# Antecedent Synoptic Environments Most Conducive to North American Polar/Subtropical Jet Superpositions

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PSU Department of Meteorology and Atmospheric Science
University Park, PA

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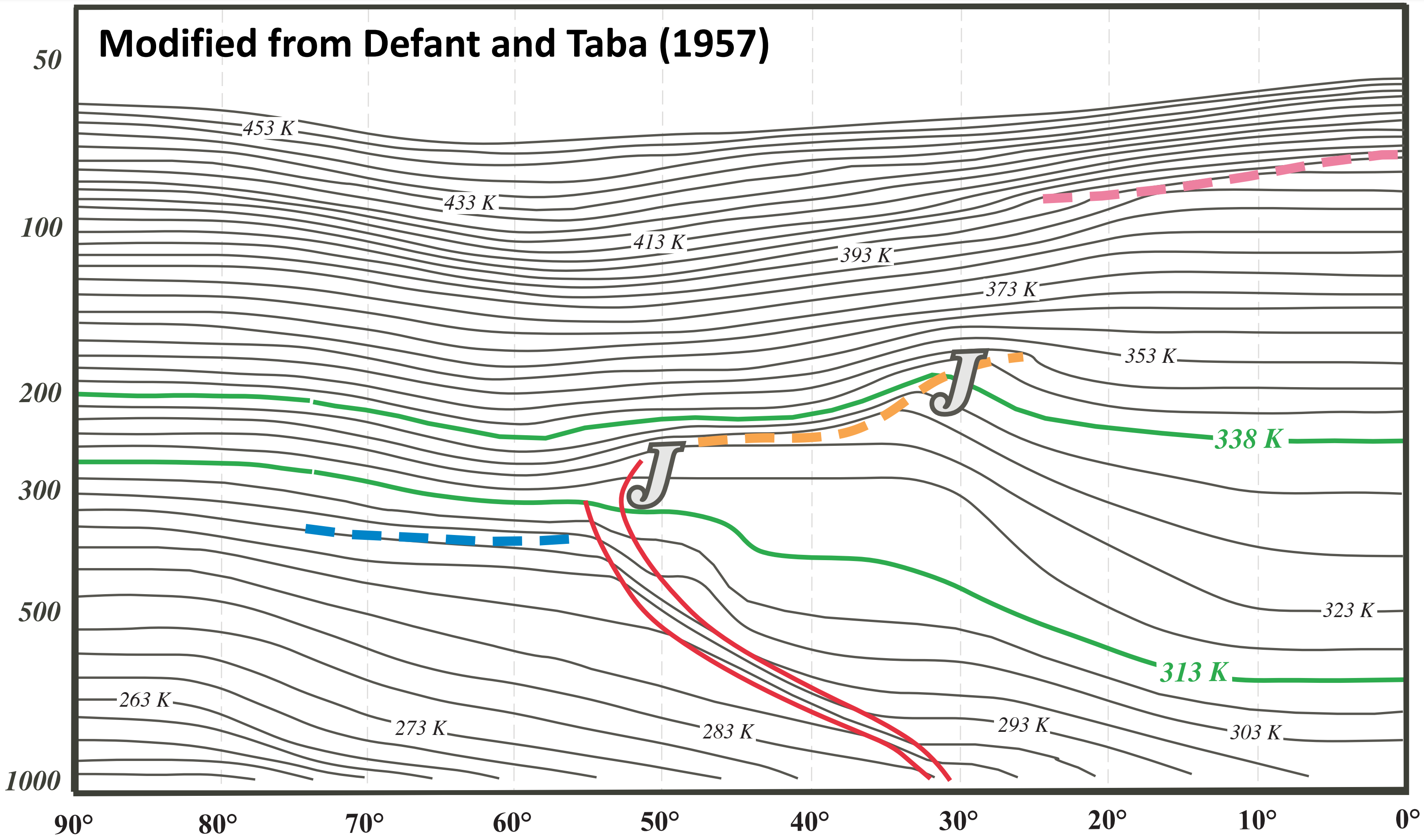
# Background



Modified from Defant and Taba (1957)

*Mean Meridional Cross-Section of θ*

- - - *Polar Tropopause*

- - - *Tropical Tropopause*

- - - *Subtropical Tropopause*

— *Polar Frontal Zone*

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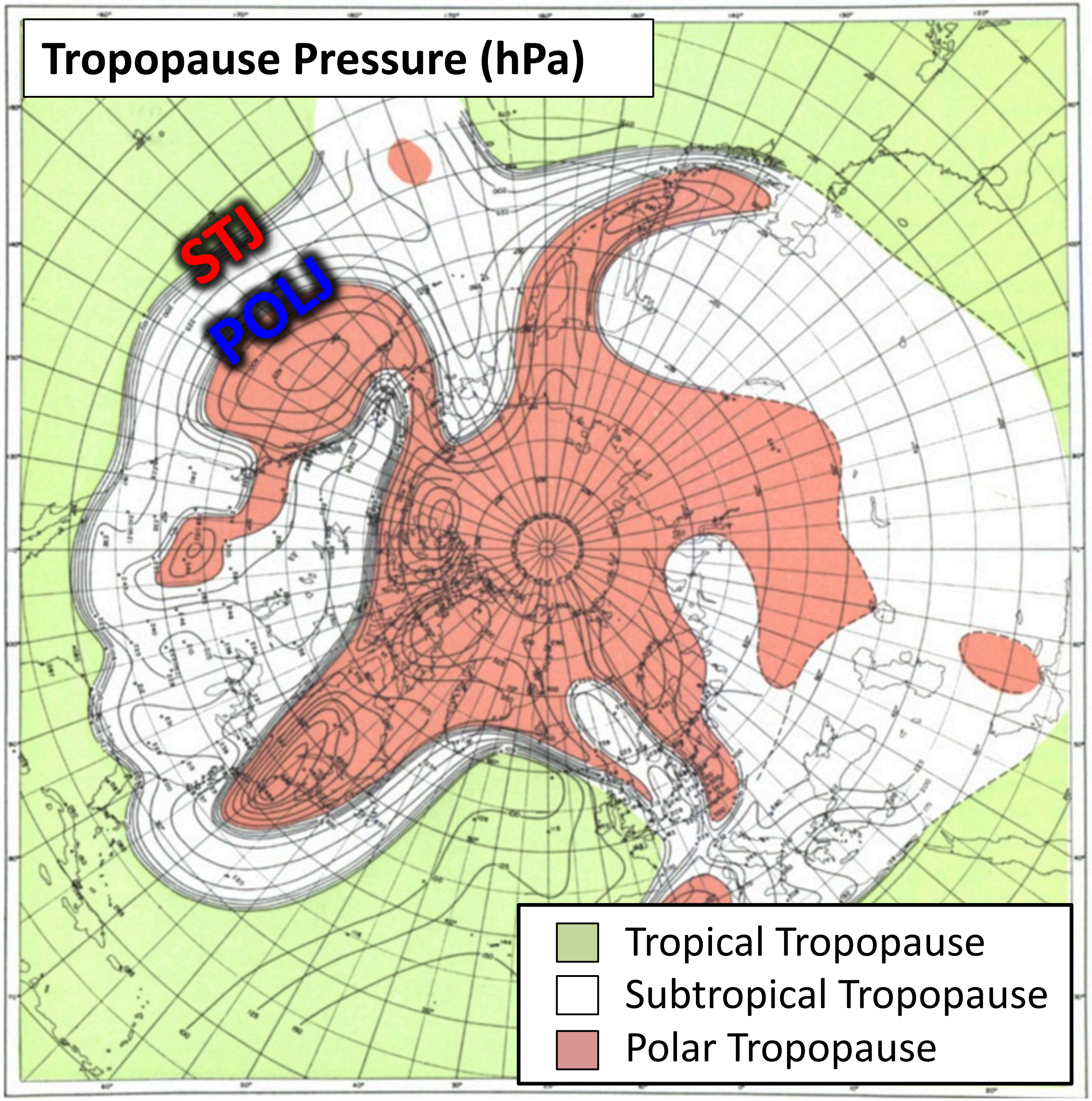

Maps of tropopause pressure help to identify the location of the jets.

While each jet occupies its own climatological latitude band, substantial meanders are common.

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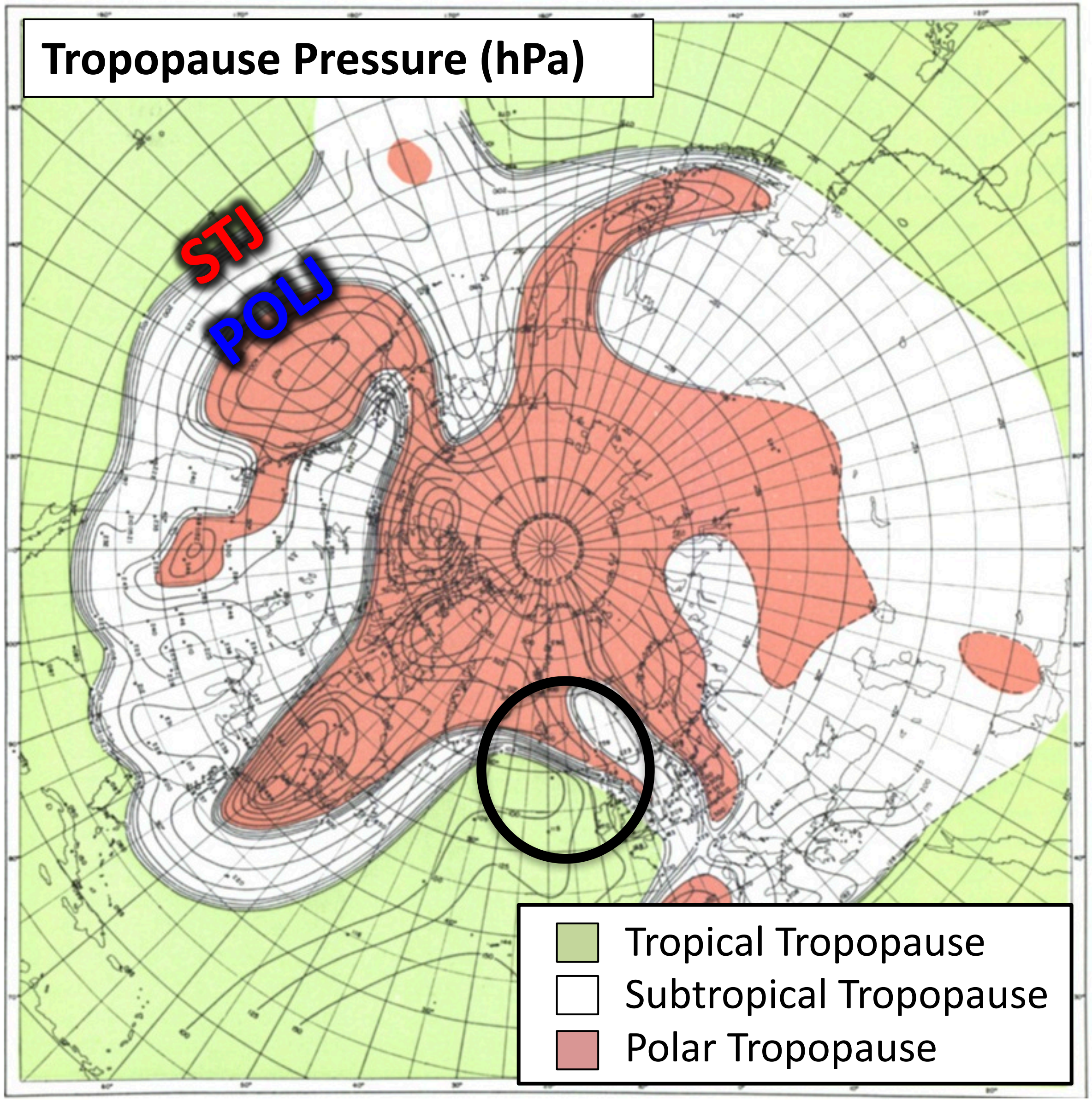

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While each jet occupies its own climatological latitude band, substantial meanders are common.

Occasionally, the latitudinal separation between the jets can vanish resulting in a vertical **jet superposition**.

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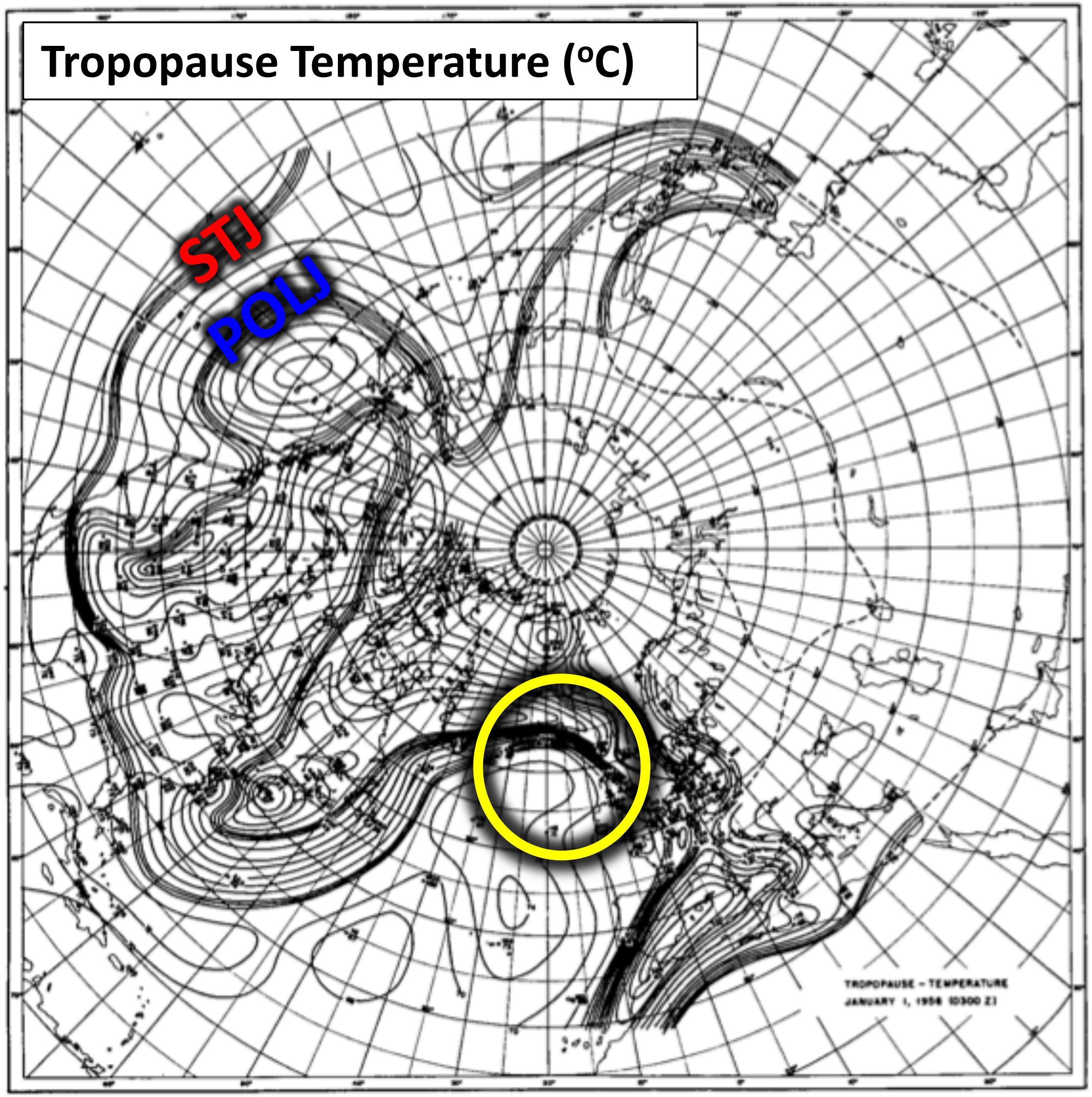

The pole-to-equator baroclinicity is combined into a much narrower zone of contrast in the vicinity of a jet superposition.

Intensified frontal structure is often attended by a strengthening of the superposed jet's transverse circulation.

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# Background

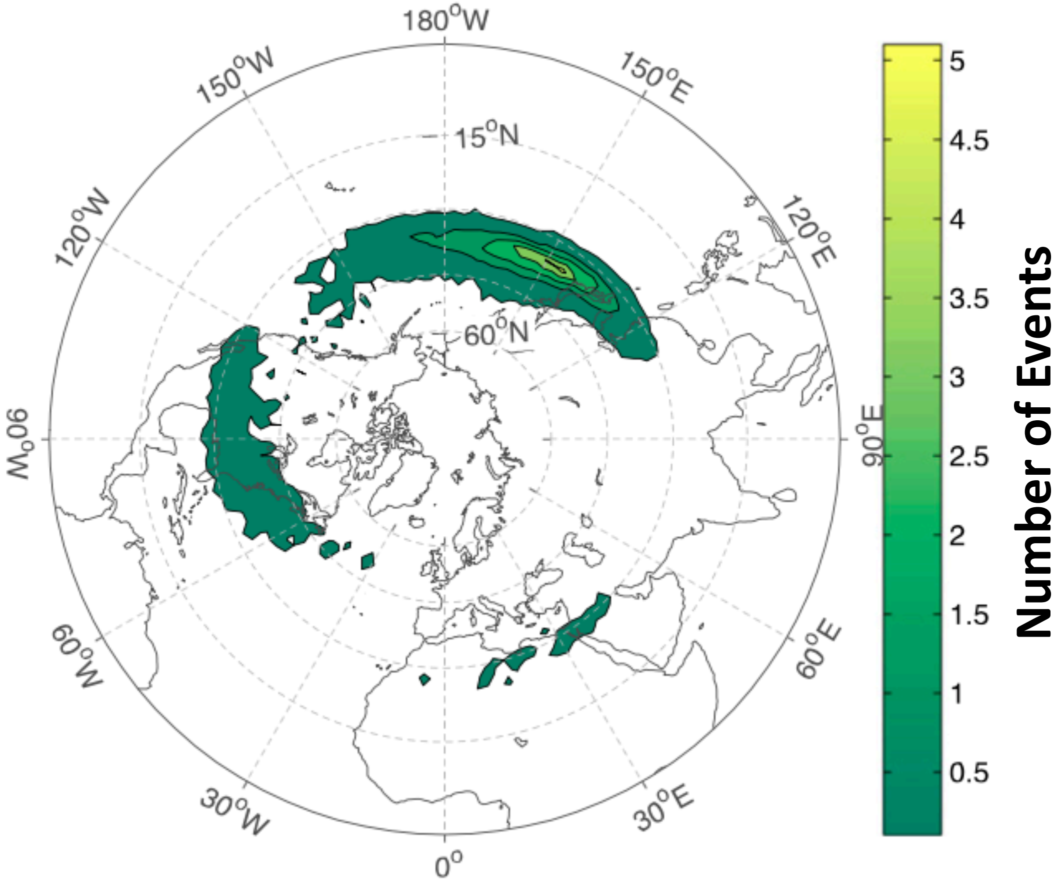
Christenson et al. (2017) highlight three locations that experience the greatest frequency of jet superpositions:

**1) Western Pacific**

**2) North America**

**3) Northern Africa**

**Climatological frequency of Northern Hemisphere jet superposition events per cold season (Nov–Mar) 1960–2010**



**Christenson et al. (2017)**

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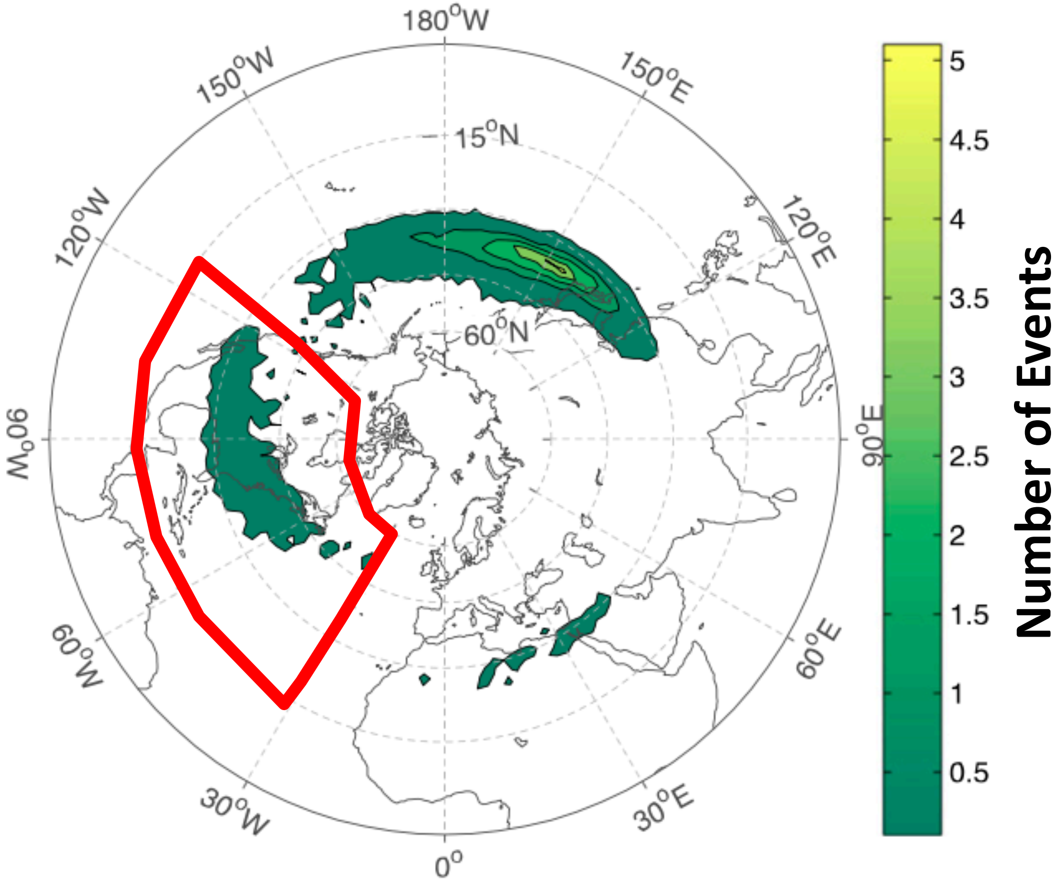
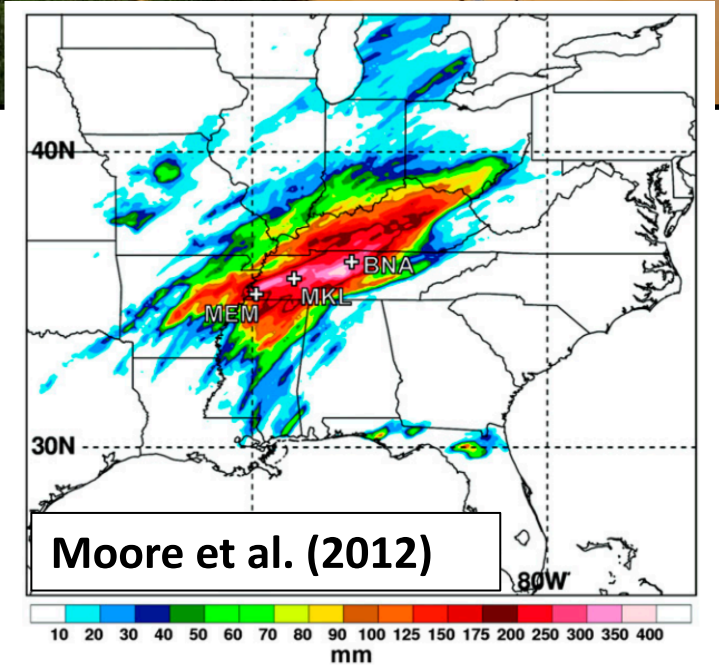


**Christenson et al. (2017)**

# Jet Superpositions and High-Impact Weather


*The Tennessean*



Moore et al. (2012)

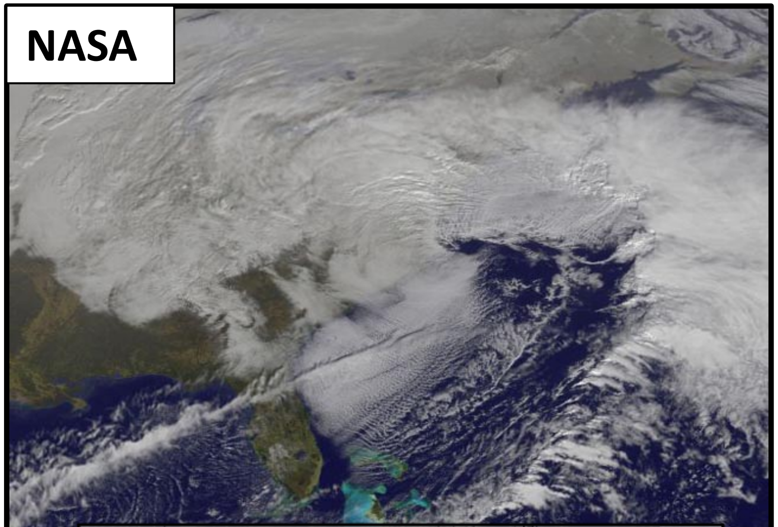
**Jet superpositions can be an element of high-impact weather events**

*1–3 May 2010 Nashville Flood*

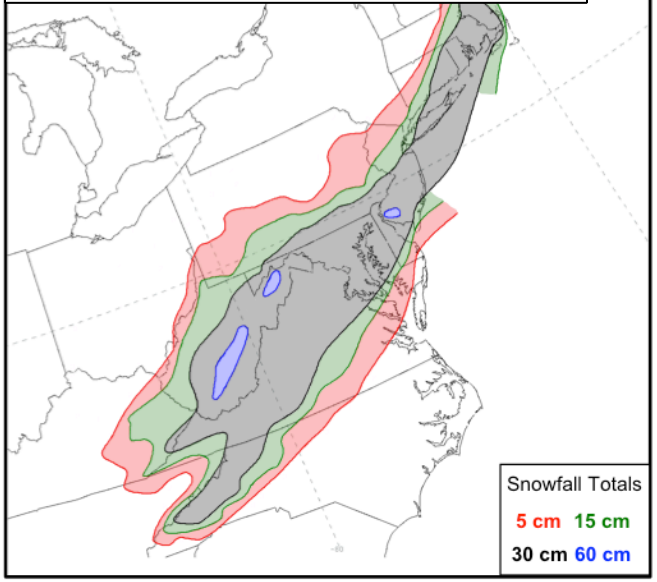
- Jet superposition enhanced the poleward moisture transport via its ageostrophic circulation (Winters and Martin 2014; 2016).

# Jet Superpositions and High-Impact Weather

**NASA**



**Winters and Martin (2016)**



## Jet superpositions can be an element of high-impact weather events

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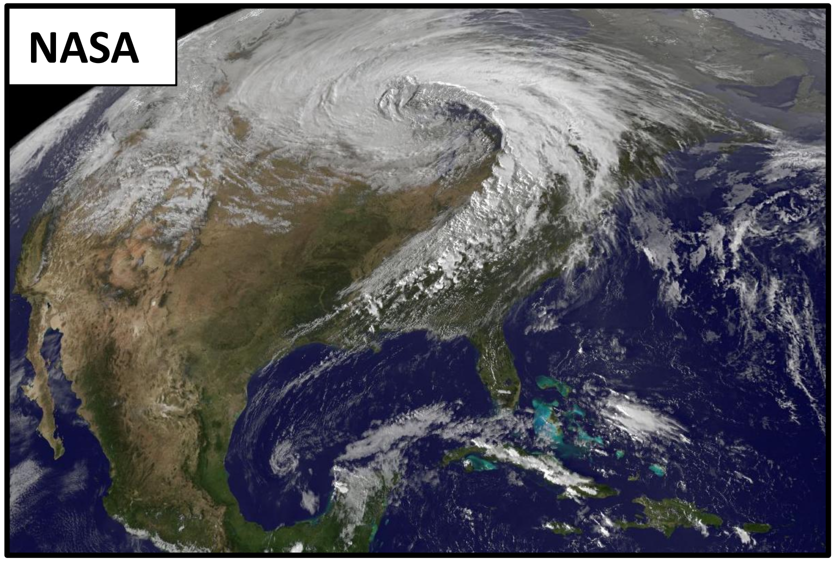
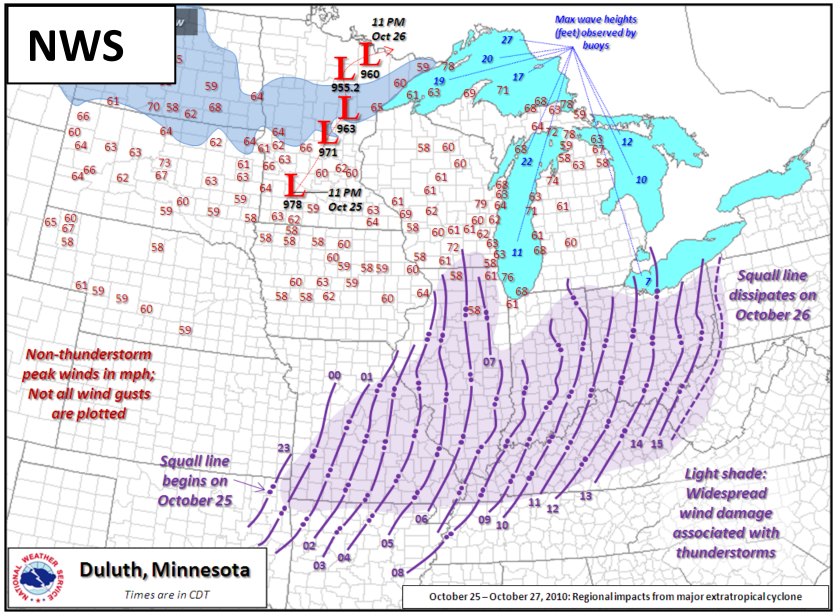
# Jet Superpositions and High-Impact Weather





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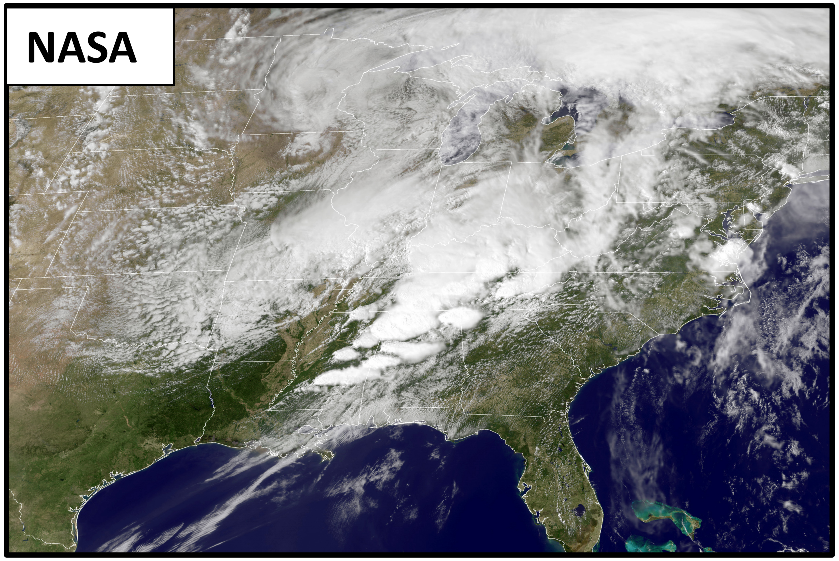
# Jet Superpositions and High-Impact Weather



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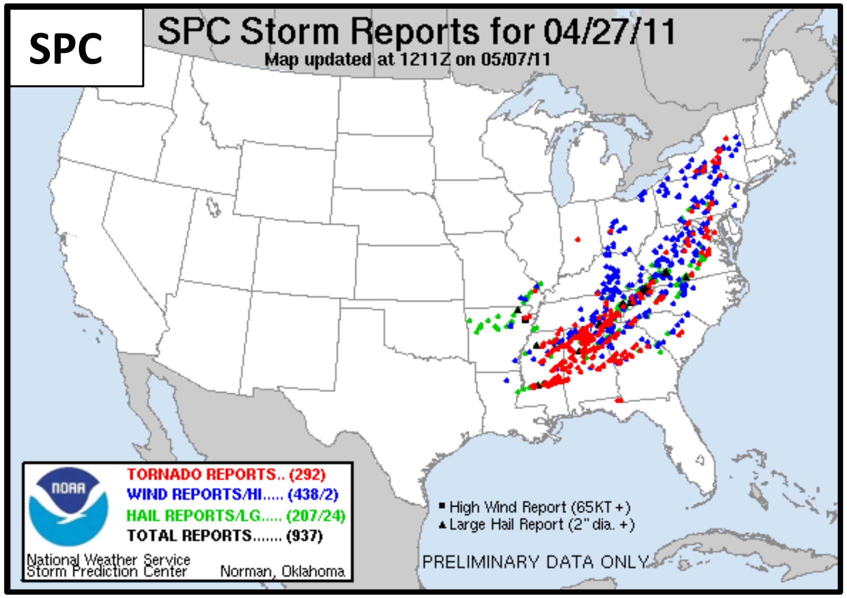

SPC

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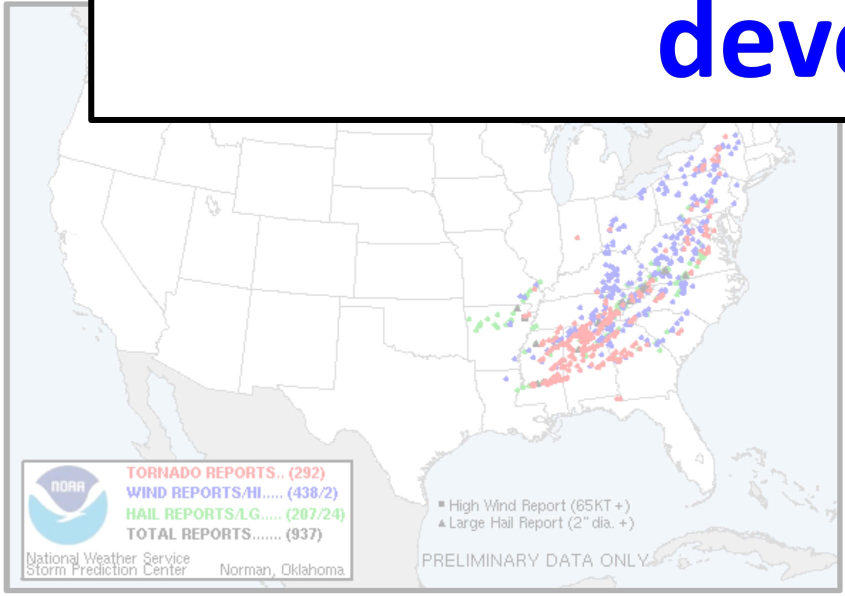
# Jet Superpositions and High-Impact Weather



**Jet superpositions can be an element of high-impact weather events**

*1–3 May 2010 Nashville Flood*

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**How do these structures develop?**

