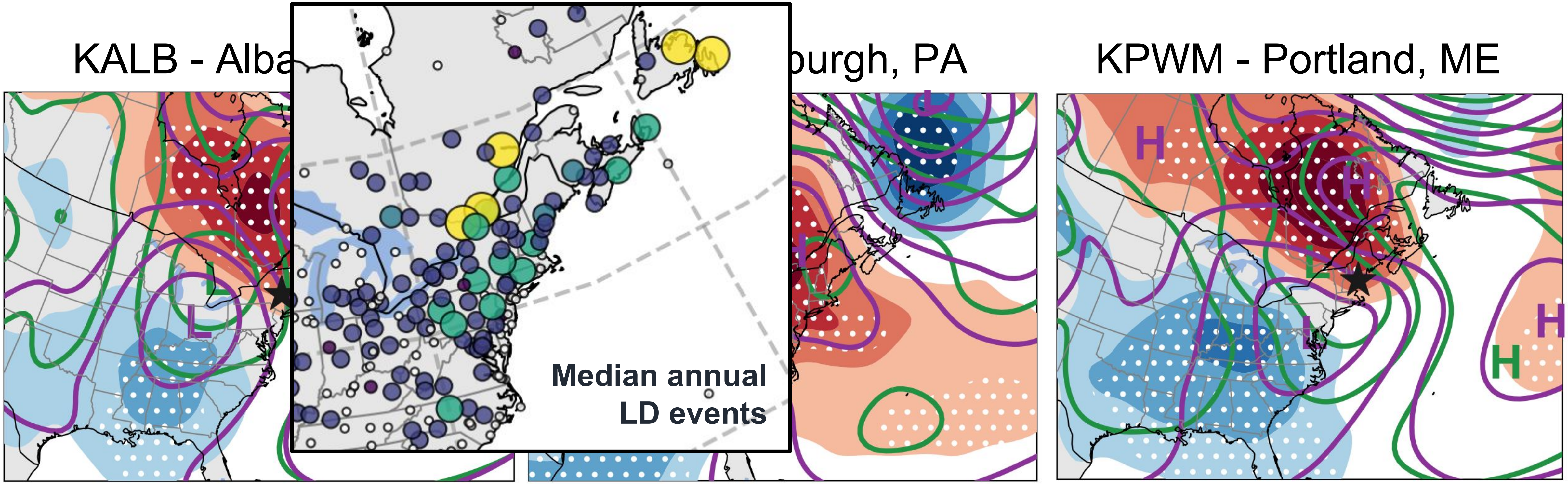
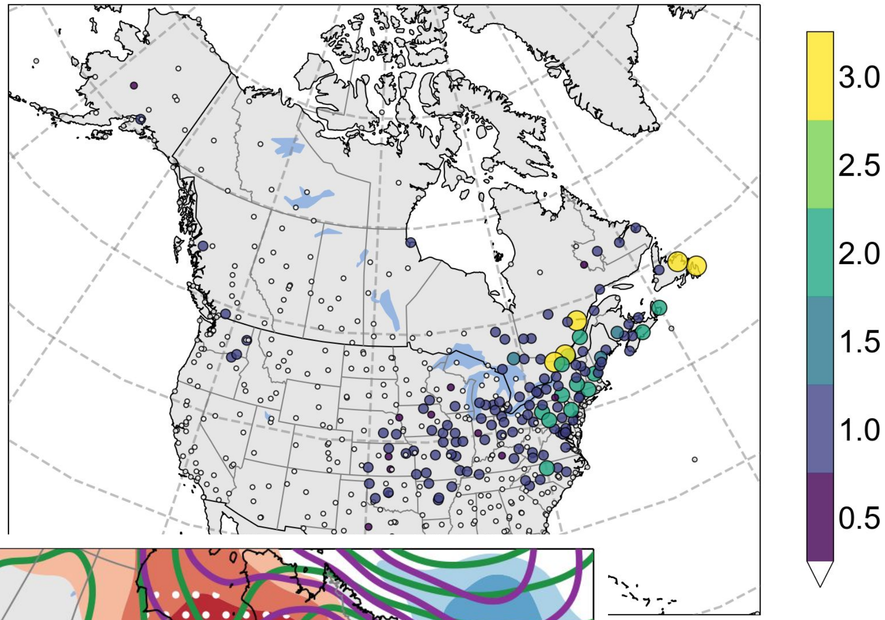
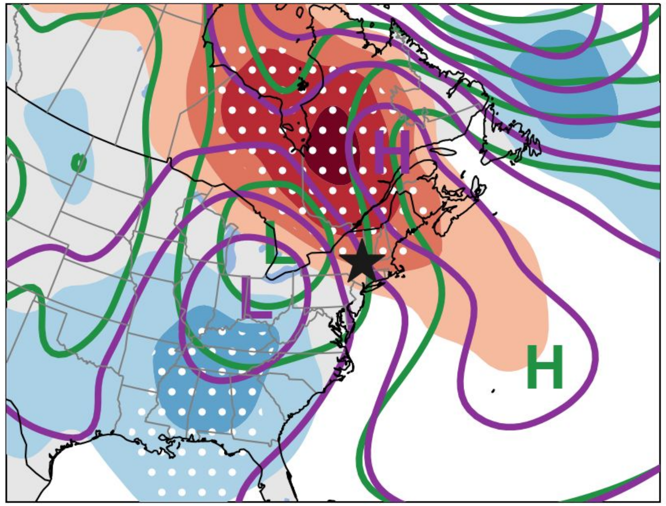


