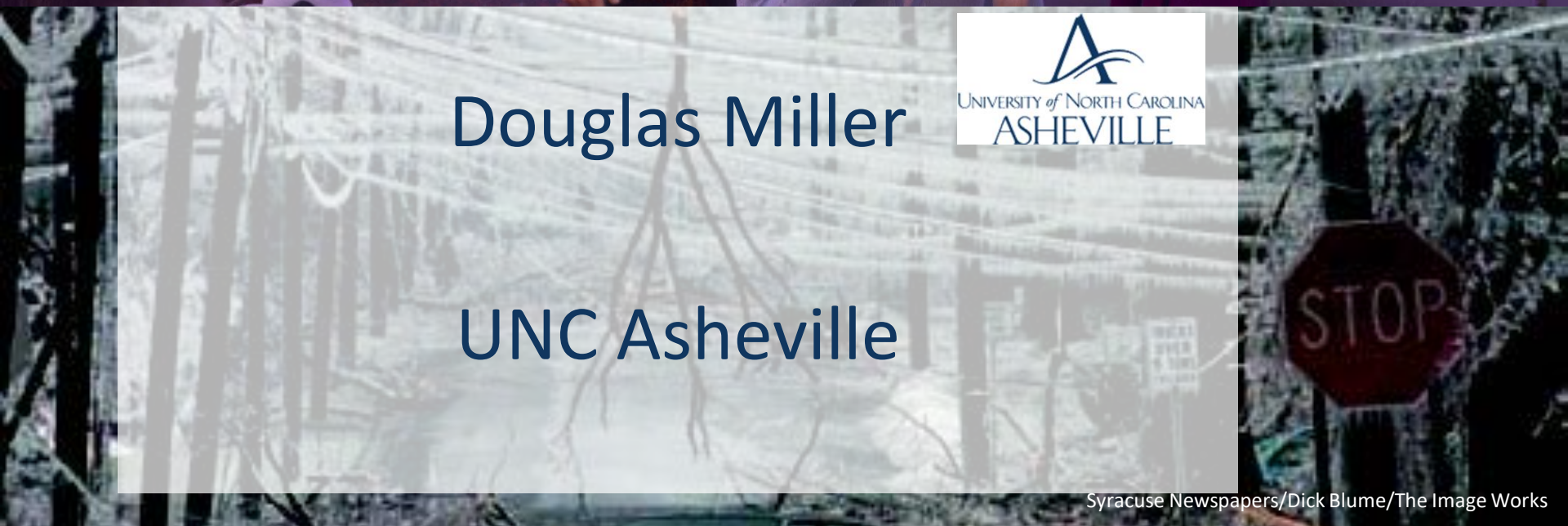
Frozen III

https://www.nytimes.com/2019/11/21/movies/frozen-2-review.html

Douglas Miller

UNC Asheville



Syracuse Newspapers/Dick Blume/The Image Works

Outline

University of North Carolina Asheville

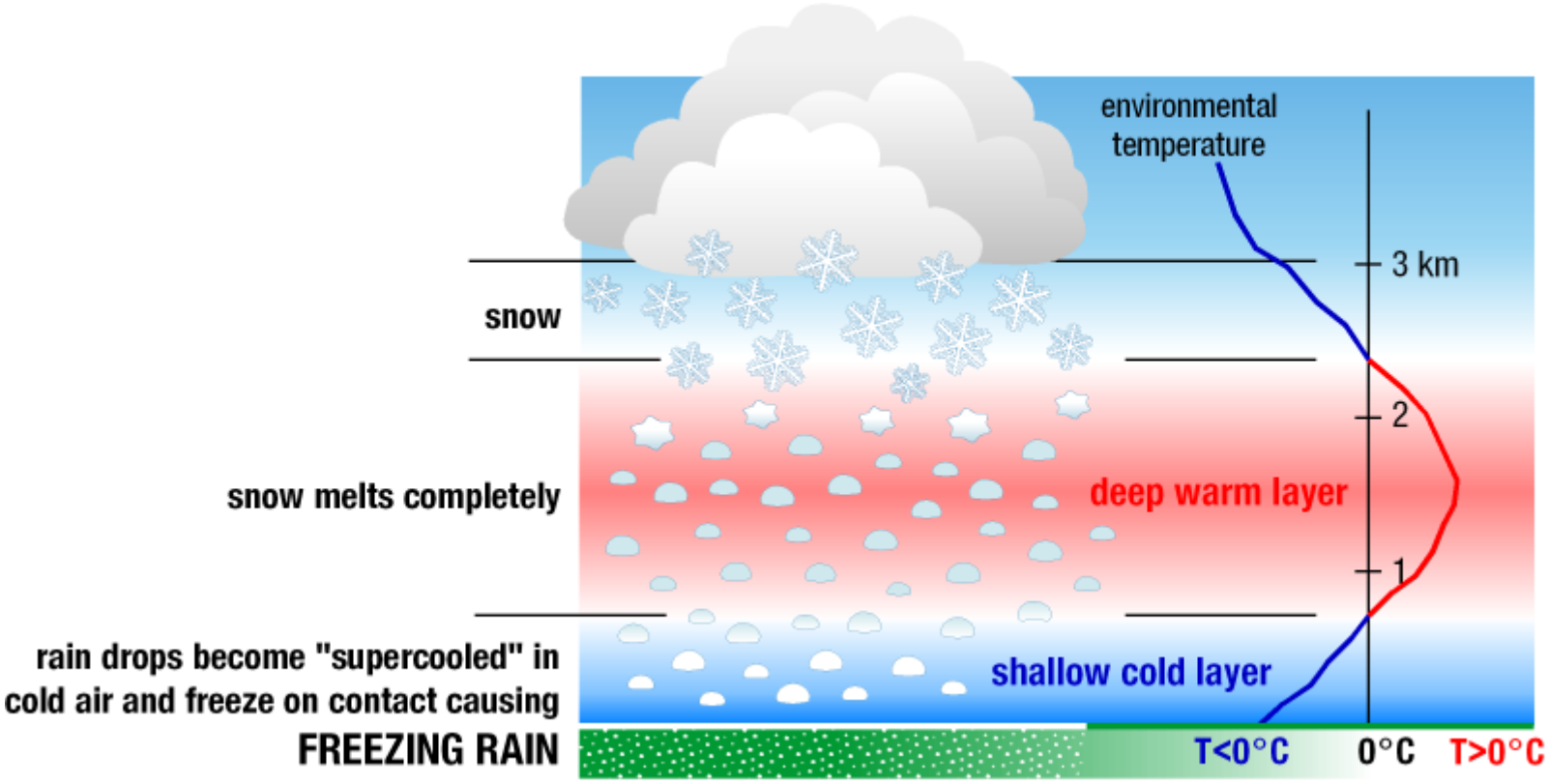
- Background
- Methodology
- Results
- Summary and conclusions

Background

- Freezing Rain (Frz Rn) Event Impacts
  - Damage to infrastructure
    - Widespread power outages (hypothermia)
  - Hazard to travel
    - Traffic accidents, flight delays or cancellations

Background

- Textbook freezing rain scenario



https://www.nssl.noaa.gov/education/svrwx101/winter/types/img/freezingrain.png

Background

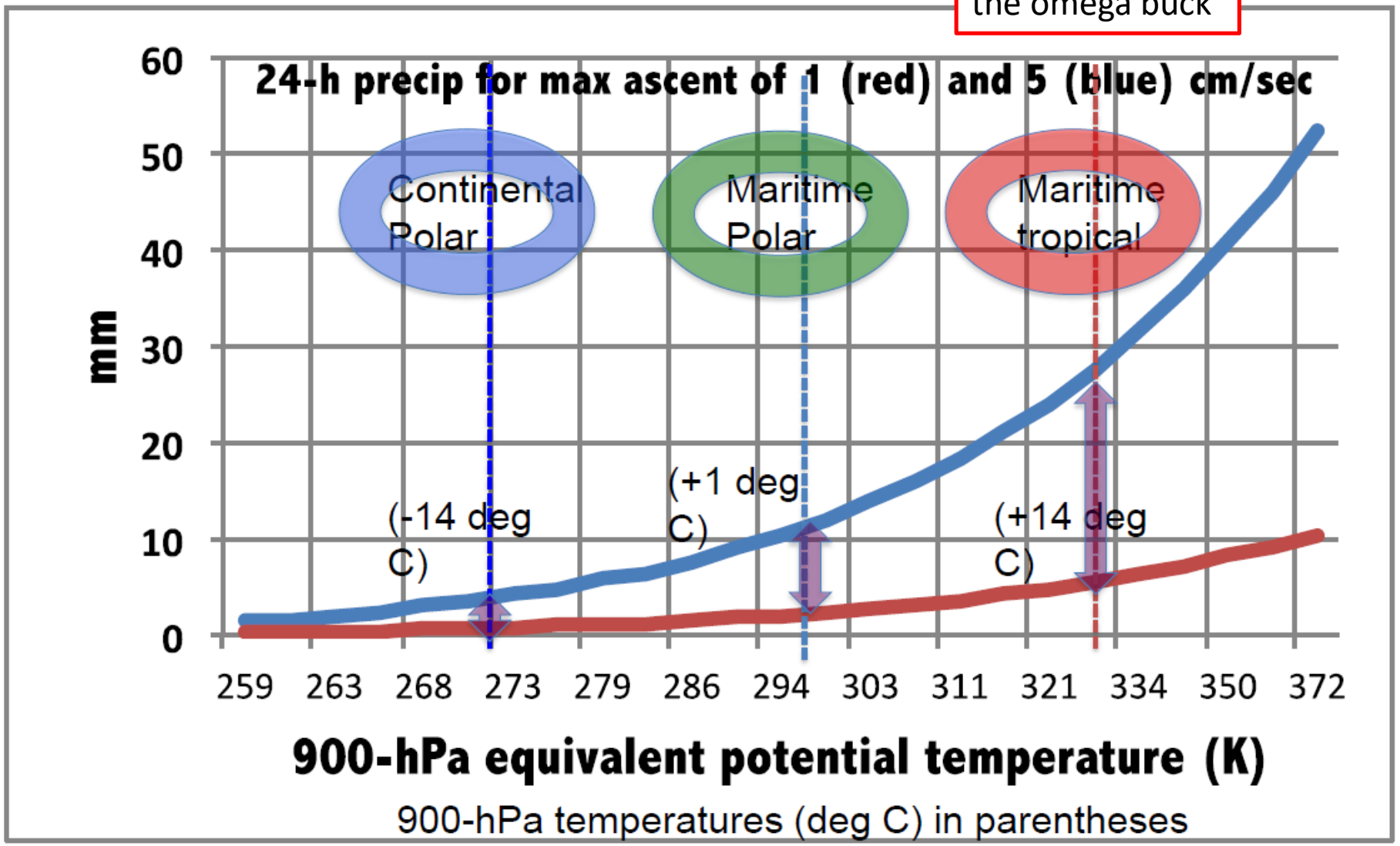
- Doswell et al. (1996)
  - Event Accum. Precipitation [mm] = Ave. P × Duration

- Gyakum (2008)
  - Precipitation rate (P [mm h^{-1}])

$$P = -(1/g) \int \omega (dr_s/dp)_{ma}\, dp, \qquad (5)$$

where g is gravity, the vertical integral extends from 1000 to 200 hPa, r_s is the saturation mixing ratio, and the subscript ma represents the appropriate moist adiabat.

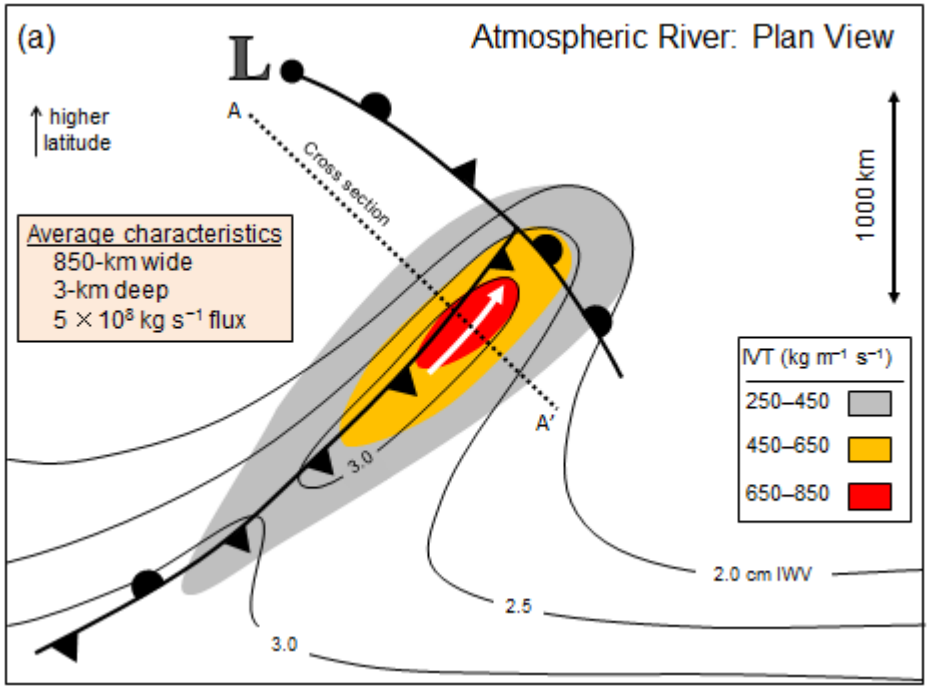
Most ‘bang’ for the omega buck

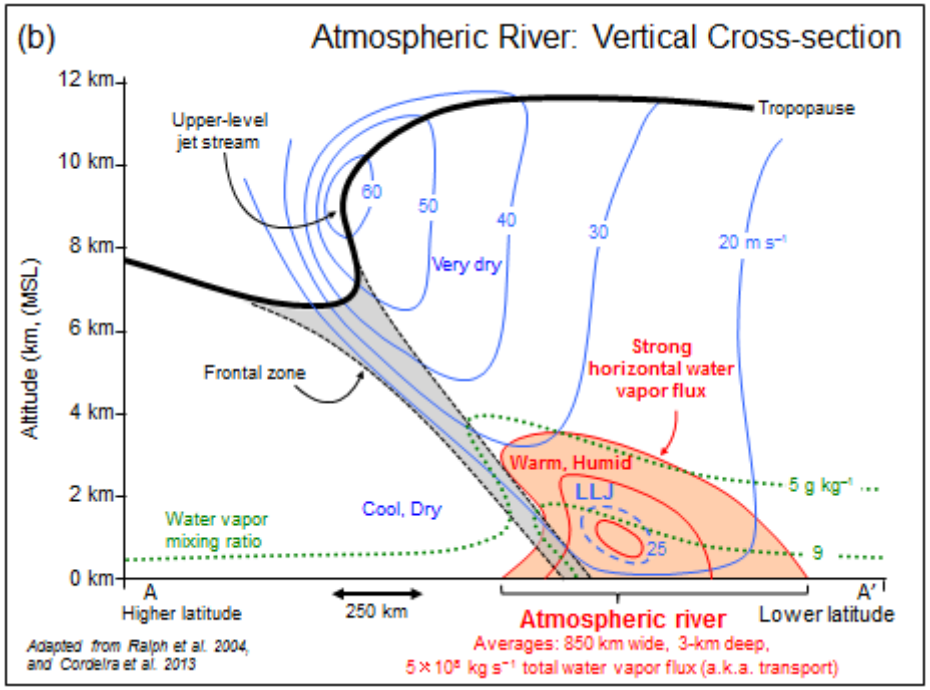


Gyakum (2016)

Atmospheric River

IVT = Integrated Vapor Transport





IVT was calculated as

$$-\int_{po}^{p}(q\mathbf{V})\frac{dp}{g}, \qquad (1)$$

where q is the specific humidity, $\mathbf{V}$ is the horizontal wind, po is 1000 hPa, p is 100 hPa, and g is the acceleration due to gravity.

http://glossary.ametsoc.org/wiki/Atmospheric_river

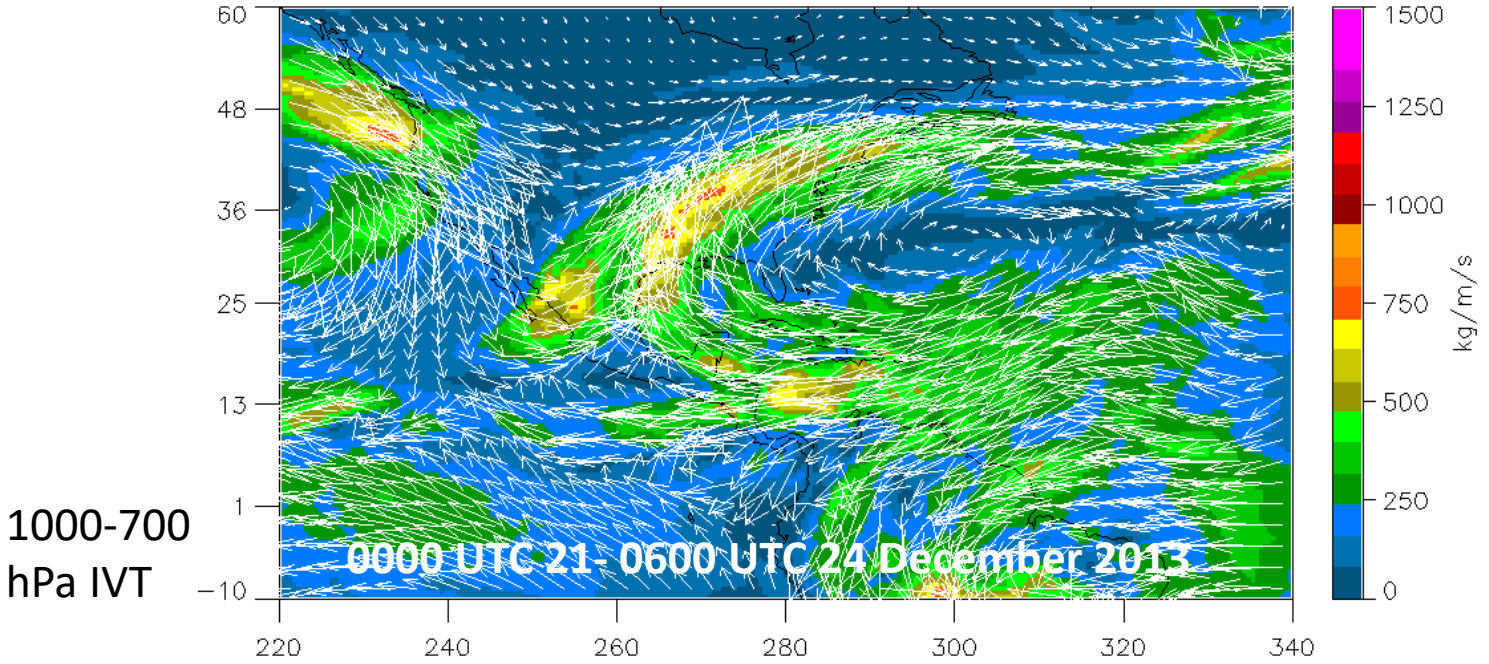
Background

- Atmospheric river definition
  - A long, narrow, and transient corridor of strong horizontal water vapor transport that is typically associated with a low-level jet stream ahead of the cold front of an extratropical cyclone. The water vapor in atmospheric rivers is supplied by tropical and/or extratropical moisture sources…Horizontal water vapor transport in the midlatitudes occurs primarily in atmospheric rivers and is focused in the lower troposphere.

http://glossary.ametsoc.org/wiki/Atmospheric_river

Background

- Hypothesis
  - Severe freezing rain events of eastern North America are likely associated with mid-latitude storms having an atmospheric river (AR)