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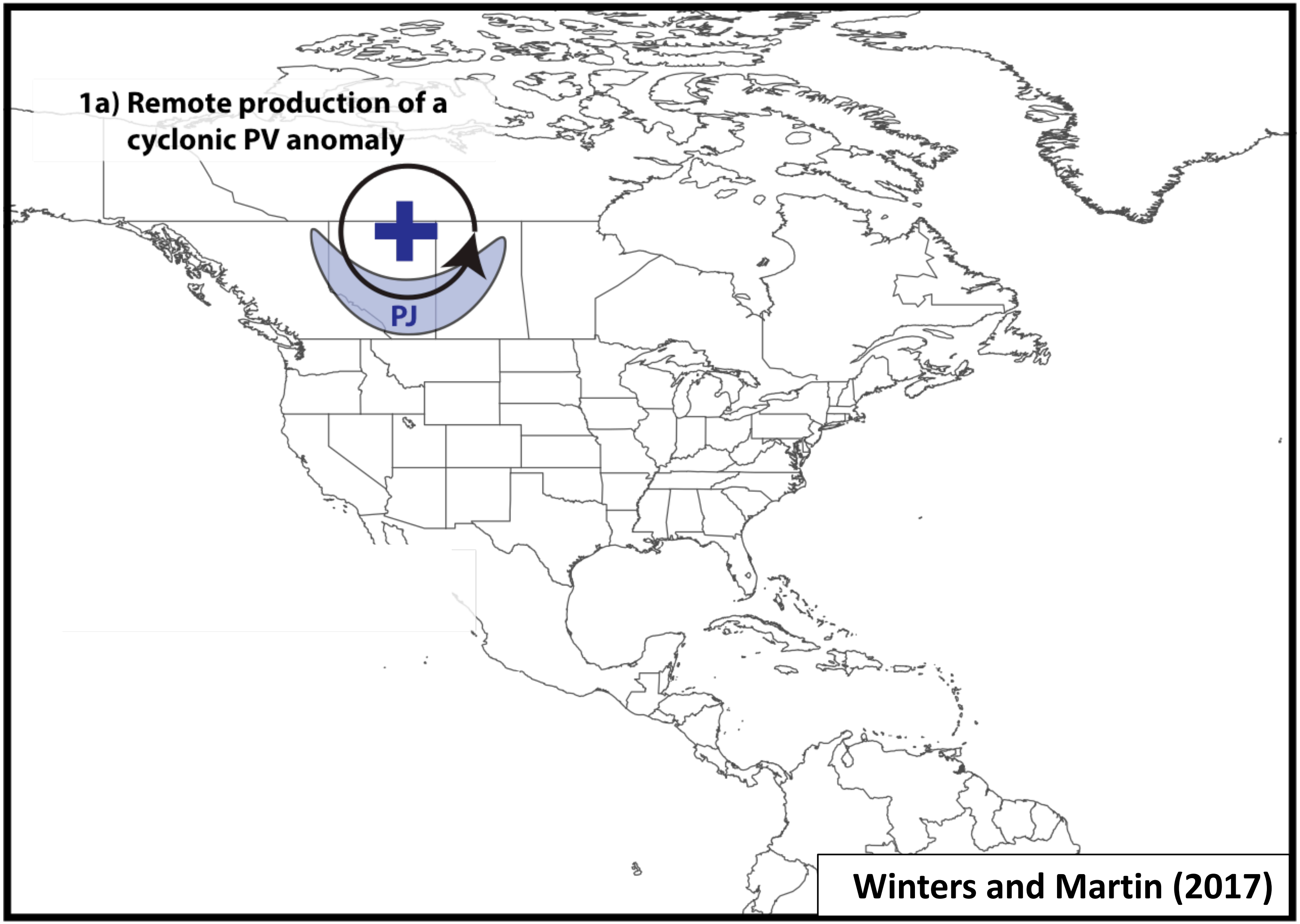
# Jet Superposition Conceptual Model



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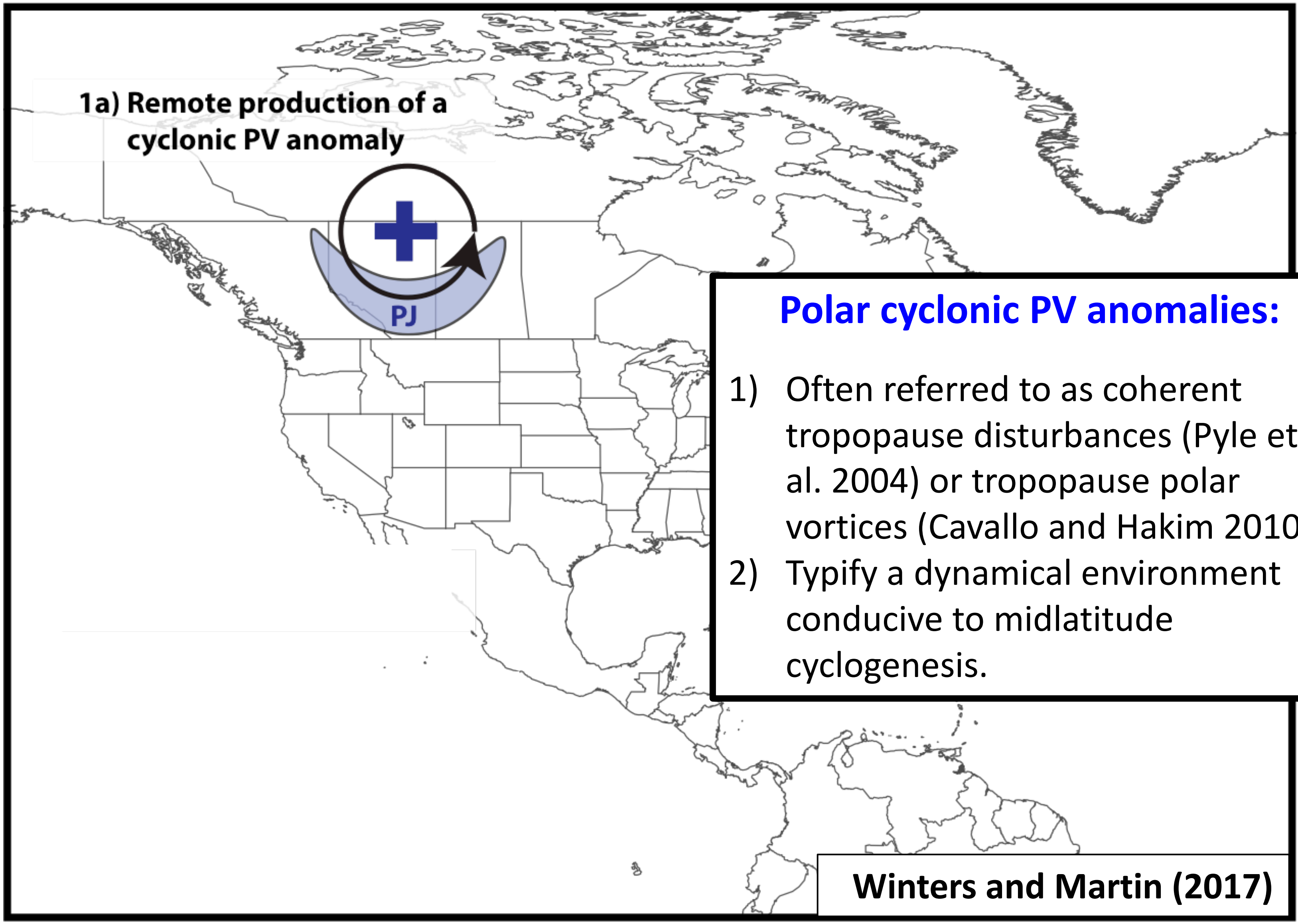

**Polar cyclonic PV anomalies:**

1) Often referred to as coherent tropopause disturbances (Pyle et al. 2004) or tropopause polar vortices (Cavallo and Hakim 2010).
2) Typify a dynamical environment conducive to midlatitude cyclogenesis.

**Winters and Martin (2017)**

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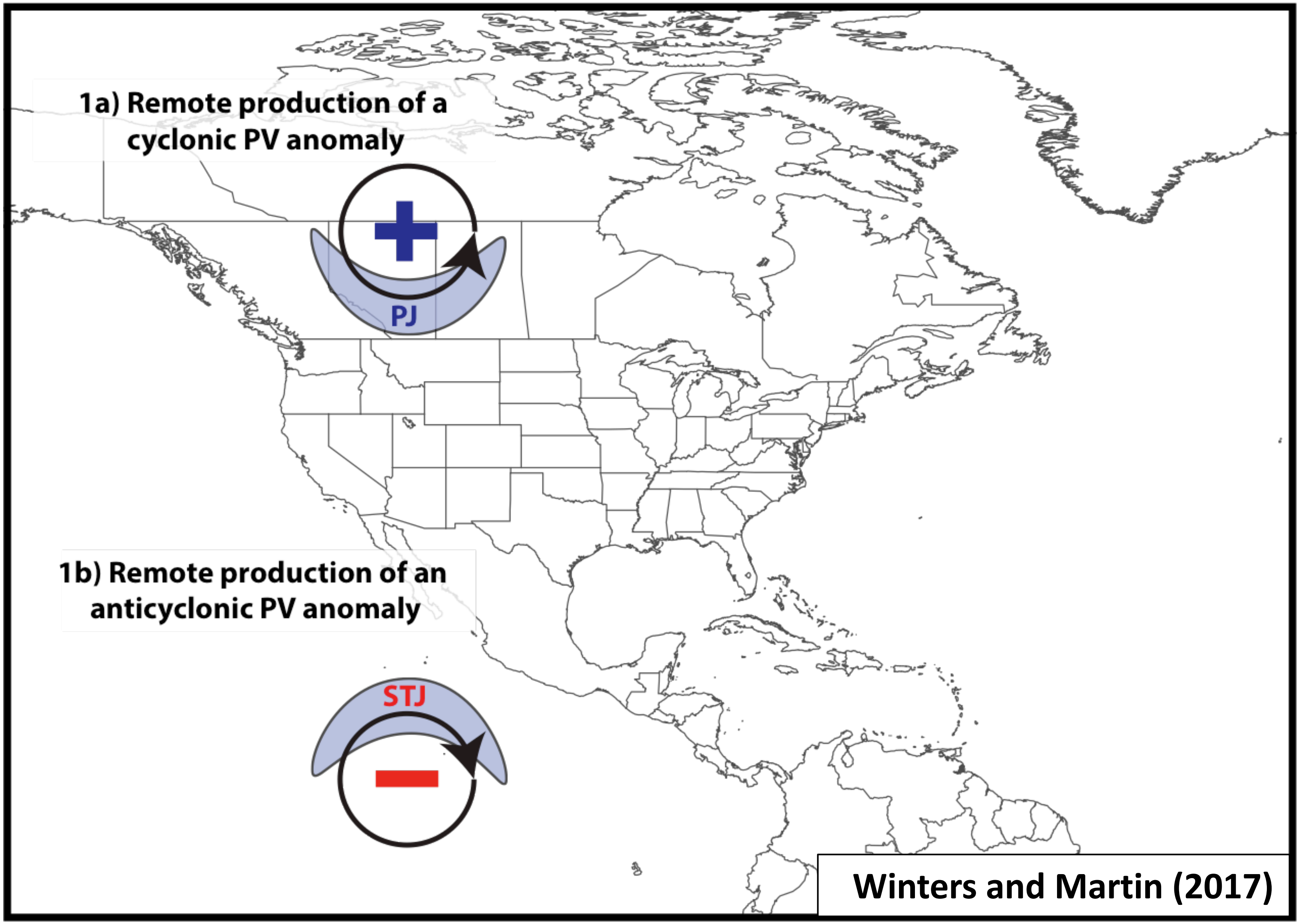

1a) Remote production of a cyclonic PV anomaly

1b) Remote production of an anticyclonic PV anomaly

Winters and Martin (2017)

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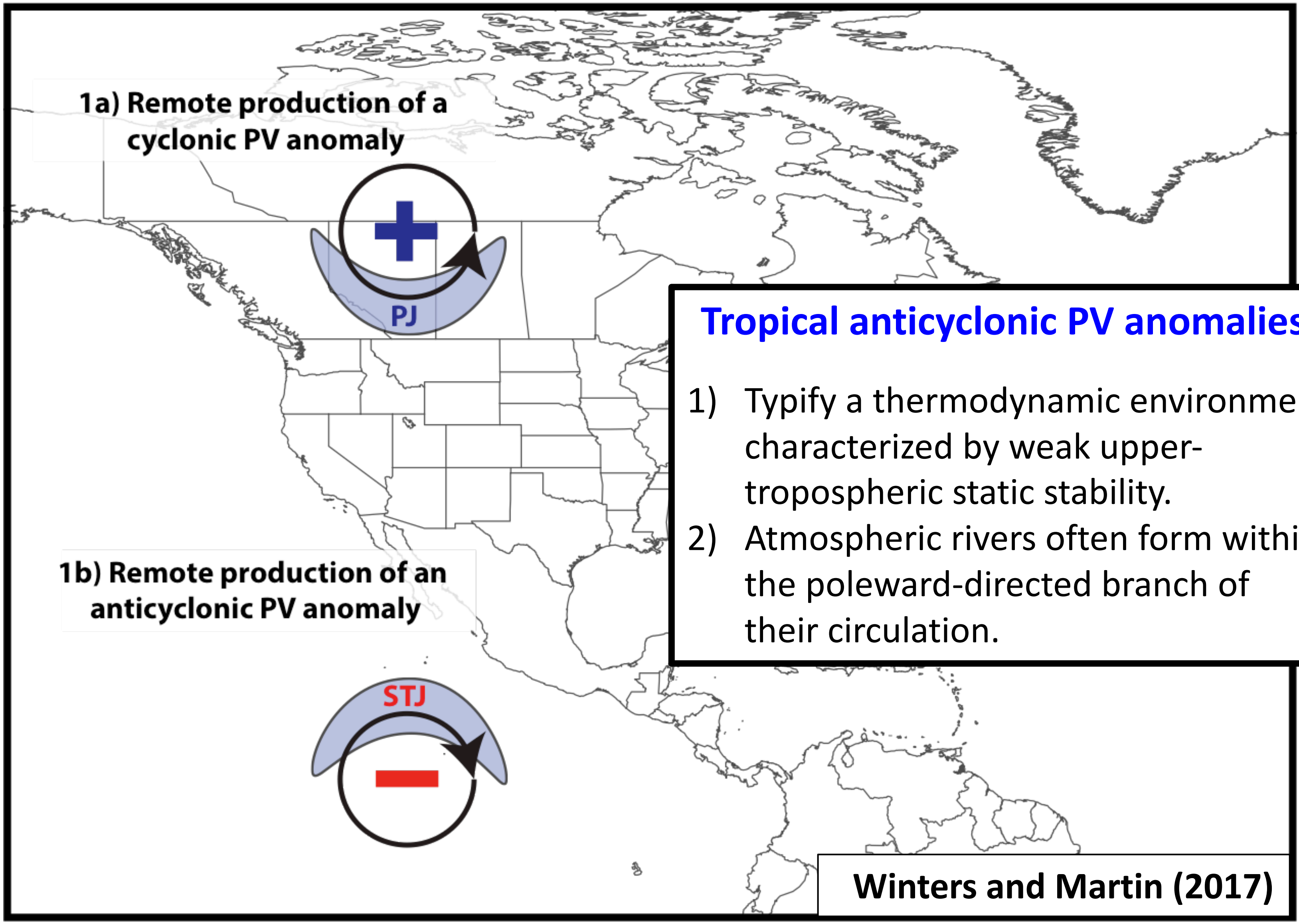

**Tropical anticyclonic PV anomalies:**

1) Typify a thermodynamic environment characterized by weak upper-tropospheric static stability.
2) Atmospheric rivers often form within the poleward-directed branch of their circulation.

**Winters and Martin (2017)**

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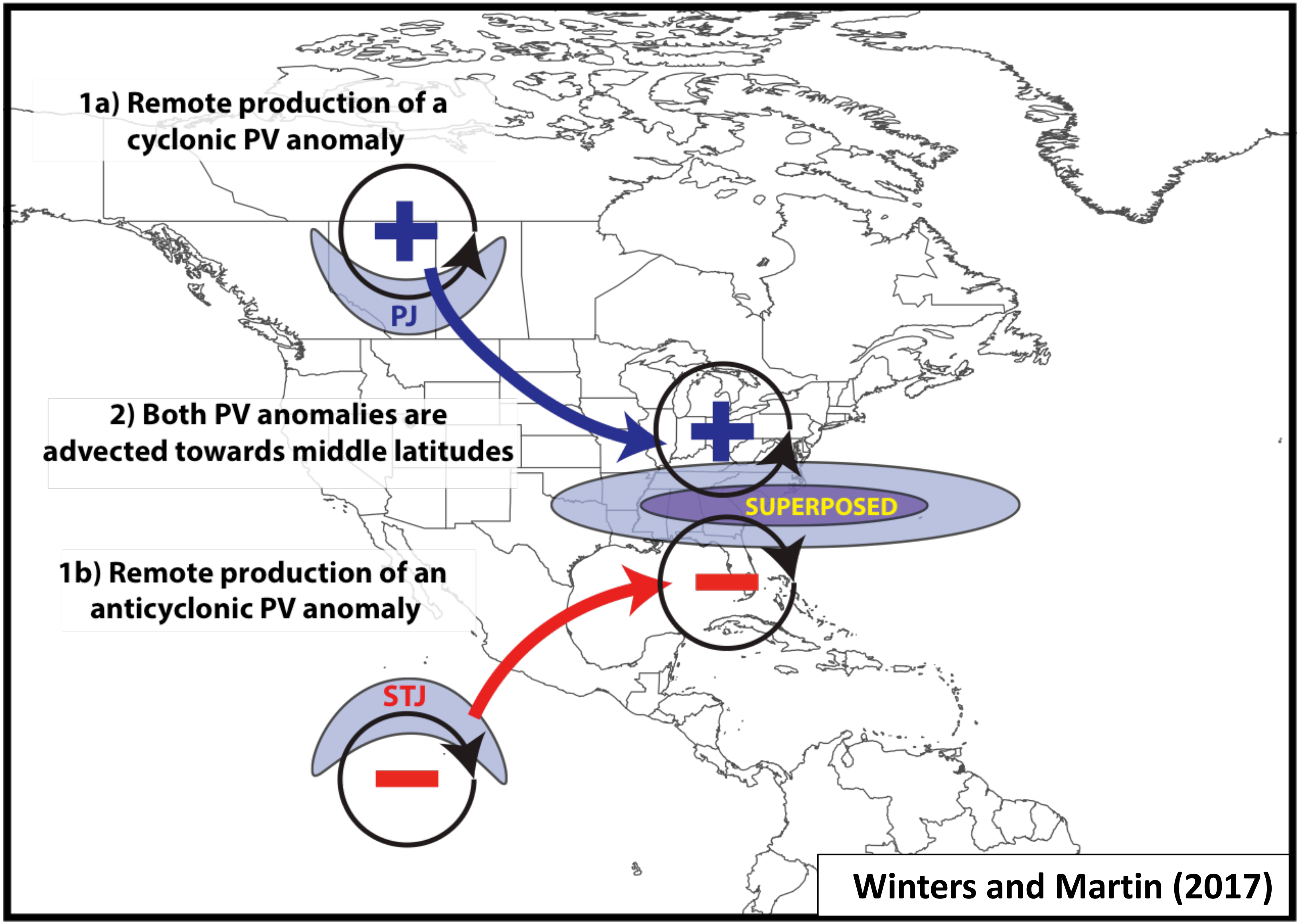

1a) Remote production of a cyclonic PV anomaly

2) Both PV anomalies are advected towards middle latitudes

1b) Remote production of an anticyclonic PV anomaly

Winters and Martin (2017)

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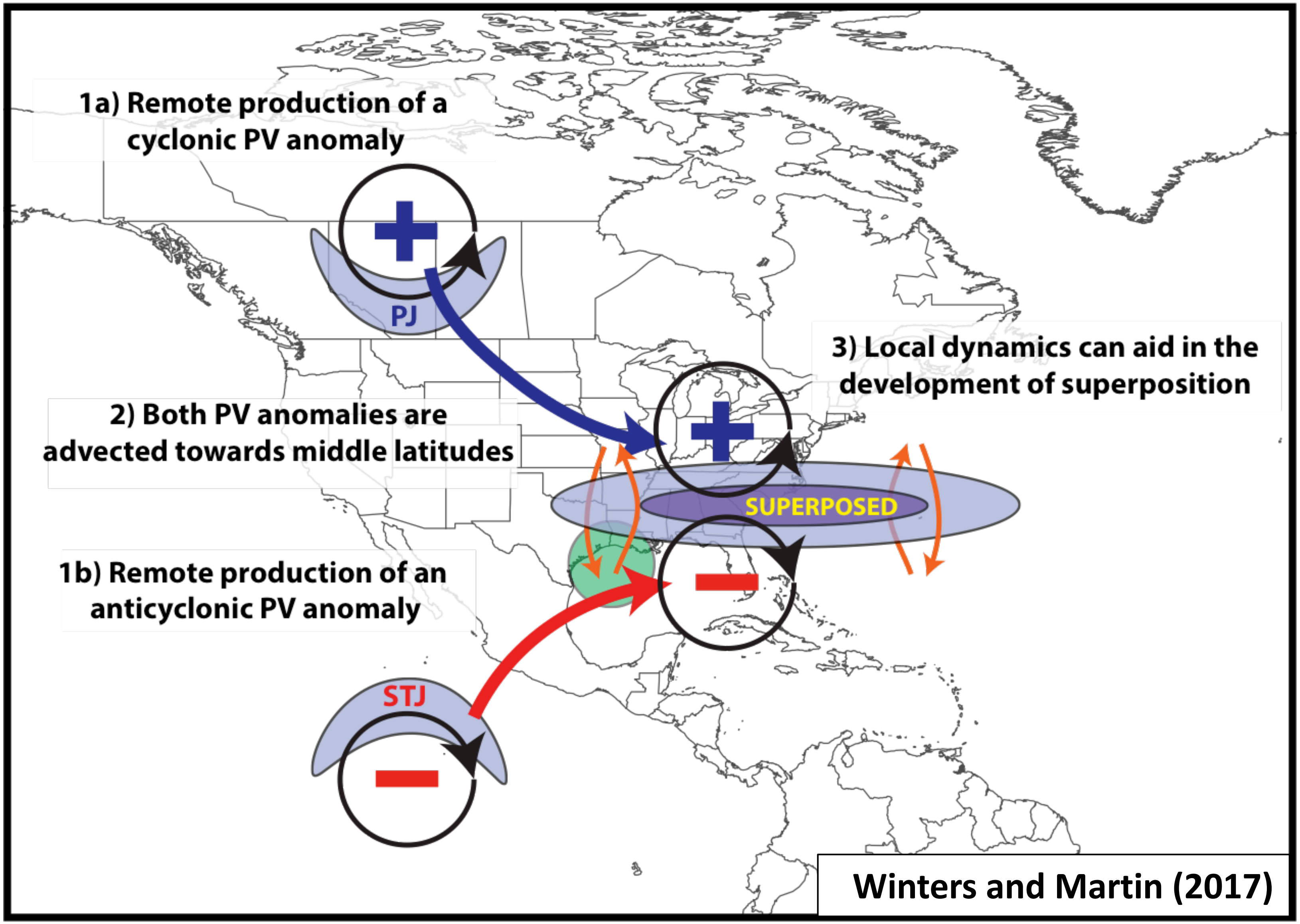

1a) Remote production of a cyclonic PV anomaly

2) Both PV anomalies are advected towards middle latitudes

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3) Local dynamics can aid in the development of superposition

Winters and Martin (2017)

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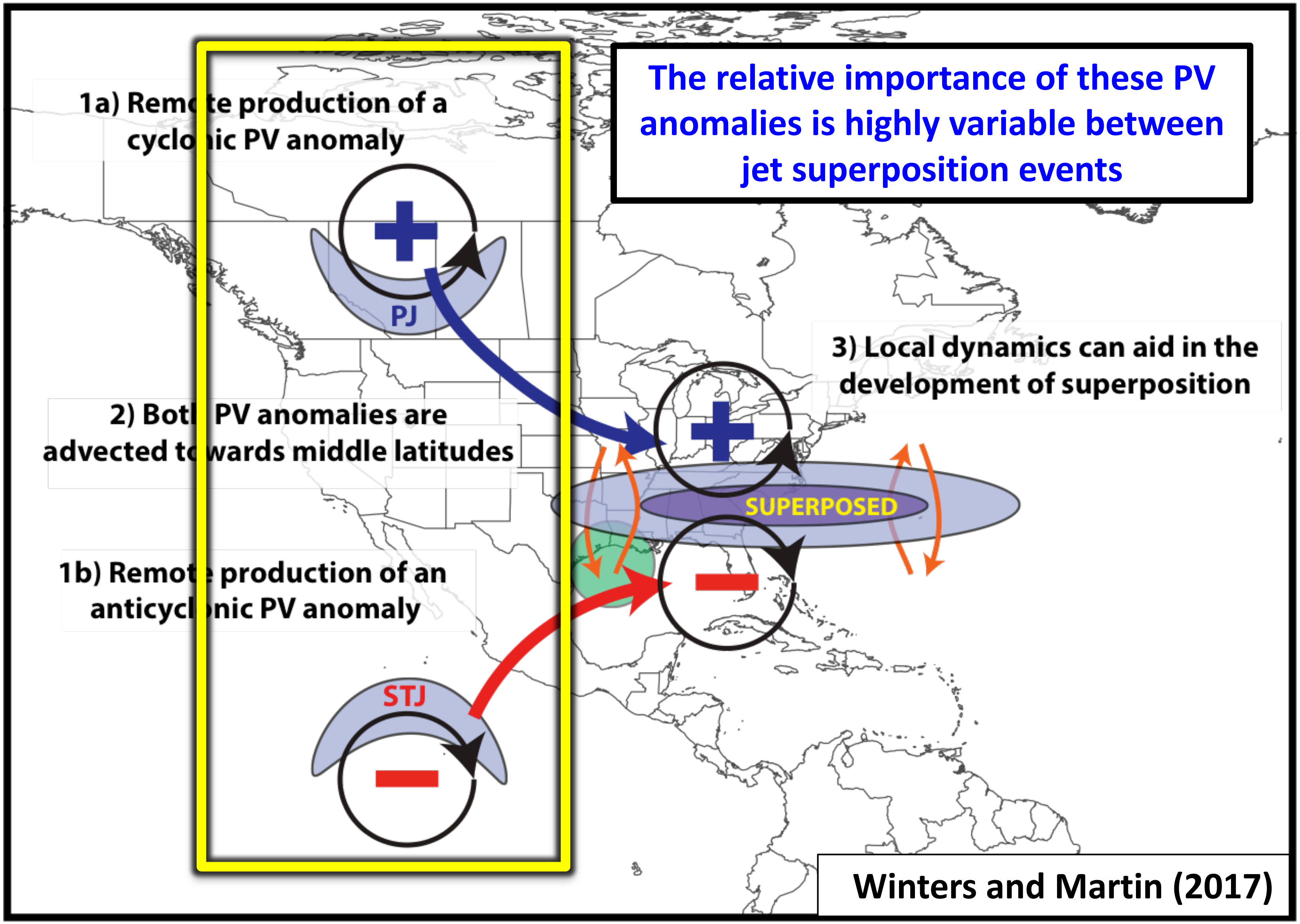


1a) Remote production of a cyclonic PV anomaly

2) Both PV anomalies are advected towards middle latitudes

1b) Remote production of an anticyclonic PV anomaly

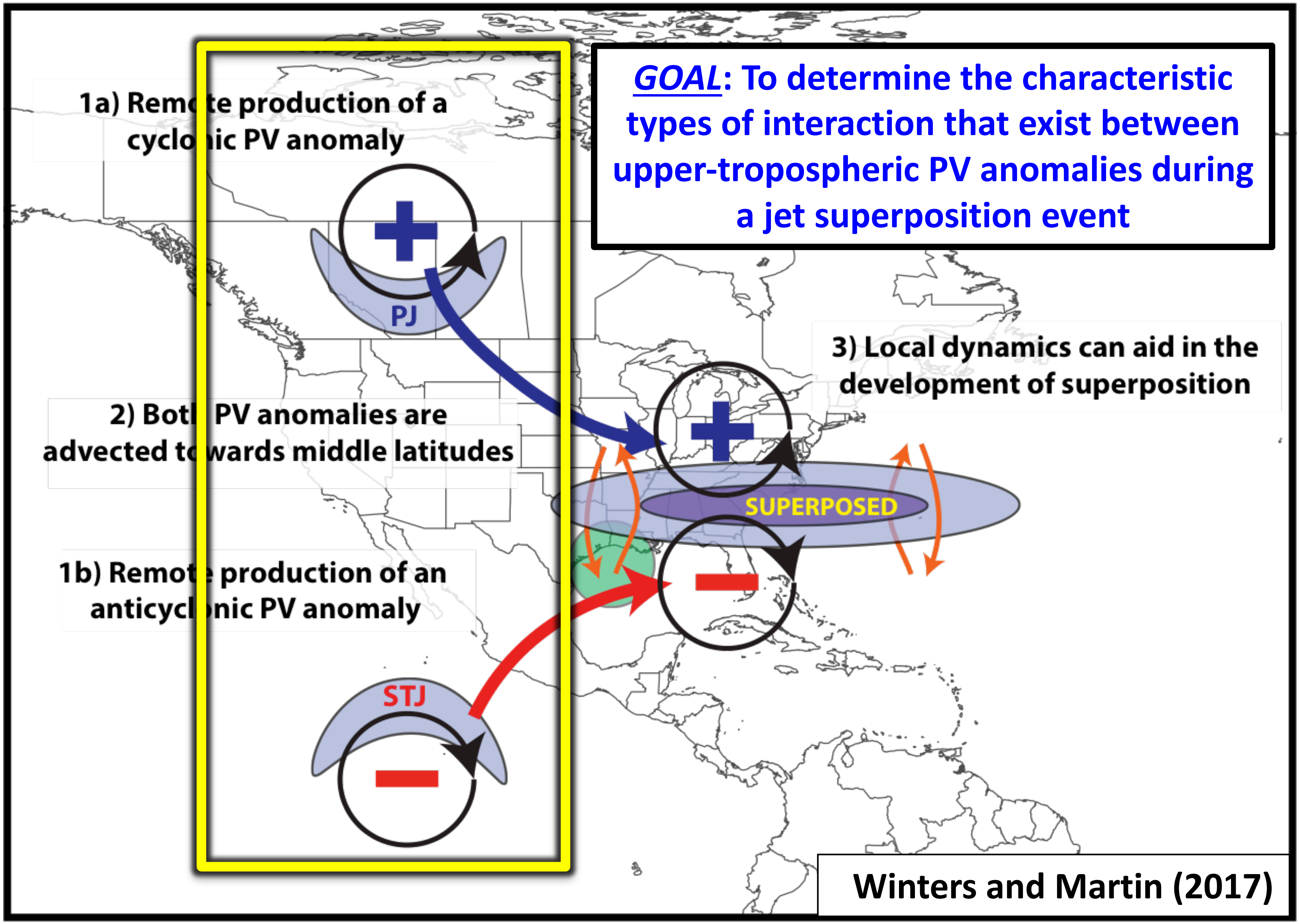
The relative importance of these PV anomalies is highly variable between jet superposition events

3) Local dynamics can aid in the development of superposition

Winters and Martin (2017)

# Jet Superposition Conceptual Model

*GOAL*: To determine the characteristic types of interaction that exist between upper-tropospheric PV anomalies during a jet superposition event



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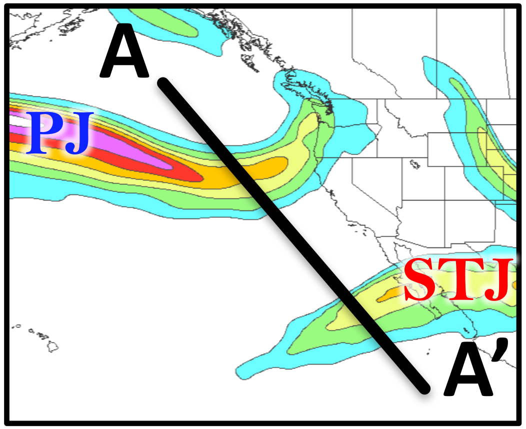
# Jet Superposition Event Identification and Classification

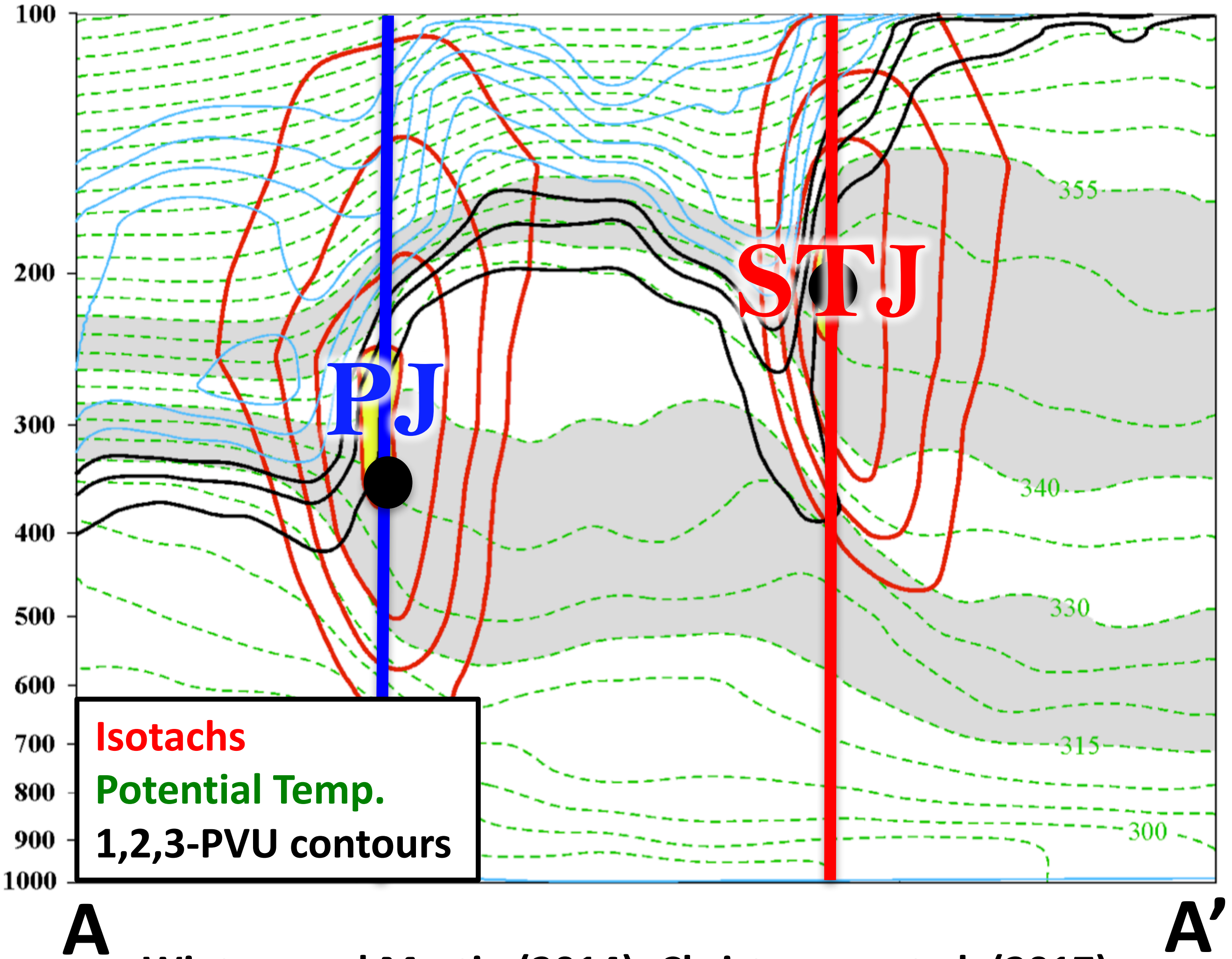
# Jet Superposition Event Identification

## 0000 UTC 27 April 2010



250-hPa wind speed

Isolated grid points over North America in the CFSR (Saha et al. 2014) characterized by a polar and subtropical jets during Nov–Mar 1979–2010.