Terrain features can support **cold air trapping/channelling** during favorable synoptic setups for freezing rain
→ Allows for longer duration events than in areas without such features

Summary

- Long-duration (LD) freezing rain events are most common over the **northeastern U.S. and southeastern Canada**
    - Storm track key, terrain produces local maxima
- **LD events**, compared with SD ones, exhibit
    - A deeper, colder onset cold layer
    - Colder surface temperatures at onset
    - A deeper anticyclone to the NE (instead of E)
    - A more distant surface cyclone/warm front





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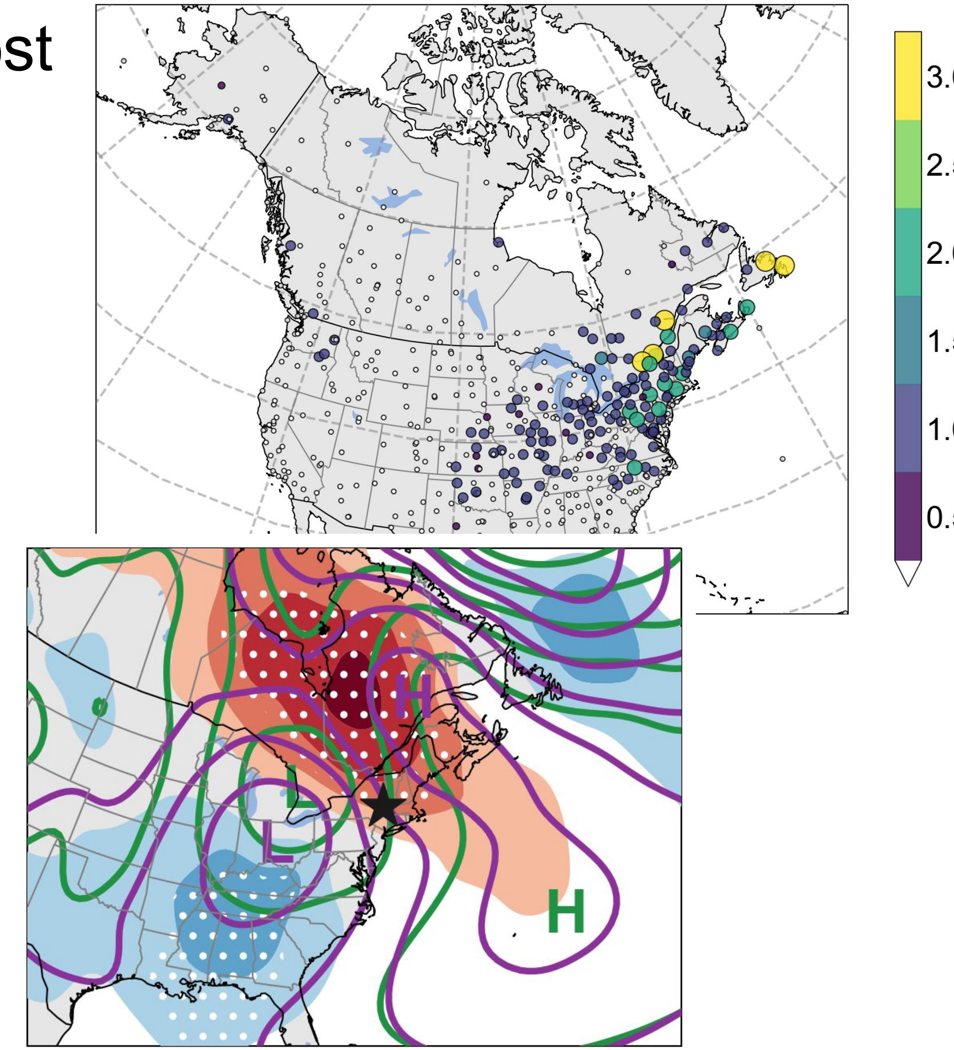
- **Future Work**
  - Further analysis of composite differences
  - How can relationships between onset characteristics and duration be applied to forecasts?



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