Methodology

- Atmospheric river (AR) events database of Guan and Waliser (2015)
  - 37 years (1979-2015) of ARs detected using the Climate Forecast System Reanalysis (CFSR) 6-hourly 0.5^{o} x 0.5^{o} gridded dataset
    - IVT based on the 85th percentile specific to each season and grid cell and a fixed lower limit of 100 kg m^{-1} s^{-1} ,
    - geometry requirements of length >2000 km, and
    - length/width ratio >2

https://doi.org/10.1002/2015JD024257

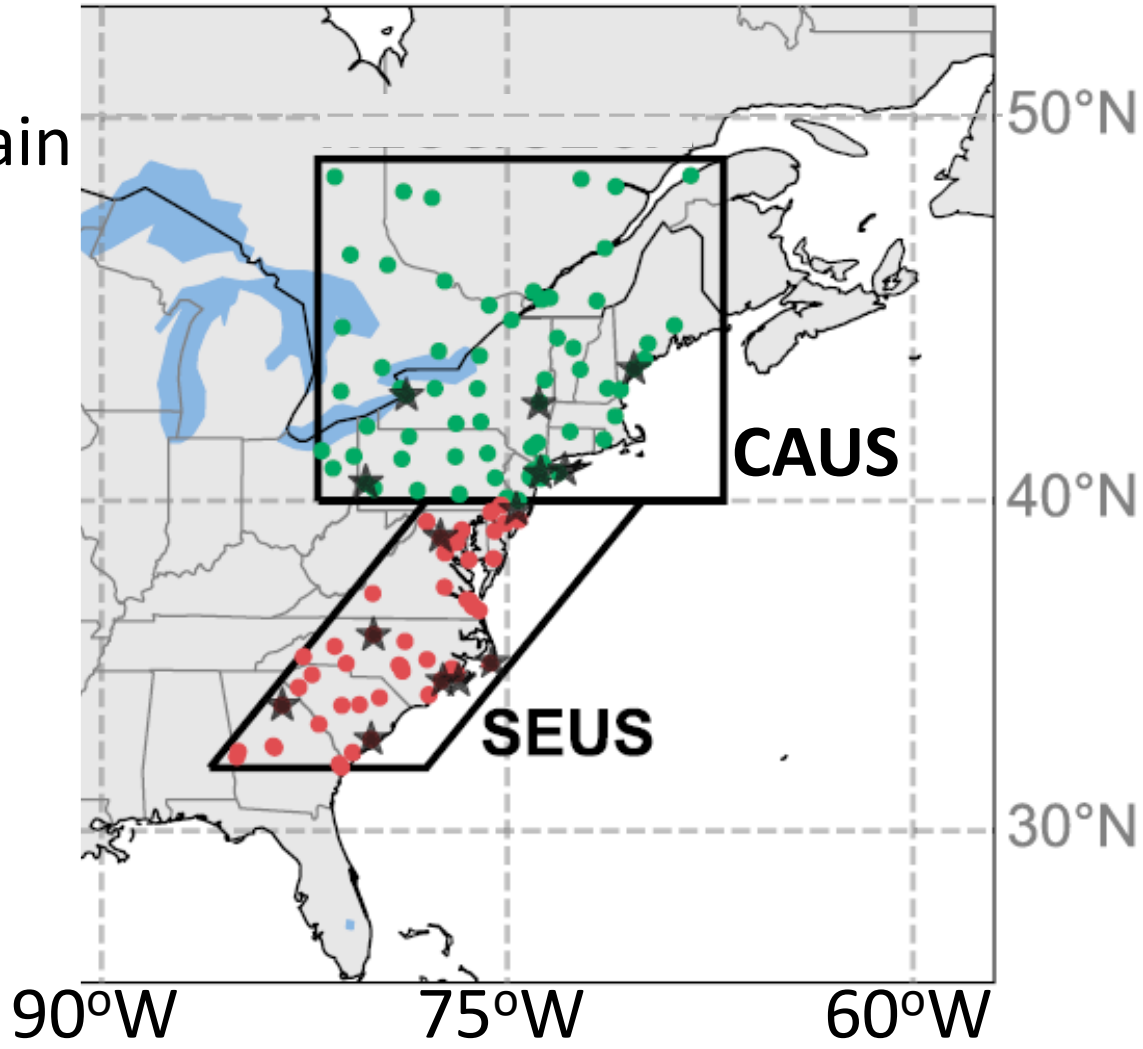
Methodology

- Freezing rain events database of McCray et al. (2019)
  - 38 years of surface weather observations (1979-2016)
    - limited to 36 year study (AR database ends in Dec. 2015)
    - define long duration (LD) freezing rain event as consecutive 6-h synoptic periods when at least one station observed freezing rain
    - event ends when 6-h synoptic period contains no freezing rain observations (Miller et al. 2018)
    - 36 freezing rain seasons are defined for two study domains
      - CAUS – southeastern Canada and northeastern U.S.
      - SEUS – southeastern U.S.

https://doi.org/10.1175/WAF-D-18-0154.1

Methodology

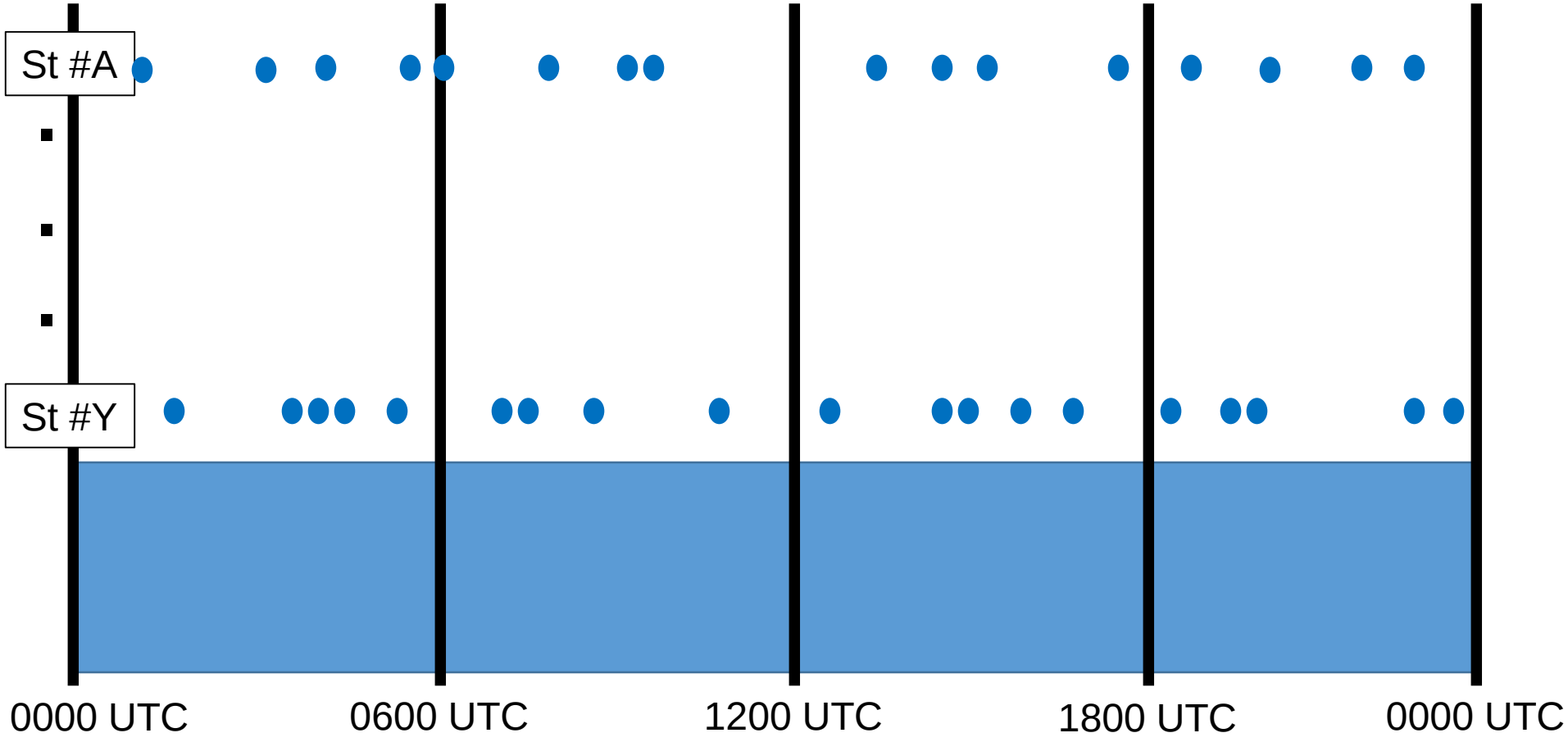
- Domain



*modified Fig. 2 of McCray et al. (2019)

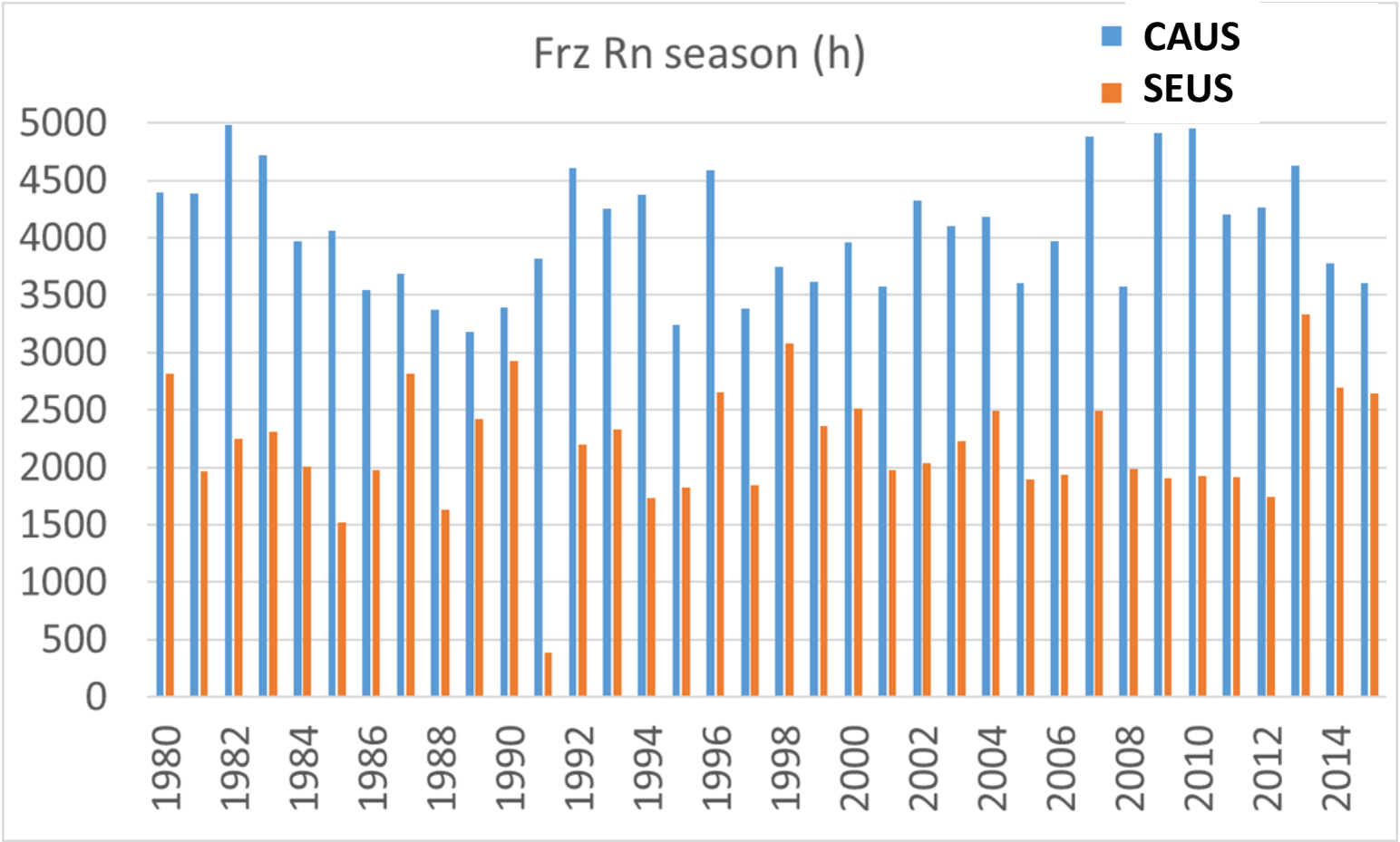
Methodology

- Freezing rain observations binned in synoptic 6-h periods



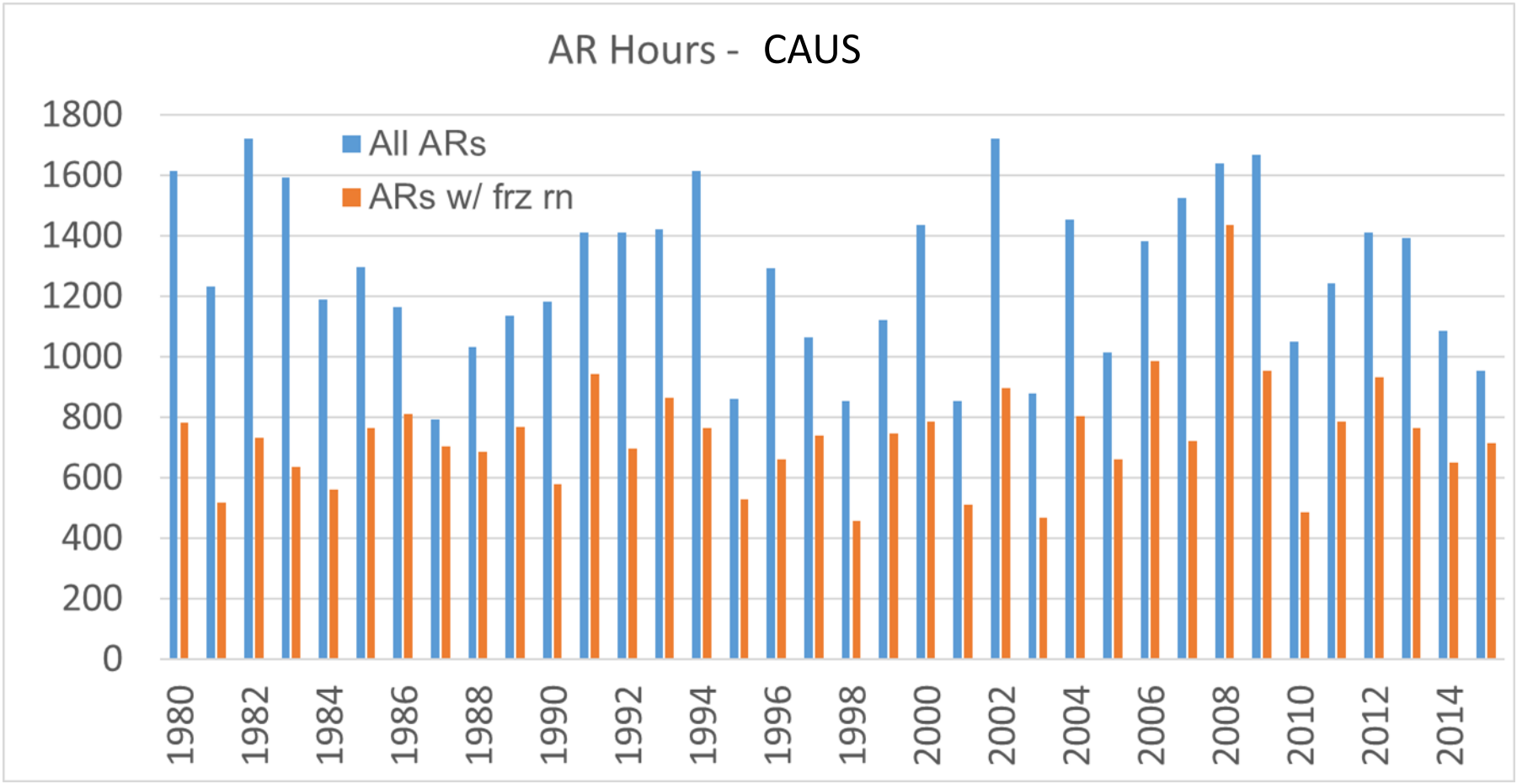
Results

- Freezing rain “seasons”



Results

- AR hours during freezing rain “seasons” - CAUS



Results

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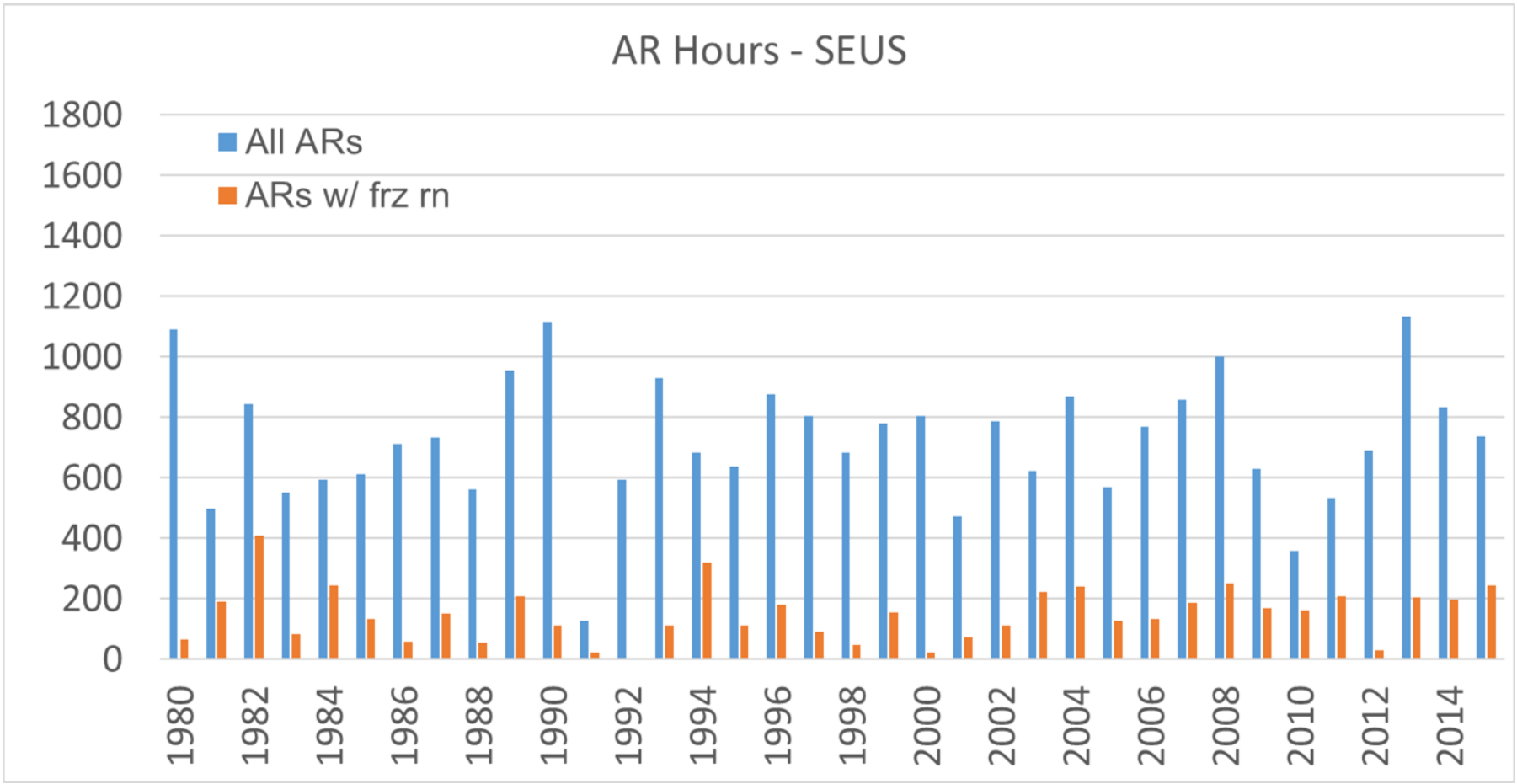
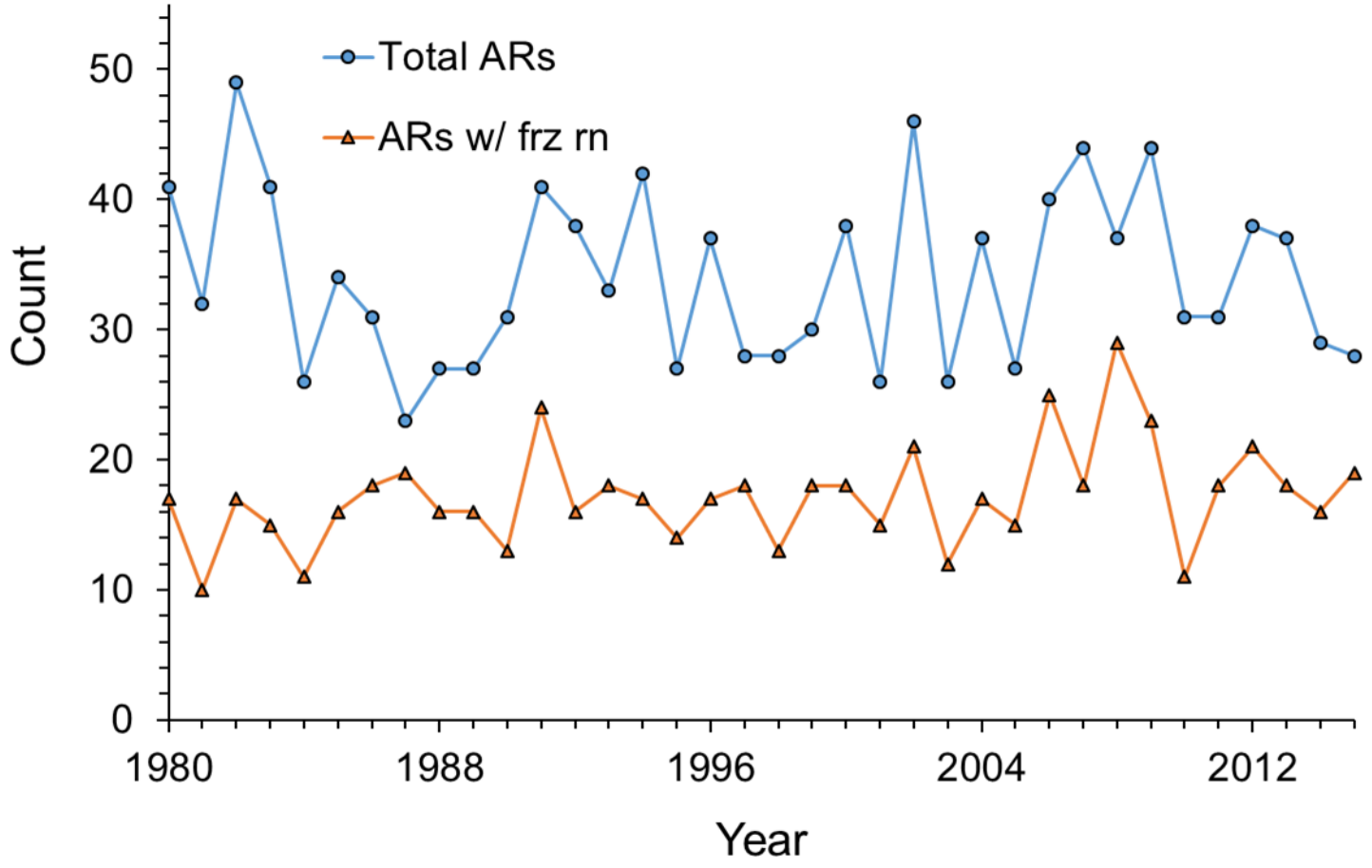
- AR hours during freezing rain “seasons” - SEUS