Winters and Martin (2014); Christenson et al. (2017)

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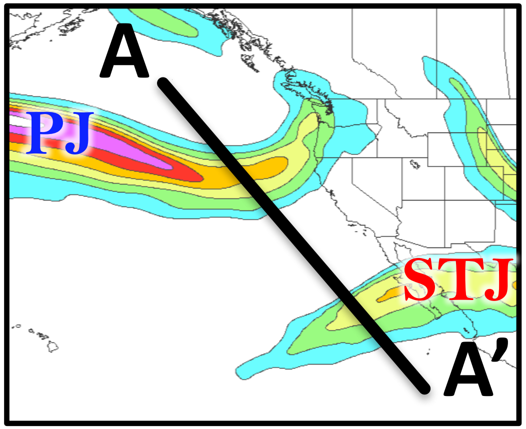

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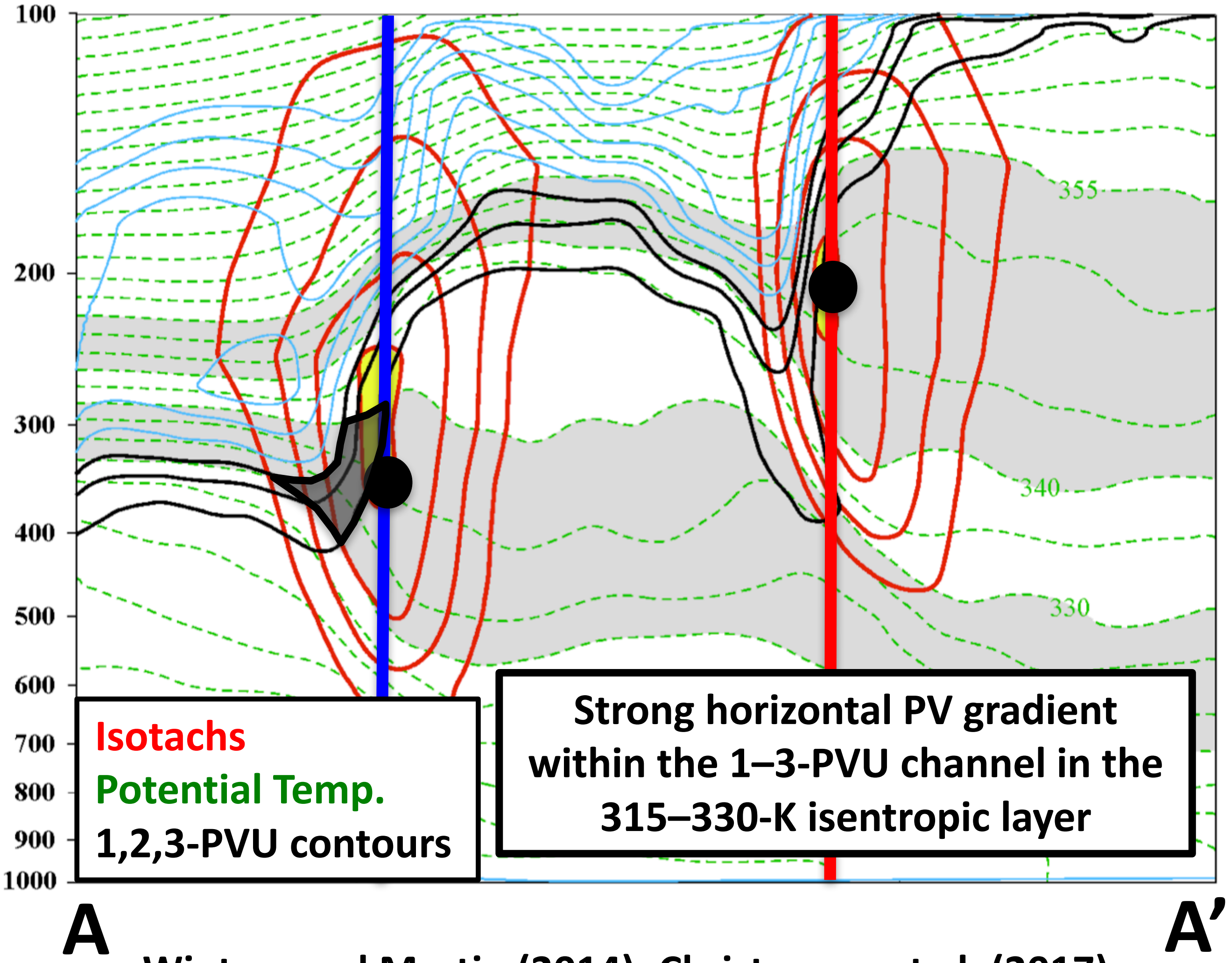

**Isotachs**
**Potential Temp.**
**1,2,3-PVU contours**

**Strong horizontal PV gradient within the 1–3-PVU channel in the 315–330-K isentropic layer**

**Winters and Martin (2014); Christenson et al. (2017)**

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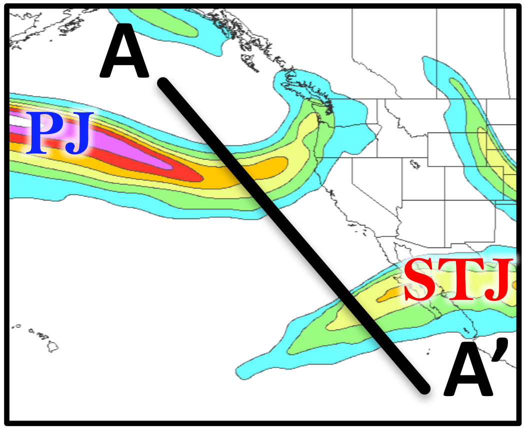

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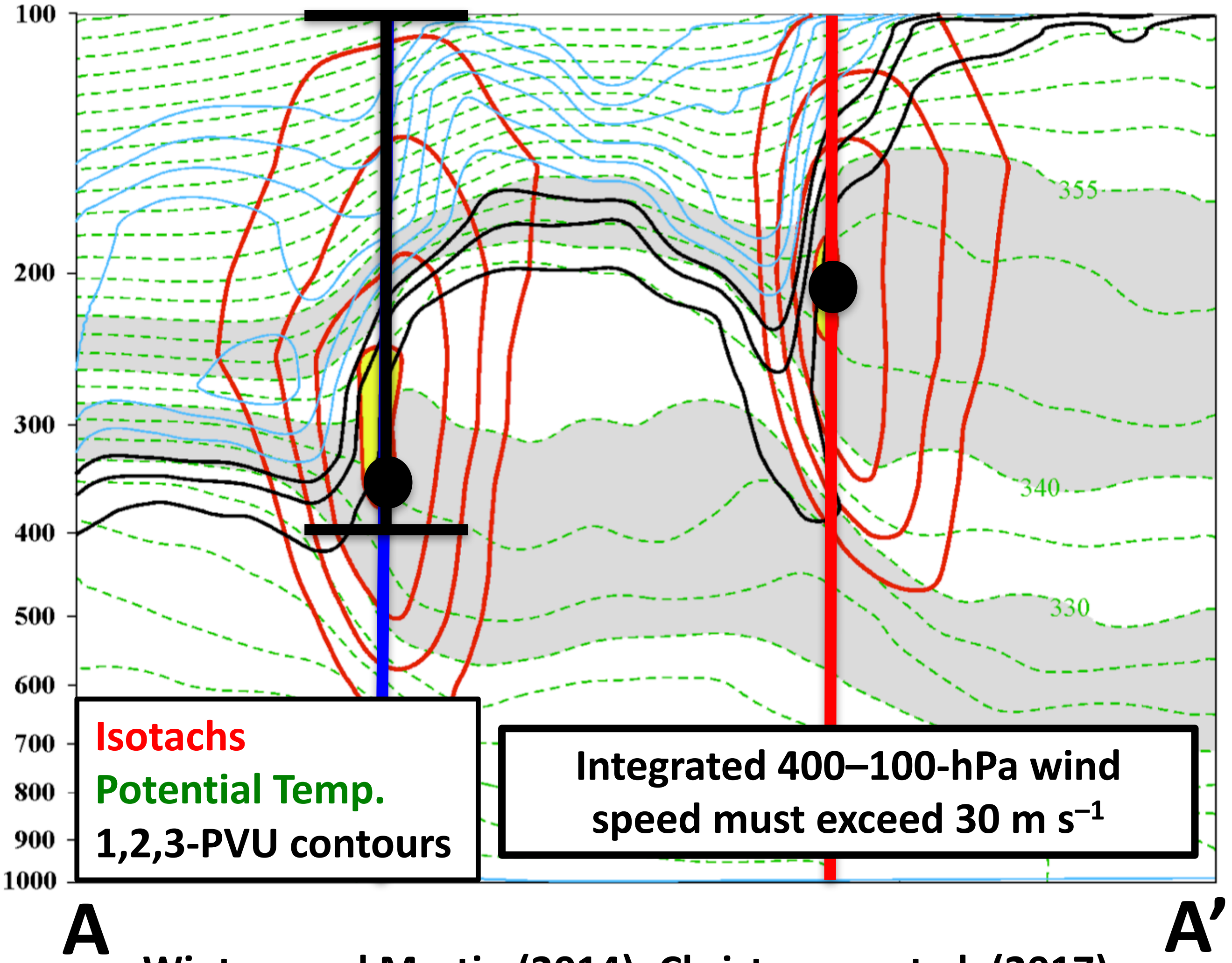

Isotachs

Potential Temp.

1,2,3-PVU contours

Integrated 400–100-hPa wind speed must exceed 30 m $s^{-1}$

Winters and Martin (2014); Christenson et al. (2017)

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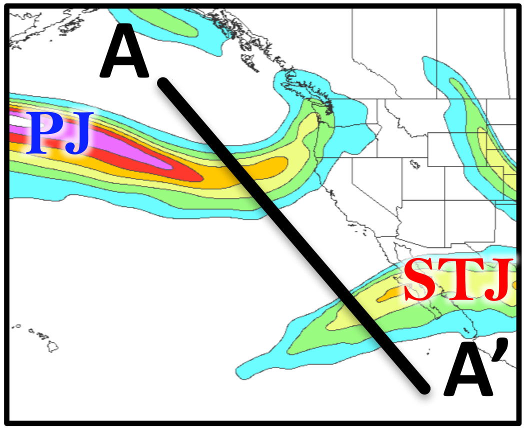

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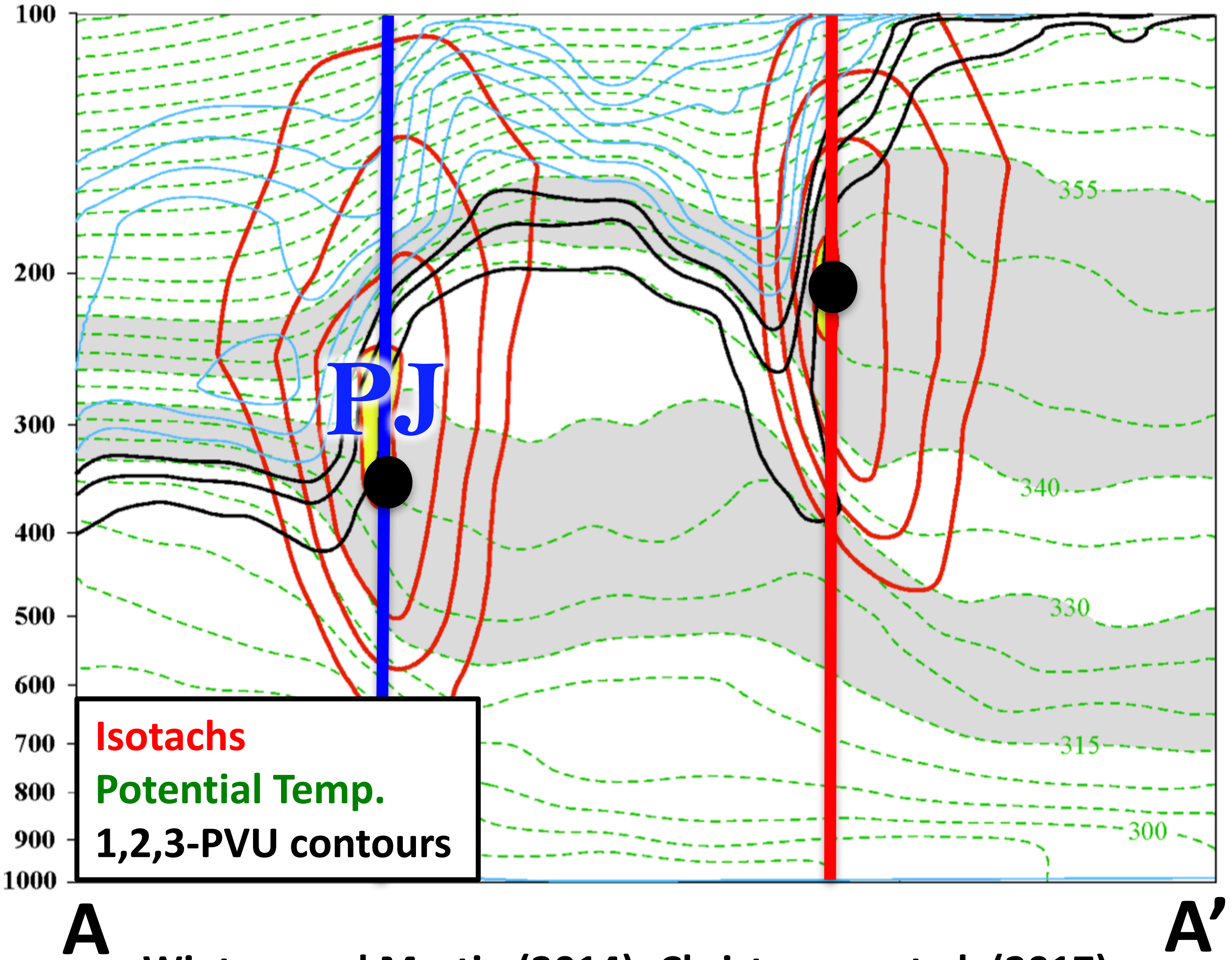

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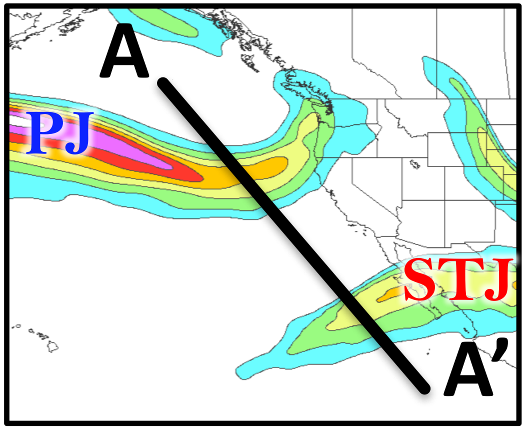

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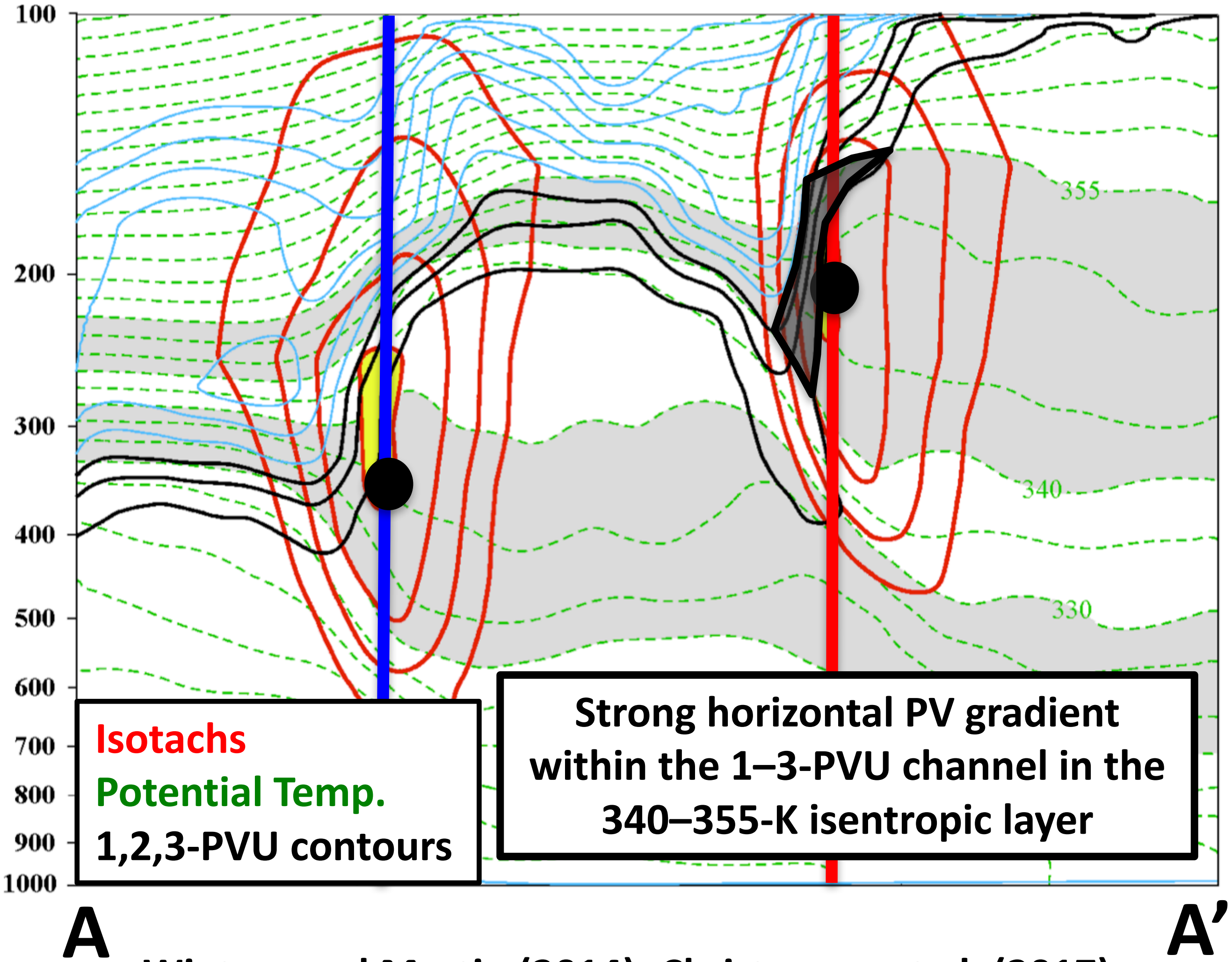

**Isotachs**
**Potential Temp.**
**1,2,3-PVU contours**

**Strong horizontal PV gradient within the 1–3-PVU channel in the 340–355-K isentropic layer**

**Winters and Martin (2014); Christenson et al. (2017)**

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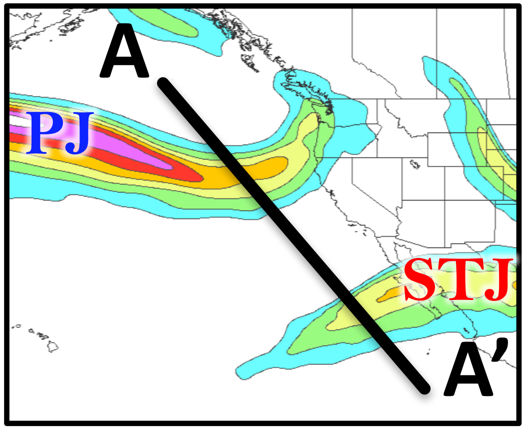

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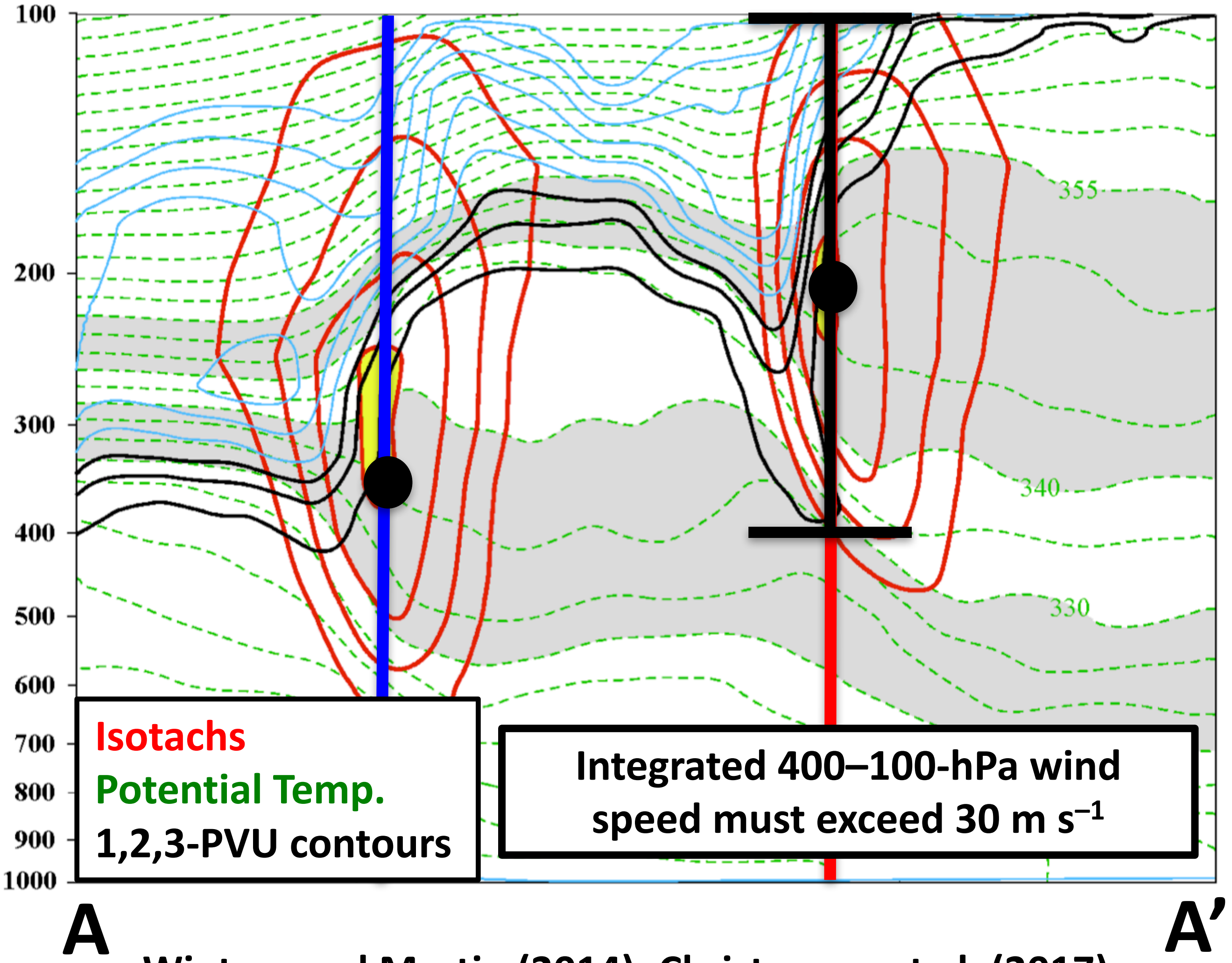

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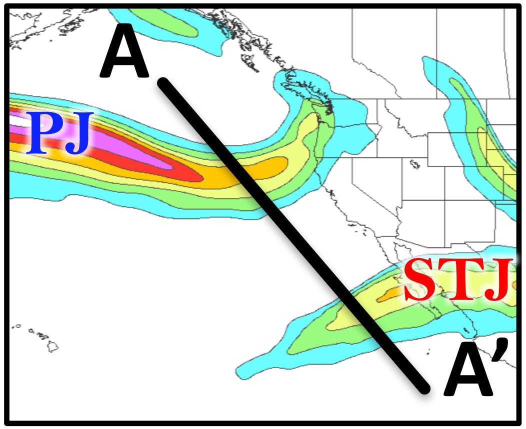

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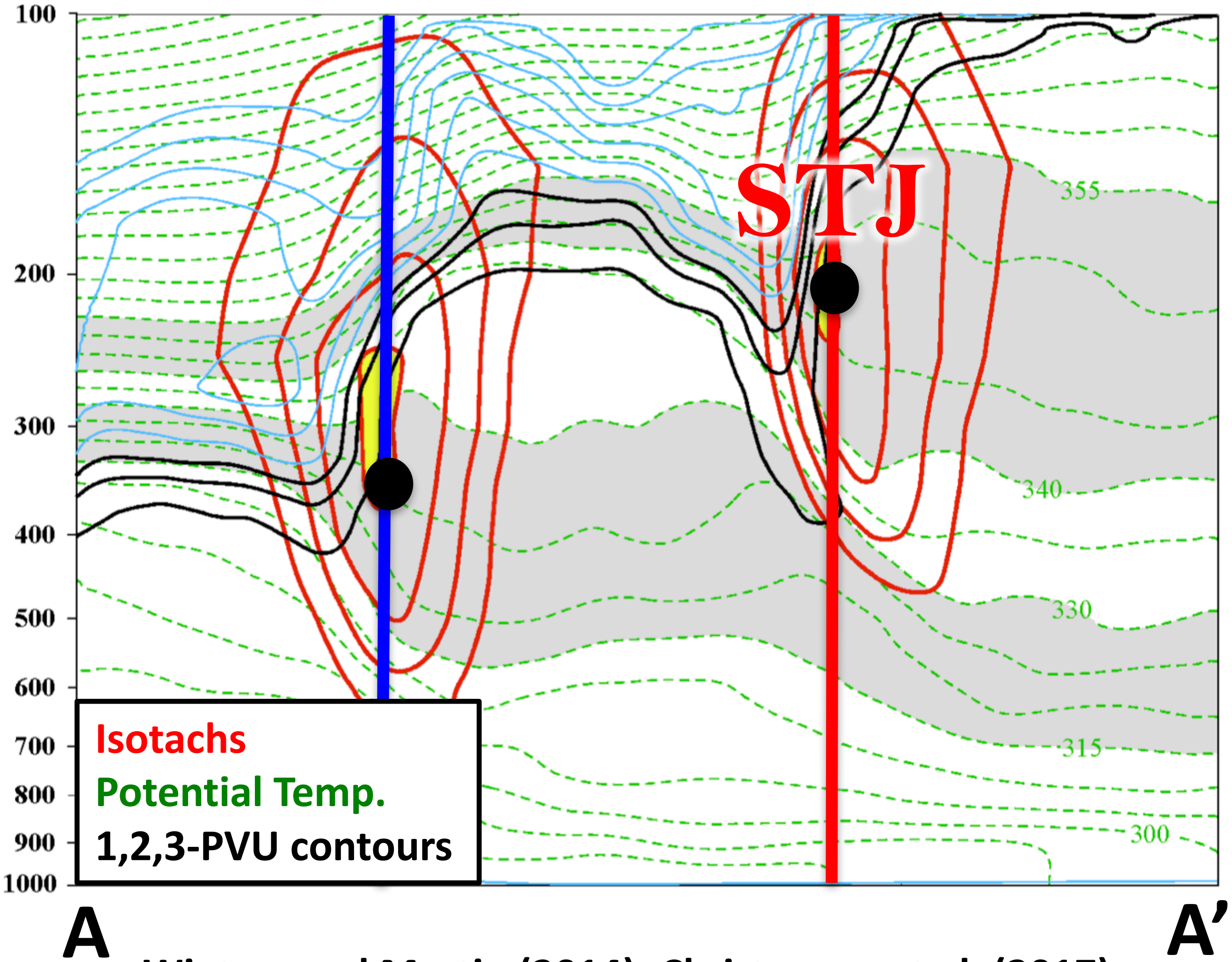

Winters and Martin (2014); Christenson et al. (2017)

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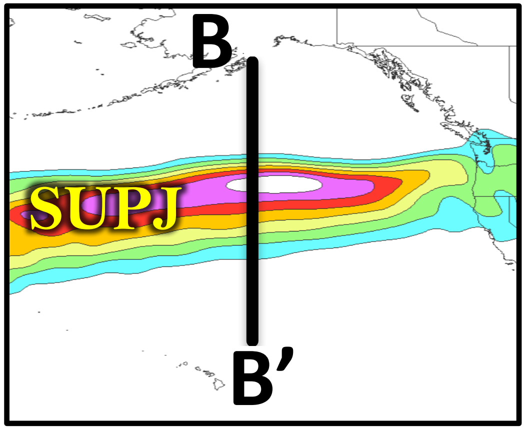

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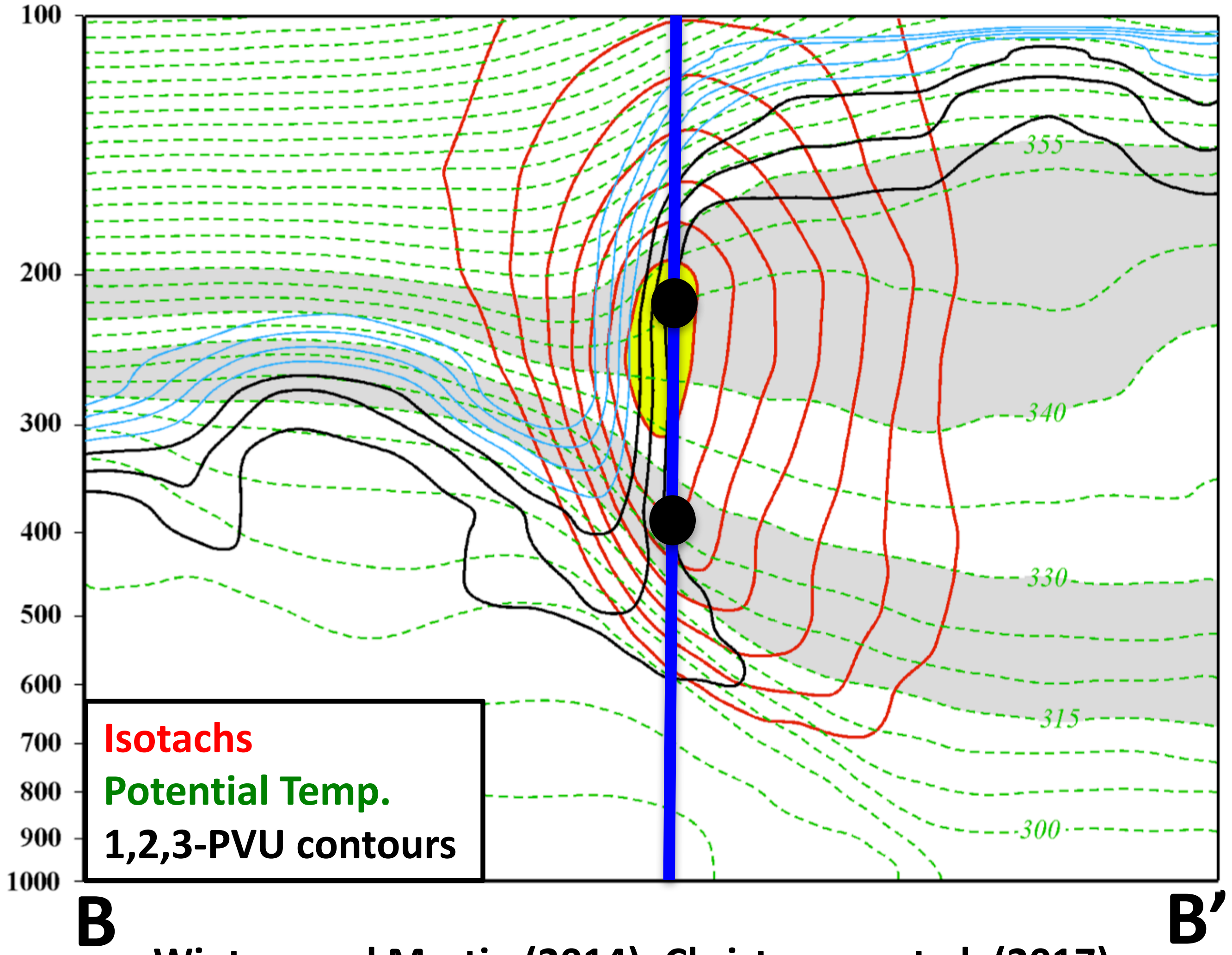

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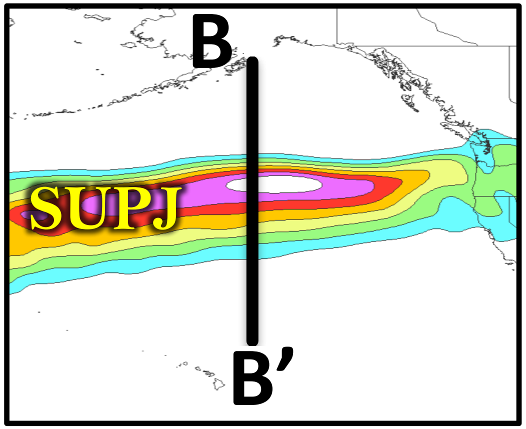

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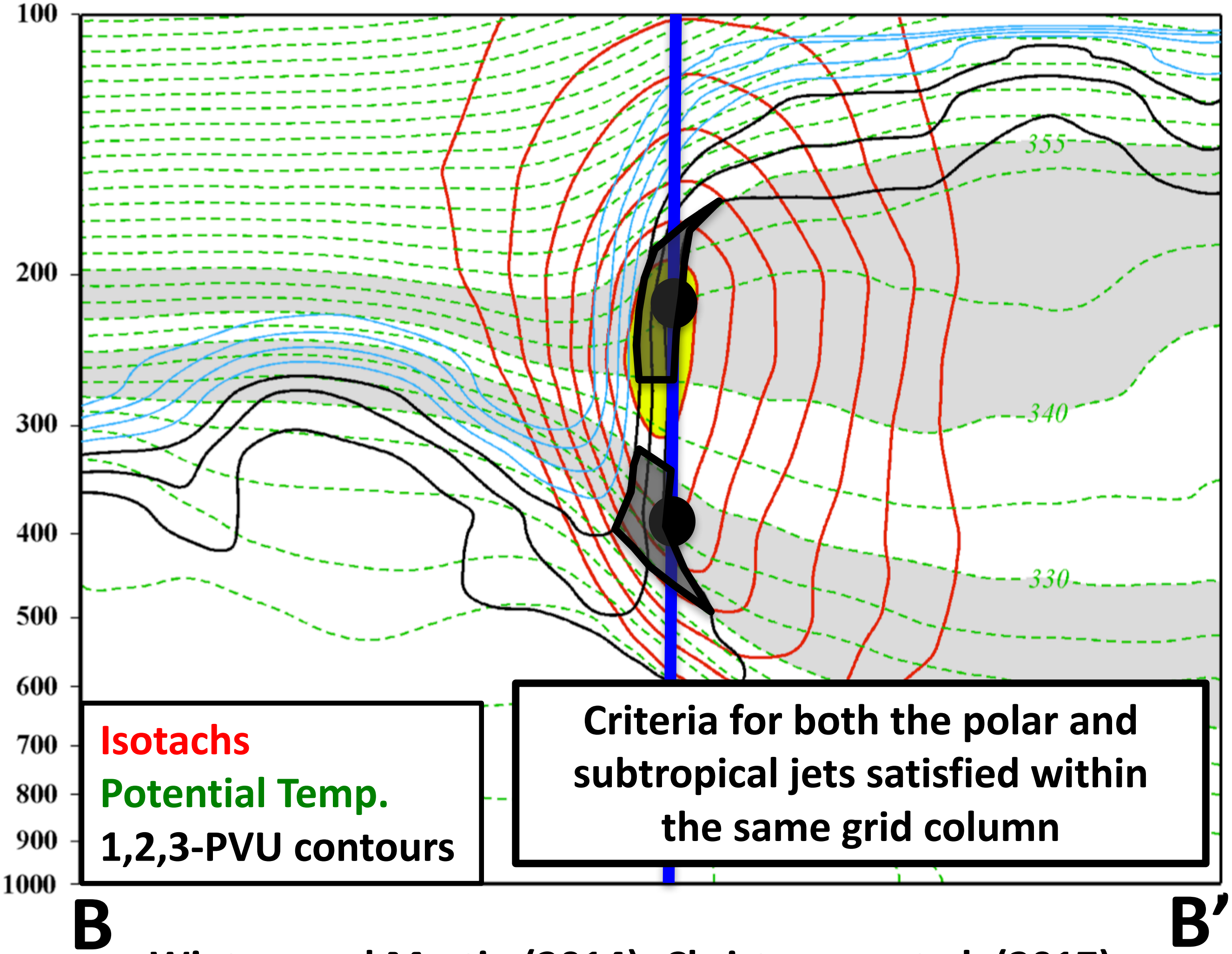

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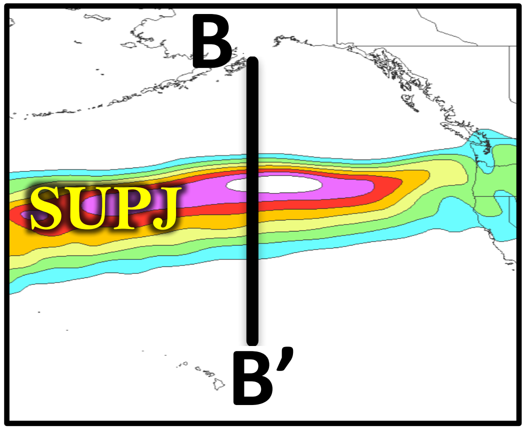

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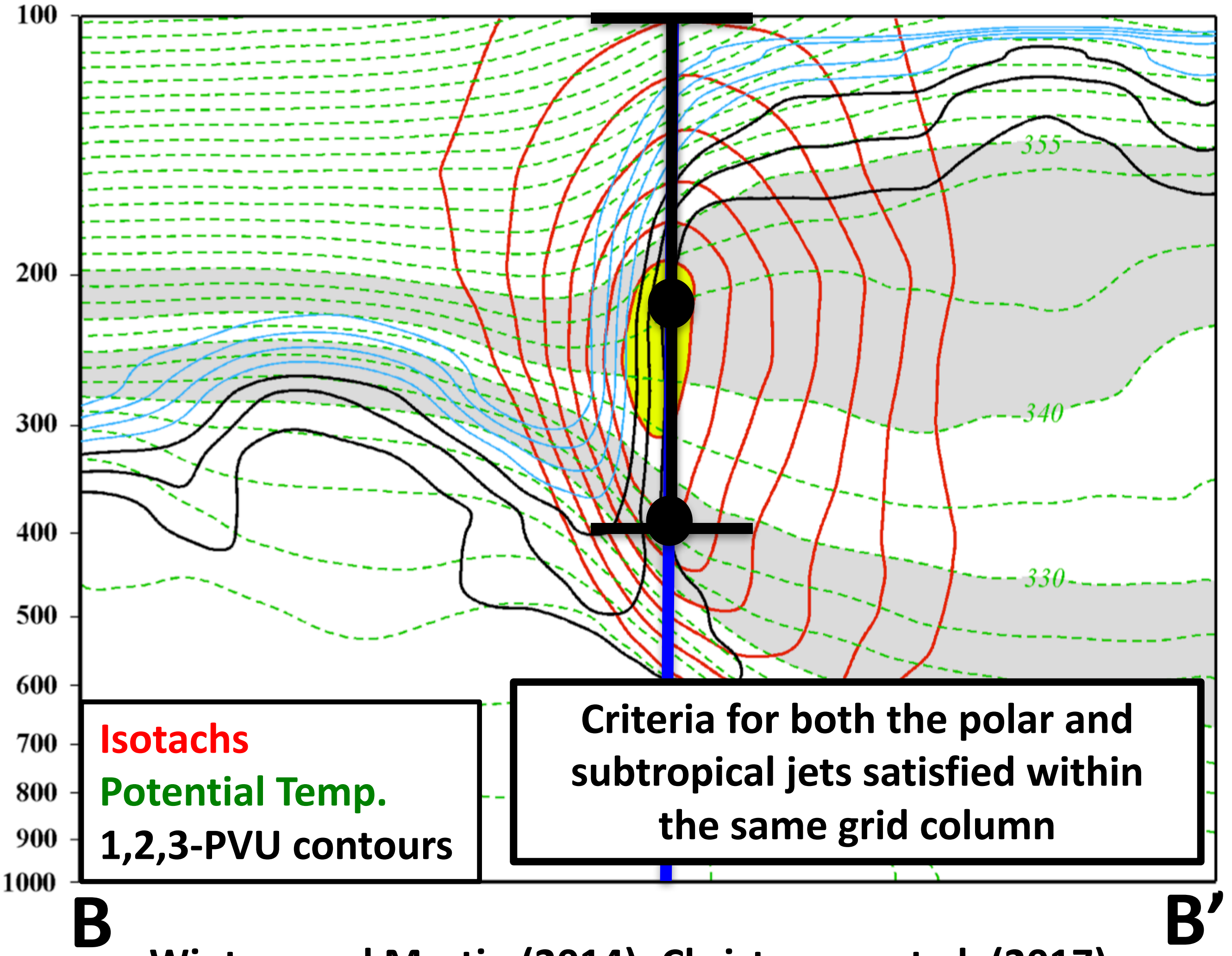

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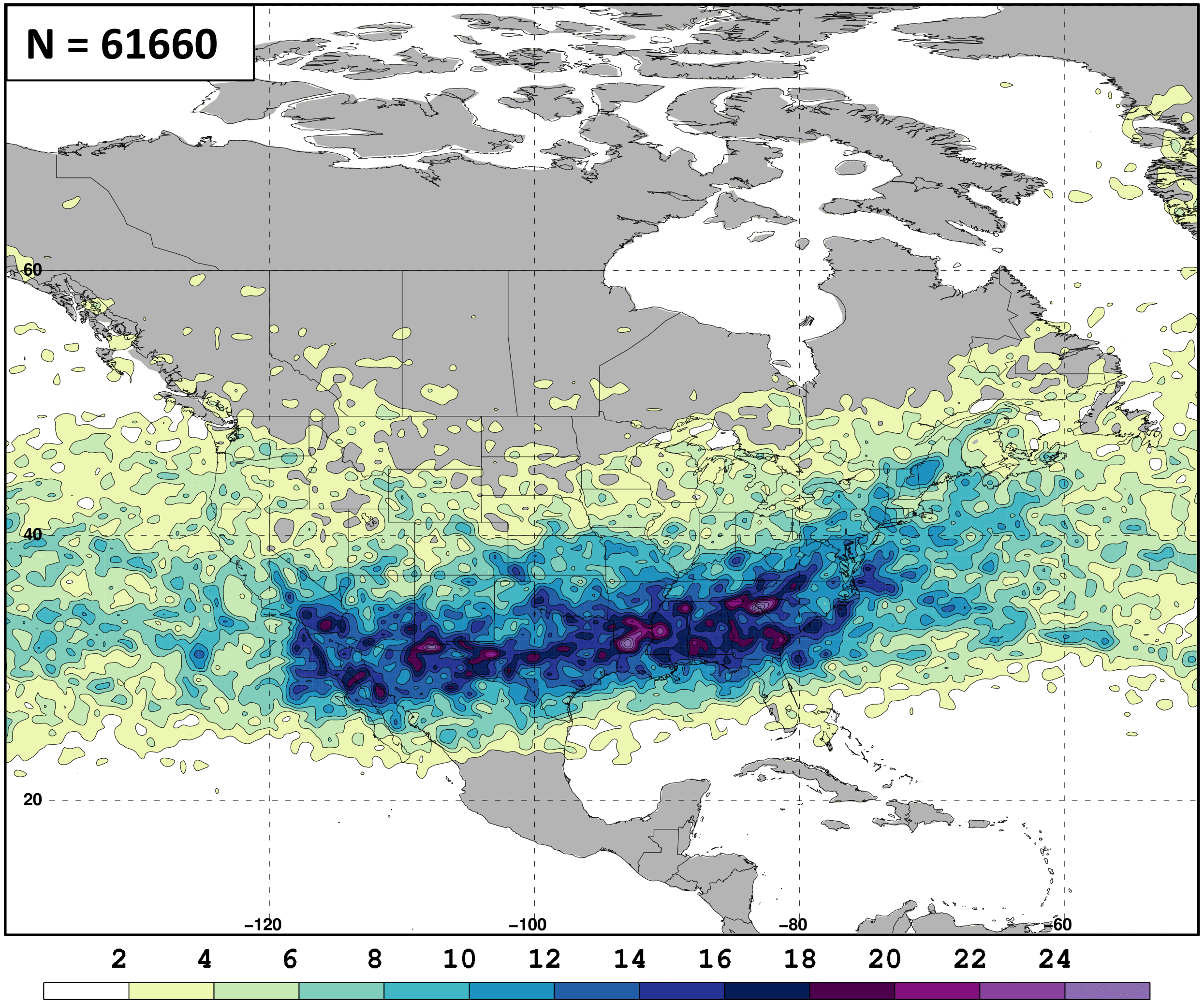
**Jet Superposition Frequency – All Times**

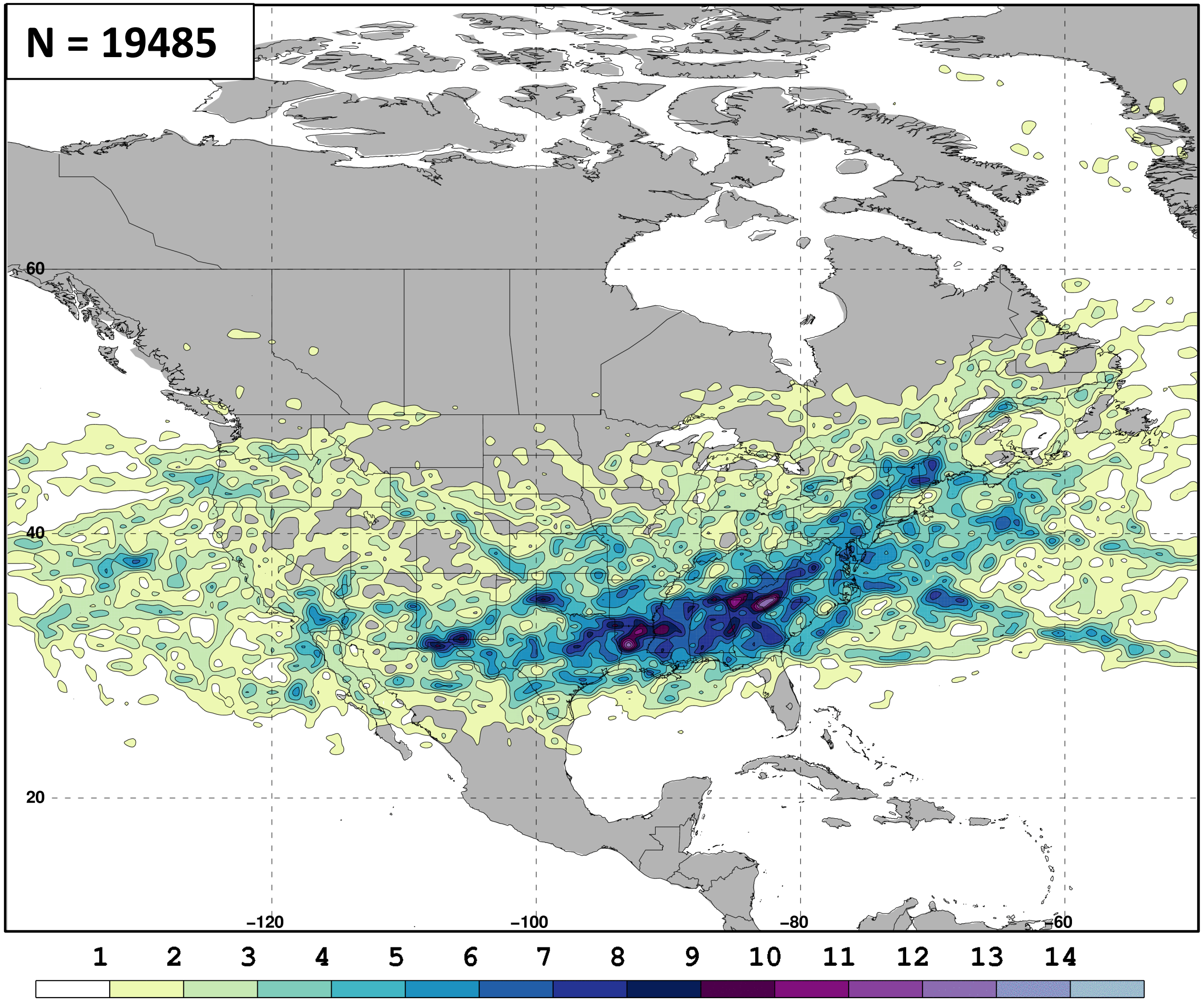


# Jet Superposition Event Identification

1. Isolated grid points over North America in the CFSR (Saha et al. 2014) characterized by a jet superposition during Nov–Mar 1979–2010.

2. Retained analysis times that rank in the top 10% in terms the number of grid points characterized by a jet superposition.

## Jet Superposition Frequency – Top 10% Times



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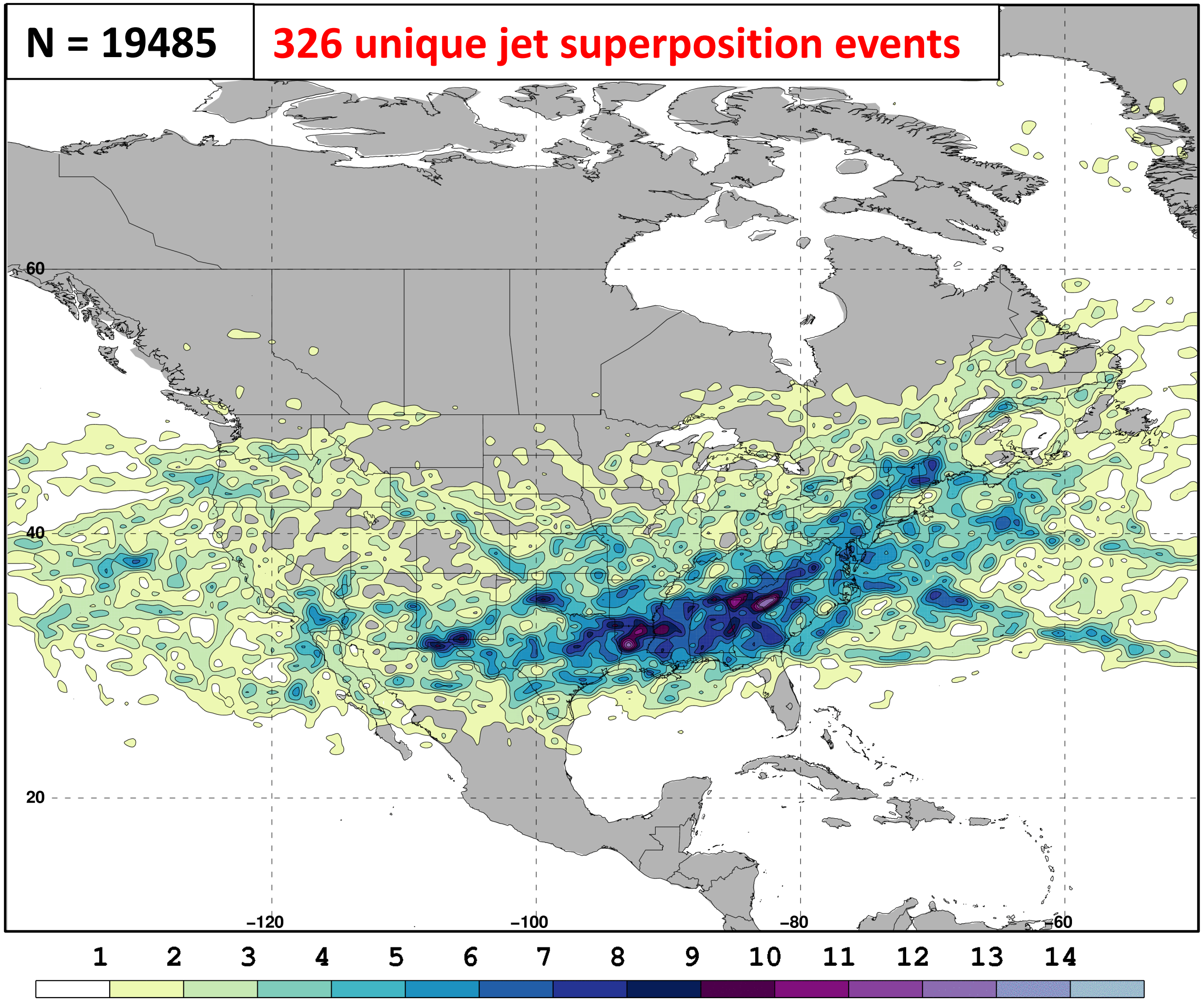
3. Filtered retained analysis times to group together jet superpositions that are < 30 h and < 1500 km of one another.

**Jet Superposition Frequency – Top 10% Times**

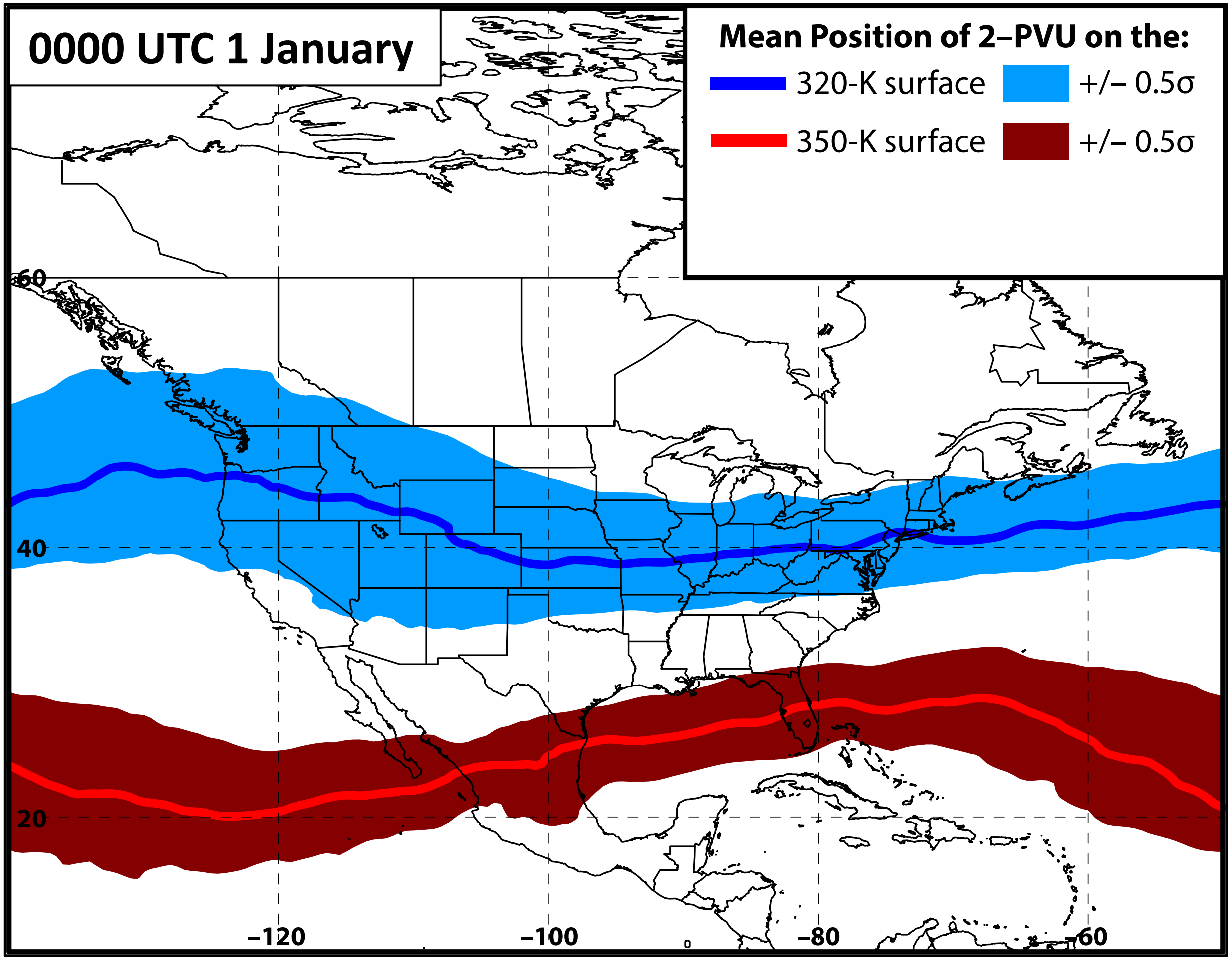


**N = 19485**

**326 unique jet superposition events**

# Jet Superposition Event Classification

1. Determined the mean position of the 2-PVU contour on the 320-K and 350-K surfaces at each analysis time in the CFSR.



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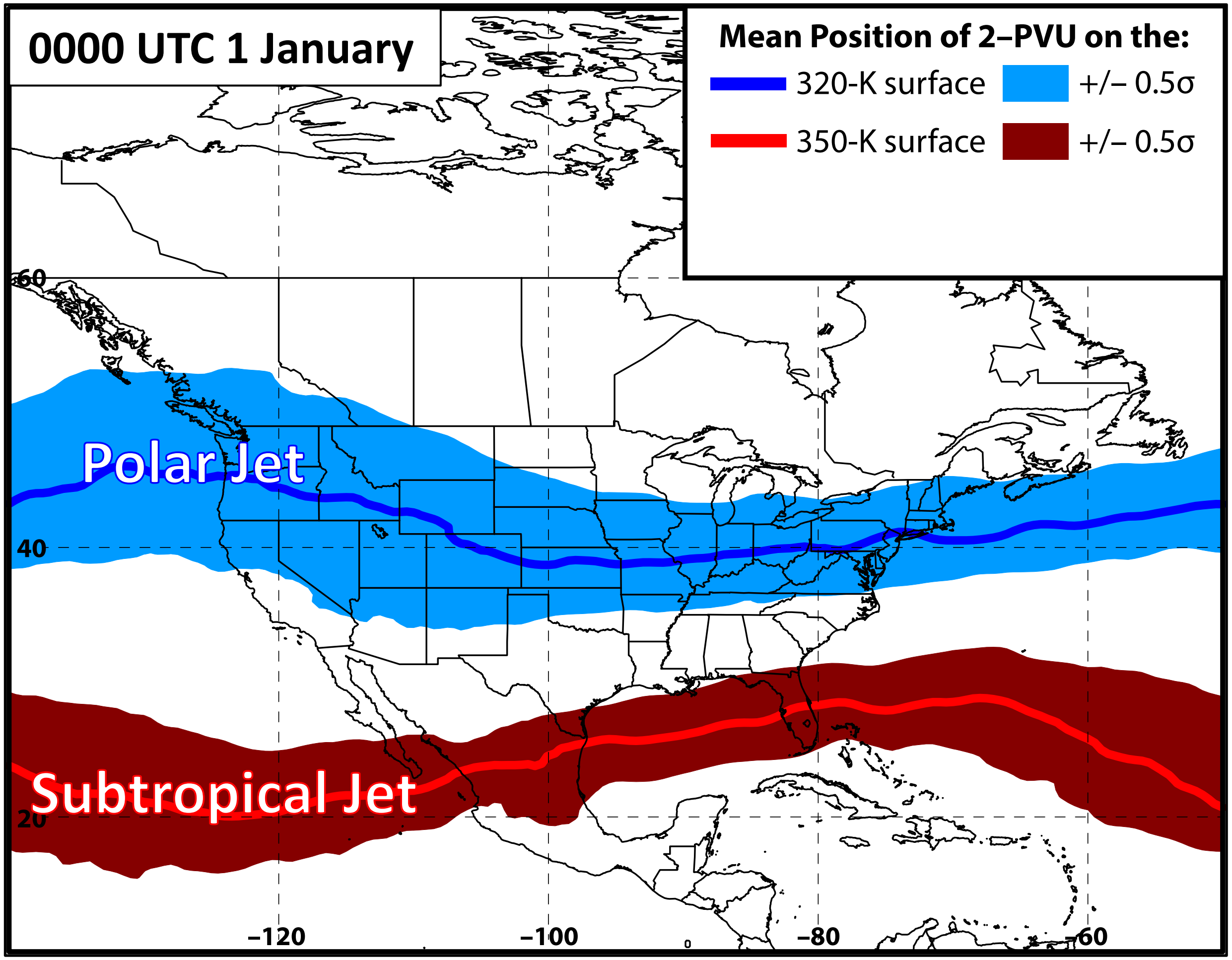

# Jet Superposition Event Classification

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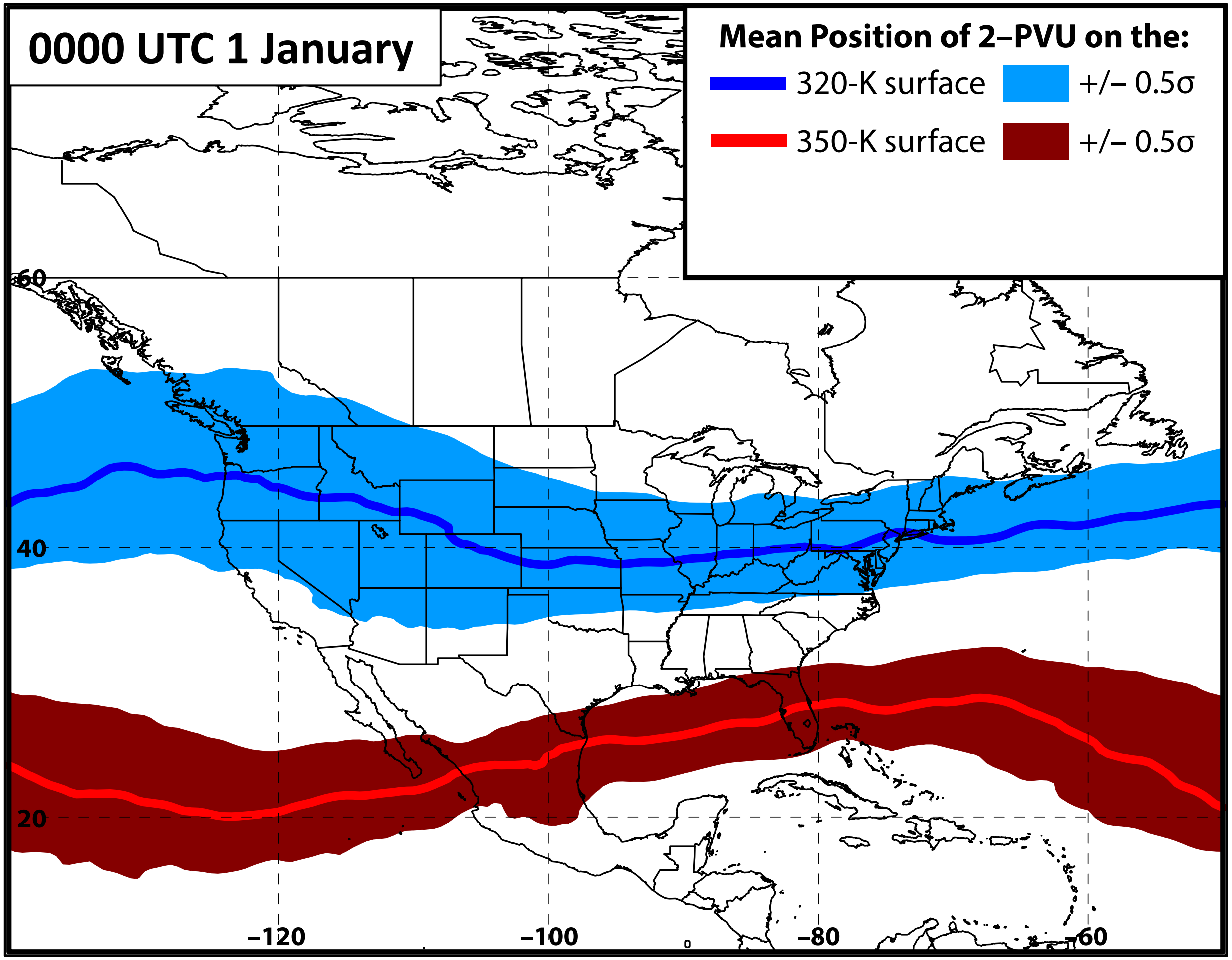
2. Compared the position of the jet superposition centroid at the start of each event against the climatological position of the 2-PVU contour.

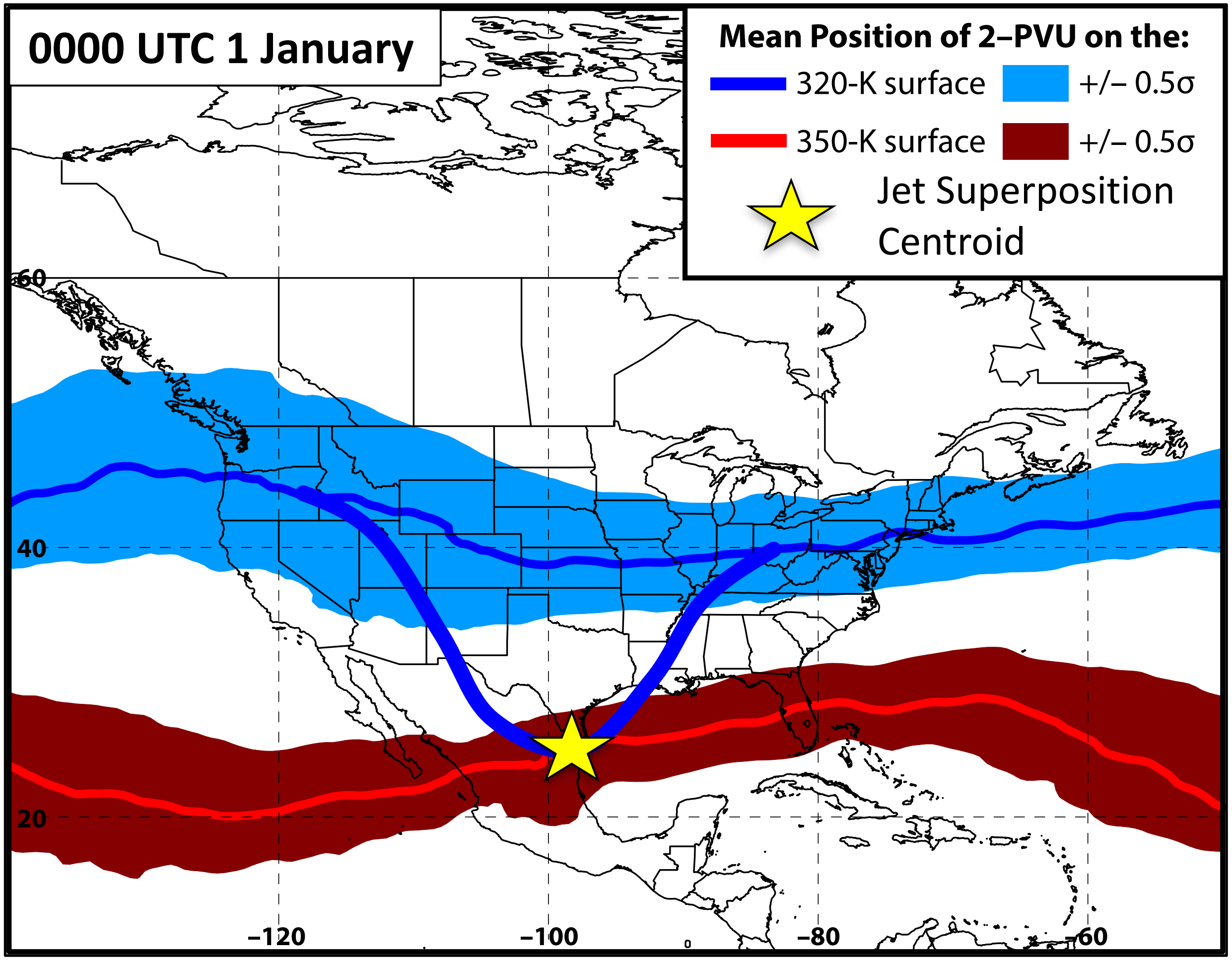


# Jet Superposition Event Classification

1. Determined the mean position of the 2-PVU contour on the 320-K and 350-K surfaces at each analysis time in the CFSR.

2. Compared the position of the jet superposition centroid at the start of each event against the climatological position of the 2-PVU contour.

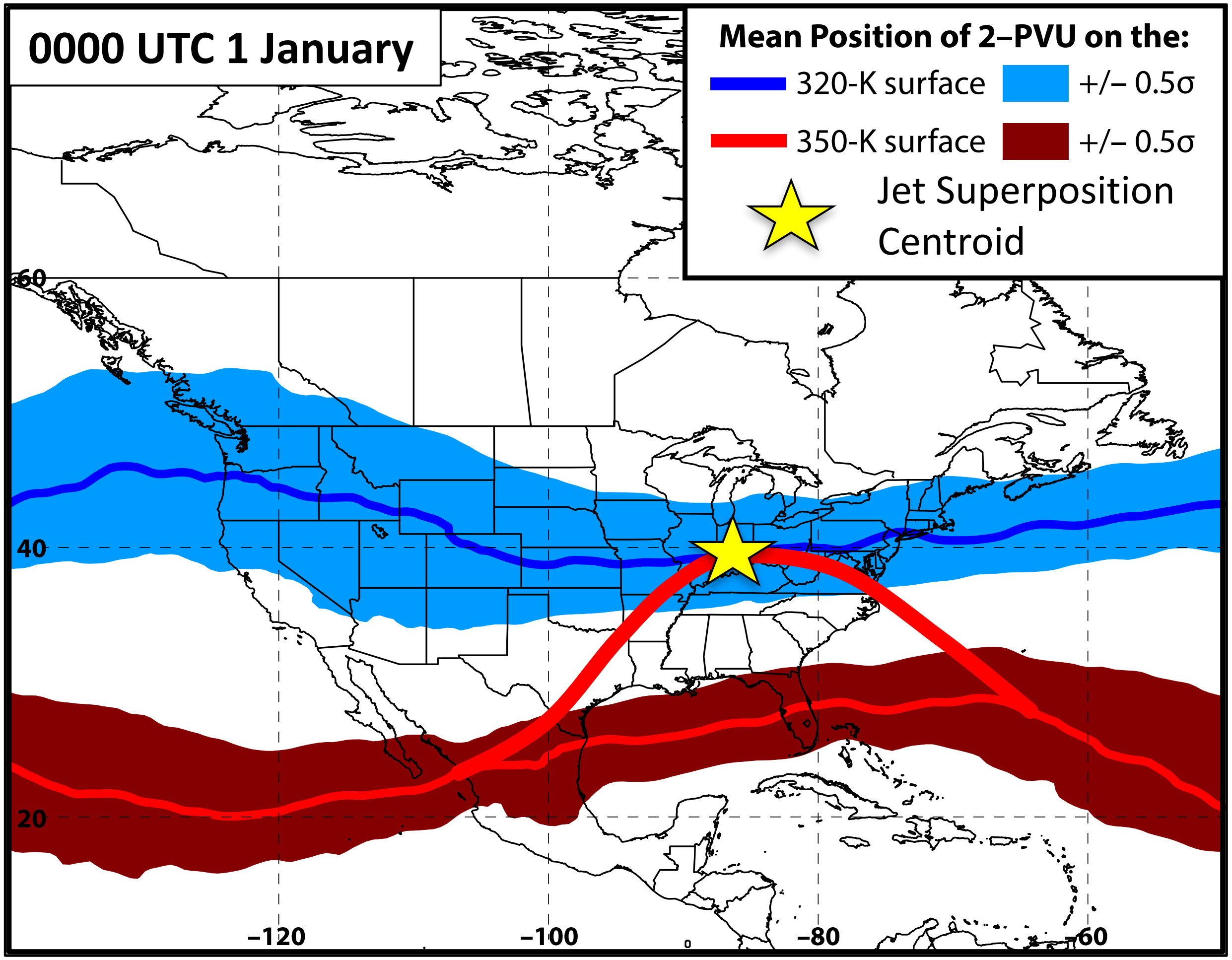
- **Polar Dominant**



# Jet Superposition Event Classification

1. Determined the mean position of the 2-PVU contour on the 320-K and 350-K surfaces at each analysis time in the CFSR.
2. Compared the position of the jet superposition centroid at the start of each event against the climatological position of the 2-PVU contour.