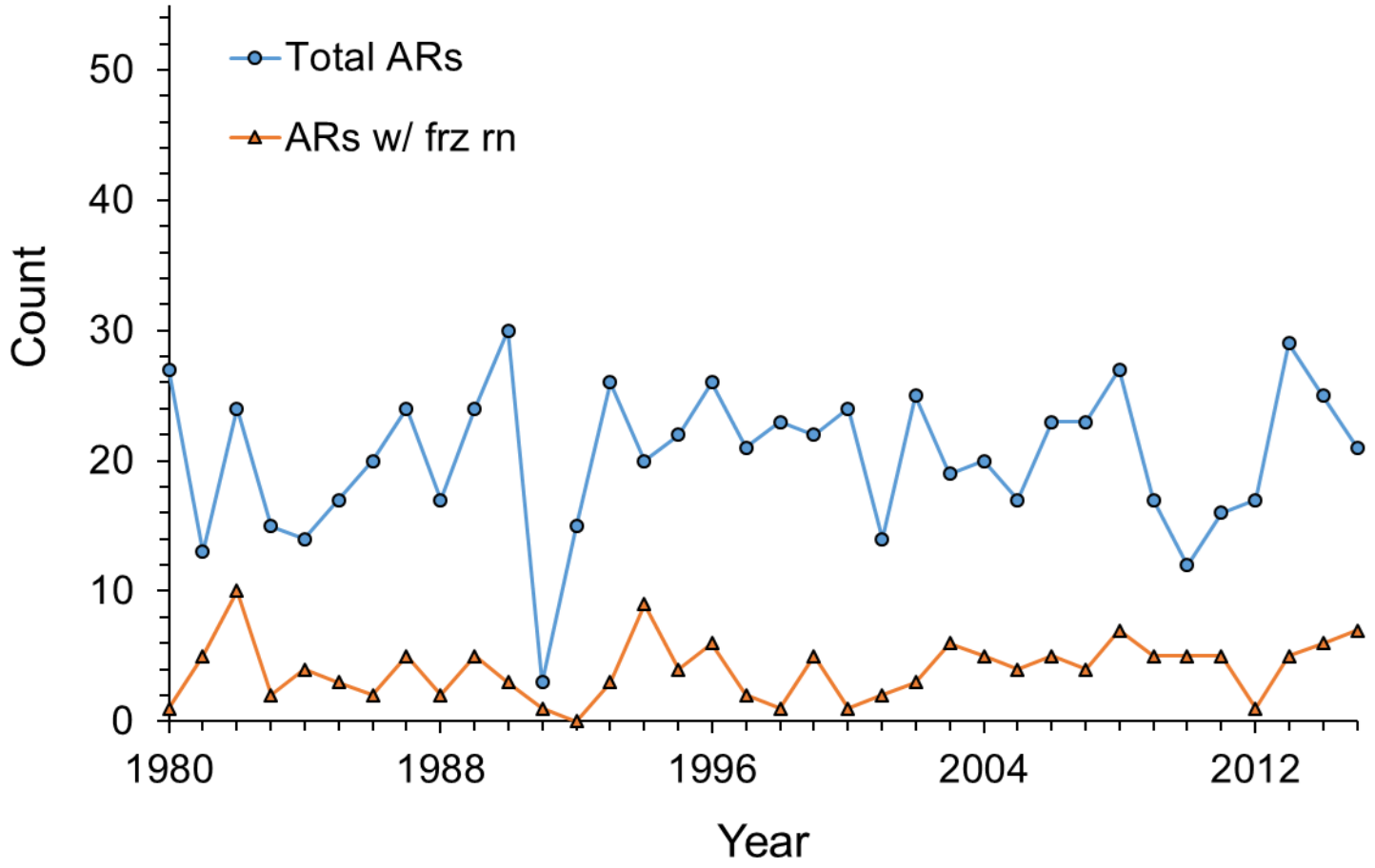
Results

- AR count during freezing rain “seasons” - CAUS



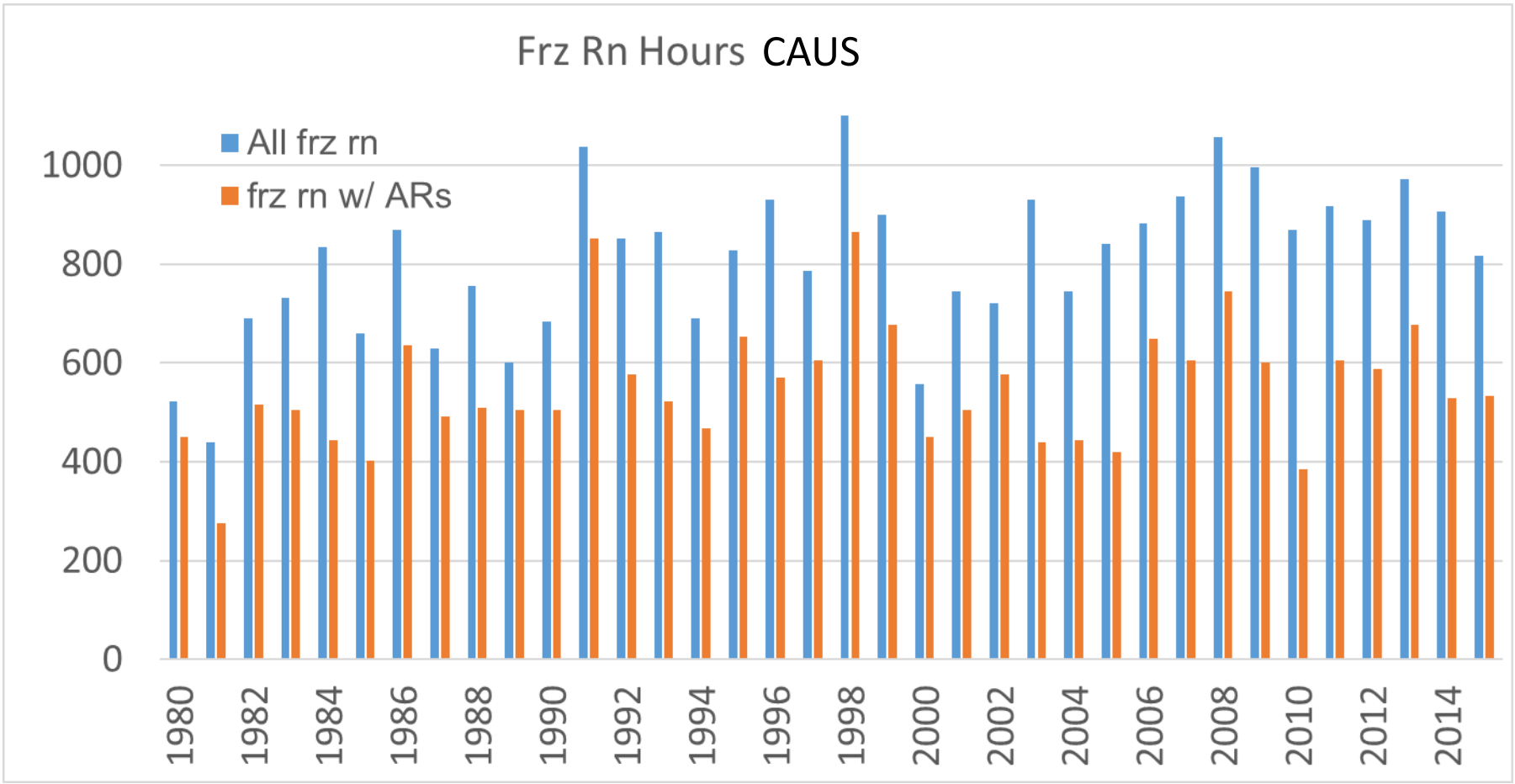
Results

- AR count during freezing rain “seasons” - SEUS



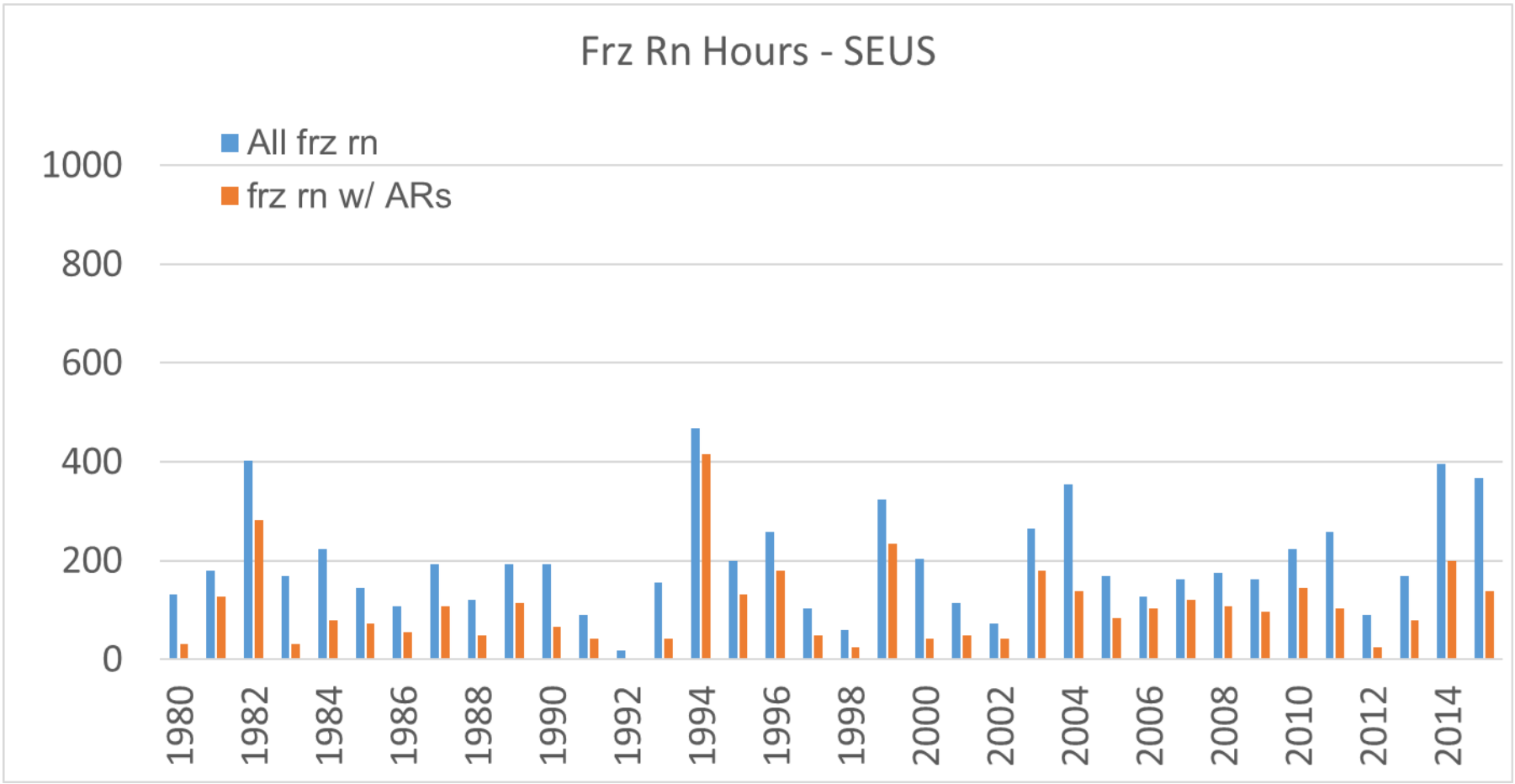
Results

- Freezing rain hours - CAUS



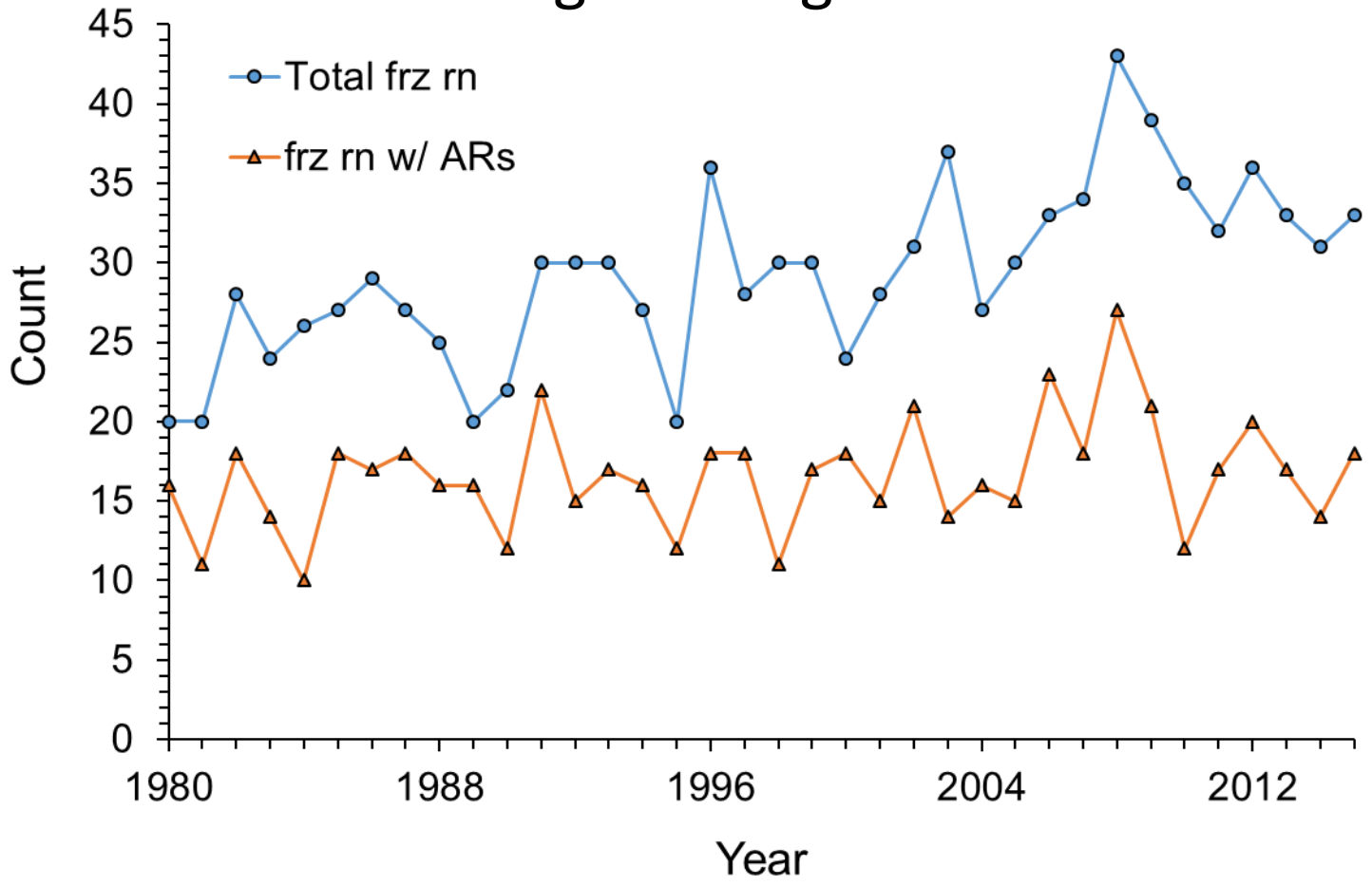
Results

- Freezing rain hours - SEUS



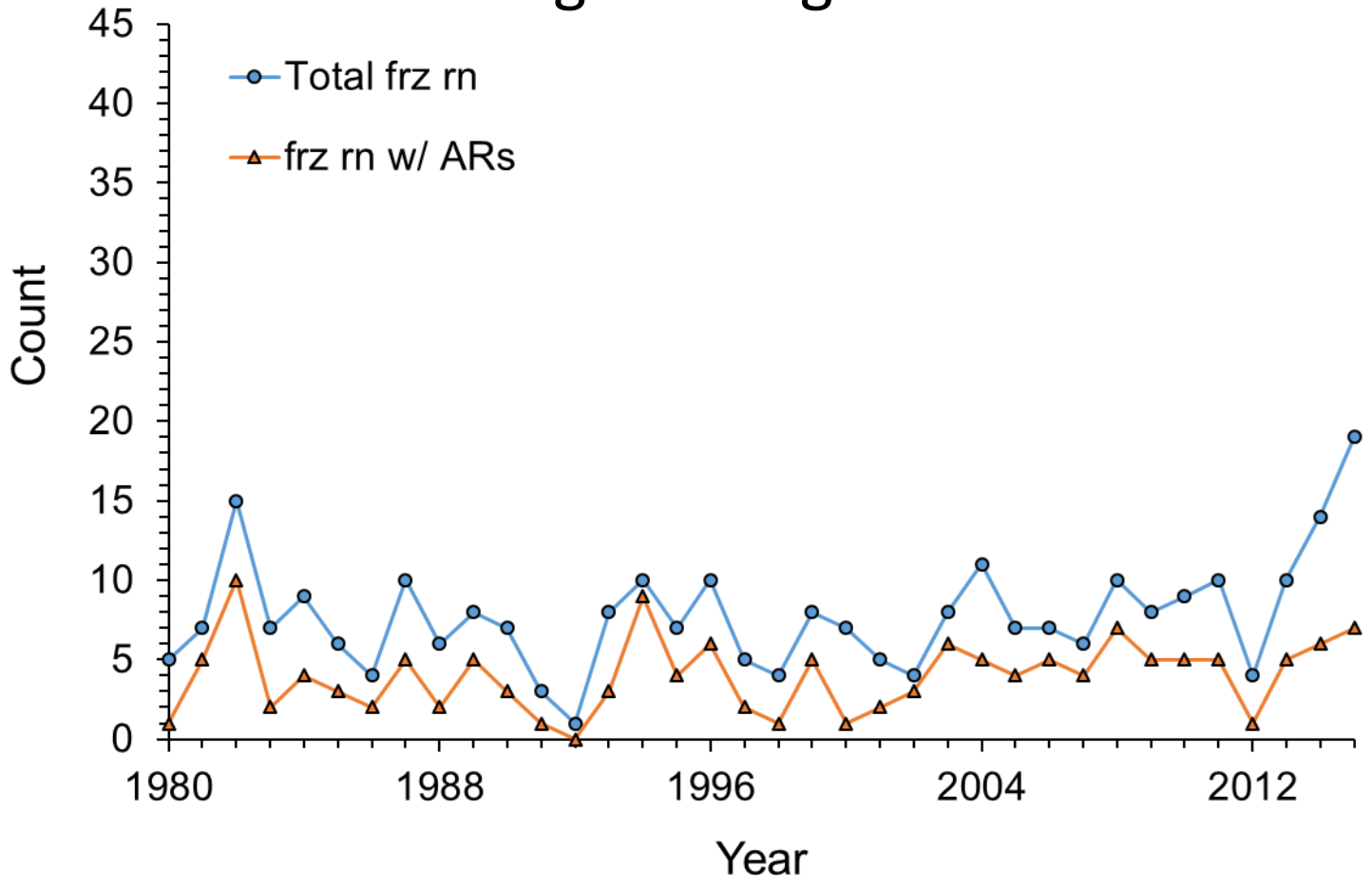
Results

- Frz rn count during freezing rain “seasons” - CAUS



Results

- Frz rn count during freezing rain “seasons” - SEUS



Results

- 36 year freezing rain and AR event totals - CAUS

CAUS	Frz rn (count)	(%)	Frz rn (h)	(%)
w/ AR	598	56.7	18168	65.4
total	1055		27768	

CAUS	AR (count)	(%)	AR (h)	(%)
w/ Frz rn	619	50.5	26454	57.9
total	1225		45678	

Results

- 36 year freezing rain and AR event totals - SEUS

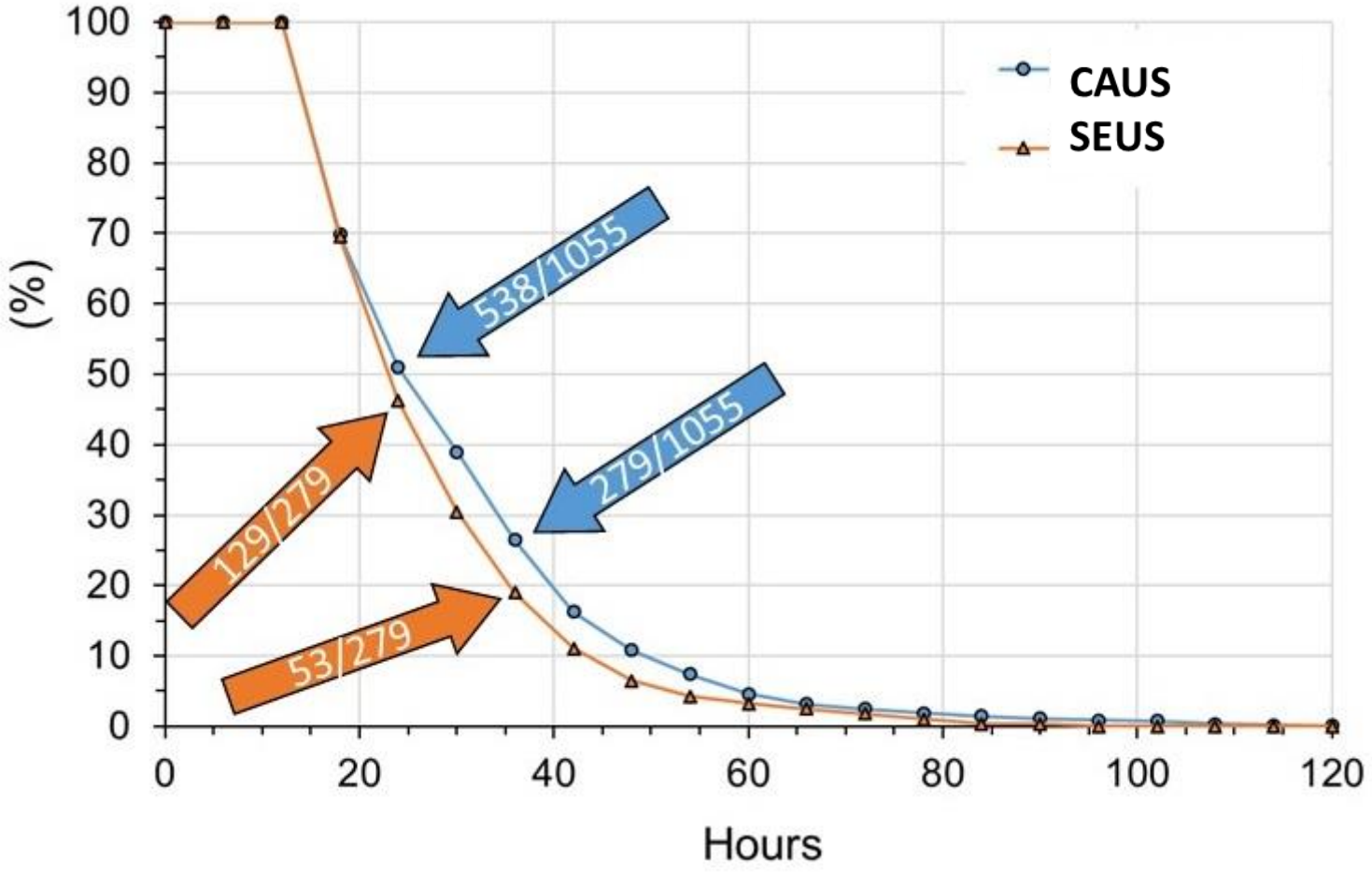
SEUS	Frz rn (count)	(%)	Frz rn (h)	(%)
w/ AR	135	48.4	3378	50.9
total	279		6636	

SEUS	AR (count)	(%)	AR (h)	(%)
w/ Frz rn	144	19.7	5346	20.5
total	732		26064	

Note: freezing rain “season” of CAUS is nearly double that of SEUS

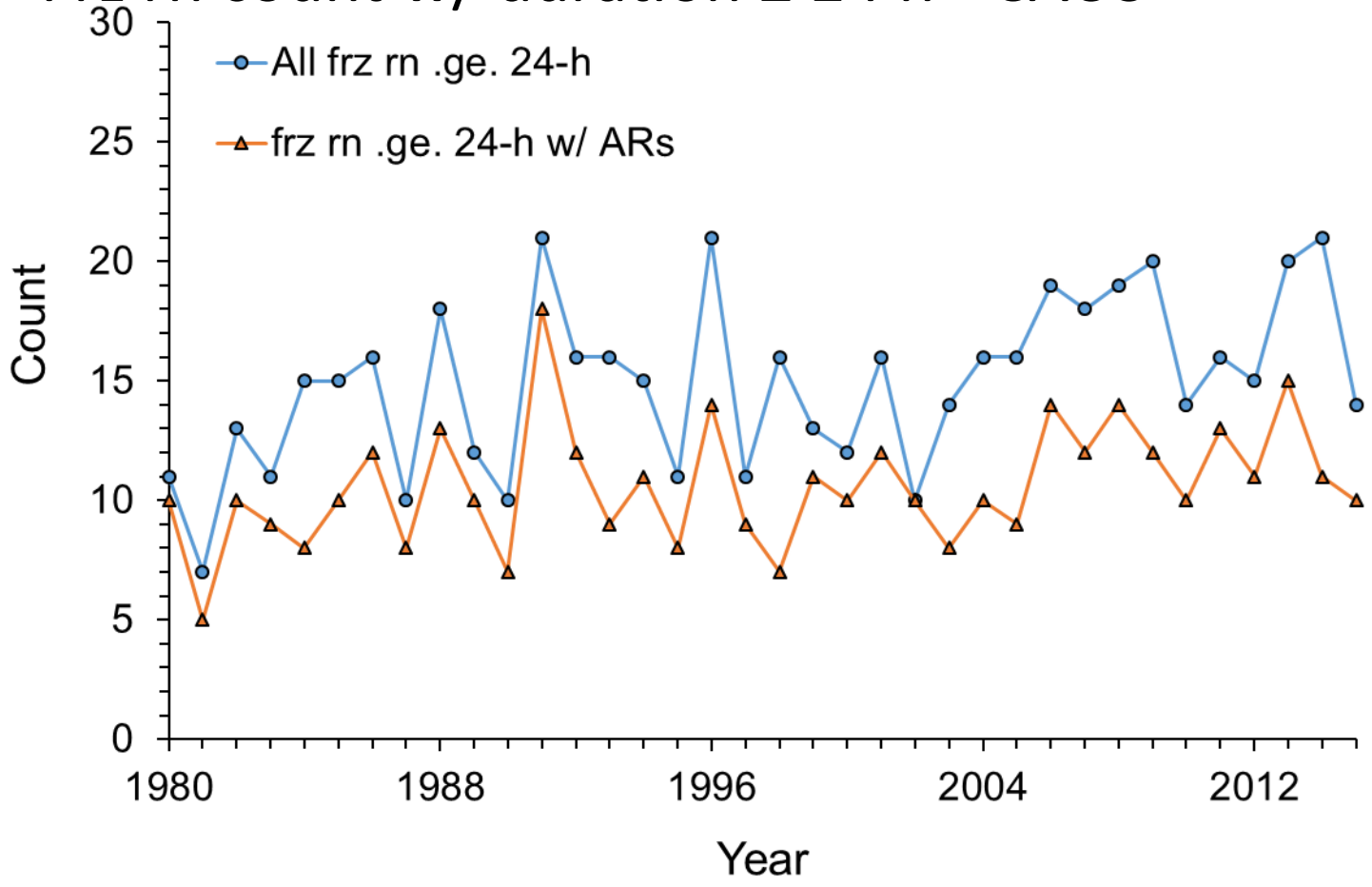
Results

- % freezing rain events ≥ LD hours



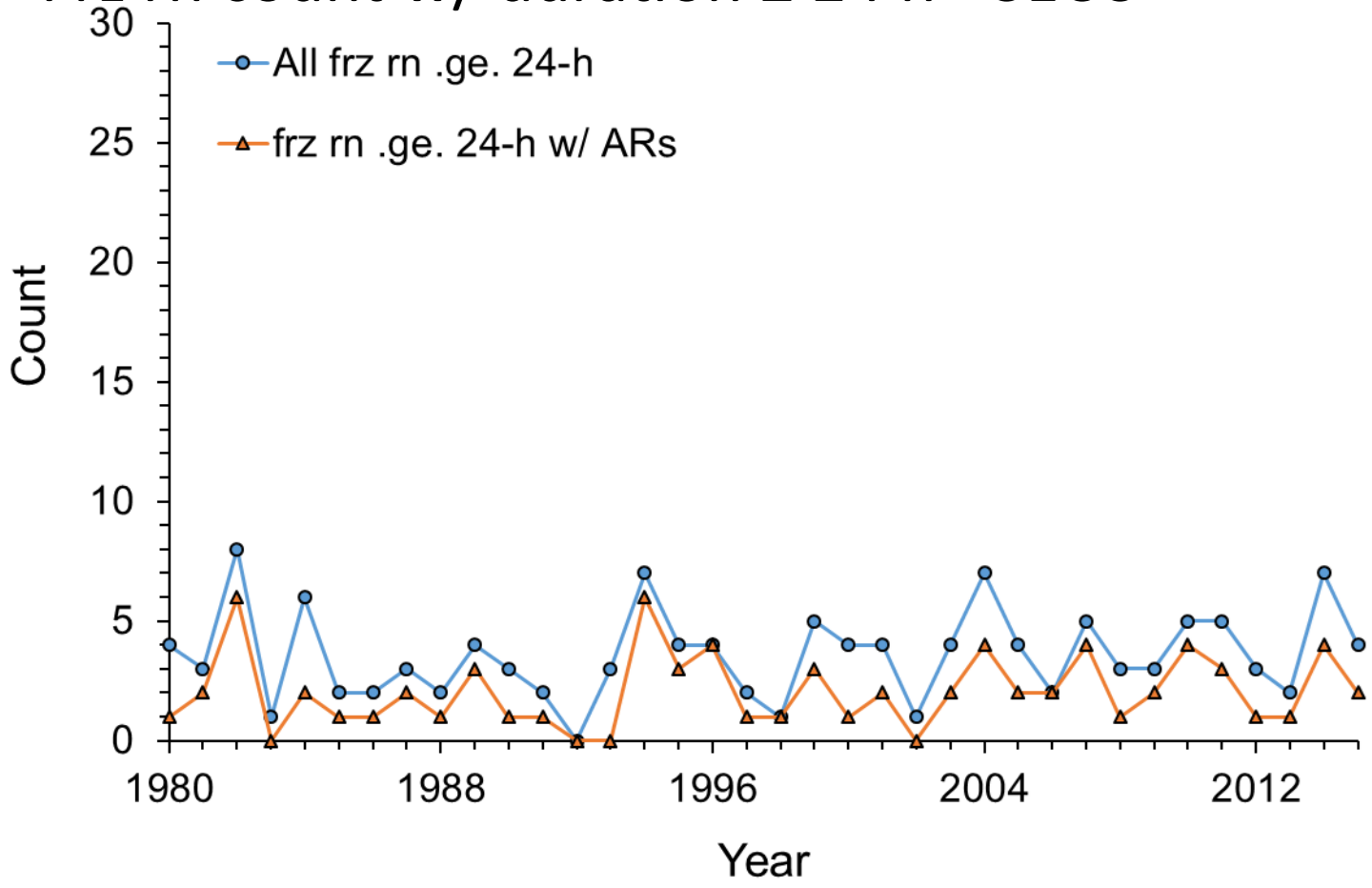
Results

- Frz rn count w/ duration ≥ 24 h - CAUS



Results

- Frz rn count w/ duration ≥ 24 h - SEUS



Results

- 36 year freezing rain event ≥ 24-h duration totals