- Polar Dominant
- **Subtropical Dominant**

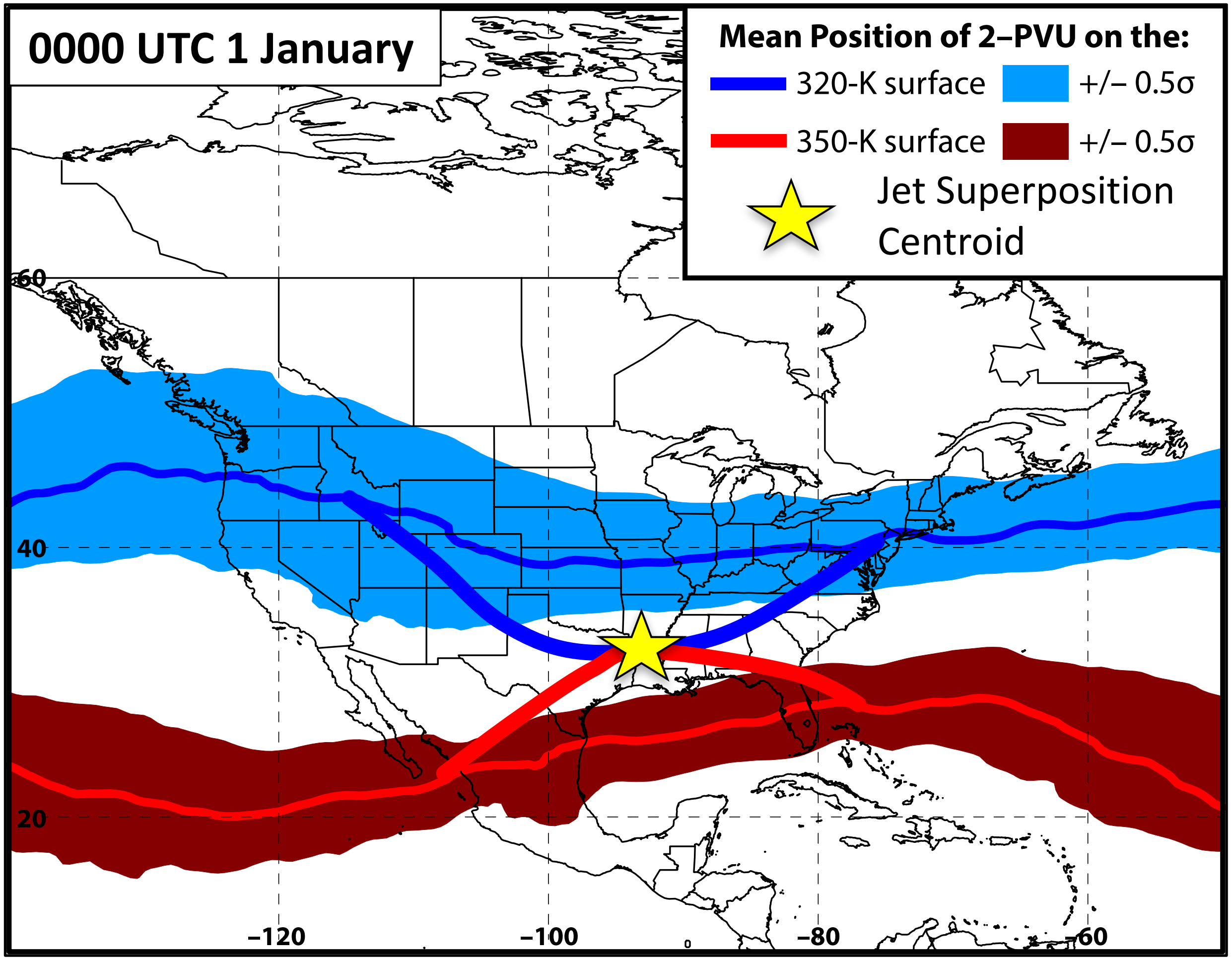


# Jet Superposition Event Classification

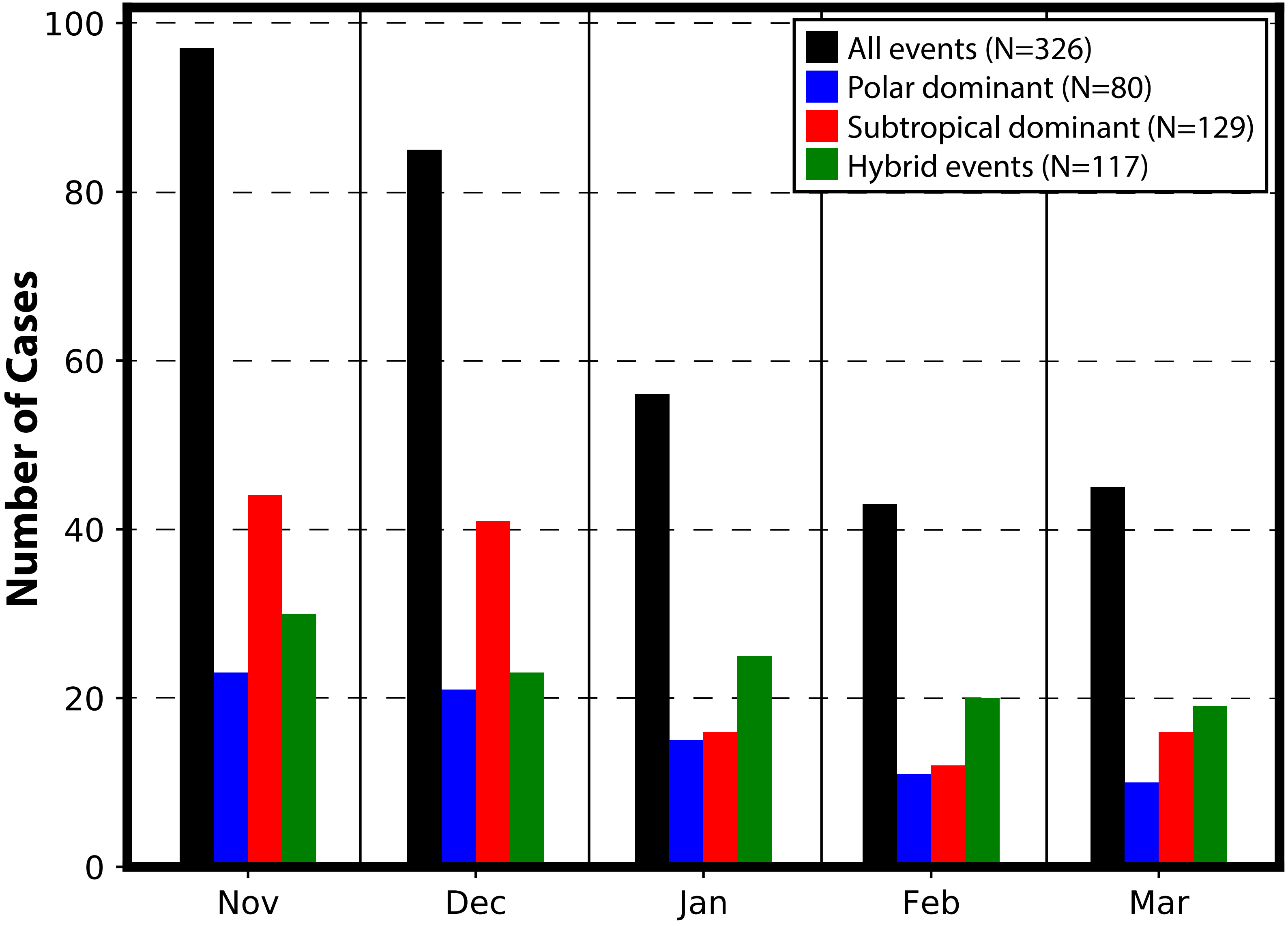
1. Determined the mean position of the 2-PVU contour on the 320-K and 350-K surfaces at each analysis time in the CFSR.

2. Compared the position of the jet superposition centroid at the start of each event against the climatological position of the 2-PVU contour.

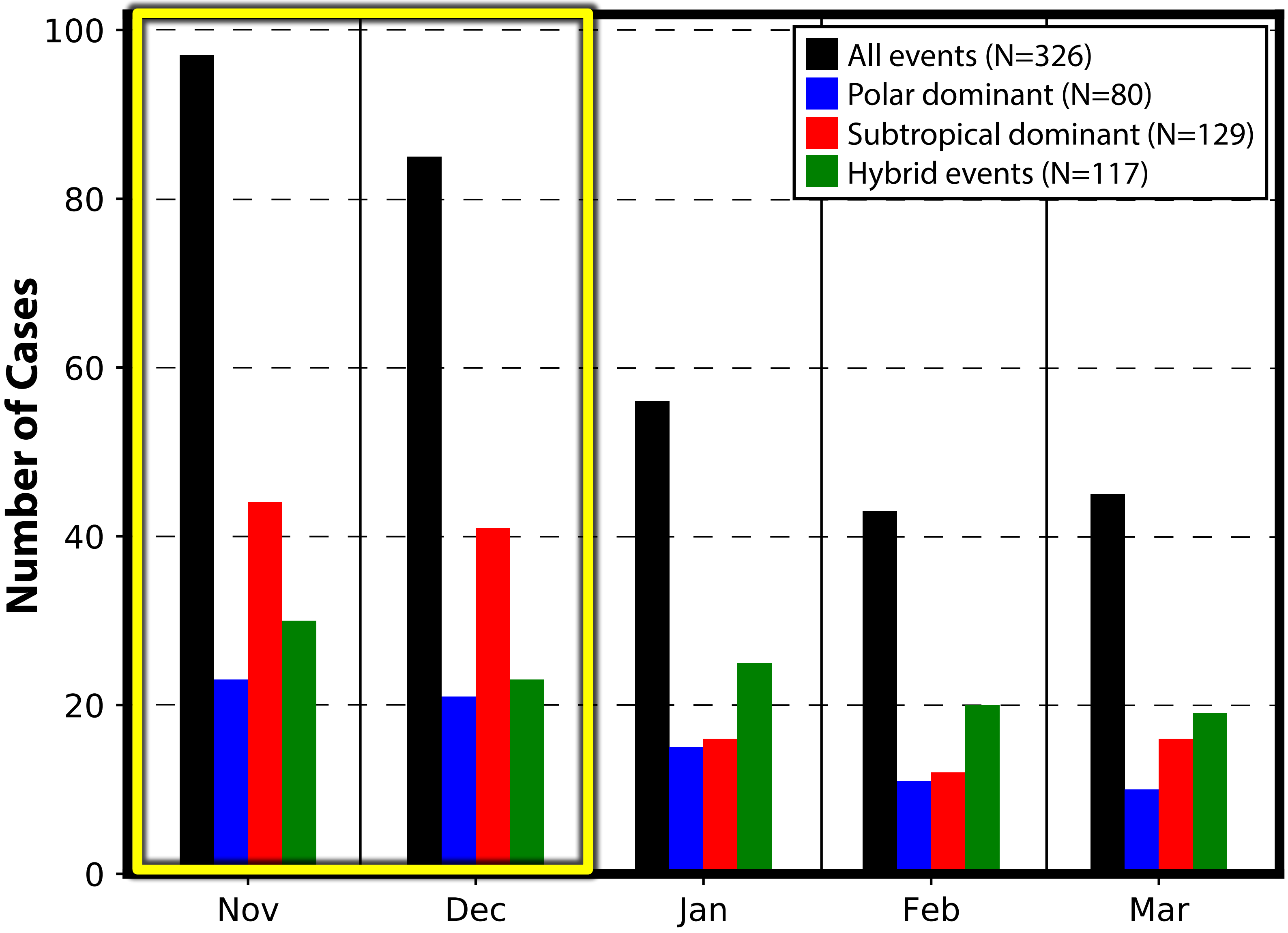
- Polar Dominant
- Subtropical Dominant
- **Hybrid**



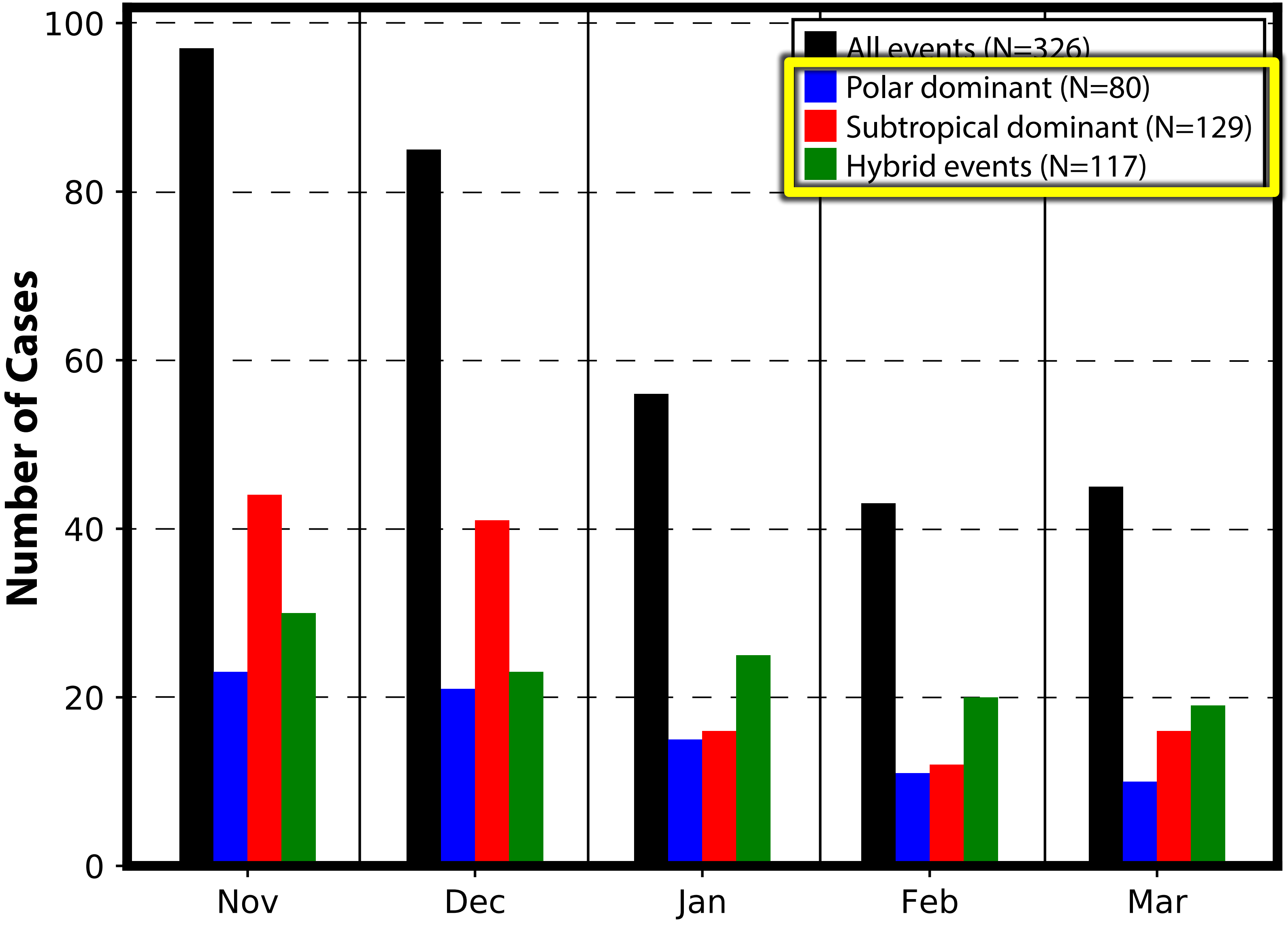
# Jet Superposition Event Classification



# Jet Superposition Event Classification

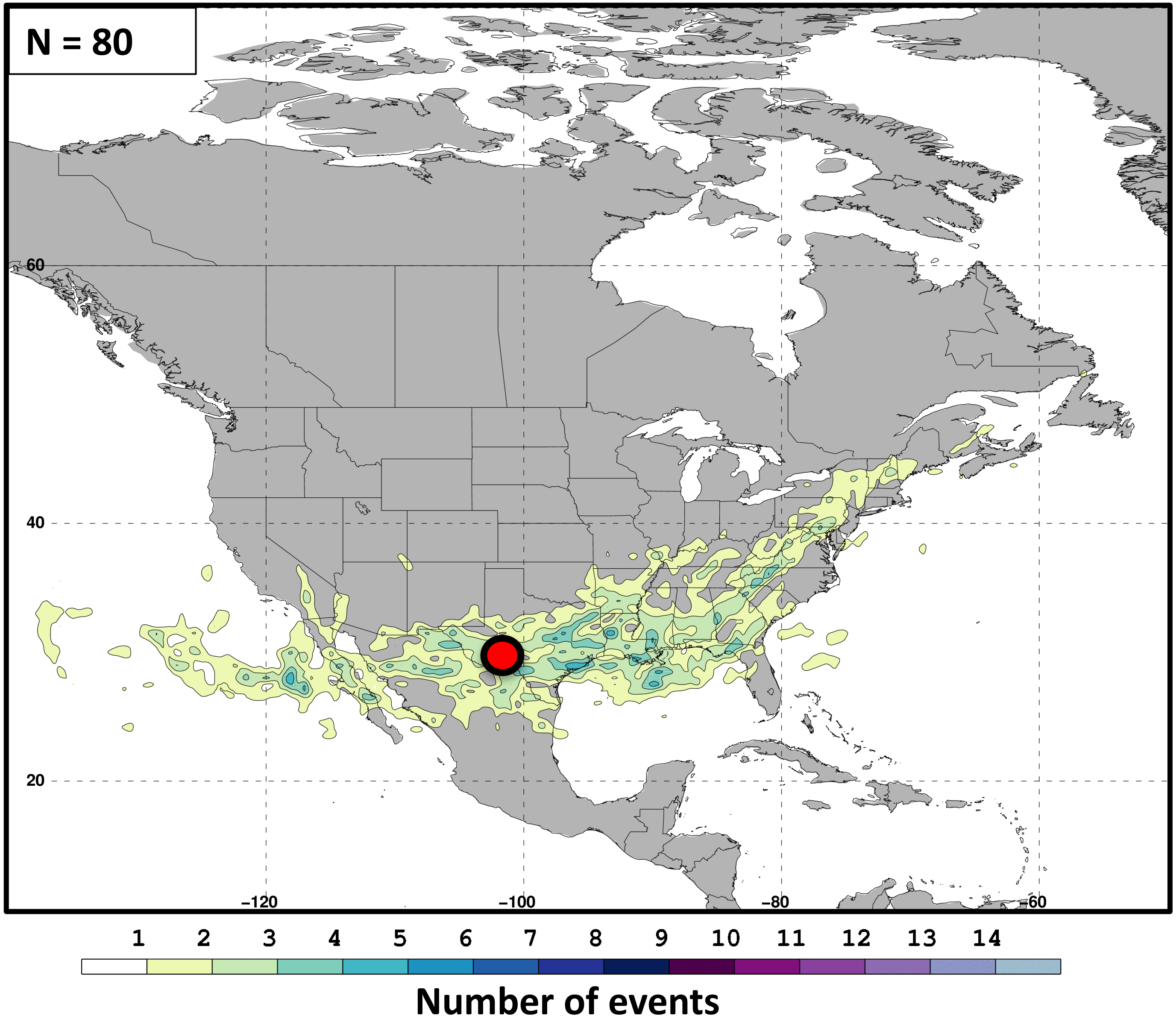


# Jet Superposition Event Classification



# Jet Superposition Event Classification

**Frequency of**
**Polar Dominant**
**Jet**
**Superposition**
**Events**

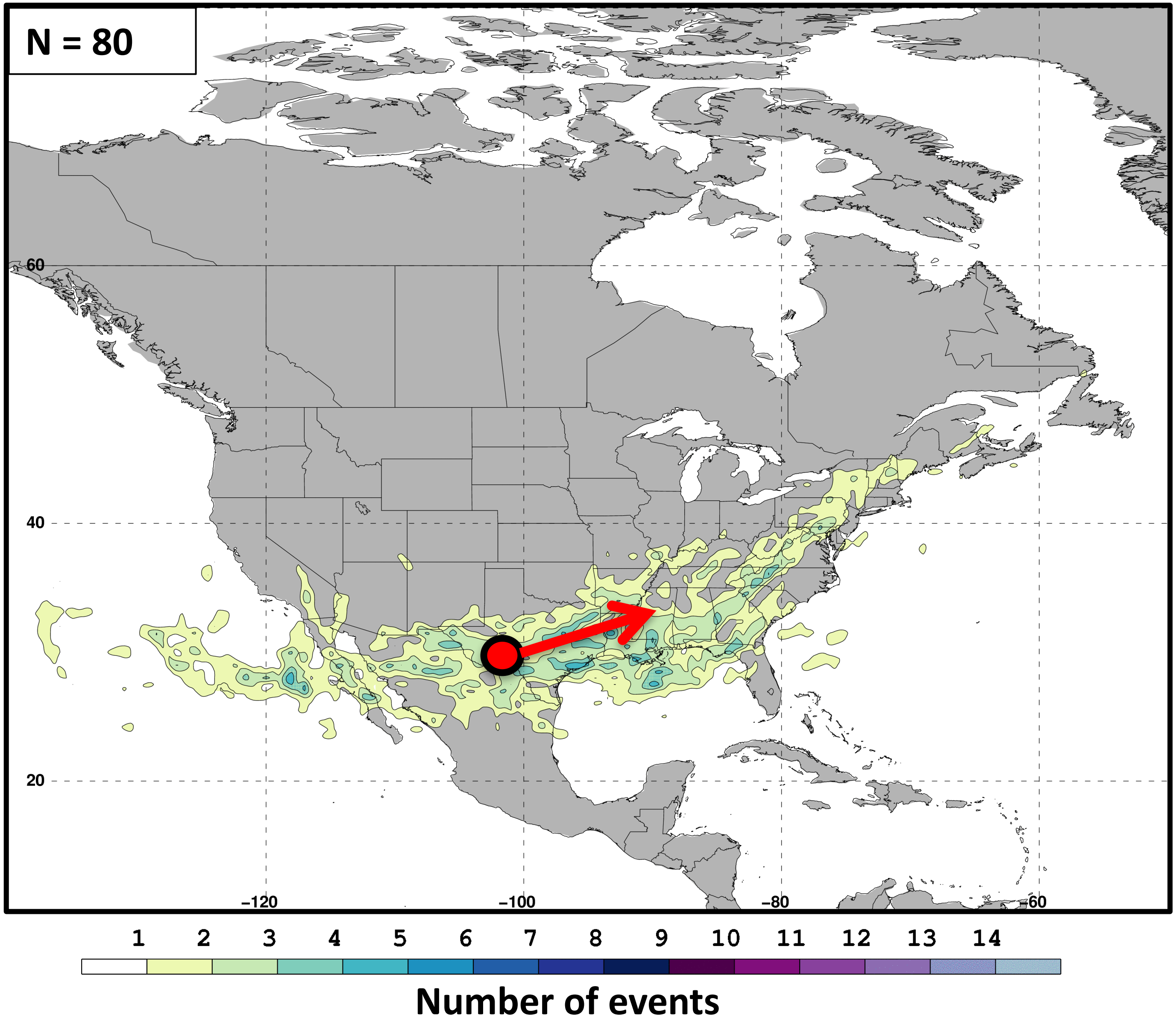


**Legend**

| | |
|---|---|
| ● | Centroid of all events |
| → | Composite movement of superposition |

# Jet Superposition Event Classification

Frequency of **Polar Dominant** Jet Superposition Events

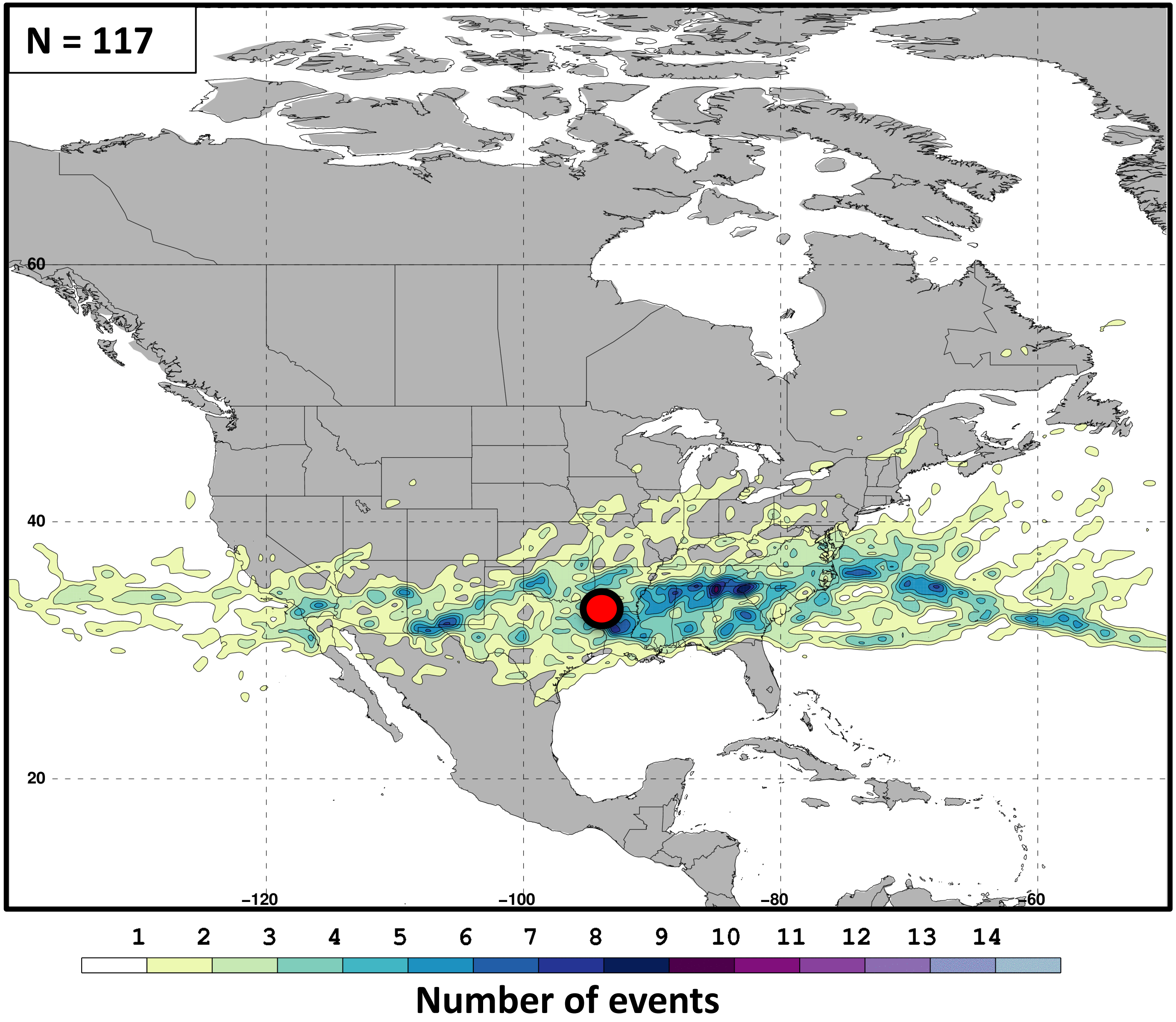


**Legend**

- ● Centroid of all events
- → Composite movement of superposition

# Jet Superposition Event Classification

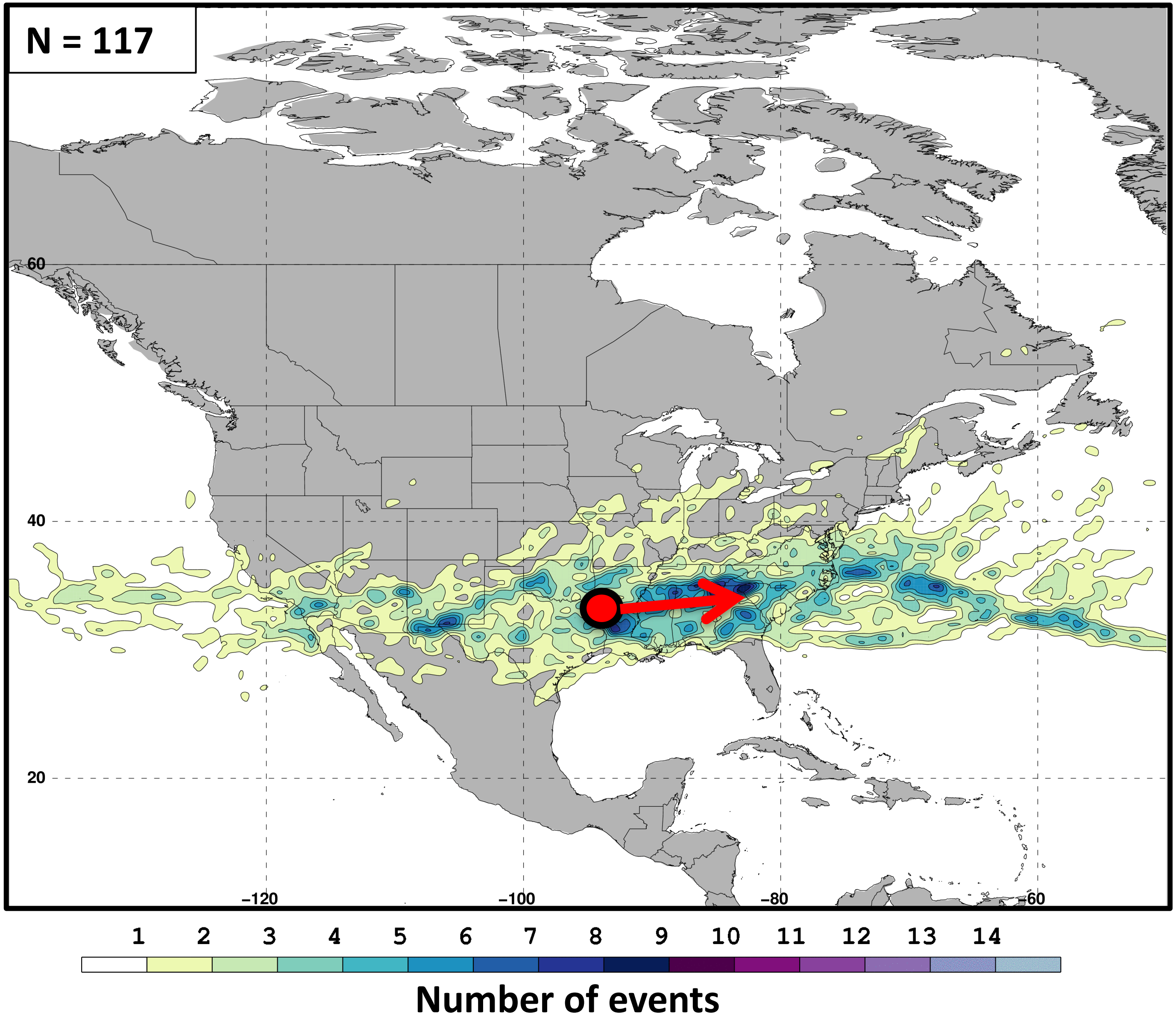
**Frequency of**
**Hybrid**
**Jet**
**Superposition**
**Events**



| **Legend** | |
|---|---|
| ● | Centroid of all events |
| → | Composite movement of superposition |

# Jet Superposition Event Classification

Frequency of
Hybrid
Jet
Superposition
Events

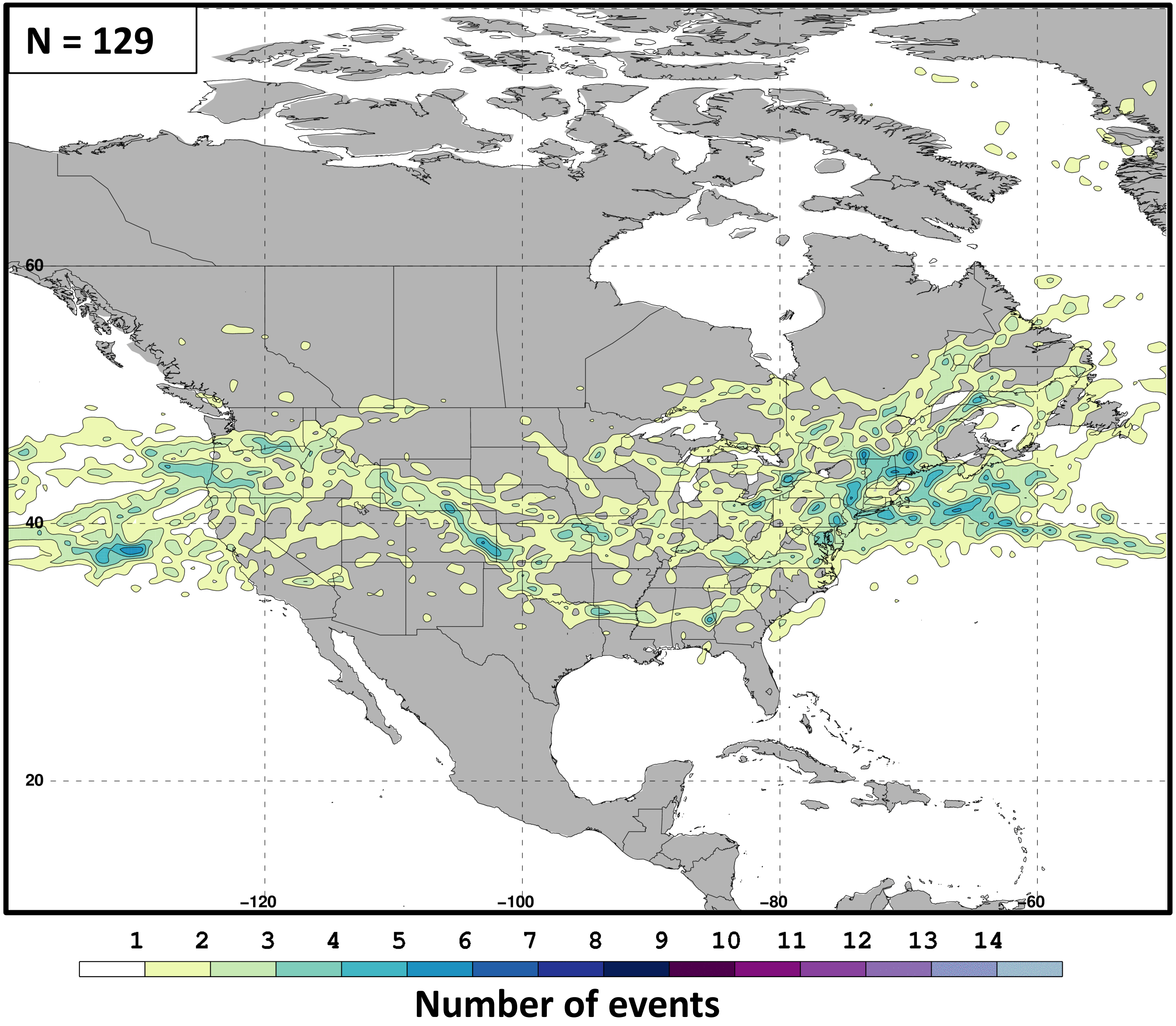


**Legend**

| | |
|---|---|
| ● | Centroid of all events |
| → | Composite movement of superposition |

# Jet Superposition Event Classification

Frequency of **Subtropical Dominant** Jet Superposition Events

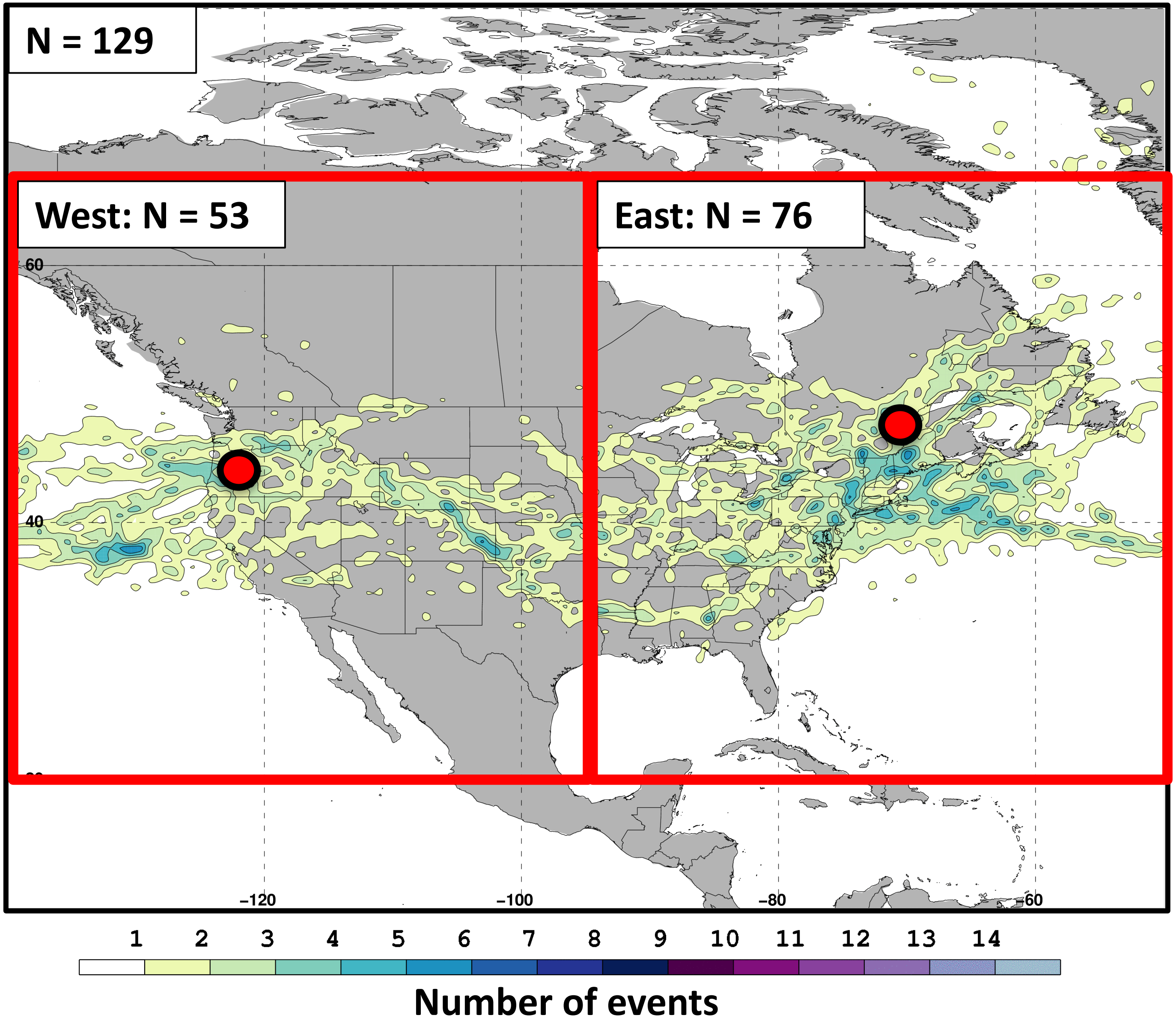


**Legend**

- ● Centroid of all events
- → Composite movement of superposition

# Jet Superposition Event Classification

**Frequency of Subtropical Dominant Jet Superposition Events**

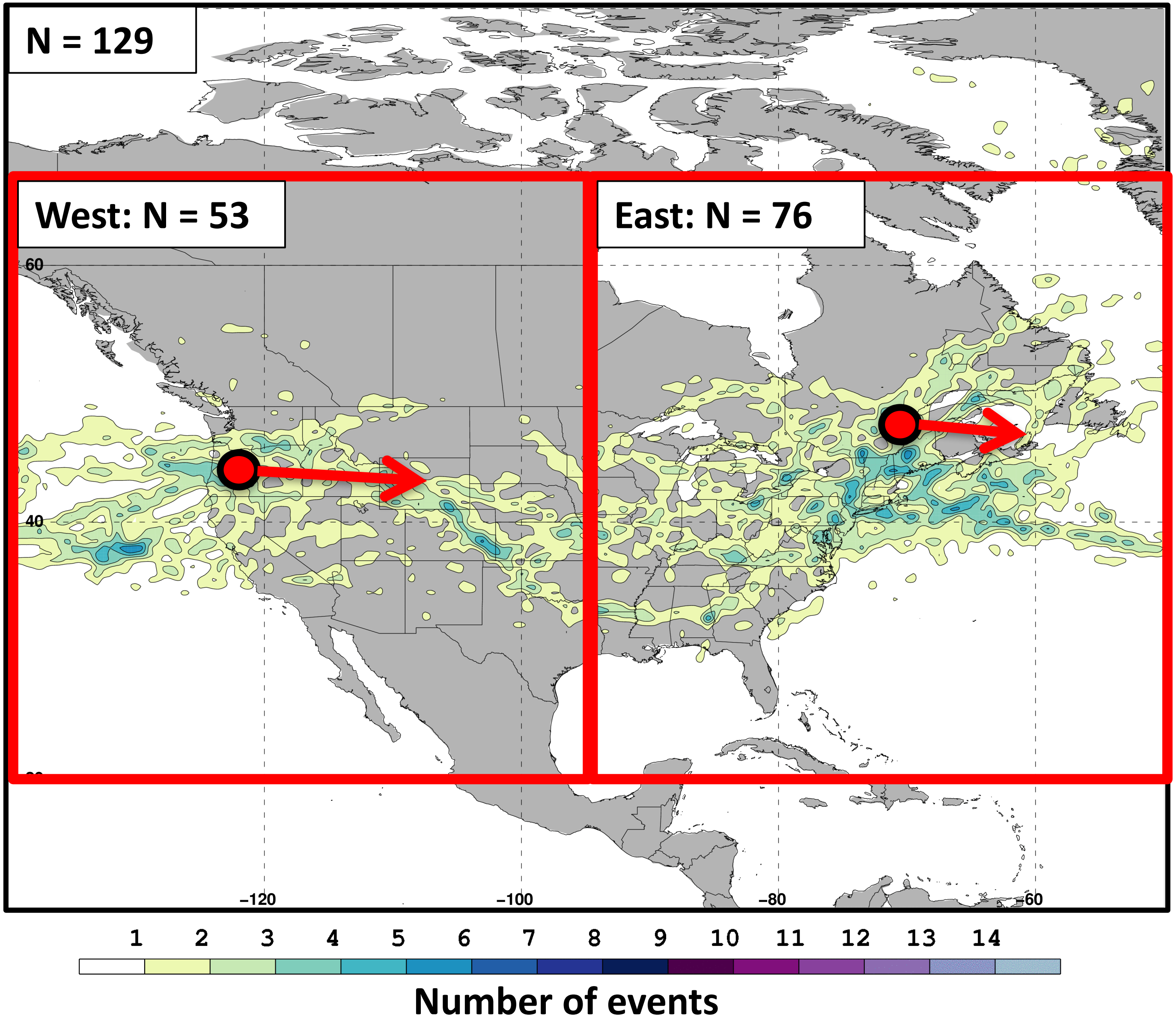


**Legend**

- ● Centroid of all events
- → Composite movement of superposition

# Jet Superposition Event Classification

**Frequency of Subtropical Dominant Jet Superposition Events**



**Legend**

● Centroid of all events

→ Composite movement of superposition

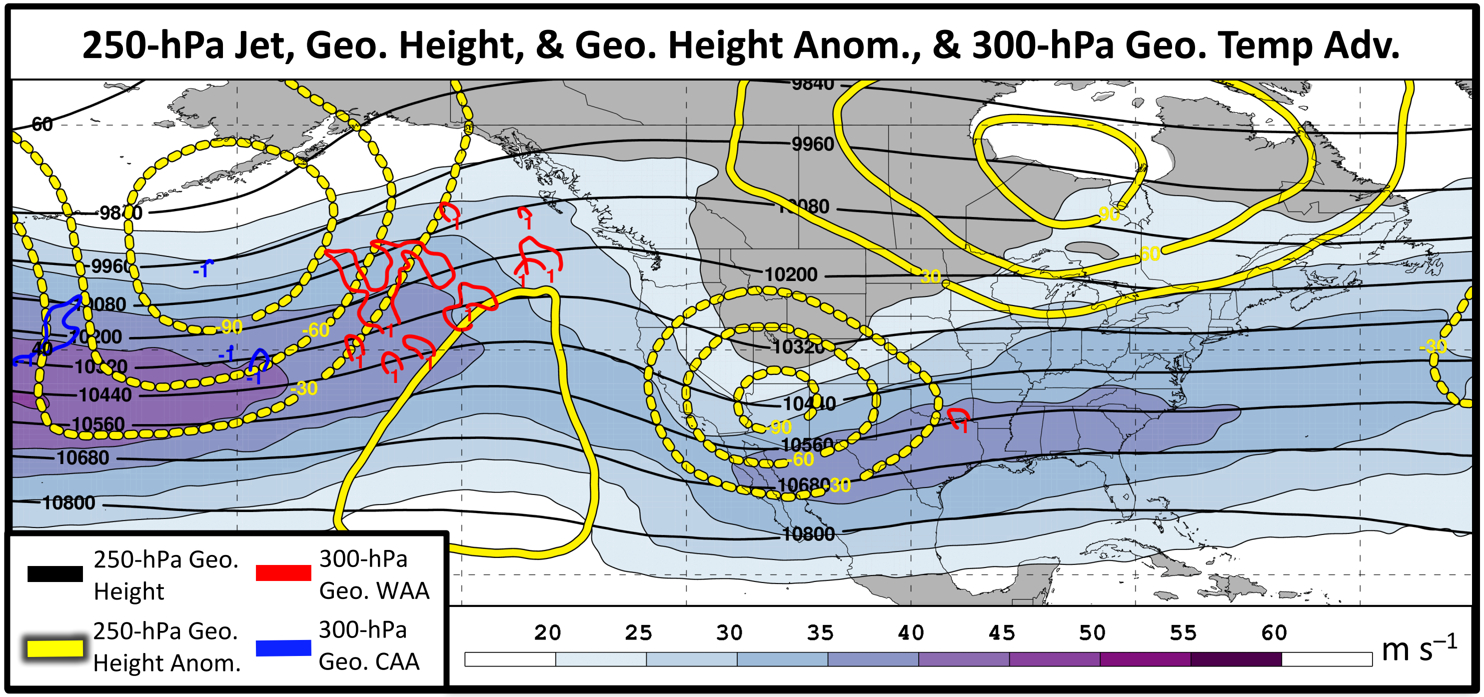
# Jet Superposition Event Composites:

## Polar Dominant
## vs.
## East Subtropical Dominant

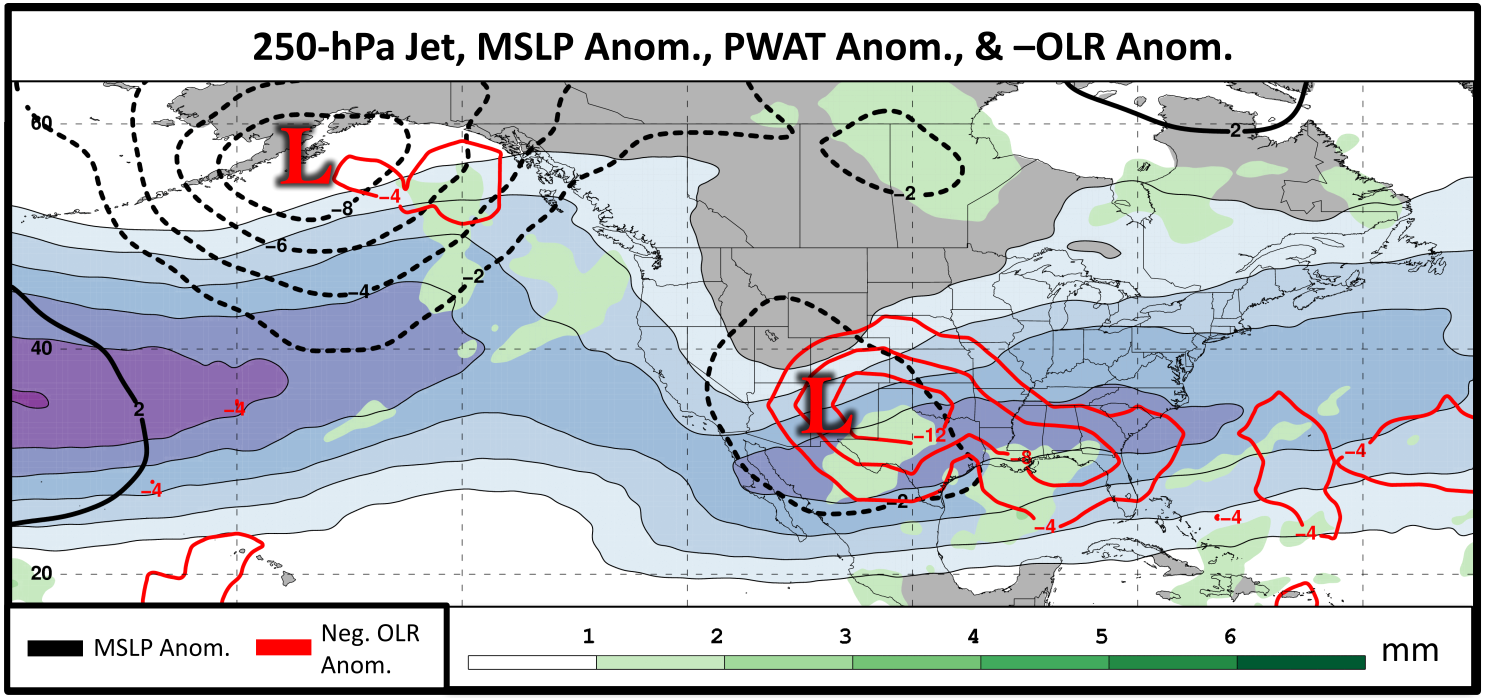
# Polar Dominant Jet Superposition Events

**2 Days Prior to Jet Superposition**

**N=80**



250-hPa Jet, Geo. Height, & Geo. Height Anom., & 300-hPa Geo. Temp Adv.



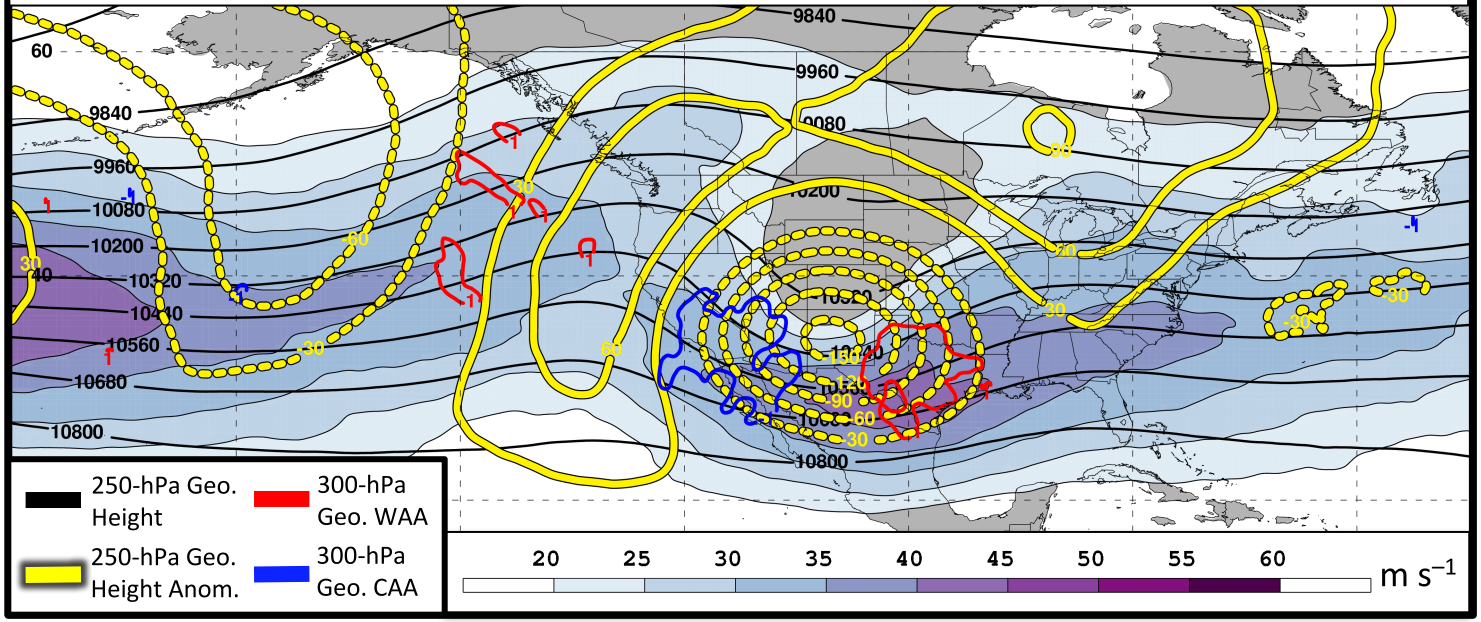
250-hPa Jet, MSLP Anom., PWAT Anom., & –OLR Anom.

# Polar Dominant Jet Superposition Events

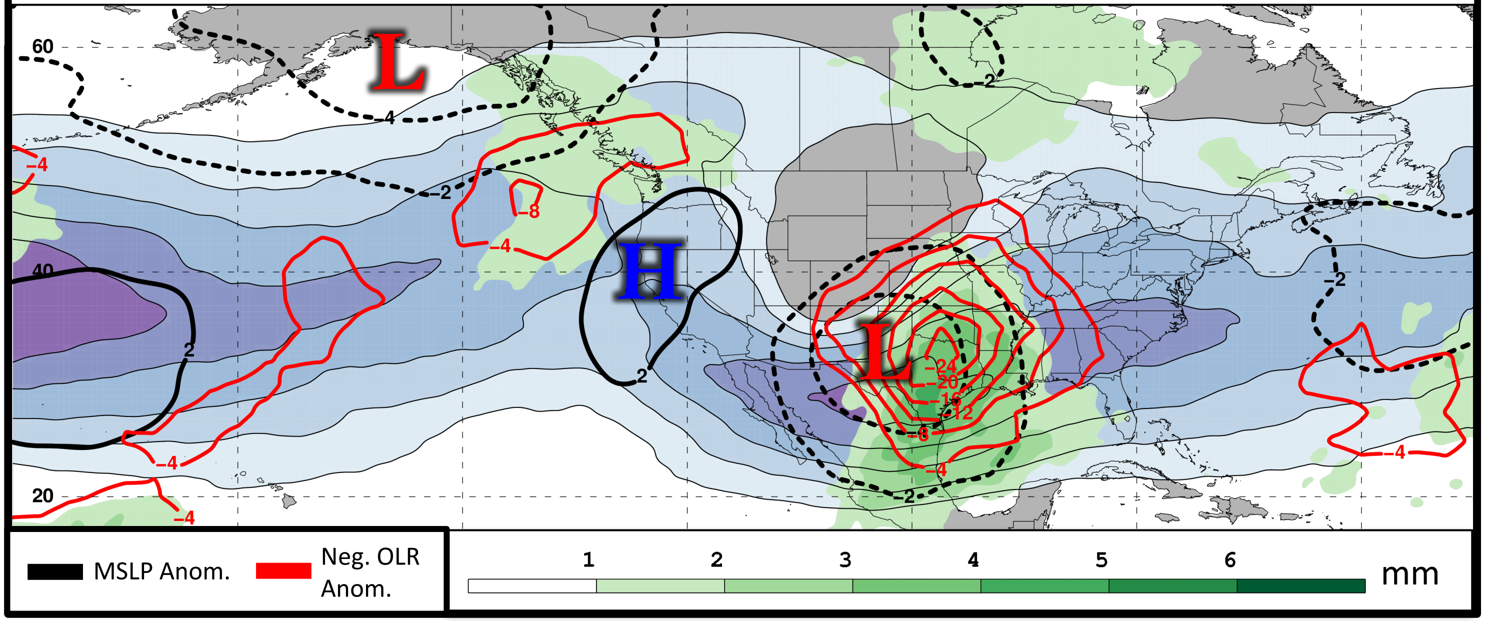
**1 Day Prior to Jet Superposition**

**N=80**

250-hPa Jet, Geo. Height, & Geo. Height Anom., & 300-hPa Geo. Temp Adv.



250-hPa Jet, MSLP Anom., PWAT Anom., & –OLR Anom.



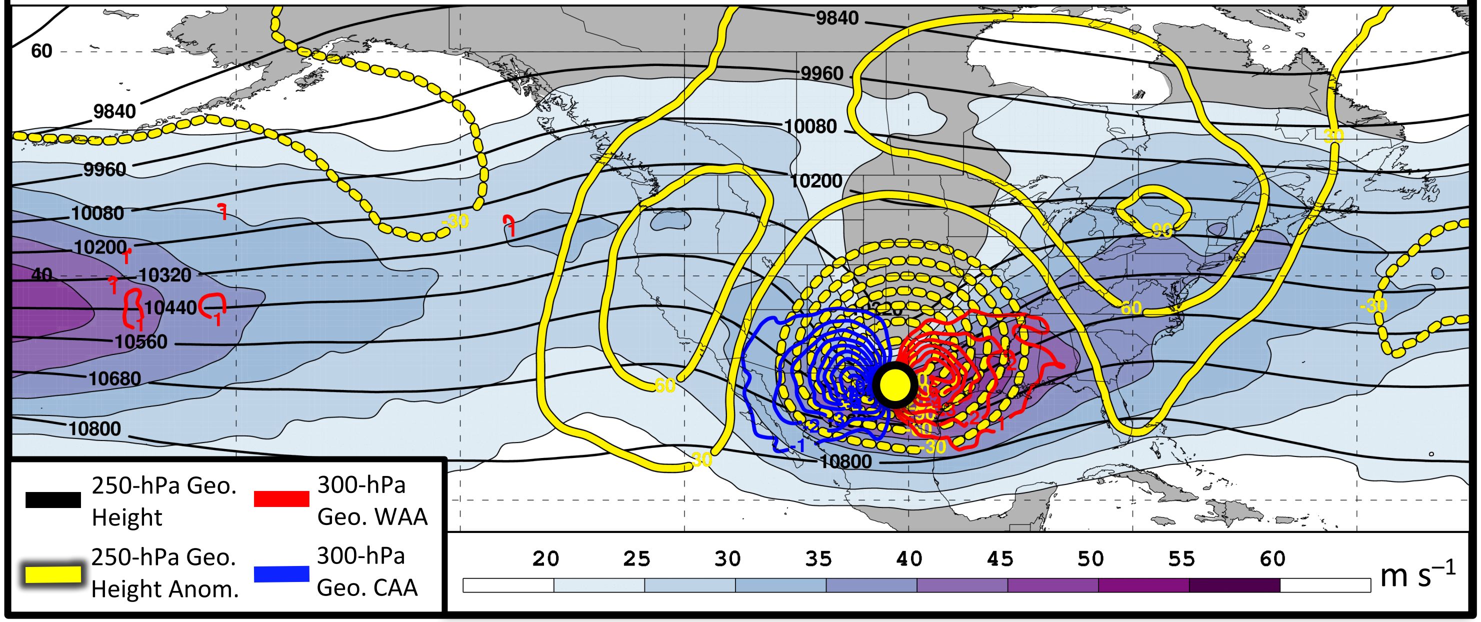
# Polar Dominant Jet Superposition Events

## 0 Days Prior to Jet Superposition

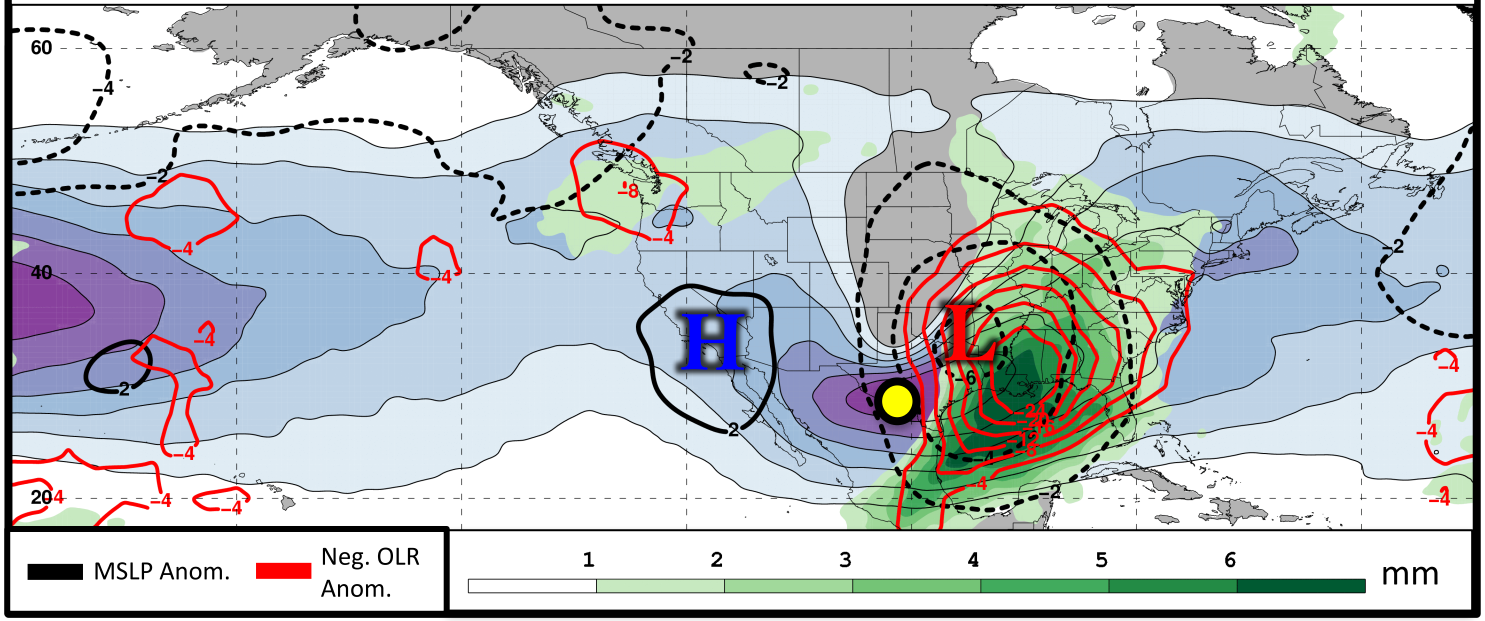
● Jet Superposition Centroid

**N=80**

250-hPa Jet, Geo. Height, & Geo. Height Anom., & 300-hPa Geo. Temp Adv.



250-hPa Jet, MSLP Anom., PWAT Anom., & –OLR Anom.



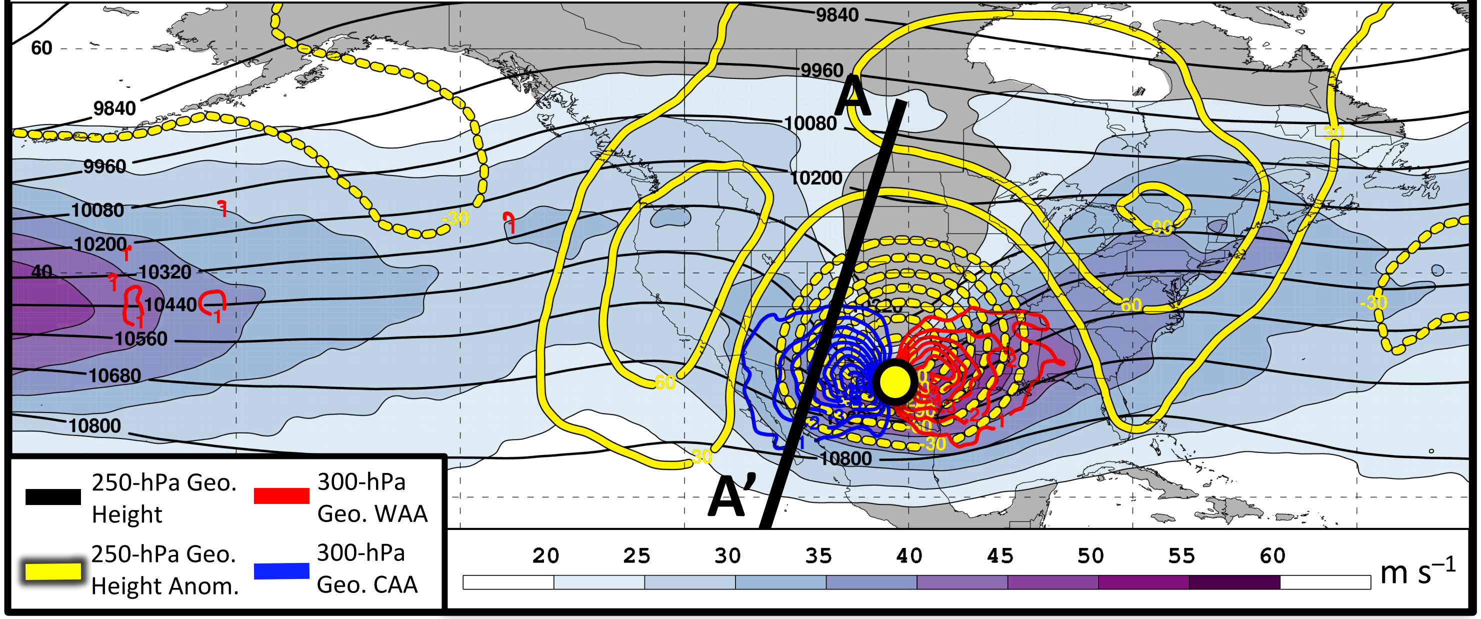
# Polar Dominant Jet Superposition Events

**0 Days Prior to Jet Superposition**

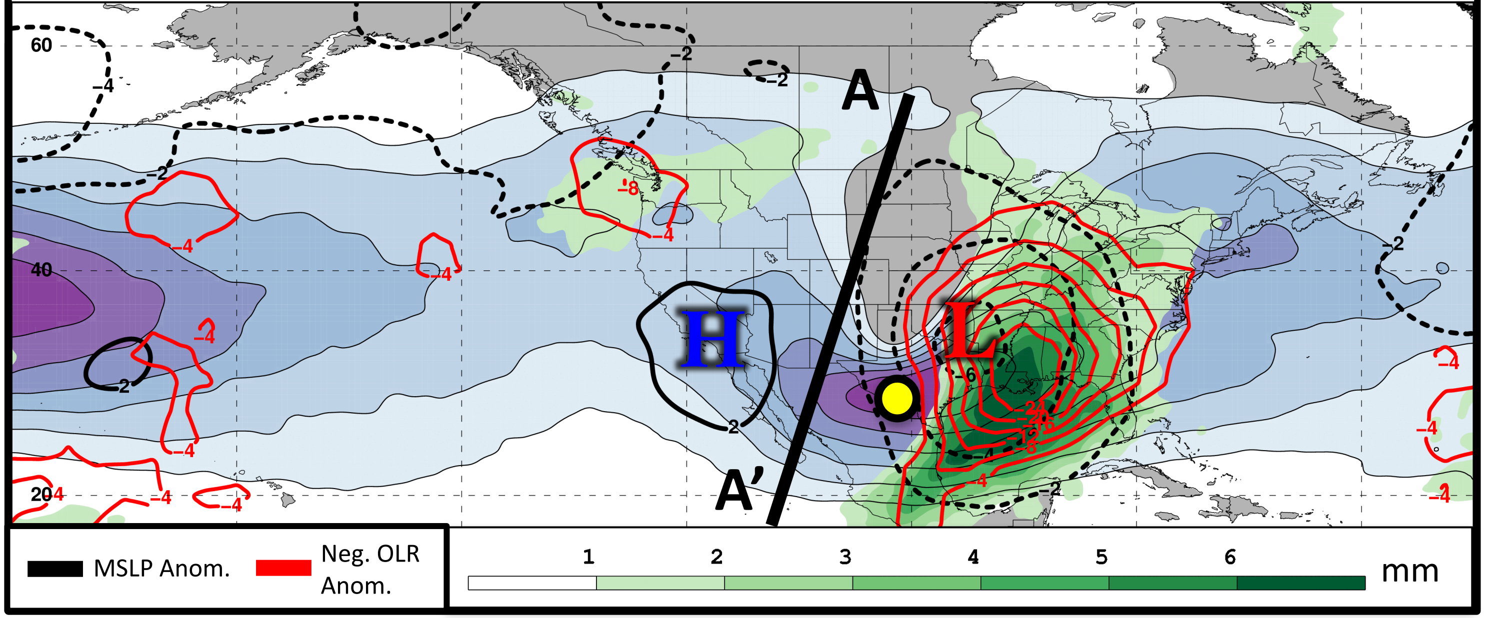
● Jet Superposition Centroid

**N=80**

**250-hPa Jet, Geo. Height, & Geo. Height Anom., & 300-hPa Geo. Temp Adv.**



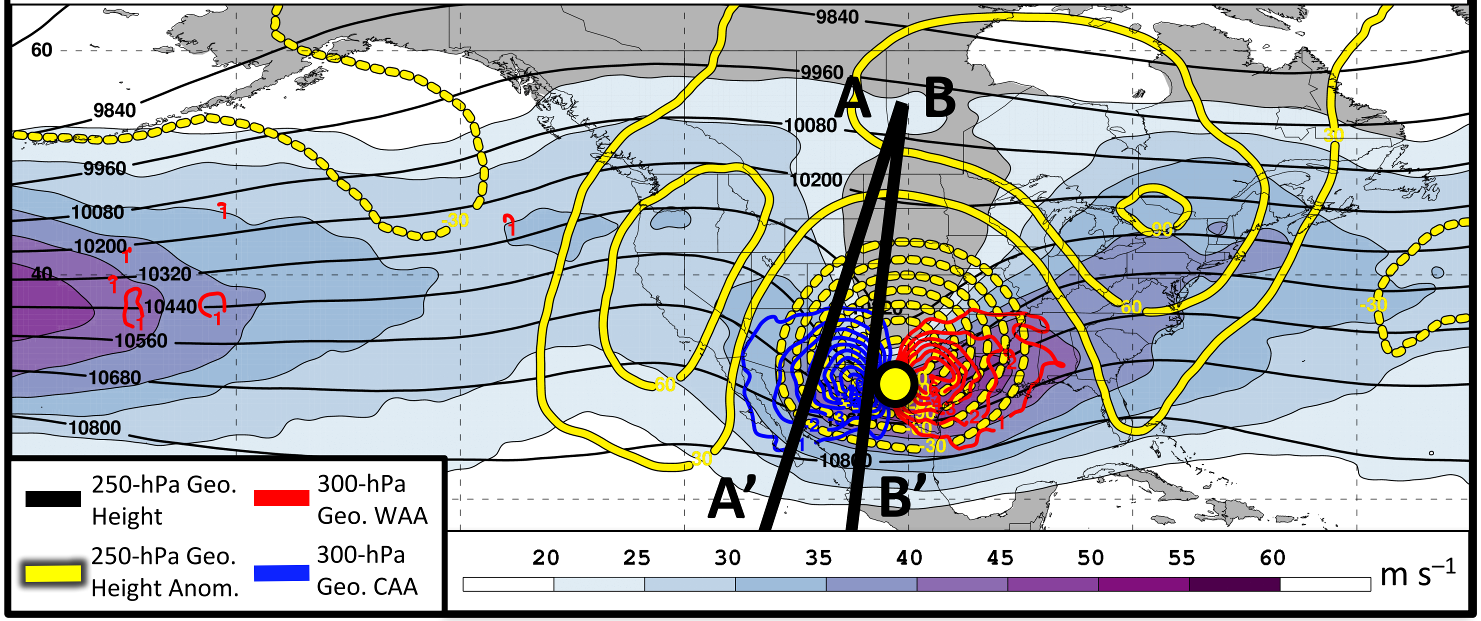
**250-hPa Jet, MSLP Anom., PWAT Anom., & –OLR Anom.**



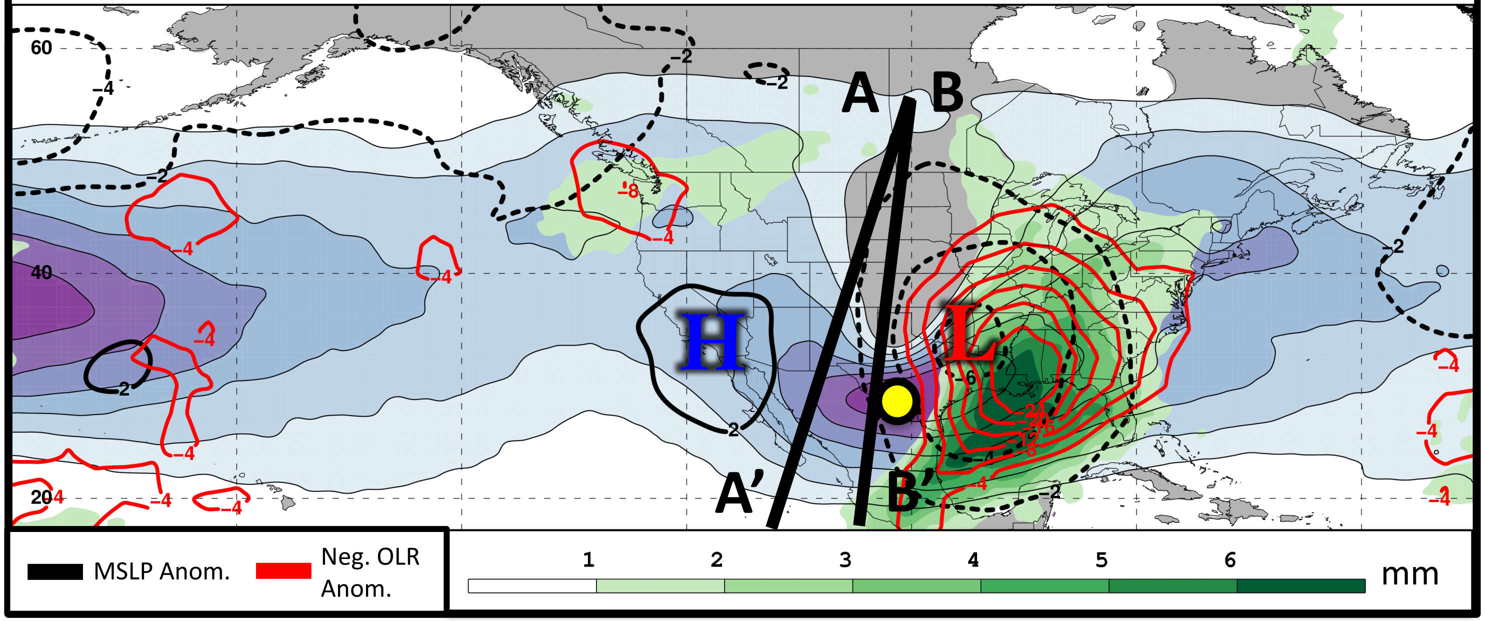
# Polar Dominant Jet Superposition Events

**0 Days Prior to Jet Superposition**

250-hPa Jet, Geo. Height, & Geo. Height Anom., & 300-hPa Geo. Temp Adv.