CAUS	Frz rn (count)	(%)	Frz rn (h)	(%)
w/ AR	382	71.0	14976	73.5
total	538	(56.7)	20370	(65.4)

SEUS	Frz rn (count)	(%)	Frz rn (h)	(%)
w/ AR	74	57.4	2490	56.0
total	129	(48.4)	4446	(50.9)

(NN) = NN%, ALL Frz rn events

Note: freezing rain "season" of CAUS is nearly double that of SEUS

Results

- Top 15 extreme freezing rain events - CAUS

Start	Duration (h)	Score	AR-influenced	Category
1998 1 3 6	180	262	Y	CAUSo
1999 112 6	102	188	Y	CAUS+
1990 21312	96	170	Y	CAUSo
1989 3 4 0	72	138	Y	CAUS+
2011 2 1 0	60	134	Y	CAUS+
20131220 0	102	129	Y	CAUSo
2002123018	114	125	N	CAUSo
1995 227 0	54	124	Y	CAUS+
1995 111 6	108	119	Y	CAUS+
2009 1 612	42	119	Y	CAUS+
2008 3 3 0	78	111	Y	CAUSo
1991 3 3 0	60	110	Y	CAUSo
1986 21618	84	107	Y	CAUSo
1994 12718	36	103	Y	CAUS+
19831212 0	90	101	Y	CAUSo

"o" = frz rn in single domain only

"+" = frz rn in both domains

Results

- Strong (top 5.0%) freezing rain events - SEUS

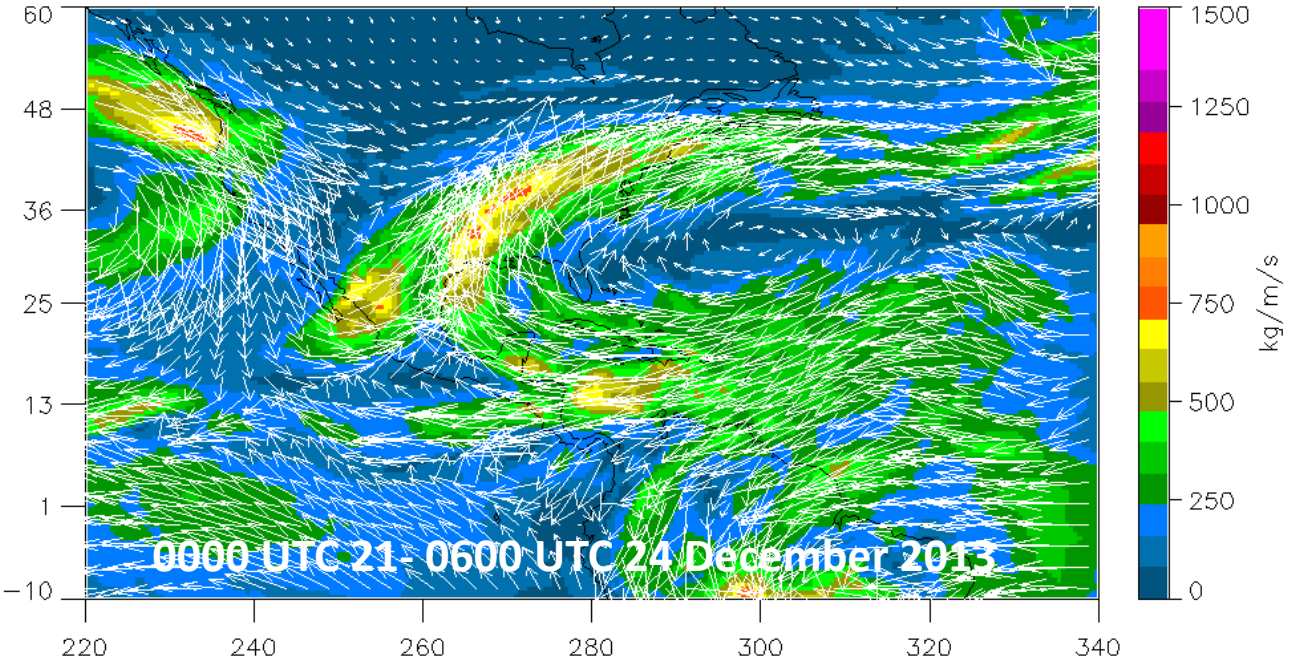
Start	Duration (h)	Score	AR-influenced	Category
1994 2 812	90	207	Y	SEUS+
2004 12512	66	139	Y	SEUS+
1998122312	78	108	Y	SEUSo
19891218 0	54	97	Y	SEUSo
2000 129 0	54	95	Y	SEUS+
2014 211 6	72	94	Y	SEUS+
2011 110 0	72	93	Y	SEUSo
1982 11218	60	91	Y	SEUSo
2005 129 0	48	77	Y	SEUSo
1996 2 2 0	42	72	Y	SEUSo
1983 12012	78	71	Y	SEUS+
200212 412	36	68	N	SEUSo
1985 2 5 6	36	59	Y	SEUSo
2003 21518	48	58	Y	SEUS+
1994 127 0	42	55	Y	SEUS+

"o" = frz rn in single domain only

"+" = frz rn in both domains

Results

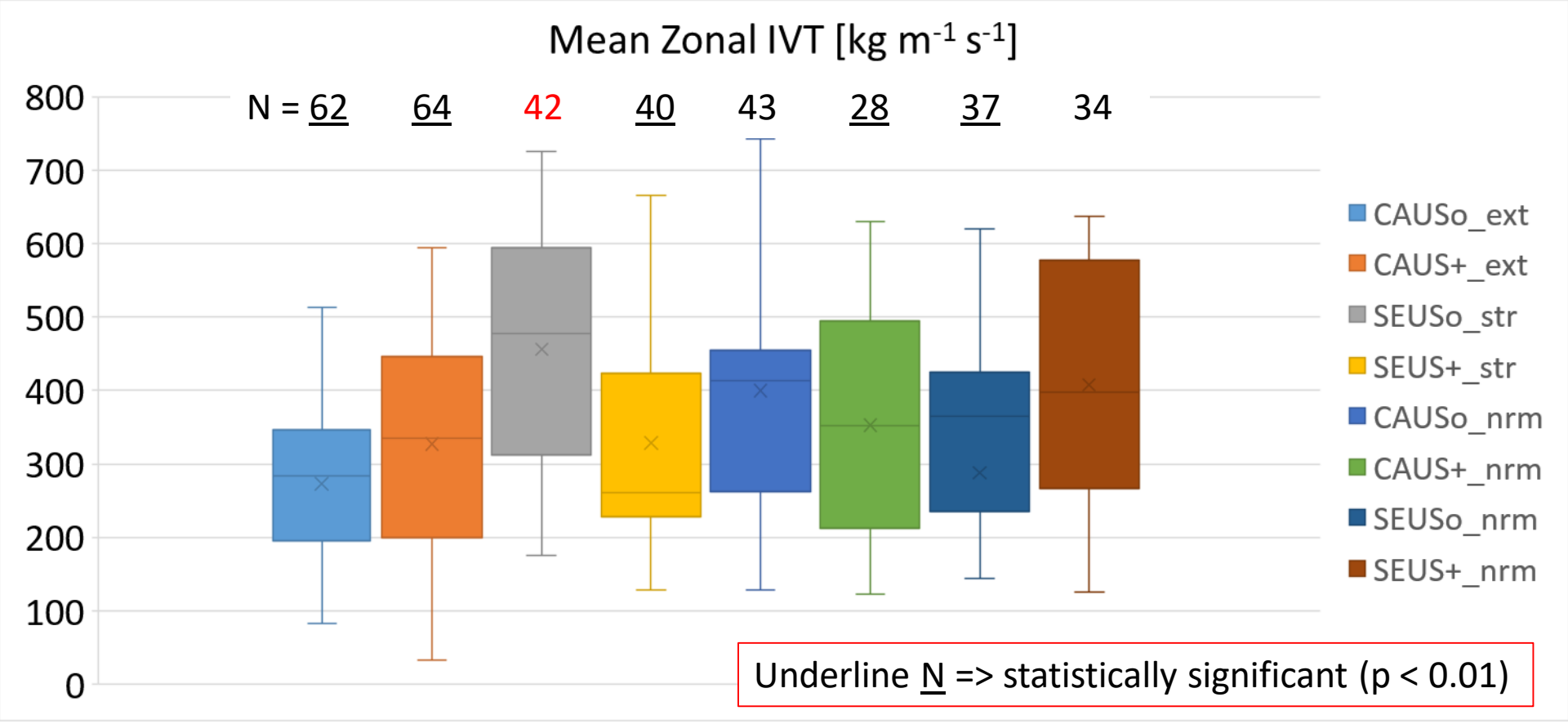
- A closer look only at AR- influenced freezing rain events falling into the top
  - 2.5 % (extreme) of CAUS domain
  - 5.0 % (strong) of SEUS domain



1000-700 hPa IVT

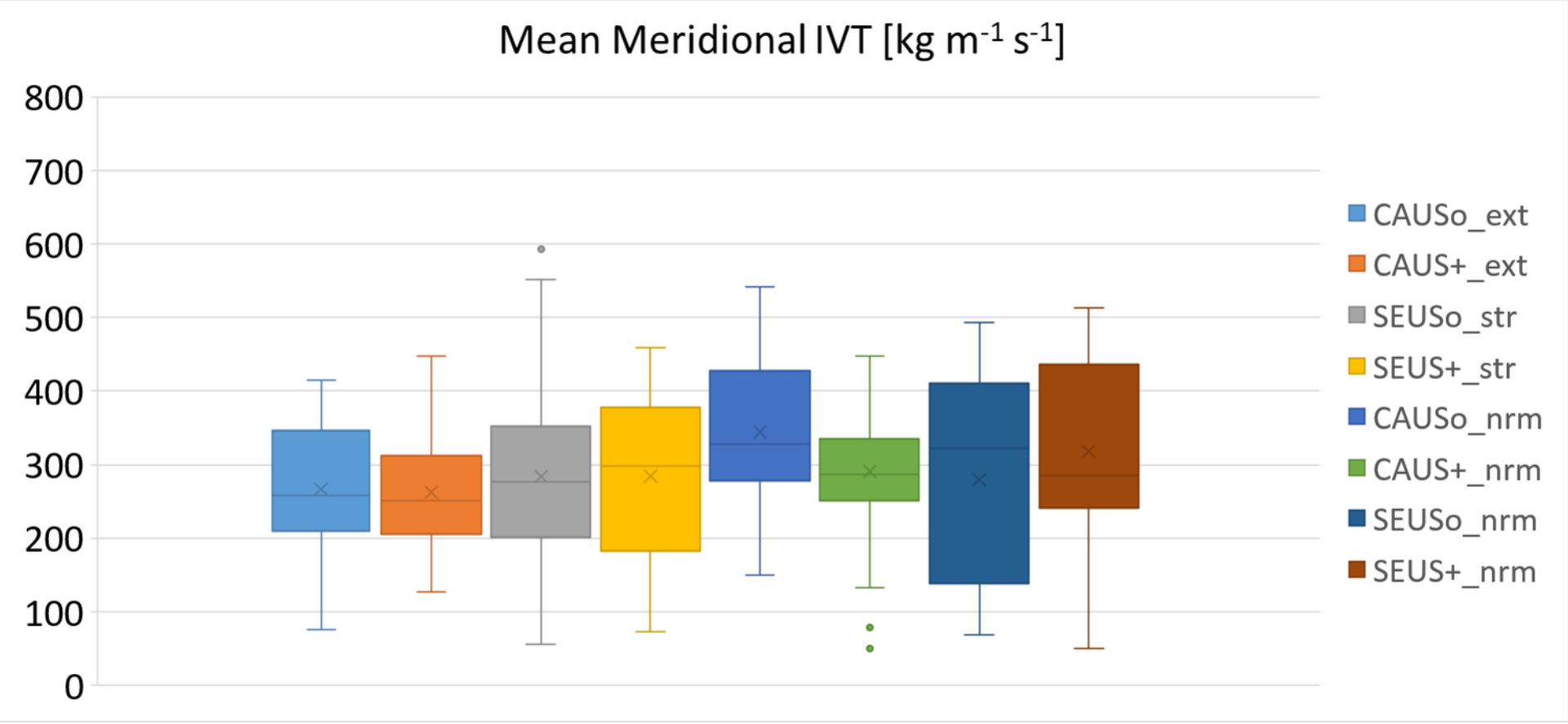
Results

- AR characteristics

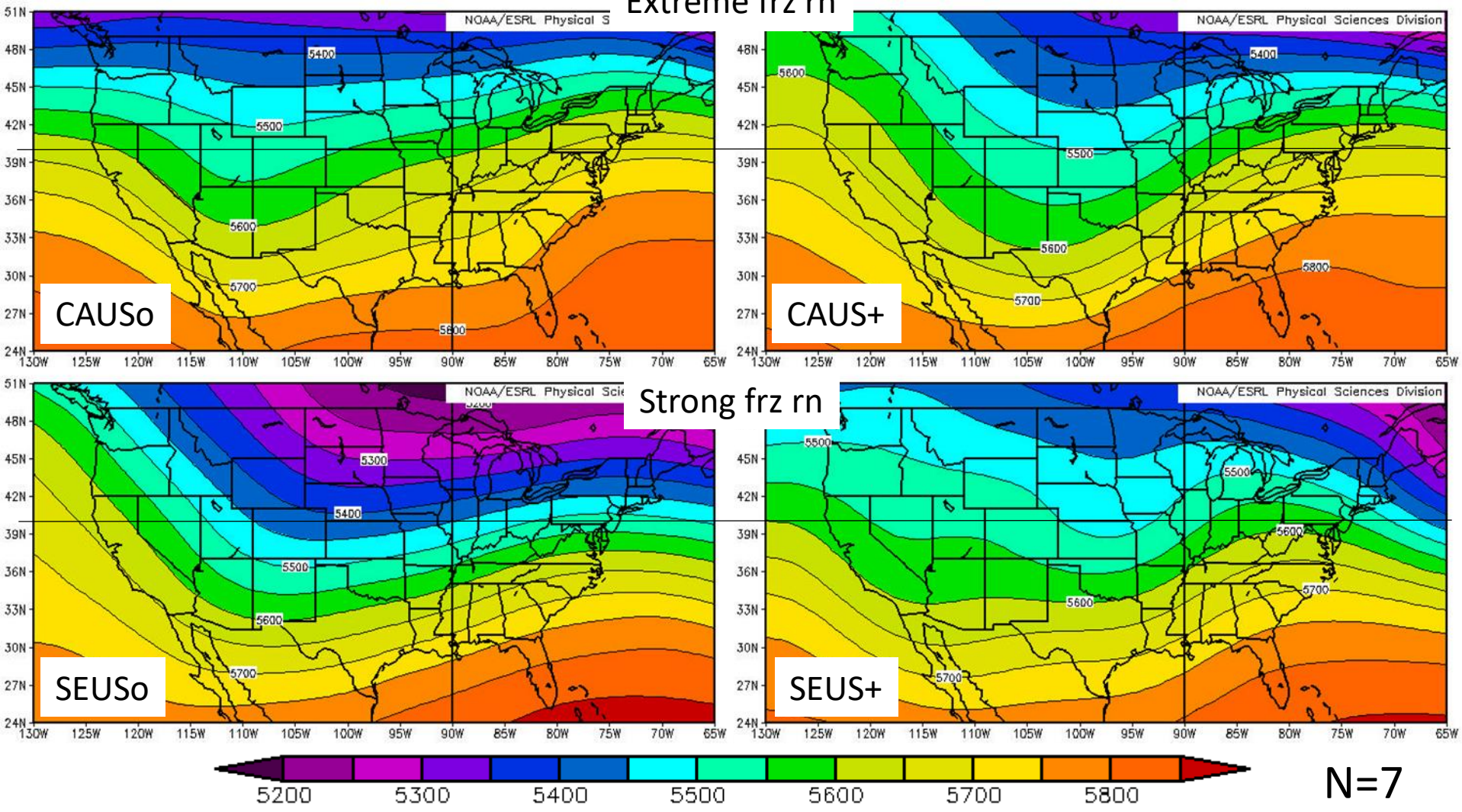


Results

- AR characteristics



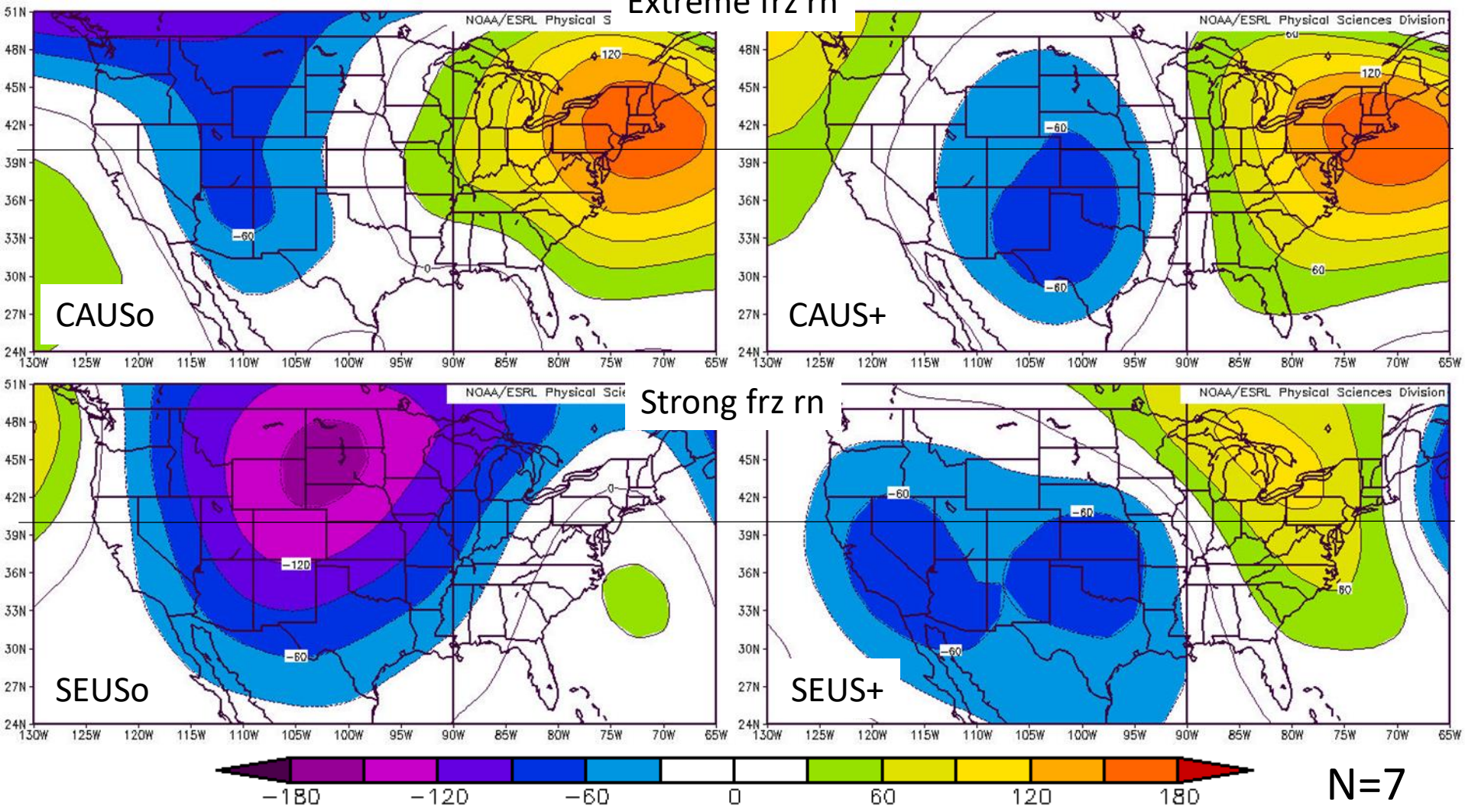
Results 500 hPa Geo. Ht. composite means