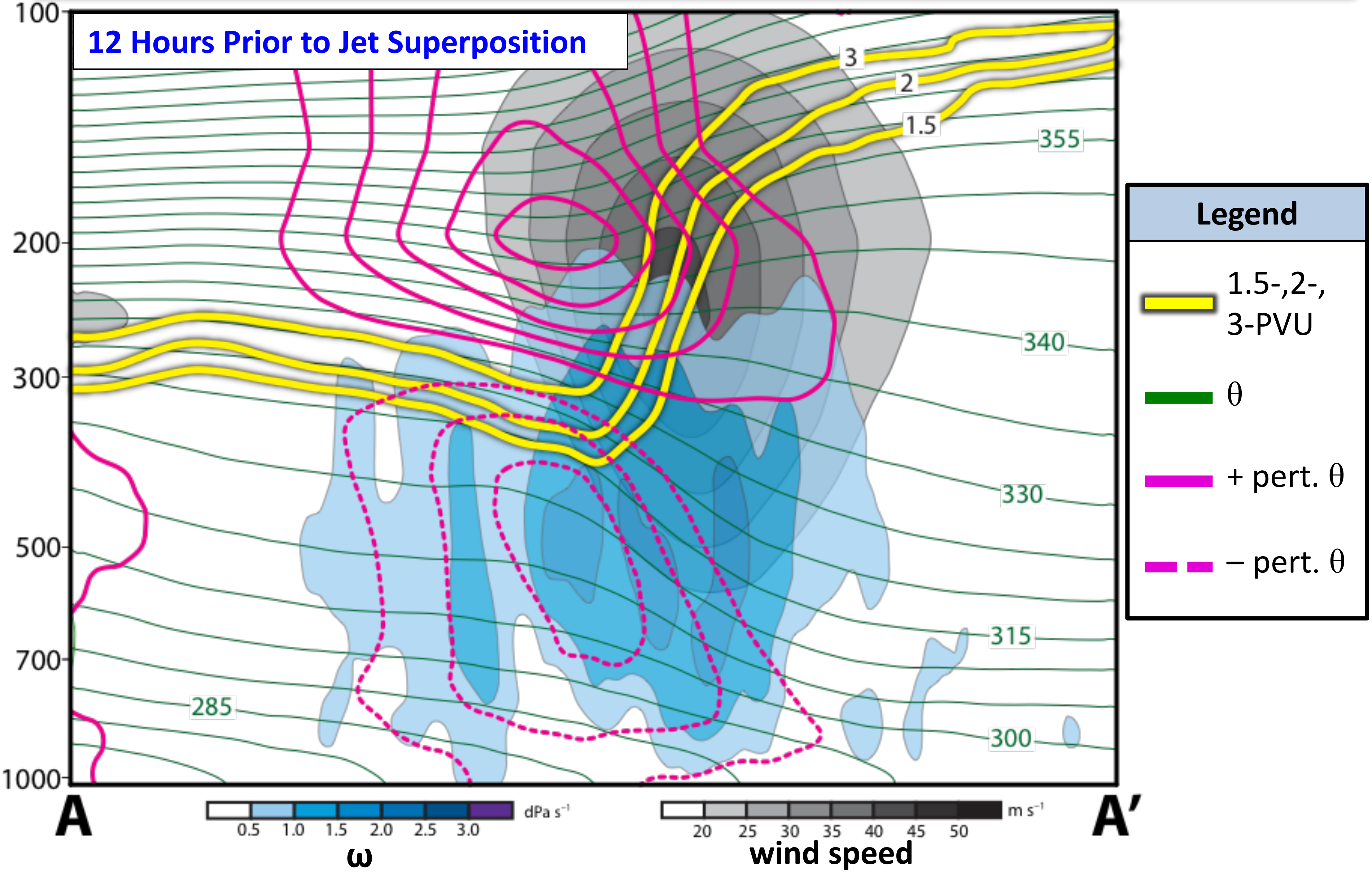
250-hPa Jet, MSLP Anom., PWAT Anom., & –OLR Anom.



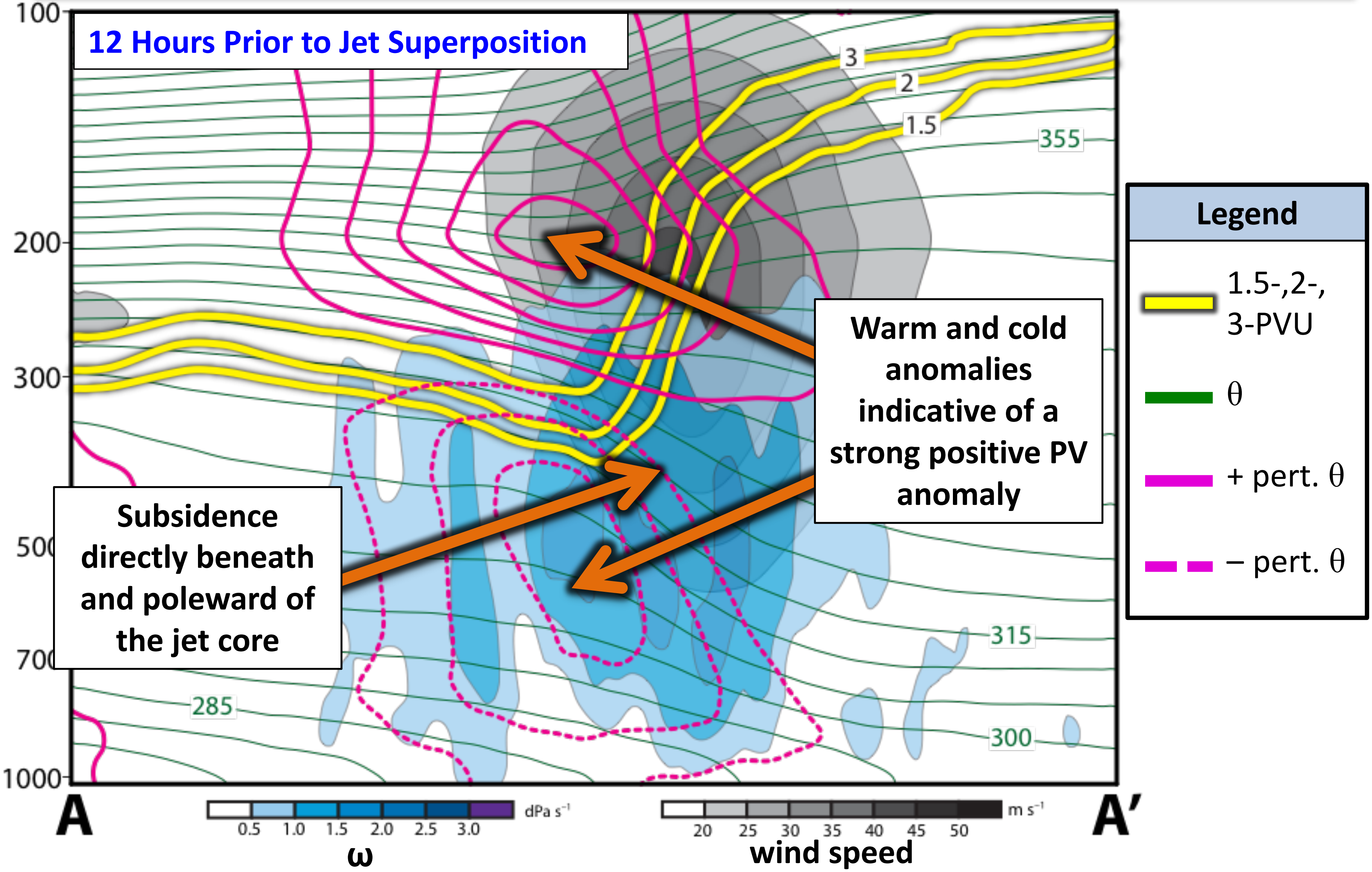
● Jet Superposition Centroid

**N=80**

# Polar Dominant Jet Superposition Events



# Polar Dominant Jet Superposition Events

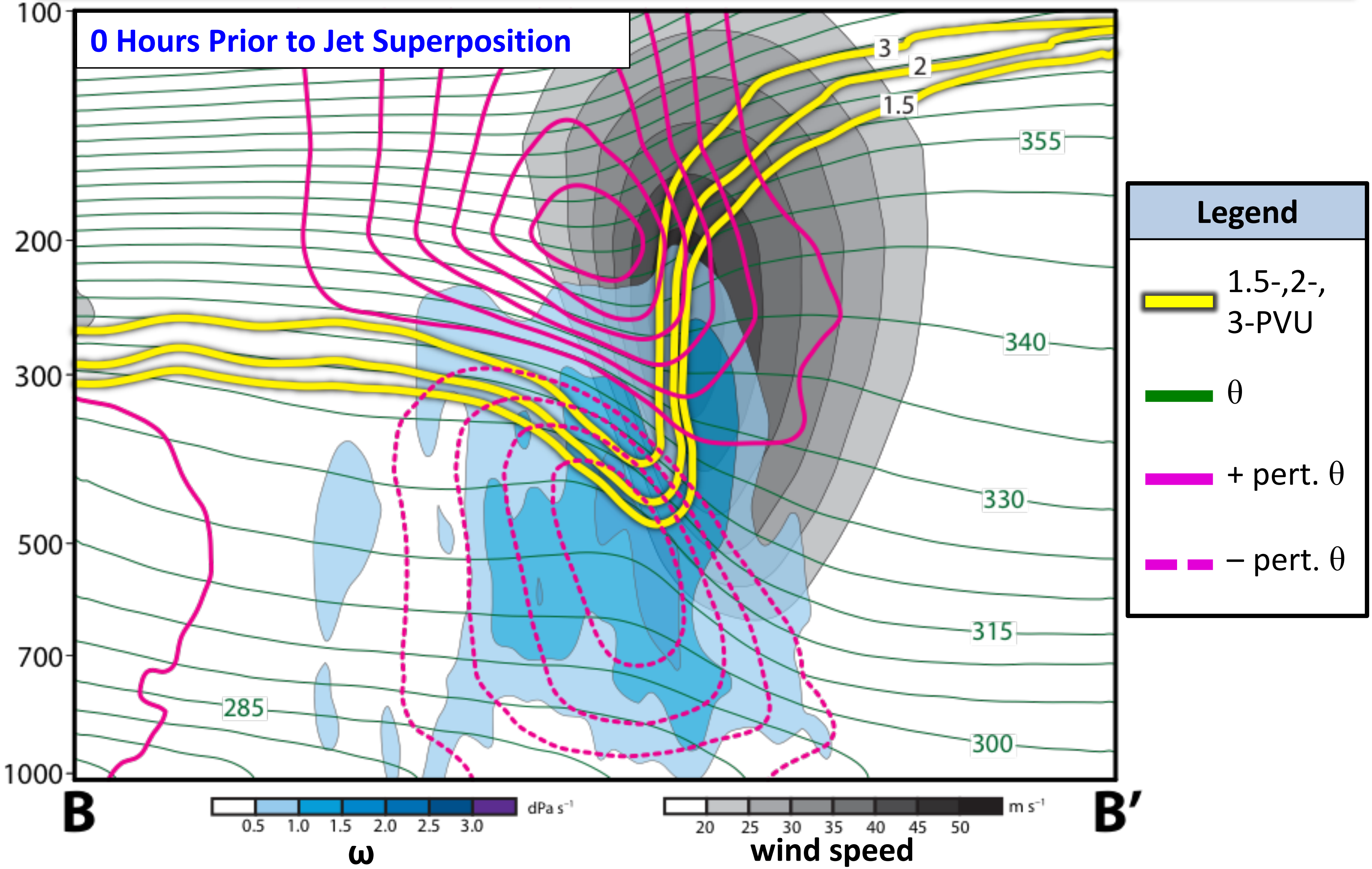


12 Hours Prior to Jet Superposition

Warm and cold anomalies indicative of a strong positive PV anomaly

Subsidence directly beneath and poleward of the jet core

# Polar Dominant Jet Superposition Events

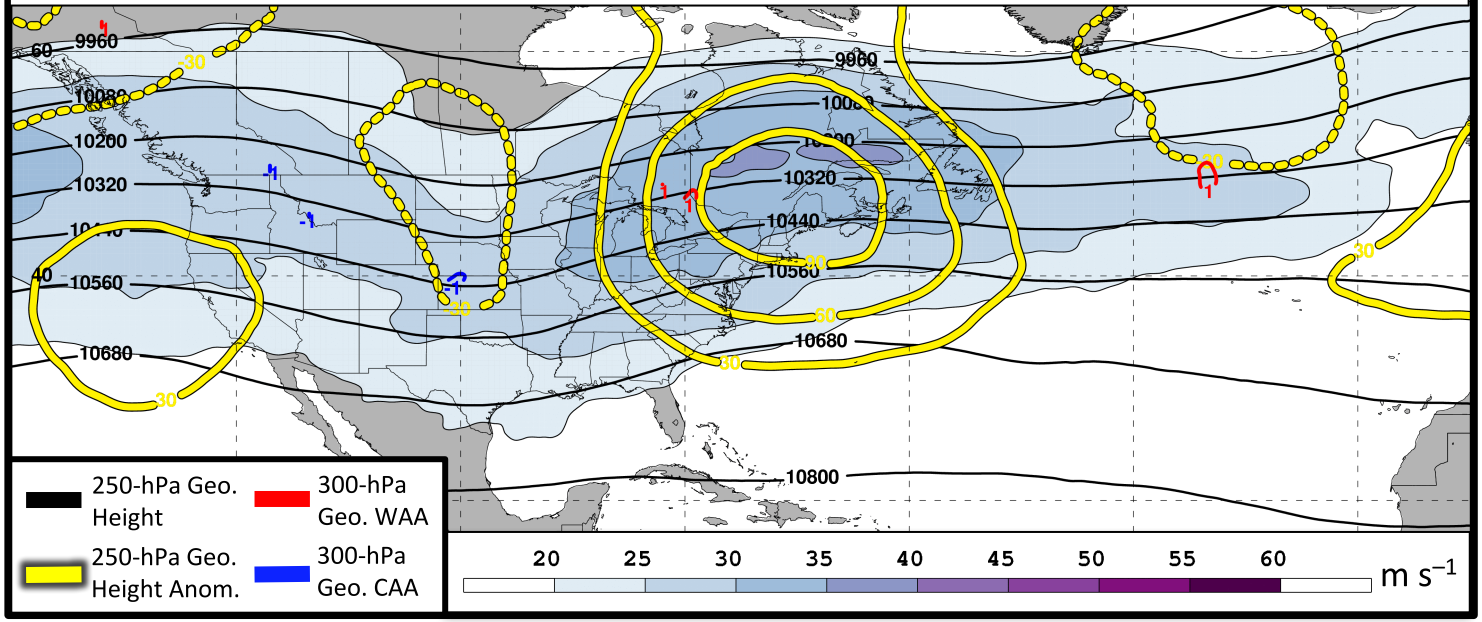


# E. Subtropical Dominant Jet Superposition Events

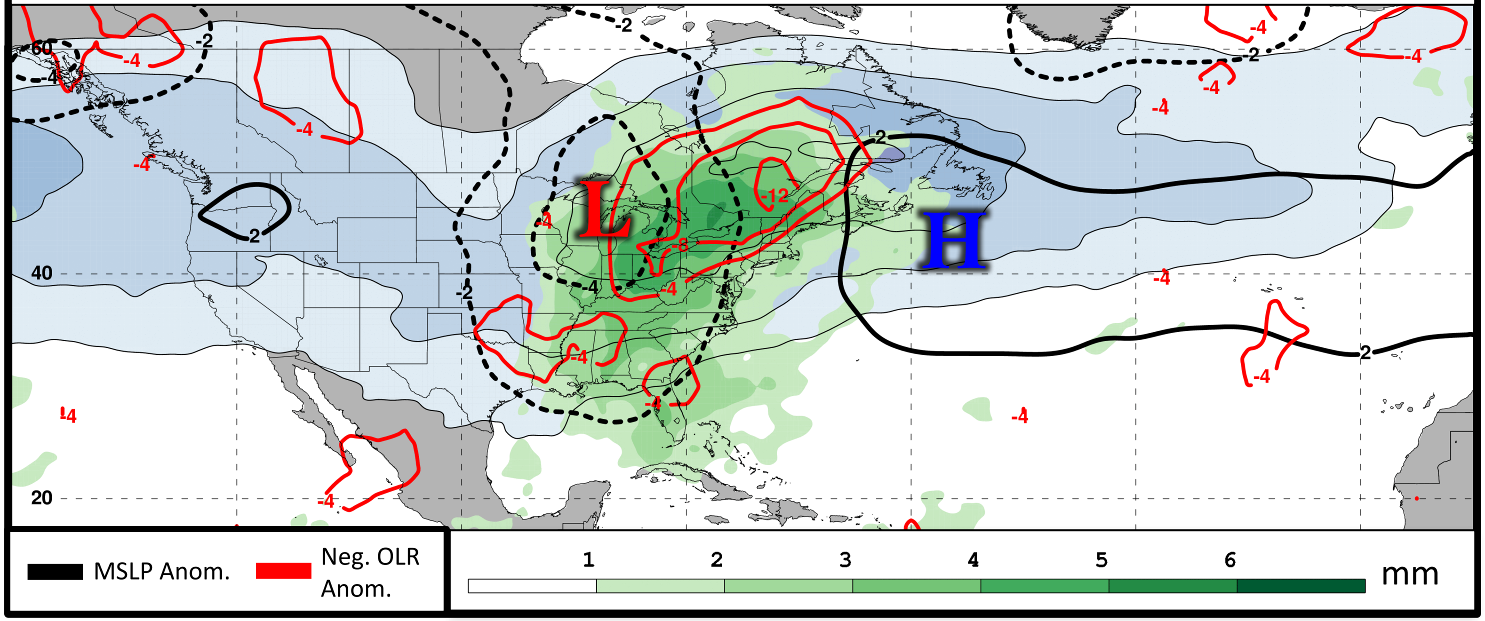
2 Days Prior to Jet Superposition

N=76

250-hPa Jet, Geo. Height, & Geo. Height Anom., & 300-hPa Geo. Temp Adv.



250-hPa Jet, MSLP Anom., PWAT Anom., & –OLR Anom.

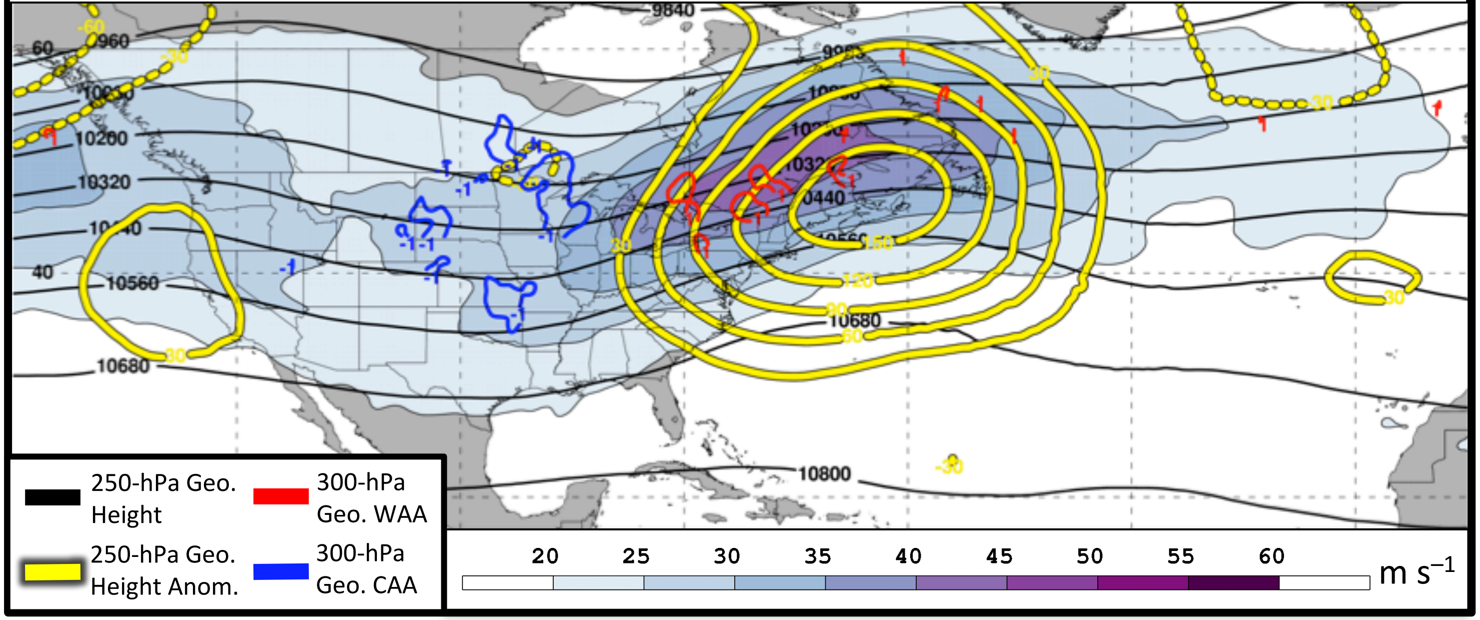


# E. Subtropical Dominant Jet Superposition Events

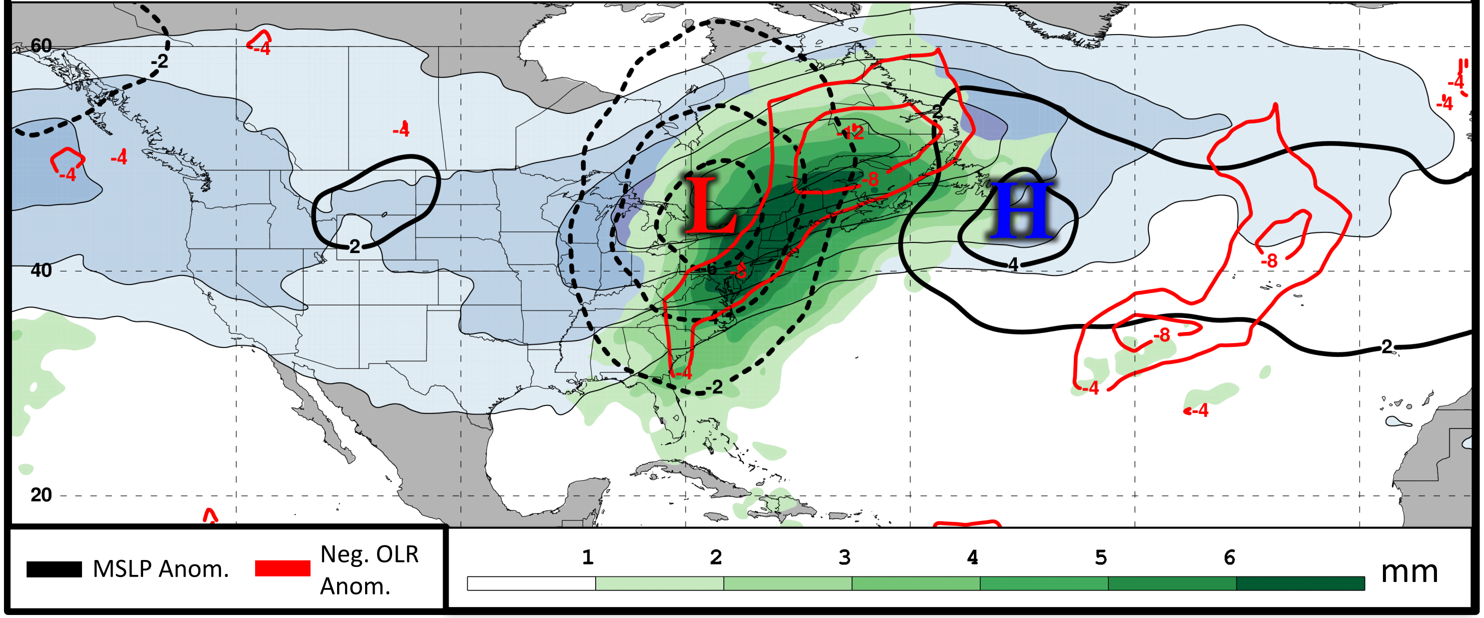
**1 Day Prior to Jet Superposition**

**N=76**

## 250-hPa Jet, Geo. Height, & Geo. Height Anom., & 300-hPa Geo. Temp Adv.



## 250-hPa Jet, MSLP Anom., PWAT Anom., & –OLR Anom.



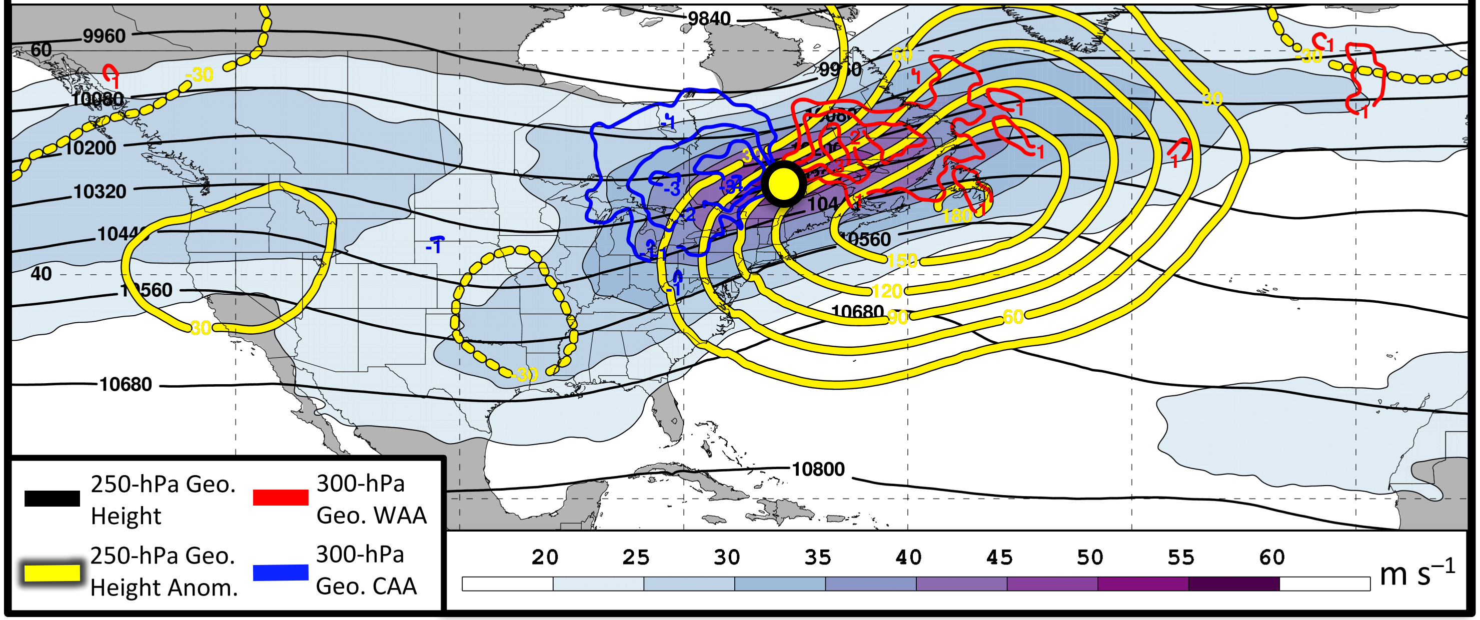
# E. Subtropical Dominant Jet Superposition Events

## 0 Days Prior to Jet Superposition

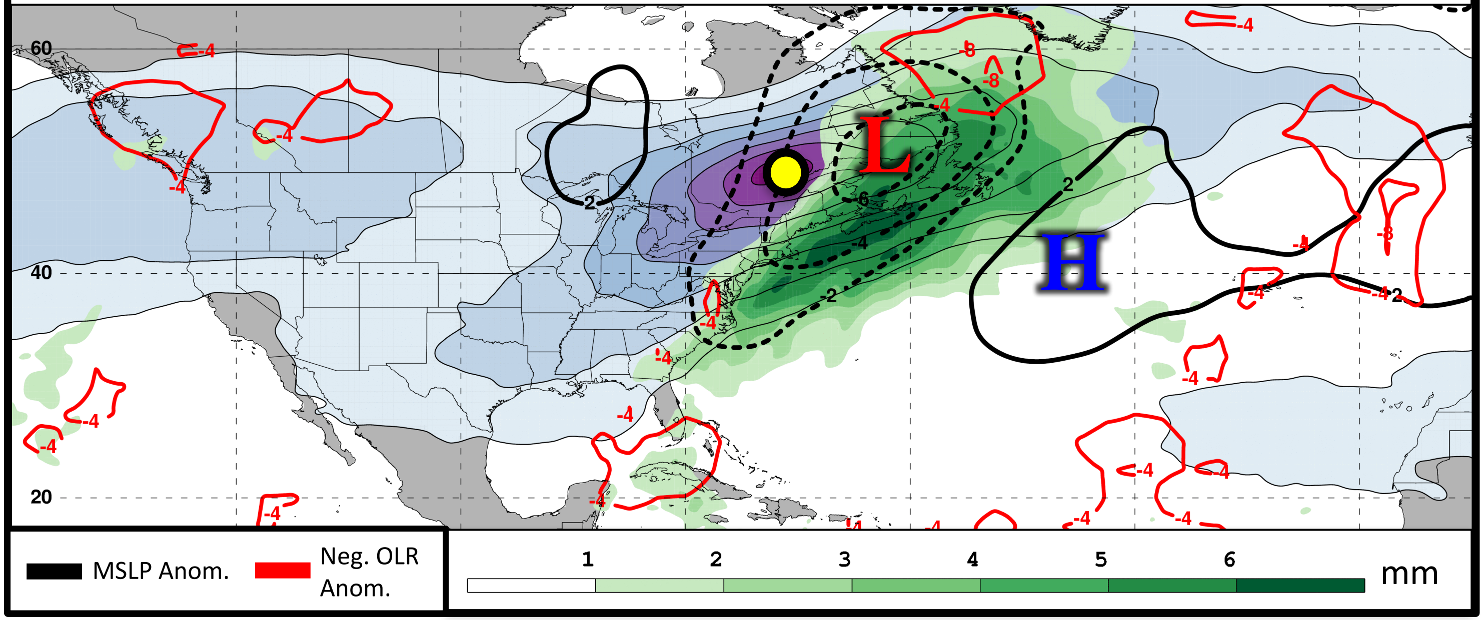
● Jet Superposition Centroid

**N=76**

250-hPa Jet, Geo. Height, & Geo. Height Anom., & 300-hPa Geo. Temp Adv.



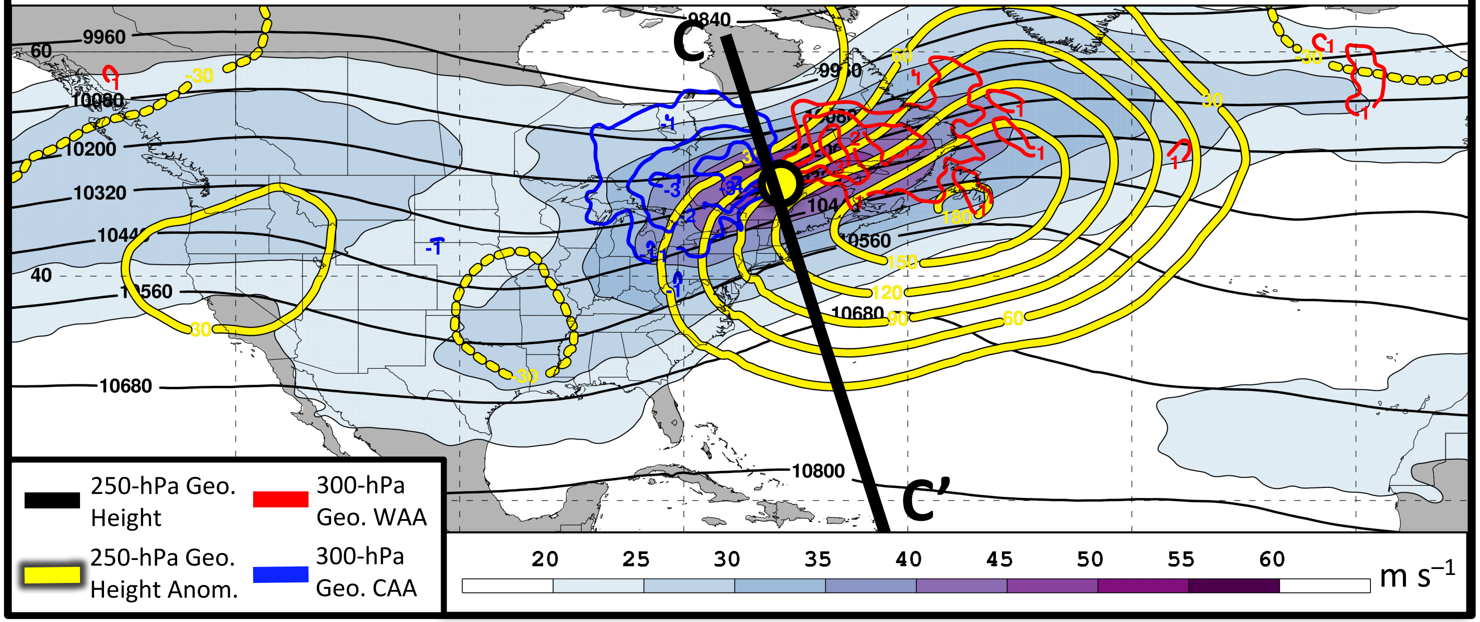
250-hPa Jet, MSLP Anom., PWAT Anom., & –OLR Anom.