N=7

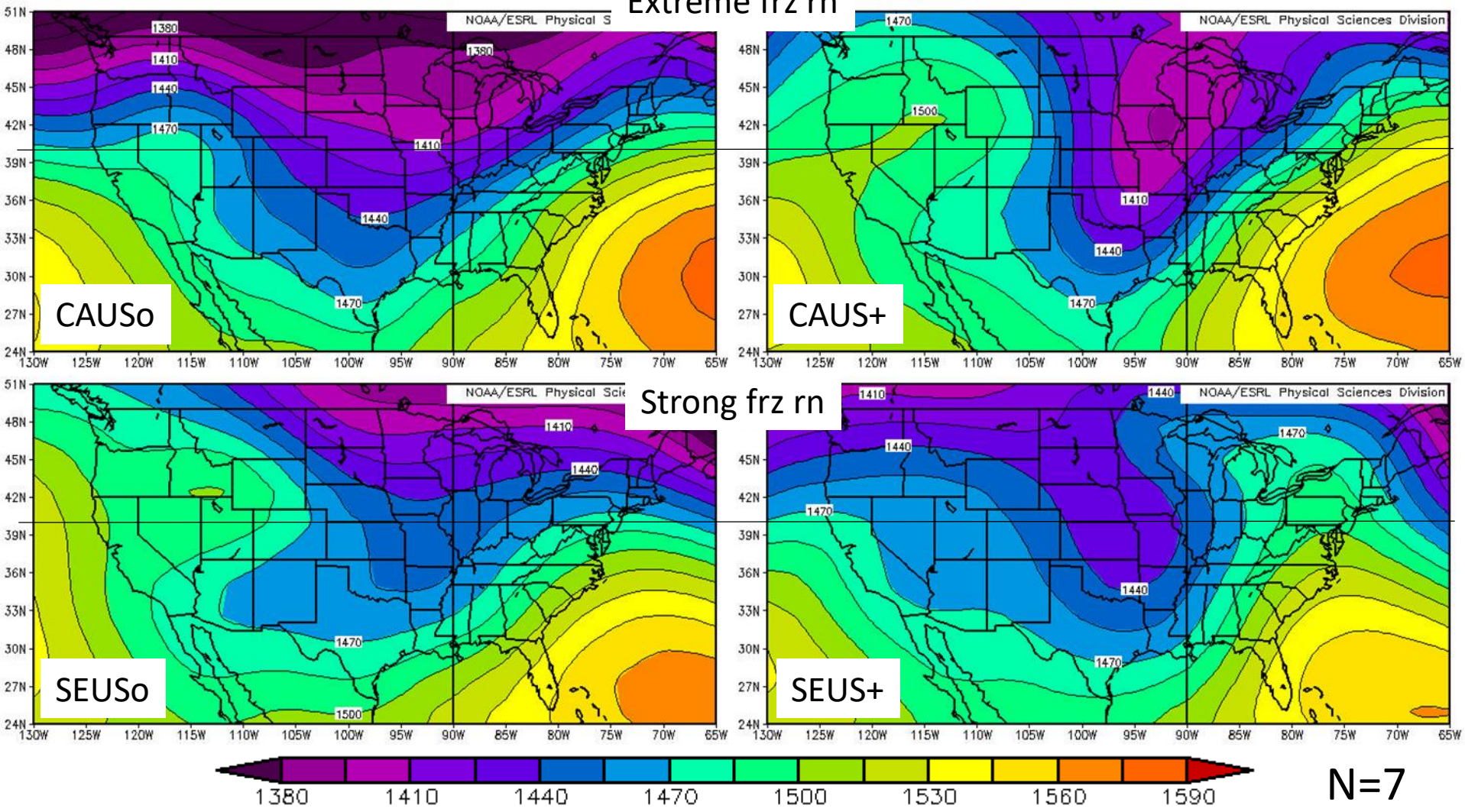
Results

500 hPa Geo. Ht. composite anoms



N=7

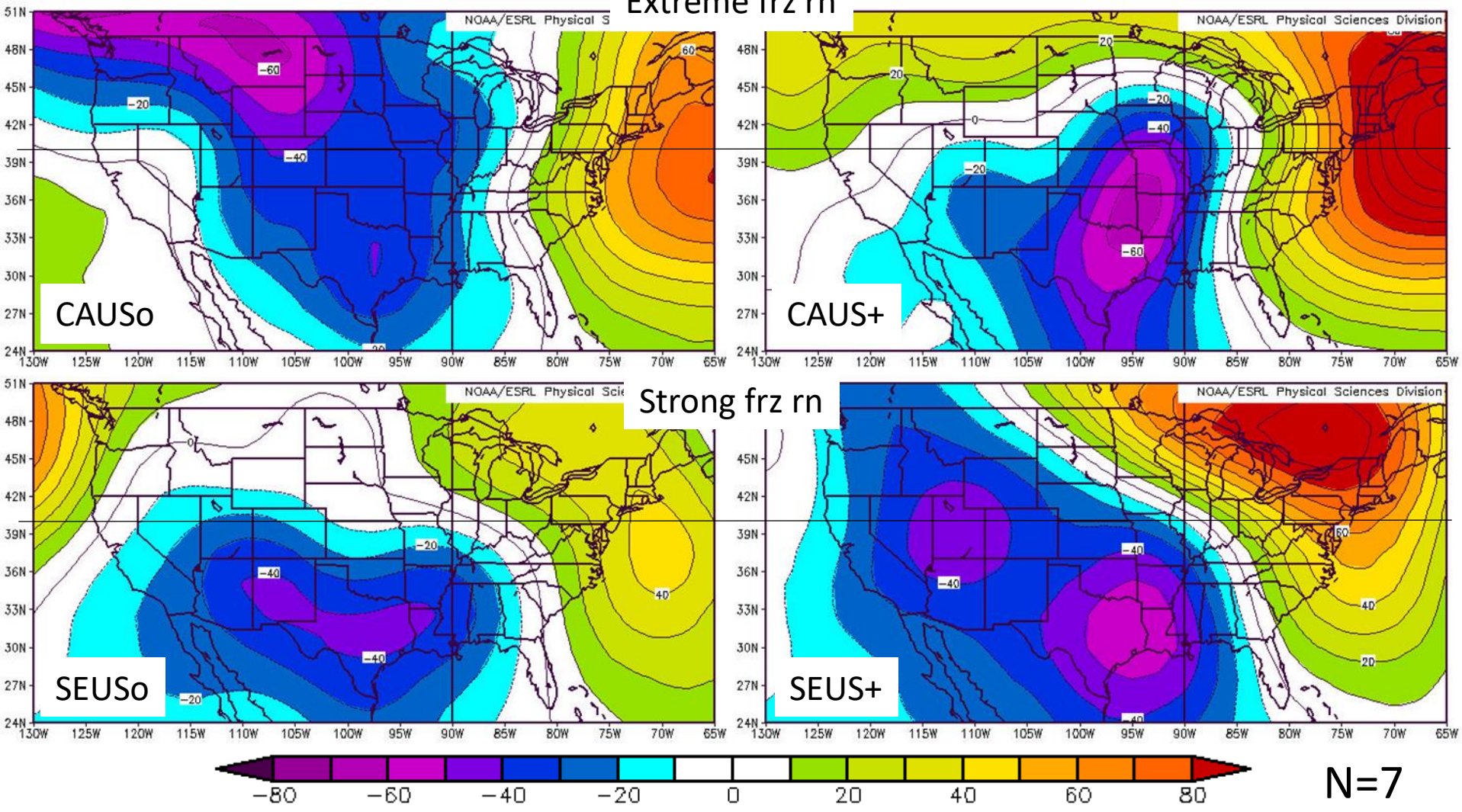
Results 850 hPa Geo. Ht. composite means



N=7

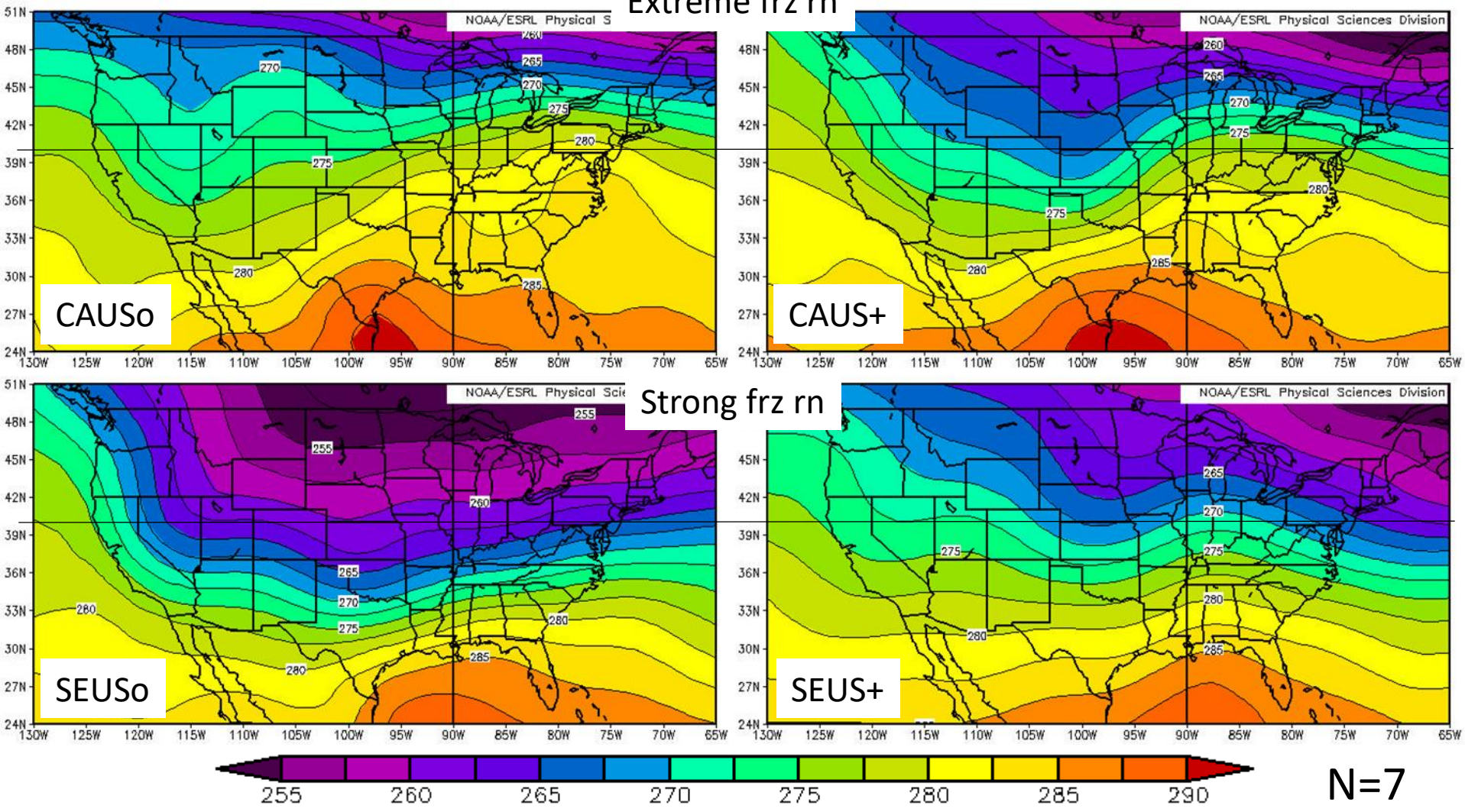
Results

850 hPa Geo. Ht. composite anoms

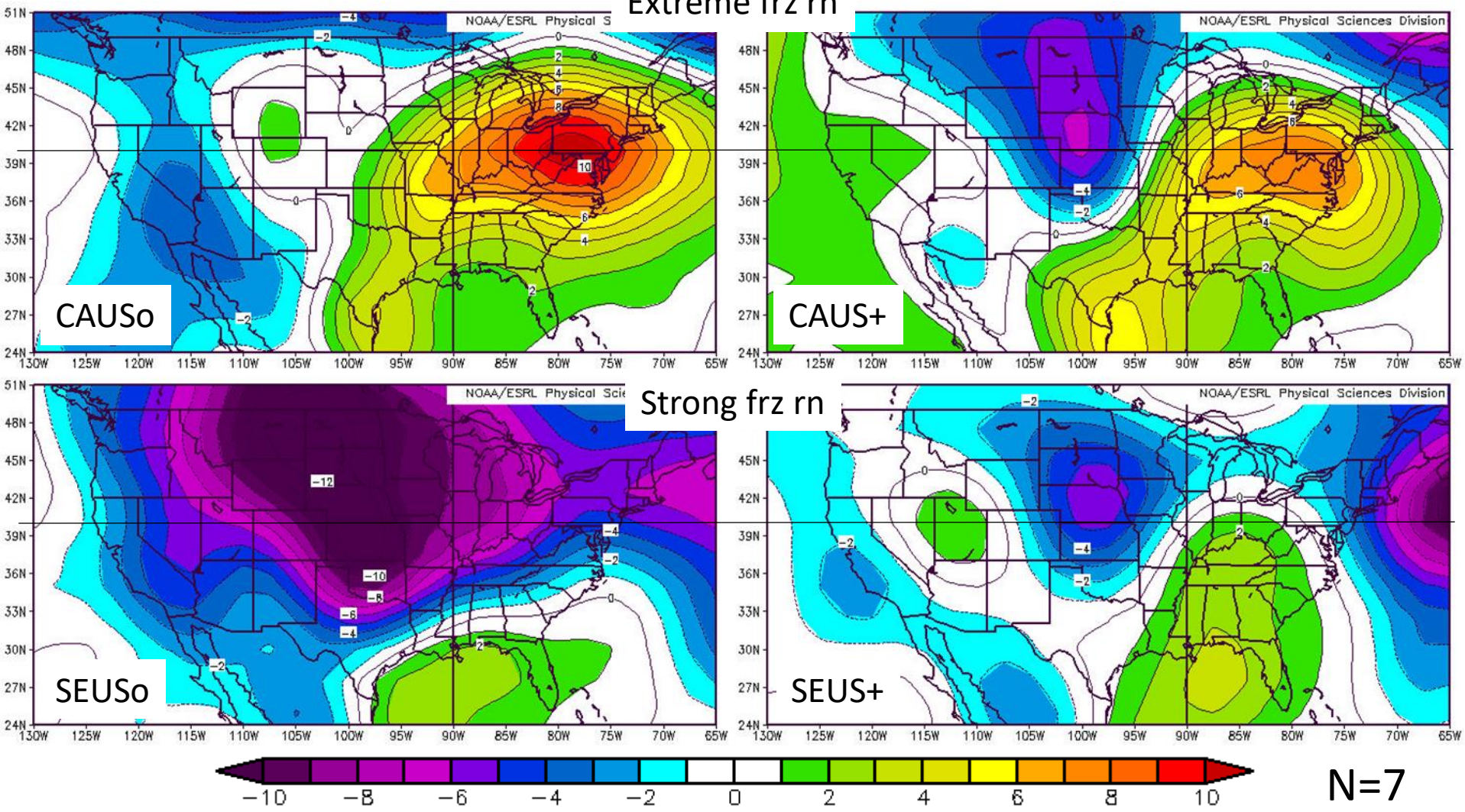


N=7

Results 850 hPa Temp. composite means



Results 850 hPa Temp. composite anoms

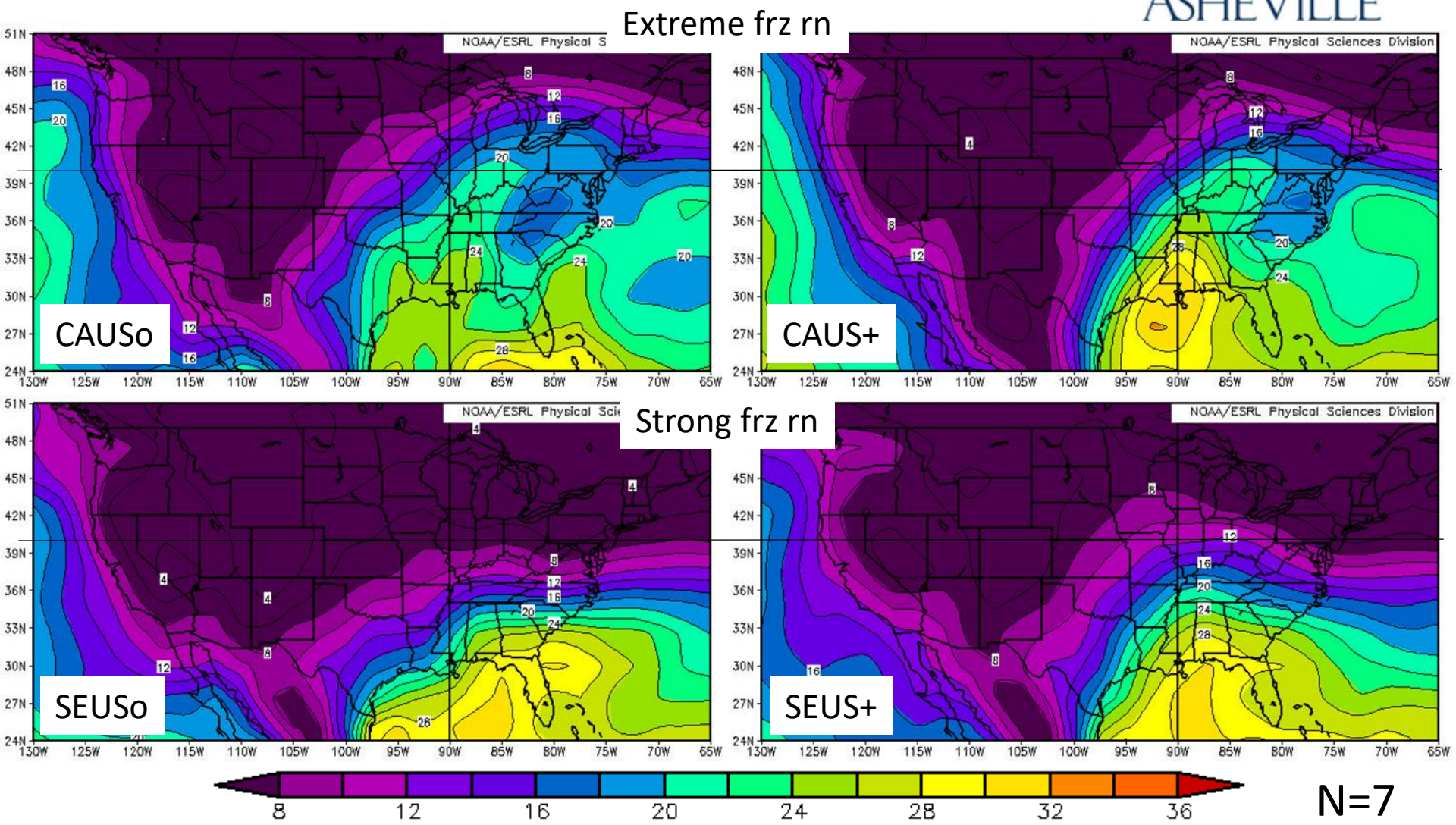


Summary and conclusions

- Extreme or strong composites
  - CAUSo and SEUSo z500 anoms have opposite dominant anoms, SEUSo; western trough, CAUSo; offshore ridge. Size of anoms suggests longer wavelengths and higher amplitude features (longer duration)
  - CAUSo frz rn events; 850 Temp is warm in SEUS -> rain, SEUSo frz rn events; 850 Temp is cold in CAUS -> snow, {T anoms weaken for CAUS+ and SEUS+ events}
  - SEUSo z500 mean shows jet axis near domain; likely reason for statistically significant stronger zonal IVT compared to others
  - Positive 850 mean trough tilt of CAUS+, negative 850 mean trough tilt of SEUS+

Results

P. Wat. composite means



Results P. Wat. composite anoms

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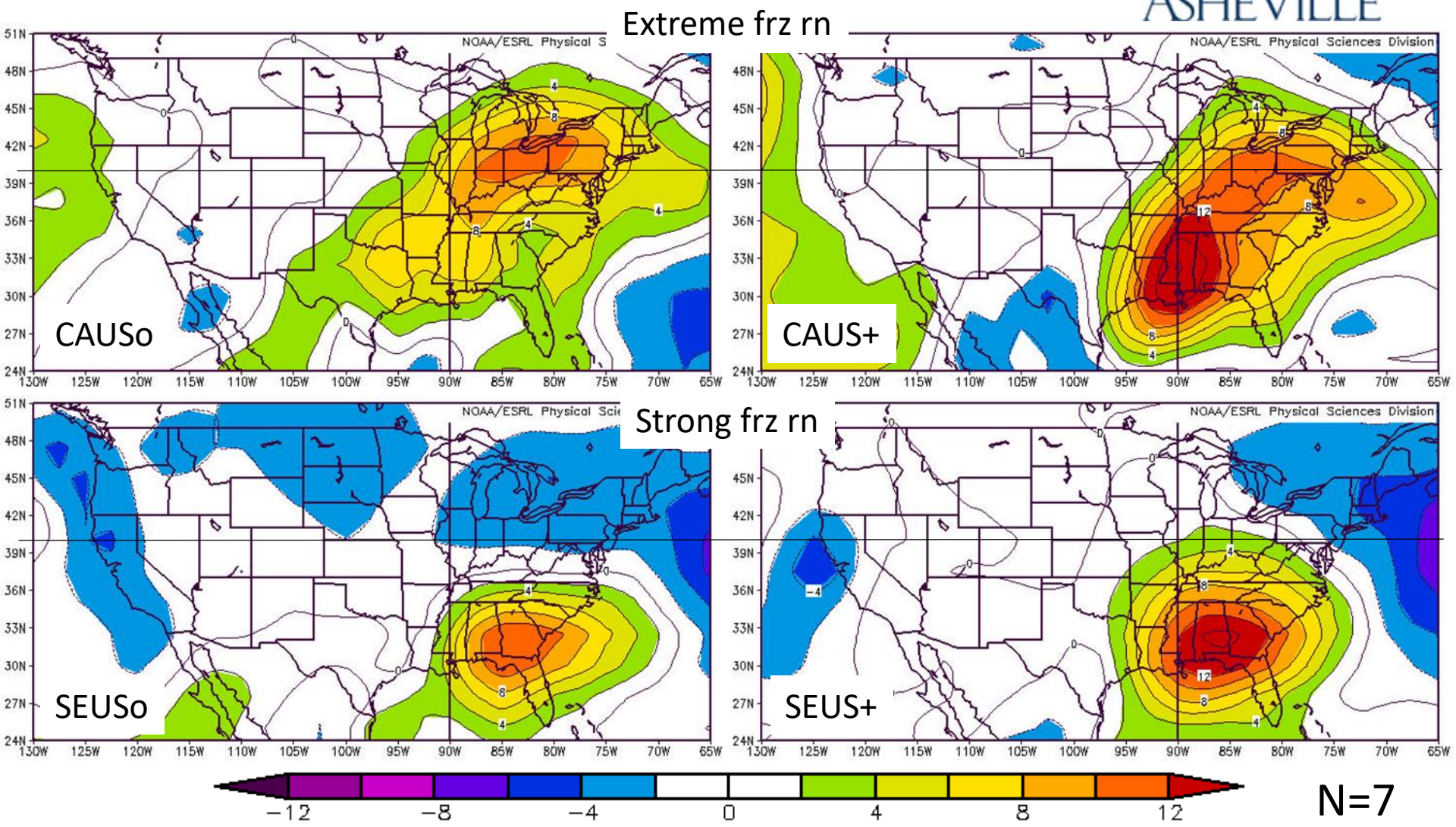


Summary and conclusions

- Extreme or strong composites
  - P. Wat. anoms are stronger for CAUS+ and SEUS+ events compared to CAUSo and SEUSo, respectively. These anoms are in a position upstream of study domain given the positive (negative) tilt of CAUS+ (SEUS+) 850 trough
  - P. Wat. anom of SEUSo is quite isolated (small-scale) compared to the anomaly expanse of other events (strong zonal IVT)

Results

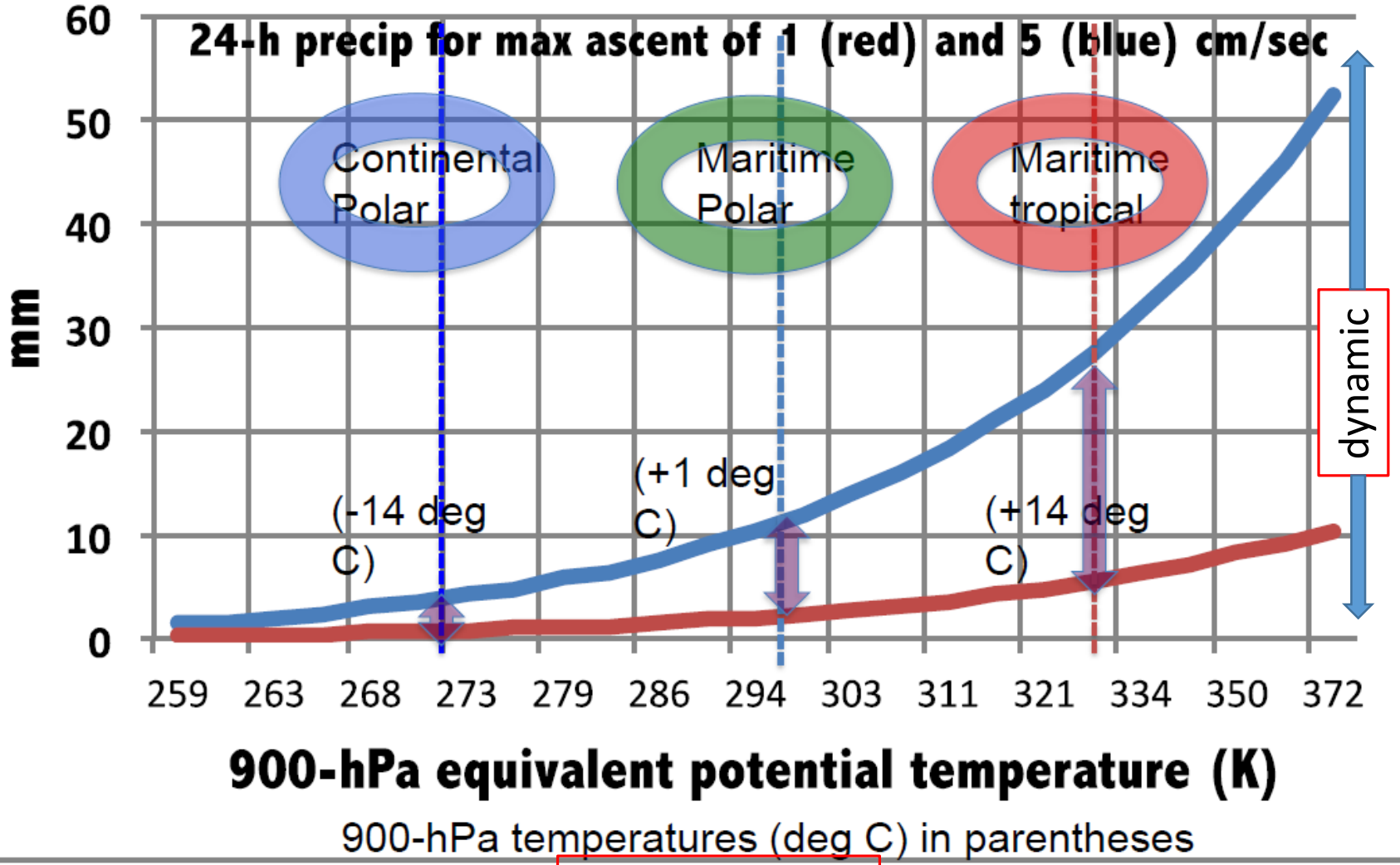
- A comparison of AR-influenced
  - Extreme frz rn events of CAUS domain
  - Strong frz rn events of SEUS domain

  to **normal** (near the median) frz rn events in both domains

  - P. Wat. composite anomaly ==> serves as a proxy for composite lower tropospheric equivalent potential temperature anomaly
    - indicator of air mass type

dynamic thermodynamic

$$P = -(1/g) \int \omega (dr_s/dp)_{ma}\, dp, \qquad (5)$$



thermodynamic

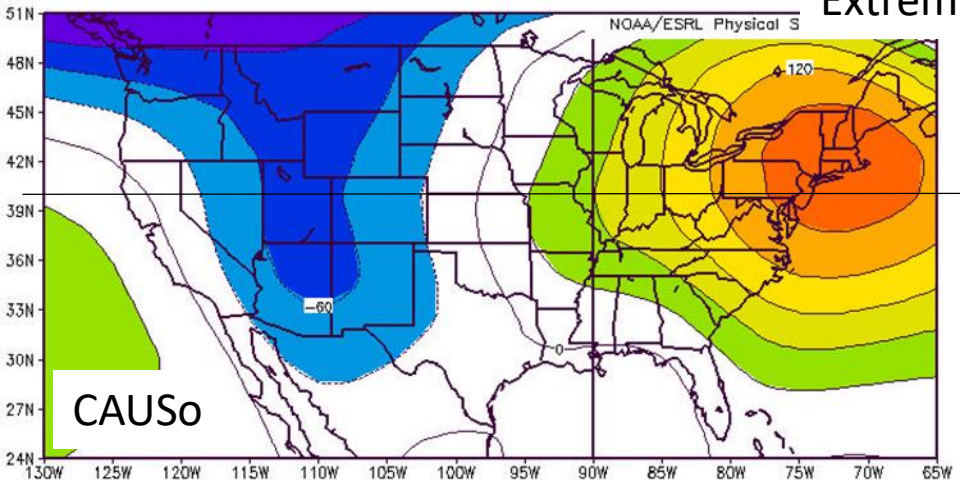
Gyakum (2008, 2016)

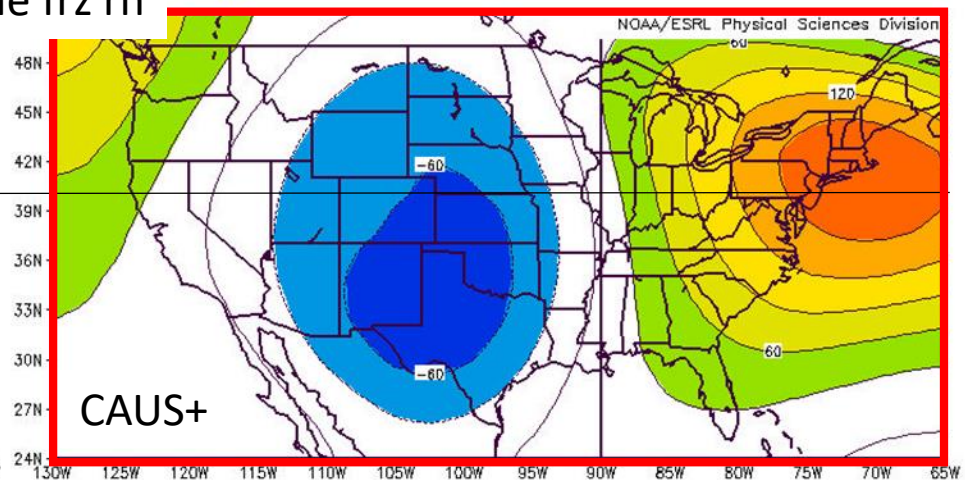
dynamic

Results

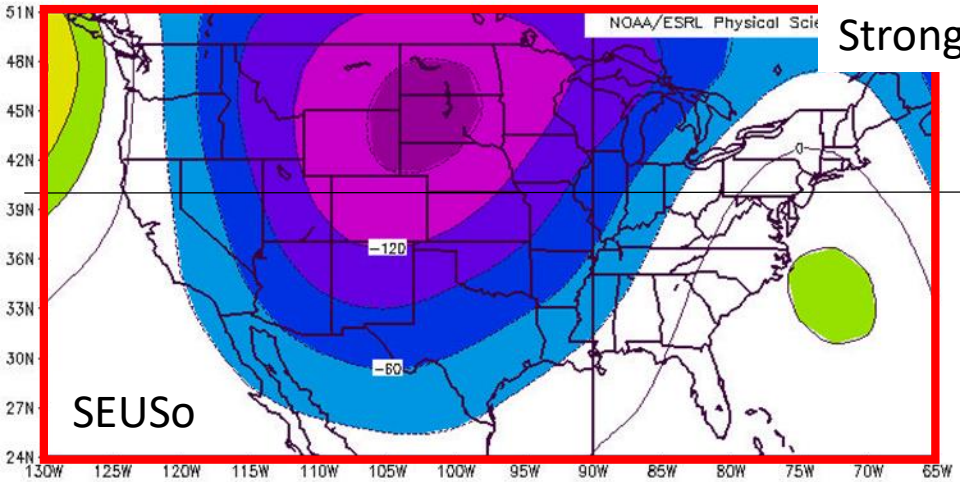
500 hPa Geo. Ht. composite anoms

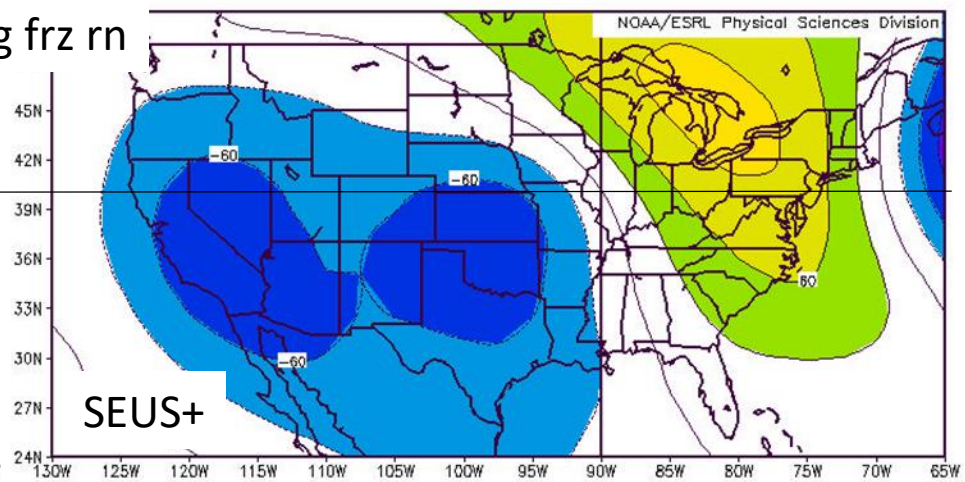
Extreme frz rn

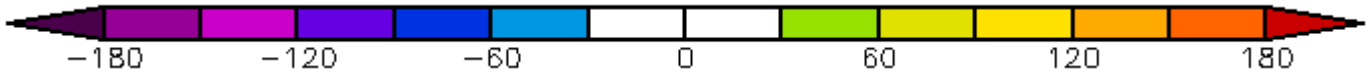




Strong frz rn







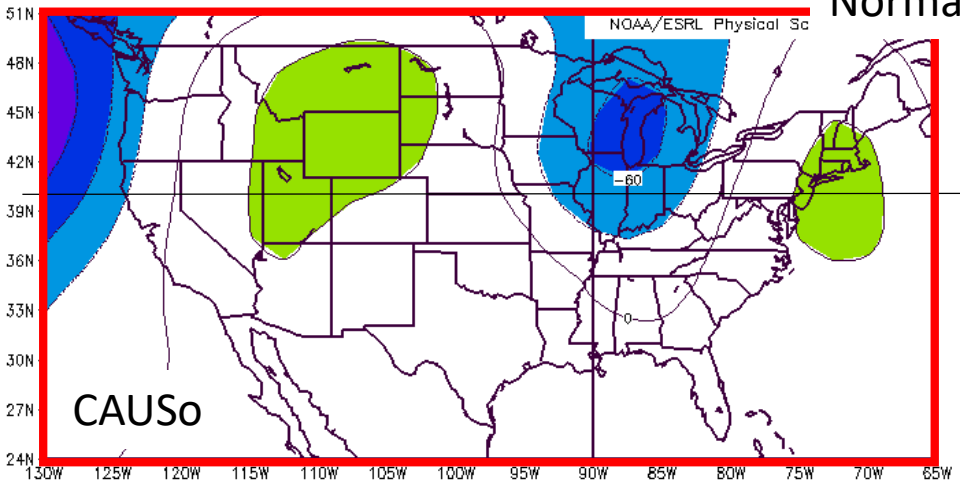
N=7

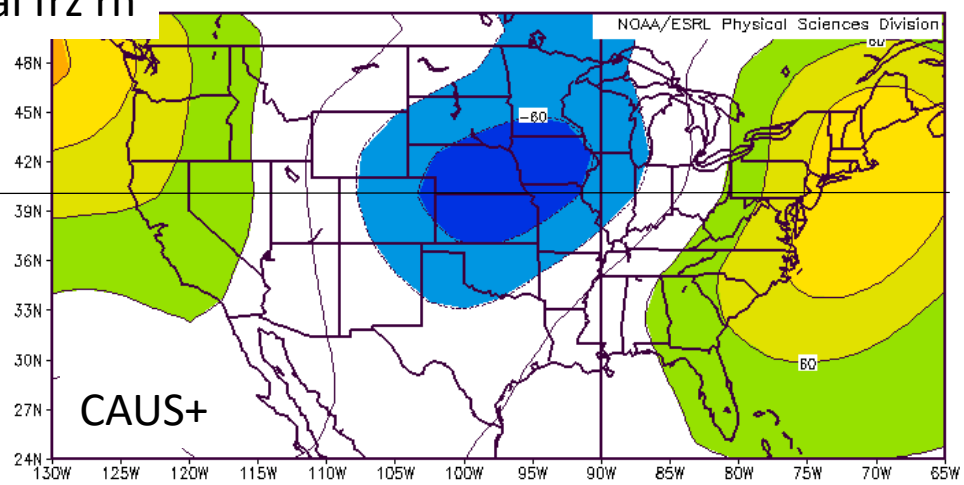
dynamic

Results

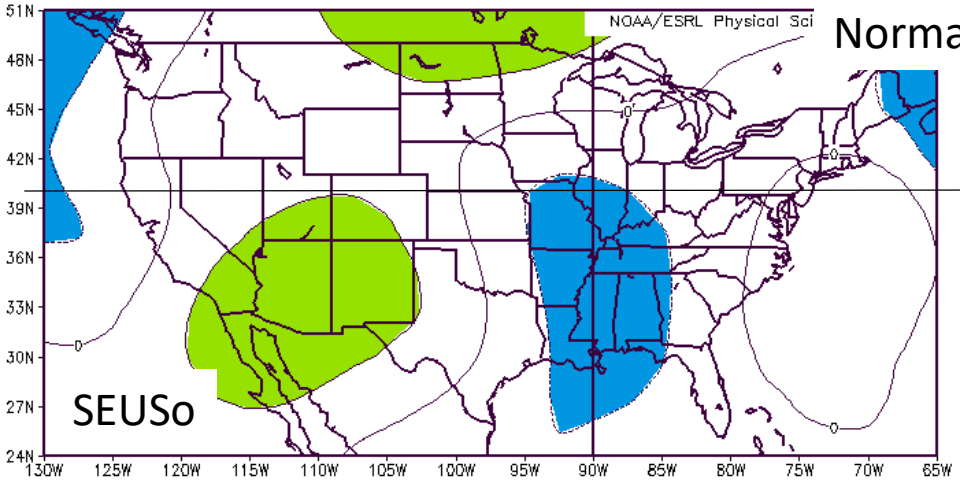
500 hPa Geo. Ht. composite anoms

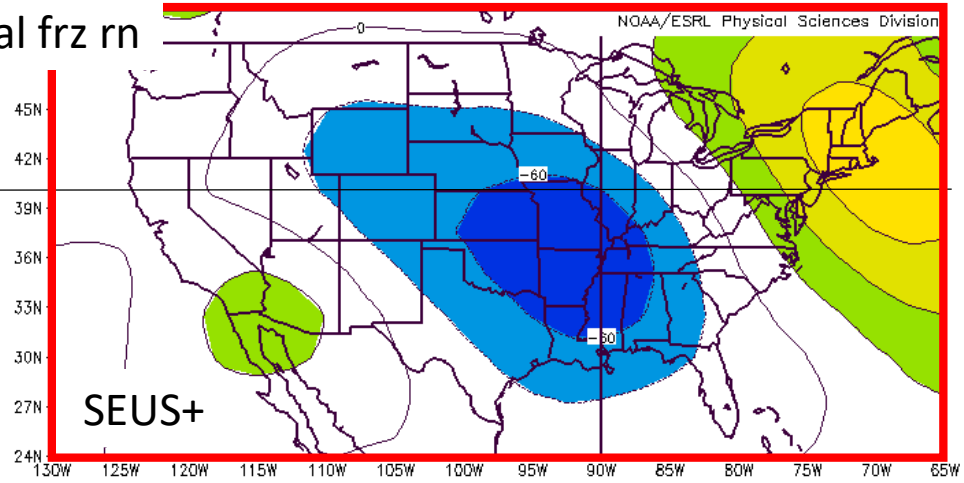
Normal frz rn

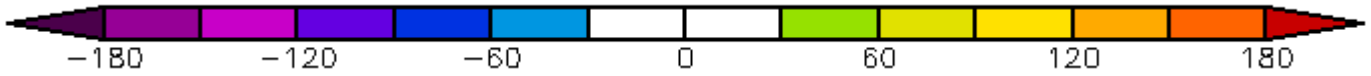




Normal frz rn







N=7

Summary and conclusions

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- Comparison ext/str v. normal anoms…
  - Scale of CAUSo and SEUSo Z 500 anoms is significantly smaller in horizontal scale for normal AR-influenced frz rn events compared with ext/str AR-influenced frz rn events (shortwaves??)
  - Significant eastward shift of Z 500 anoms of SEUS+ frz rn AR-influenced events from ext/str to normal composites
  - Significant shift in orientation of Z 500 anoms of CAUS+ frz rn AR-influenced events from ext/str to normal composites (more positively tilted trough; more progressive?)

thermodynamic

Results

P. Wat. composite anoms

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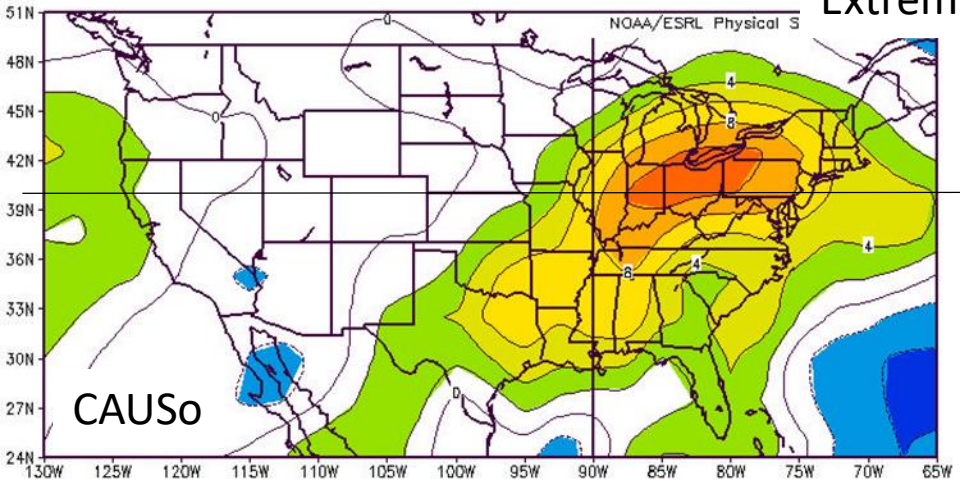
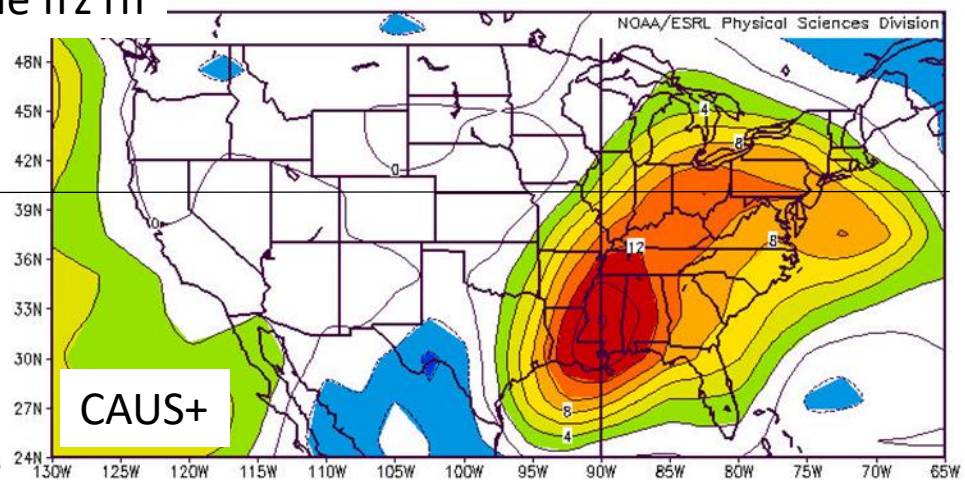
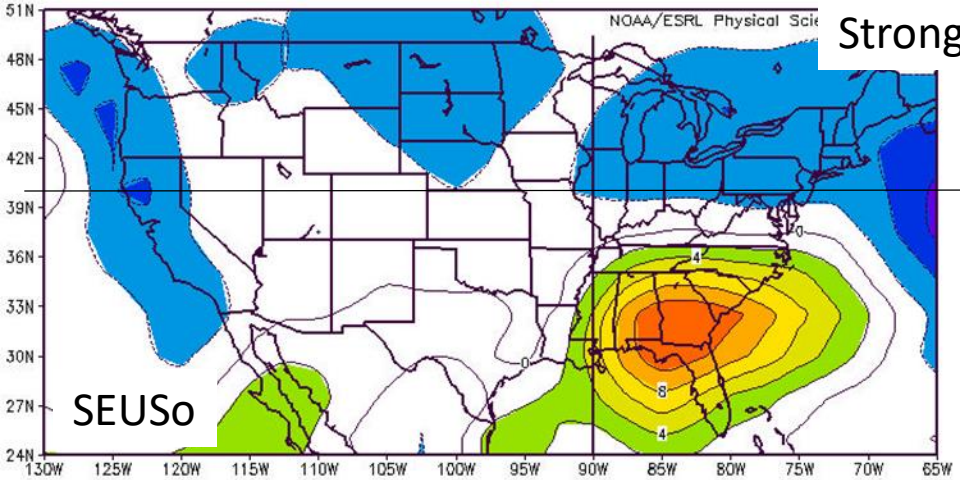
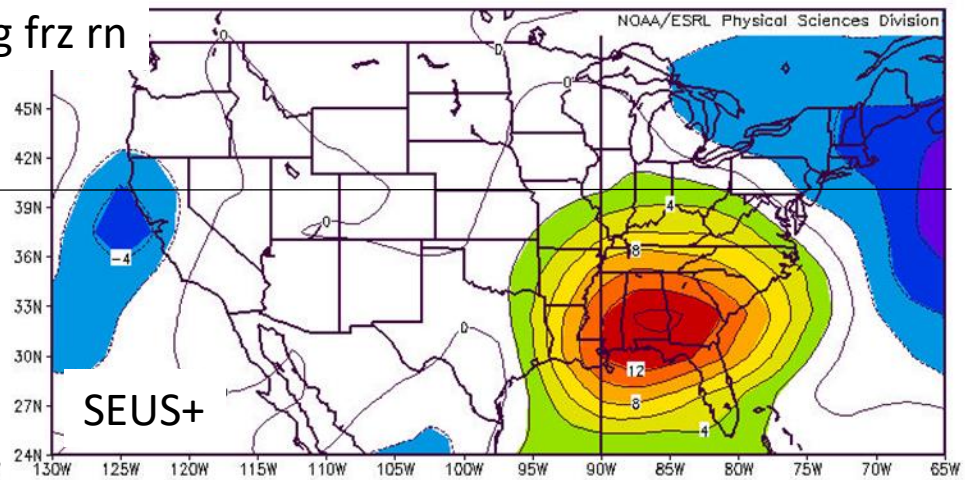
Extreme frz rn

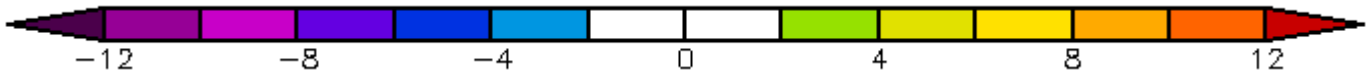




Strong frz rn







N=7

thermodynamic

Results

P. Wat. composite anoms

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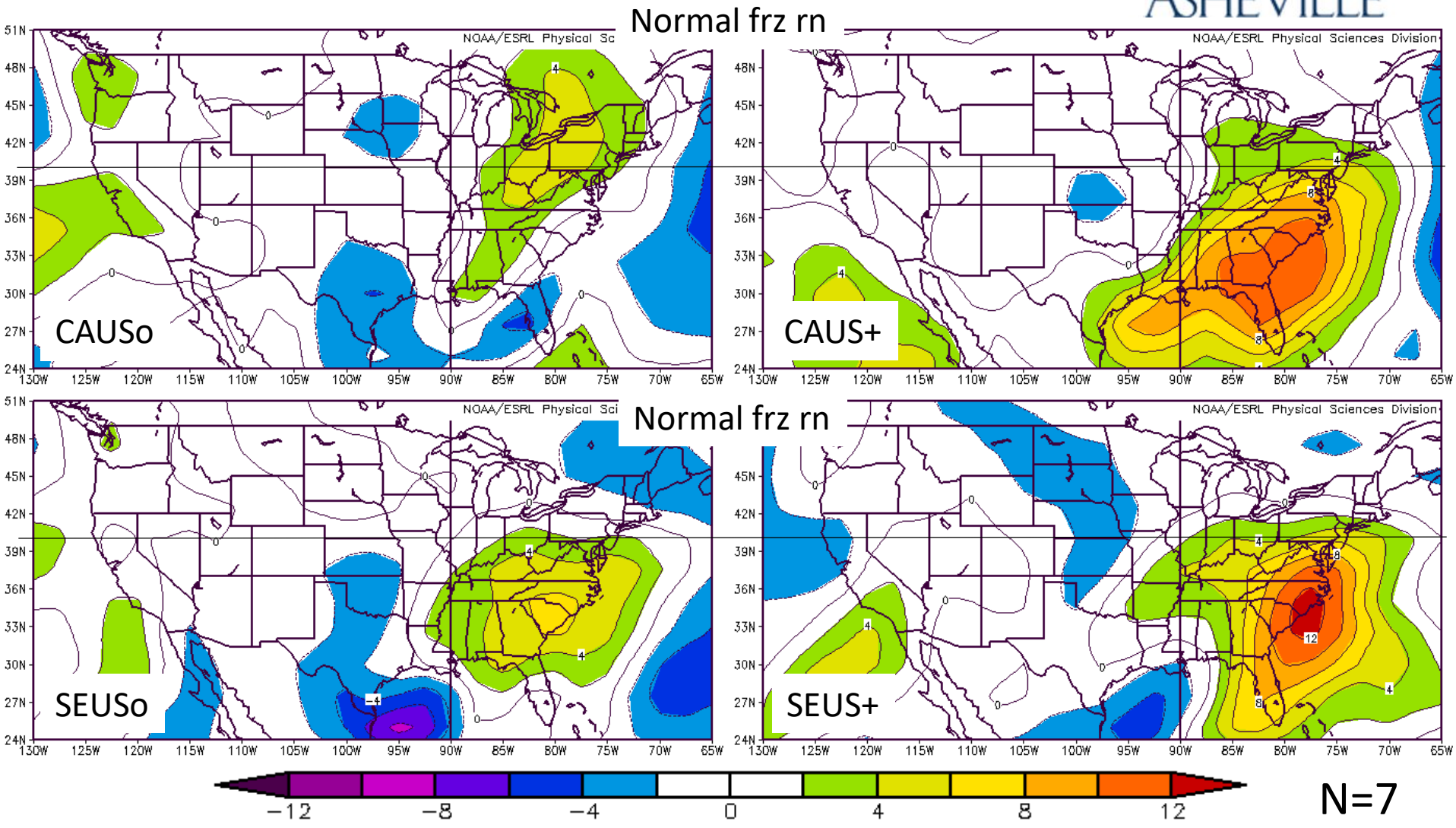

Summary and conclusions

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- Comparison ext/str v. normal anoms…
  - omeg 850 anoms of CAUSo and SEUS+ [not shown] for normal events > those of ext/str events. P. Wat. anoms for these normal events is much weaker than for ext/str events; hence, thermodynamic effect > dynamic effect for CAUSo and SEUS+ in driving ext/str events [air mass is of weaker maritime tropical intensity for normal frz rn events; L-to-R on Gyakum (2016) graph]
  - For CAUS+ and SEUSo events, omeg 850 anoms for ext/str events > normal events while PWat anoms for ext/str events > normal events; hence, thermodynamic effect & dynamic effect both drive enhanced P of Gyakum (2008) Eq. (5) for ext/str events

Summary and conclusions

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- Comparison ext/str v. normal anoms…
  - P. Wat. anom position of CAUS+ and SEUS+ normal events has a distinct eastward shift compared to ext/str events; hence, a less-than optimal position relative to CAUS and SEUS study domains; reduced maritime tropical intensity overhead

Summary and conclusions

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- Conclusions
  - 15 of 16 top extreme frz rn events in CAUS domain and 14 of 15 strong frz rn events in SEUS domain were AR-influenced
  - Events had large P. Wat. anomalies suggestive of intense (seasonally warm and humid) maritime tropical air masses
  - AR-influenced extreme or strong frz rn events were of very long duration
    - CAUS (15 extreme); 36-180 h
    - SEUS (14 strong); 36-90 h

Summary and conclusions

- Conclusions
  - **Normal** (less-severe) freezing rain events influenced by ARs;
    - Strong dynamics (omega)
      - Moisture ridge of mT air mass shifted downstream of forecast domain
    - Moderate-to-weak dynamics (omega)
      - Less ‘intense’ mT air mass (decreased equivalent potential temperature; lower temperature and humidity) when moisture ridge is located within forecast domain
    - Shorter wavelength, transient (shorter duration)
      - CAUS (14 normal); 12-30 h
      - SEUS (14 normal); 12-36 h

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  - sharing freezing rain event observations database and taking the time to explain isolated data ‘quirks’

- Prof. Gyakum
  - ‘planting the seed’ for the study (2016 IAR Conference), sharing figures, and initiating the connection with Dr. McCray

Extras

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Results

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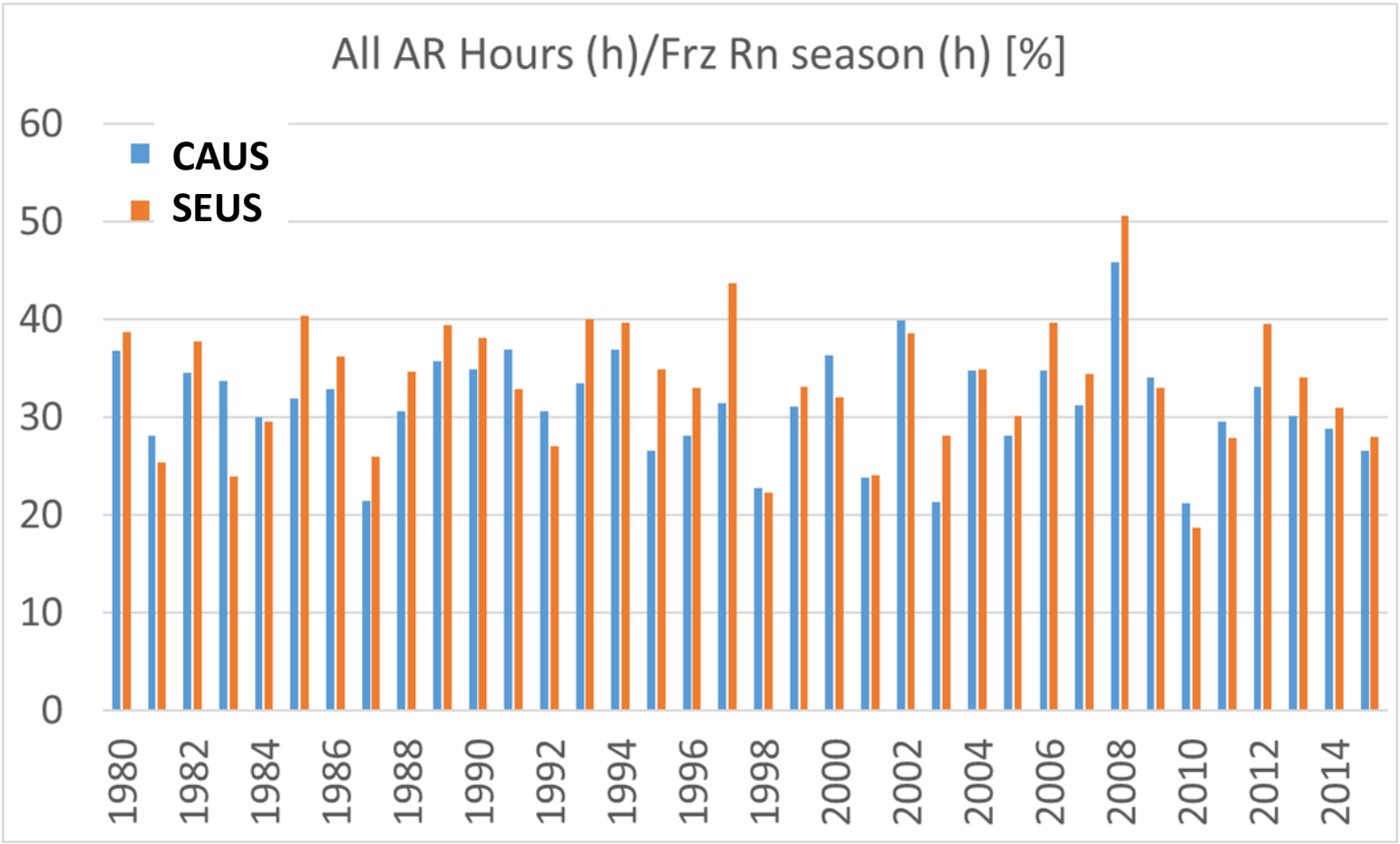
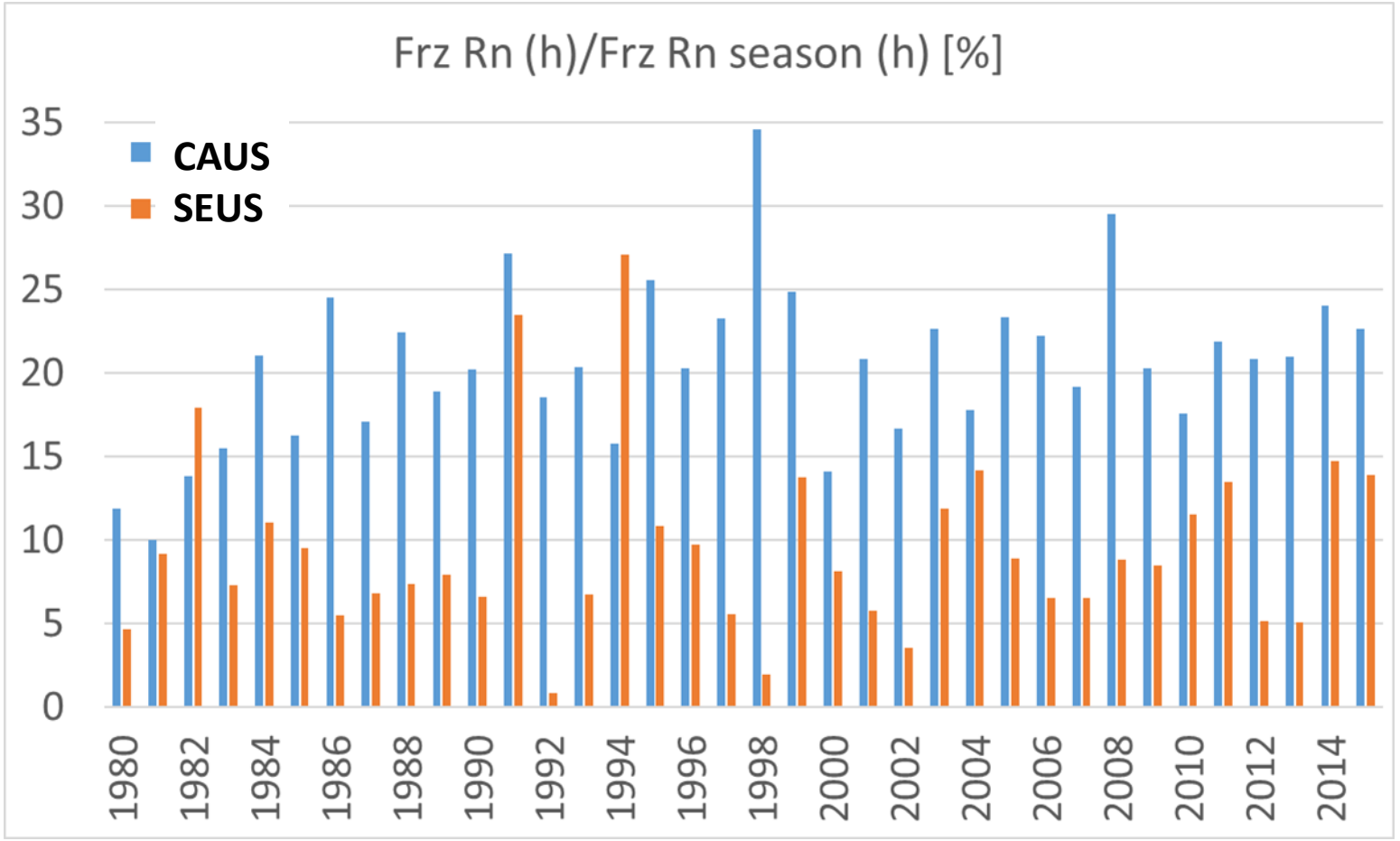
- AR hours normalized by freezing rain “seasons”



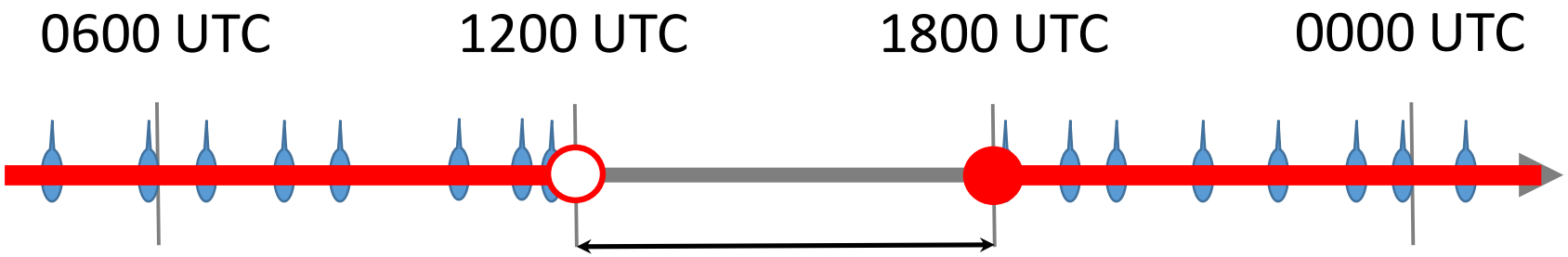
Results

- Frz rn hours normalized by freezing rain “seasons”



Methodology

- Timeline



Δt = 6-h