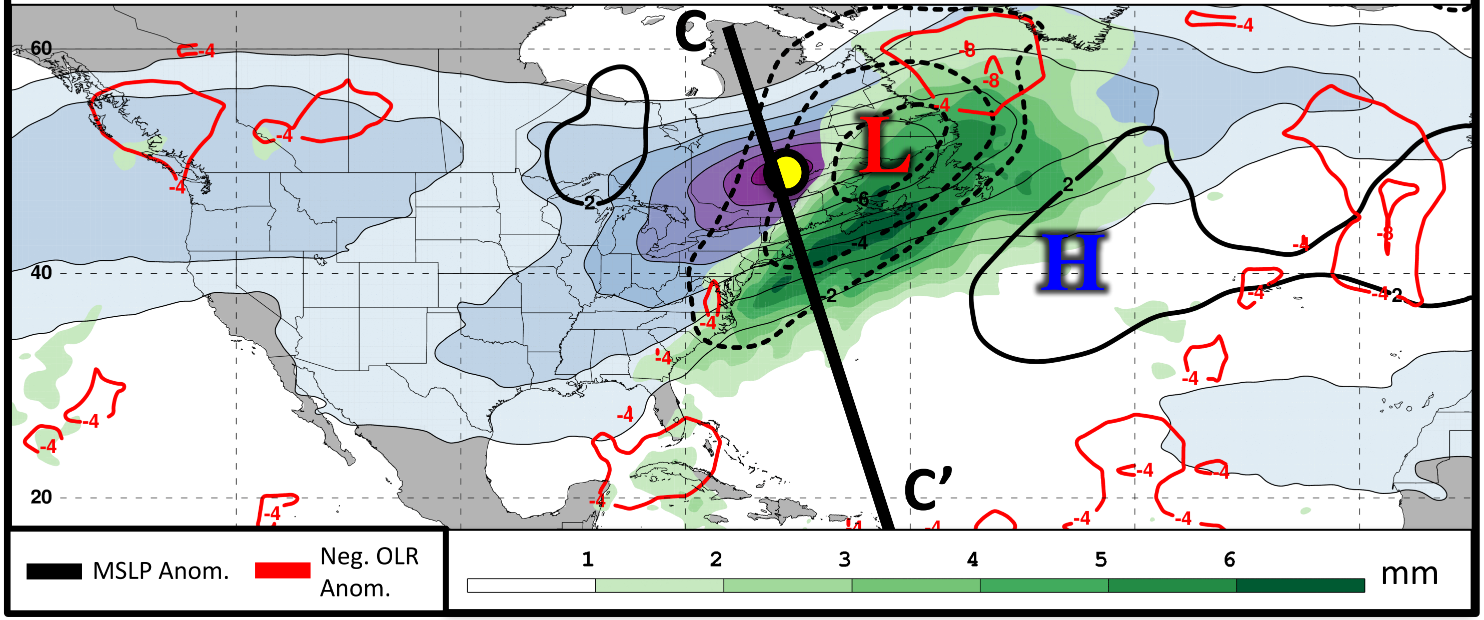
# E. Subtropical Dominant Jet Superposition Events

## 0 Days Prior to Jet Superposition

250-hPa Jet, Geo. Height, & Geo. Height Anom., & 300-hPa Geo. Temp Adv.



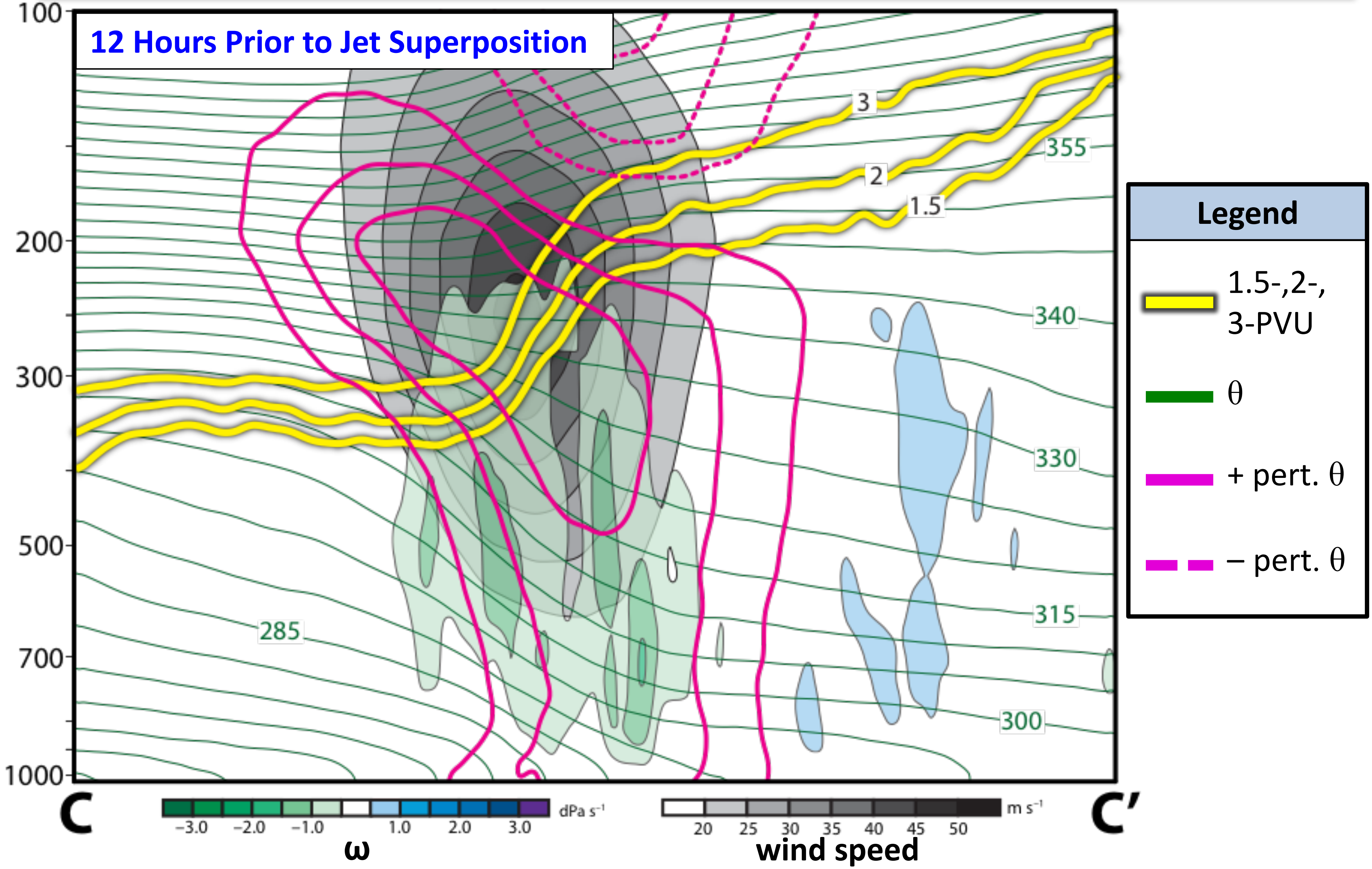
250-hPa Jet, MSLP Anom., PWAT Anom., & –OLR Anom.



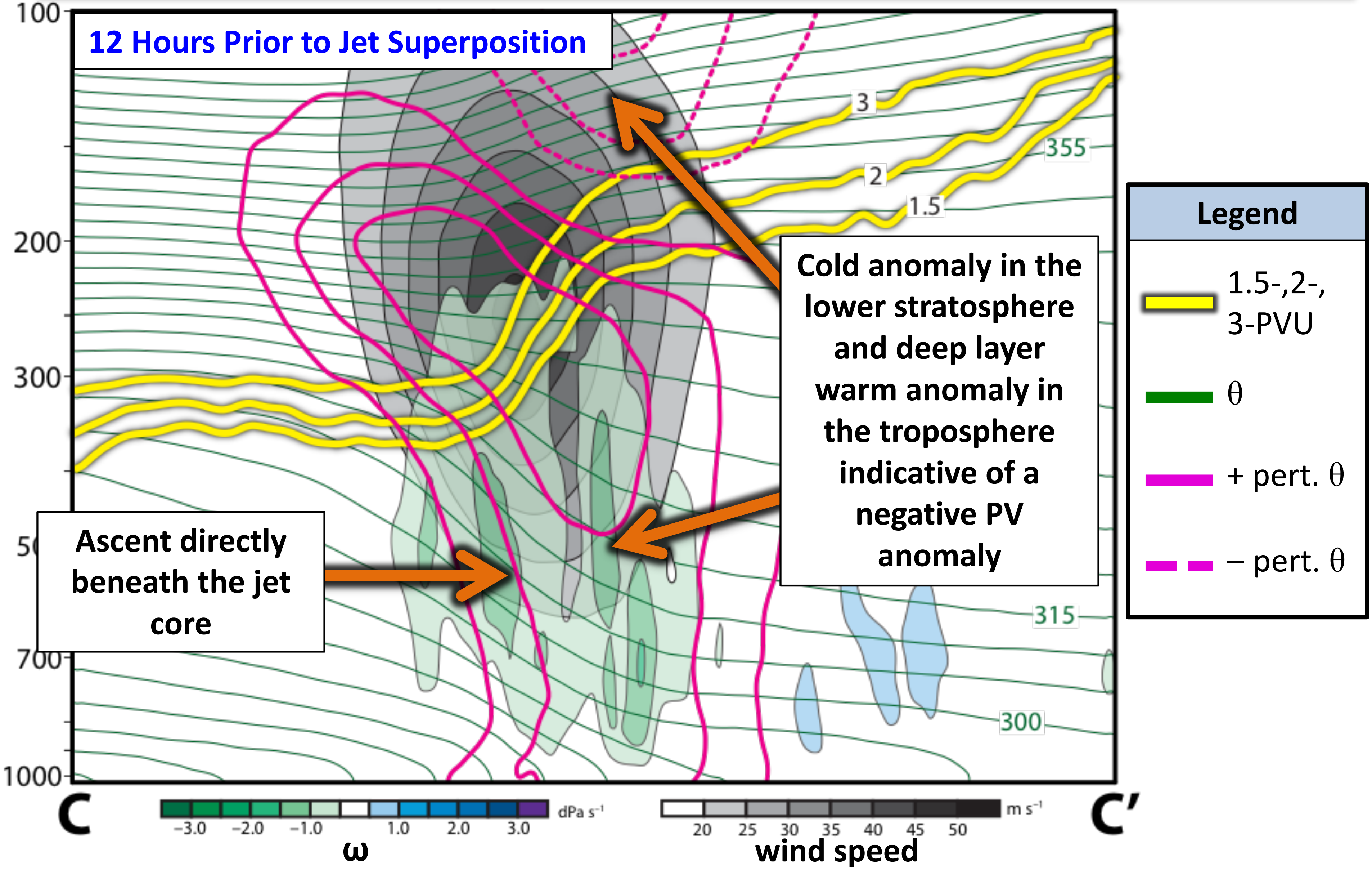
● Jet Superposition Centroid

**N=76**

# E. Subtropical Dominant Jet Superposition Events


12 Hours Prior to Jet Superposition

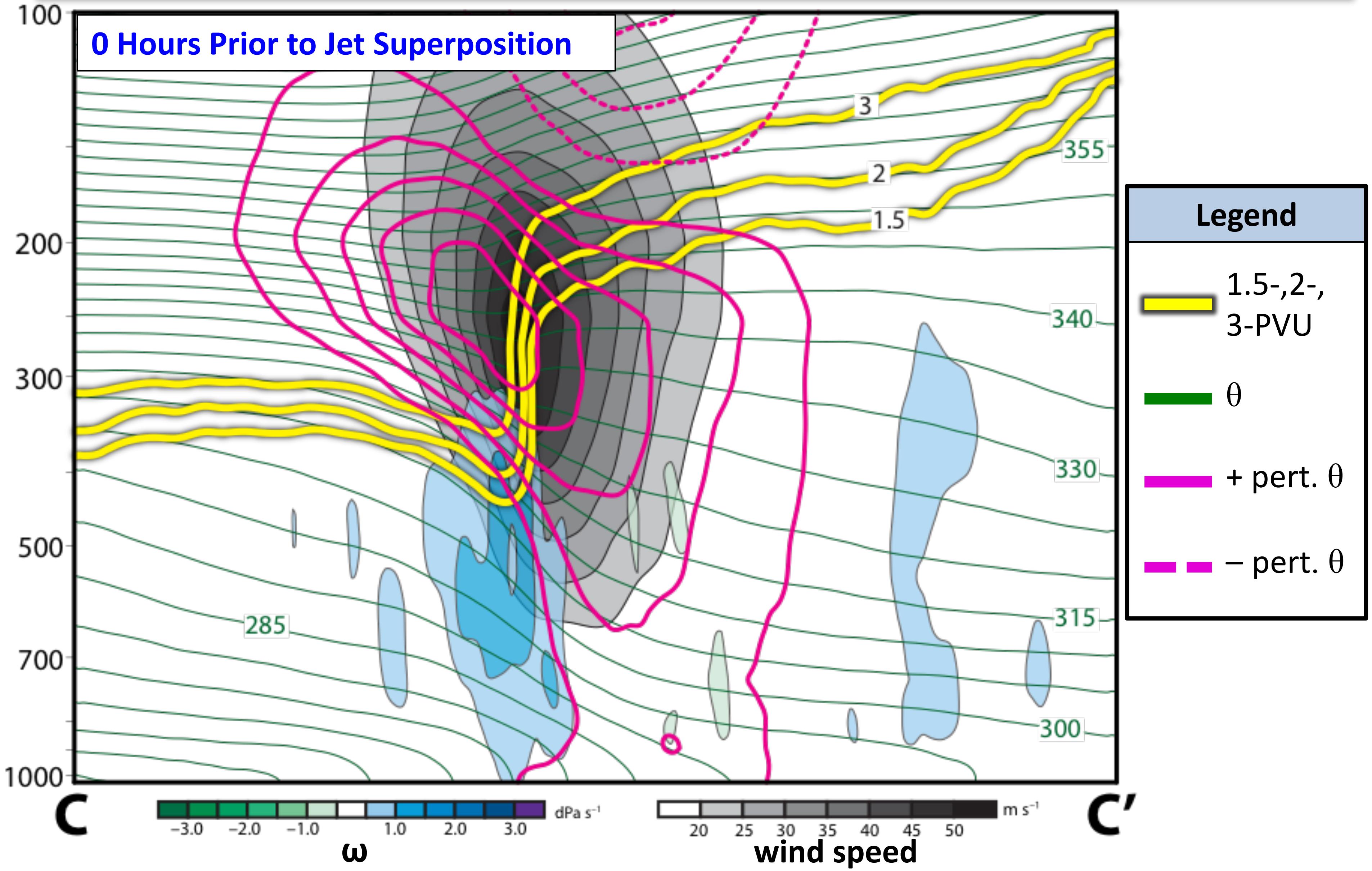
# E. Subtropical Dominant Jet Superposition Events



Cold anomaly in the lower stratosphere and deep layer warm anomaly in the troposphere indicative of a negative PV anomaly

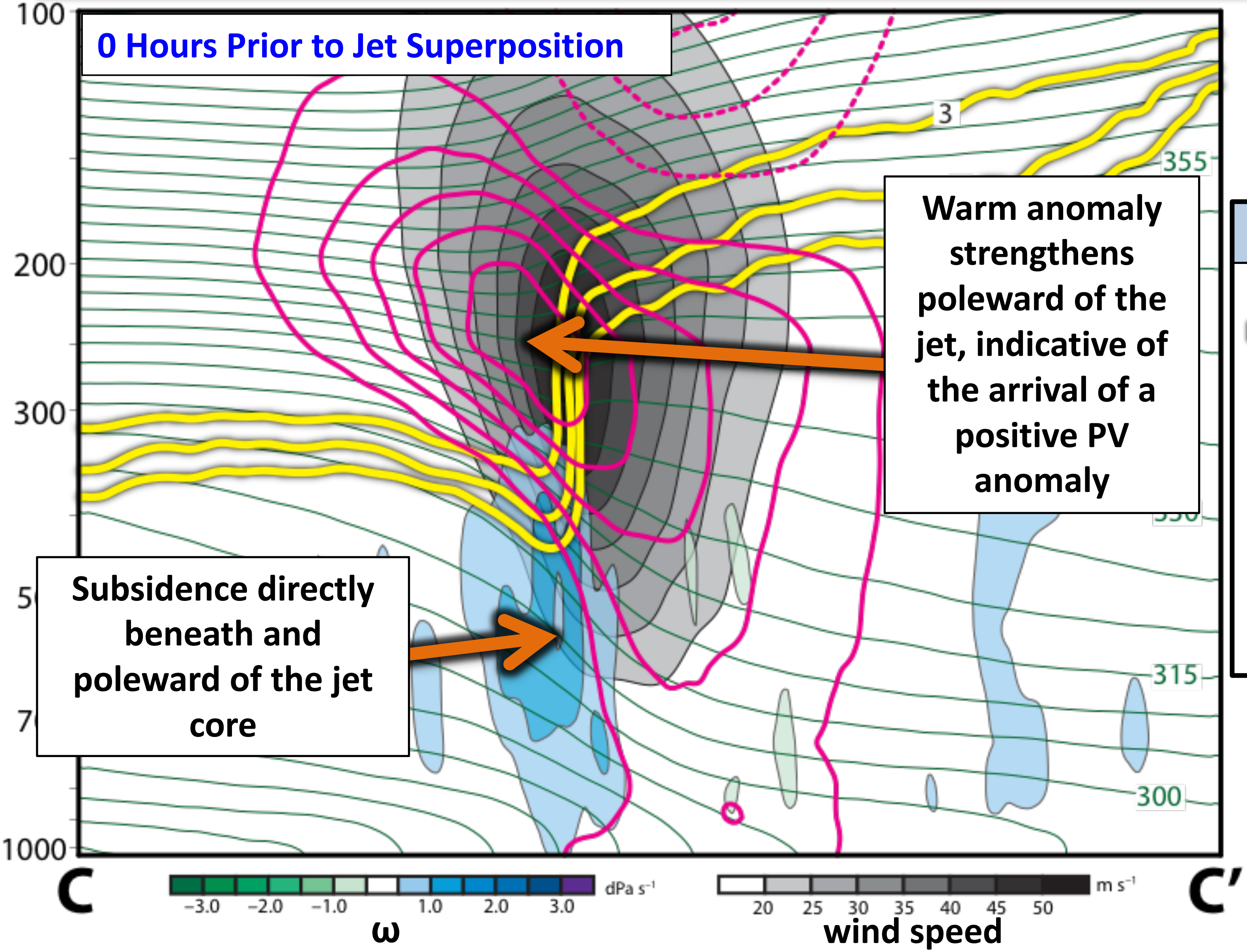
Ascent directly beneath the jet core

# E. Subtropical Dominant Jet Superposition Events



0 Hours Prior to Jet Superposition

# E. Subtropical Dominant Jet Superposition Events



Warm anomaly strengthens poleward of the jet, indicative of the arrival of a positive PV anomaly

Subsidence directly beneath and poleward of the jet core

**Legend**

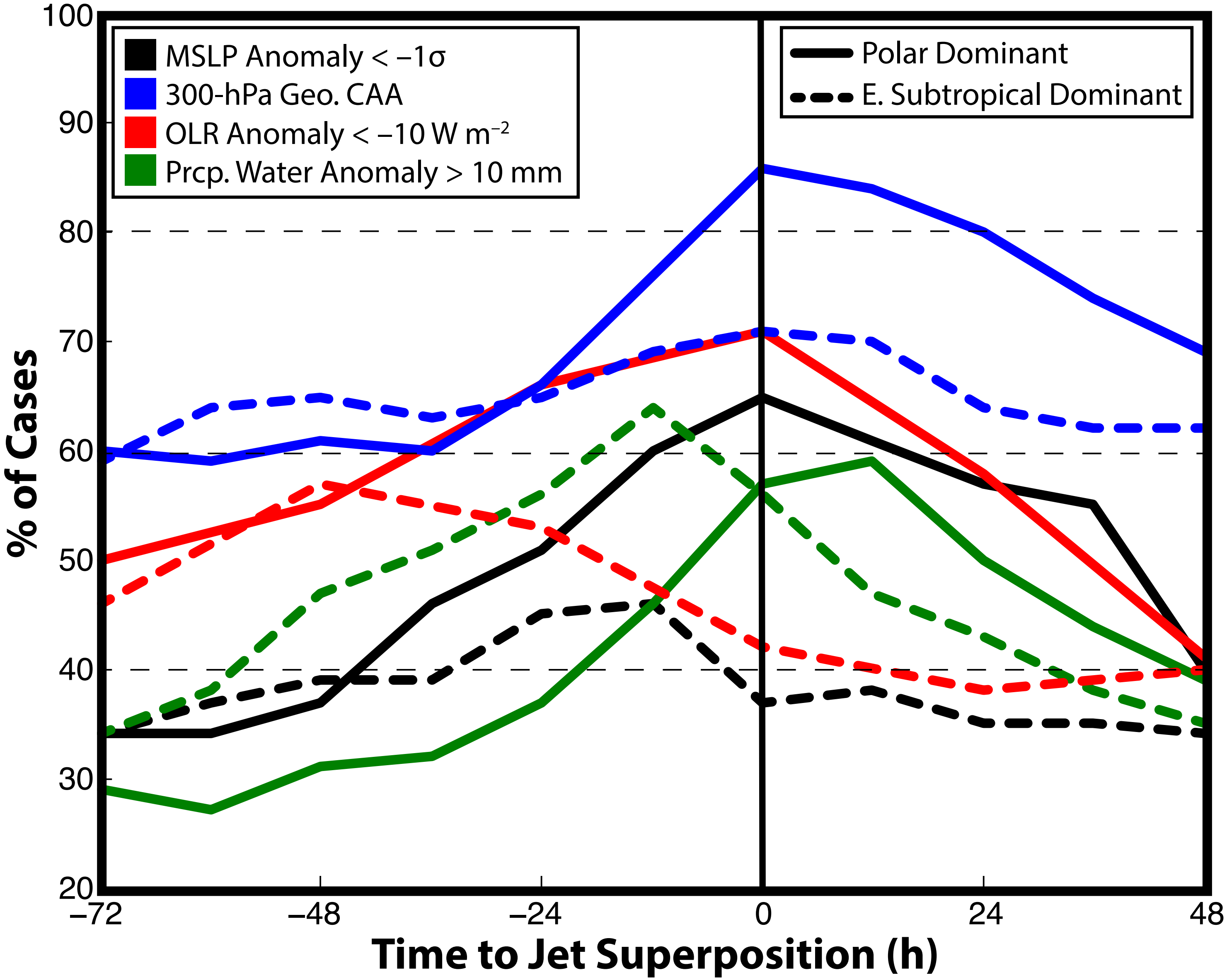
🟨 1.5-,2-, 3-PVU

🟩 θ

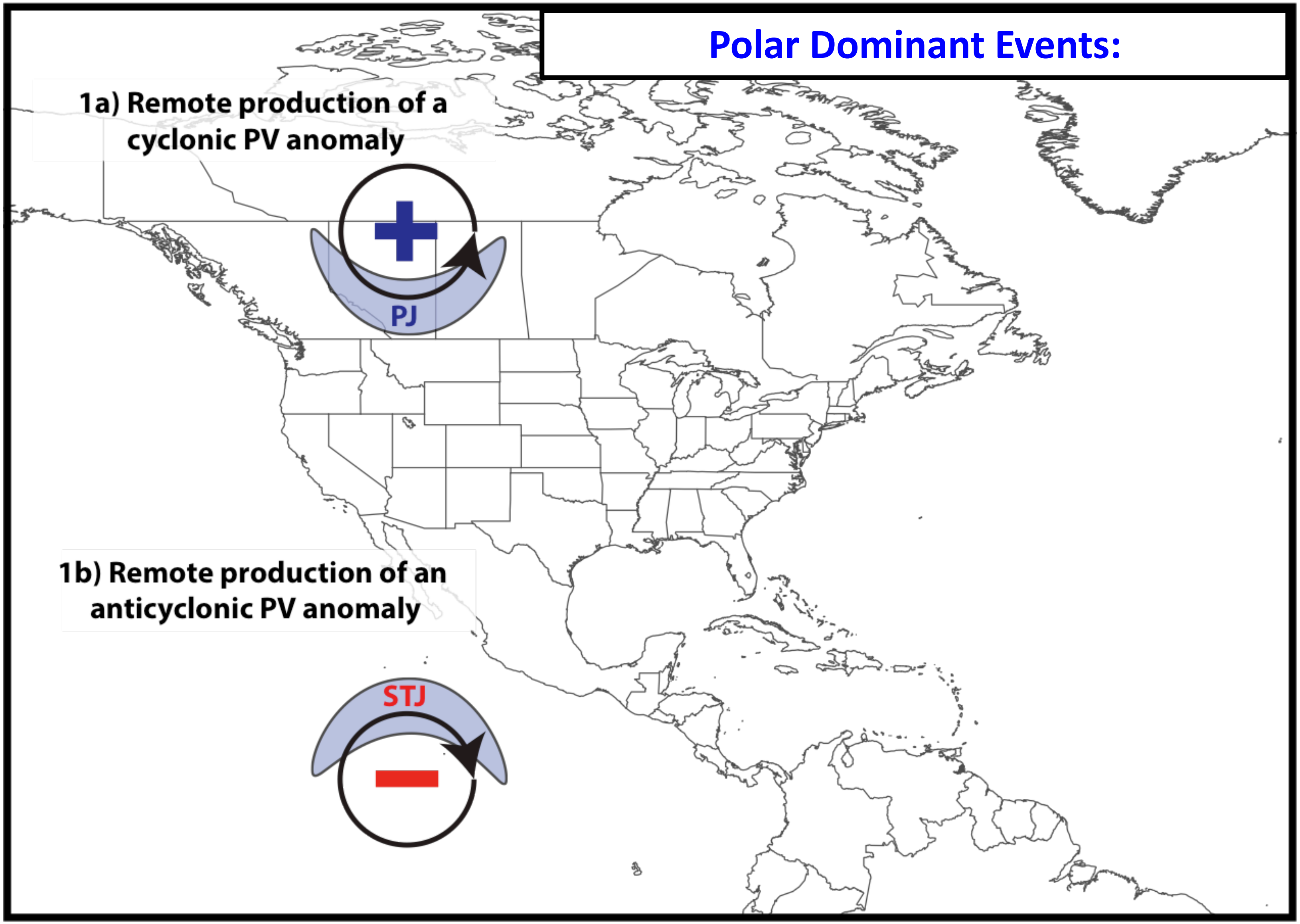
+ pert. θ

− pert. θ

# Summary


MSLP Anomaly < −1σ
300-hPa Geo. CAA
OLR Anomaly < −10 W m−2
Prcp. Water Anomaly > 10 mm
Polar Dominant
E. Subtropical Dominant
% of Cases
100
90
80
70
60
50
40
30
20
−72
−48
−24
0
24
48
Time to Jet Superposition (h)

# Summary

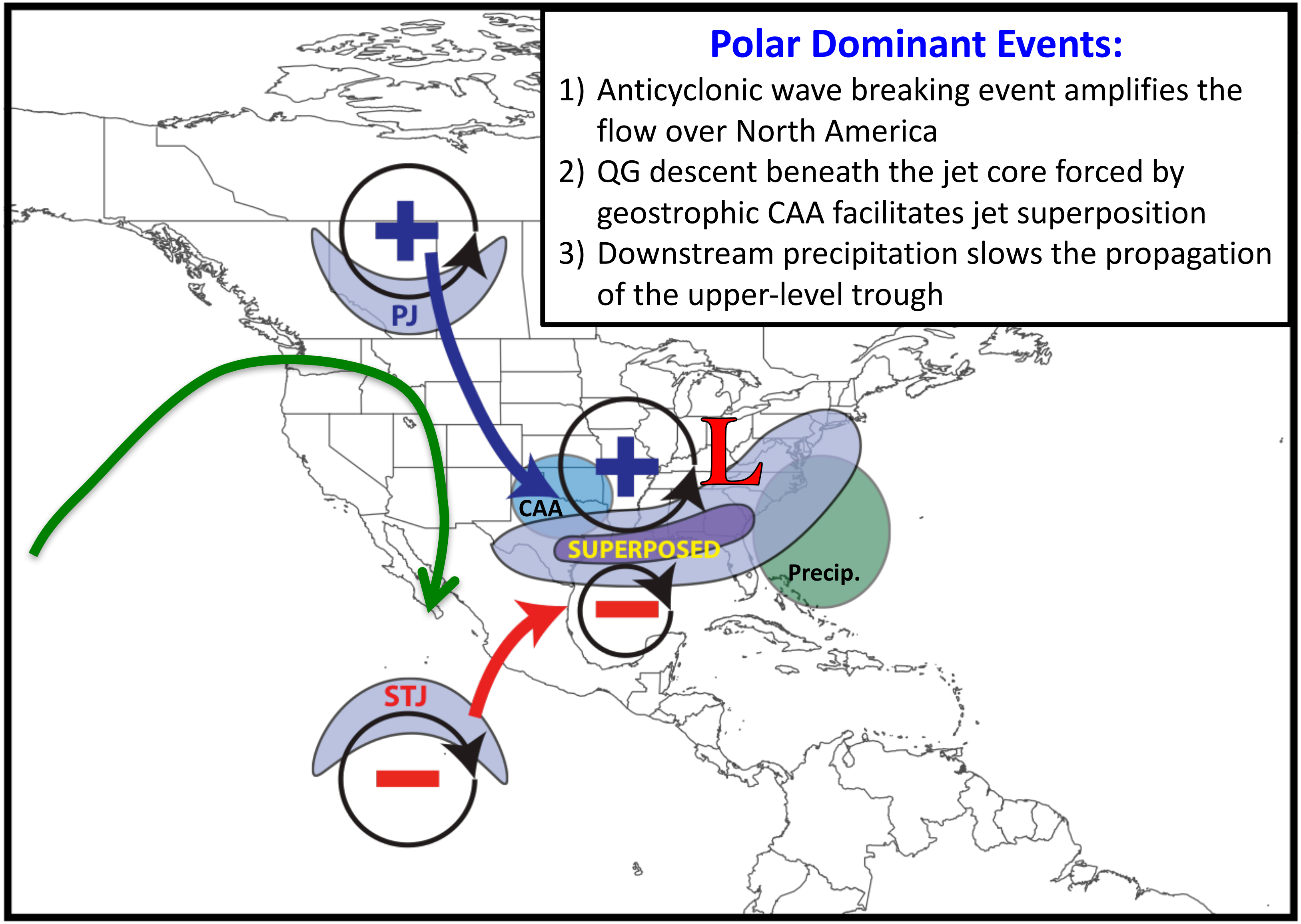


**Polar Dominant Events:**

1a) Remote production of a cyclonic PV anomaly

1b) Remote production of an anticyclonic PV anomaly

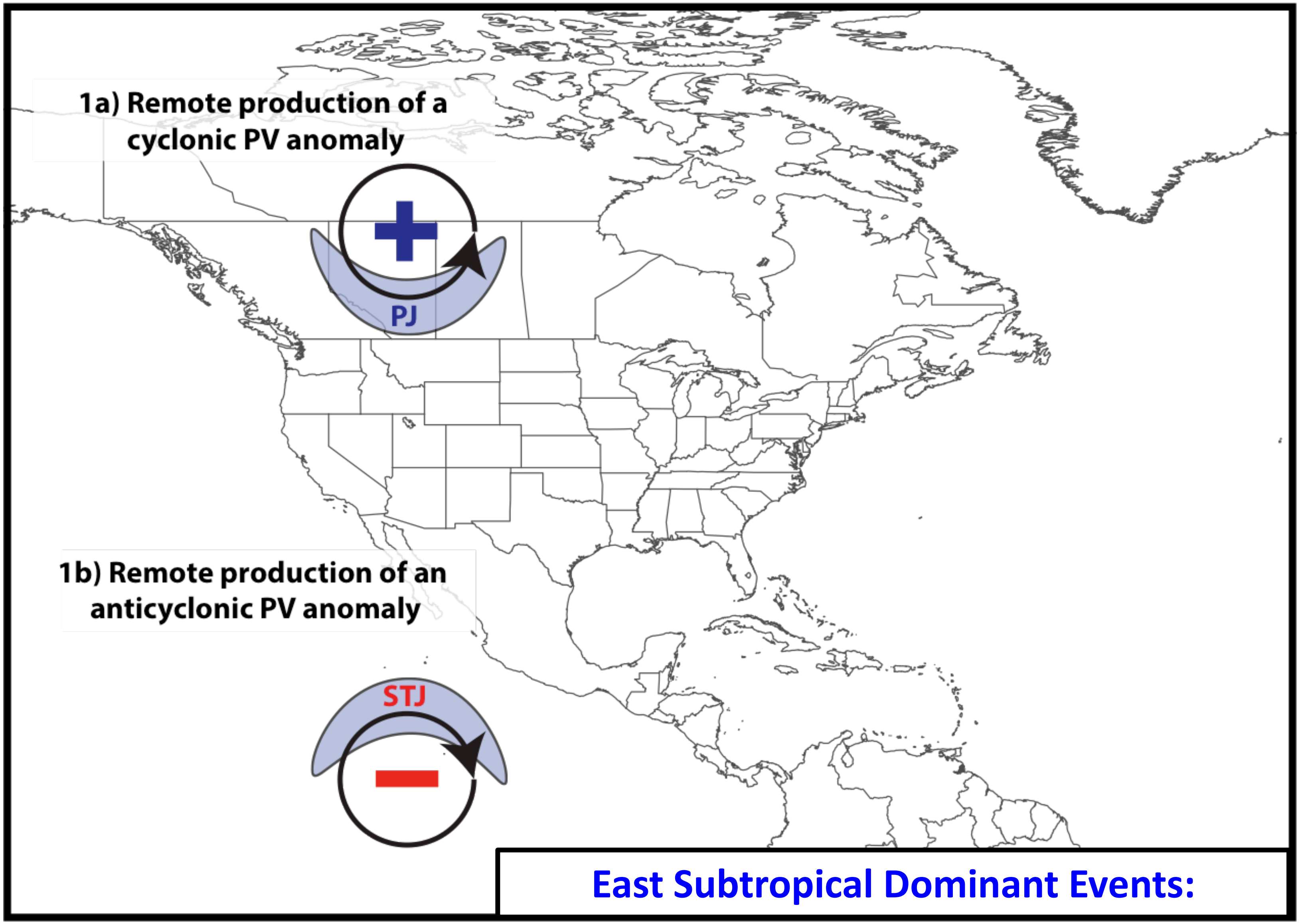
# Summary



## Polar Dominant Events:

1) Anticyclonic wave breaking event amplifies the flow over North America
2) QG descent beneath the jet core forced by geostrophic CAA facilitates jet superposition
3) Downstream precipitation slows the propagation of the upper-level trough

# Summary

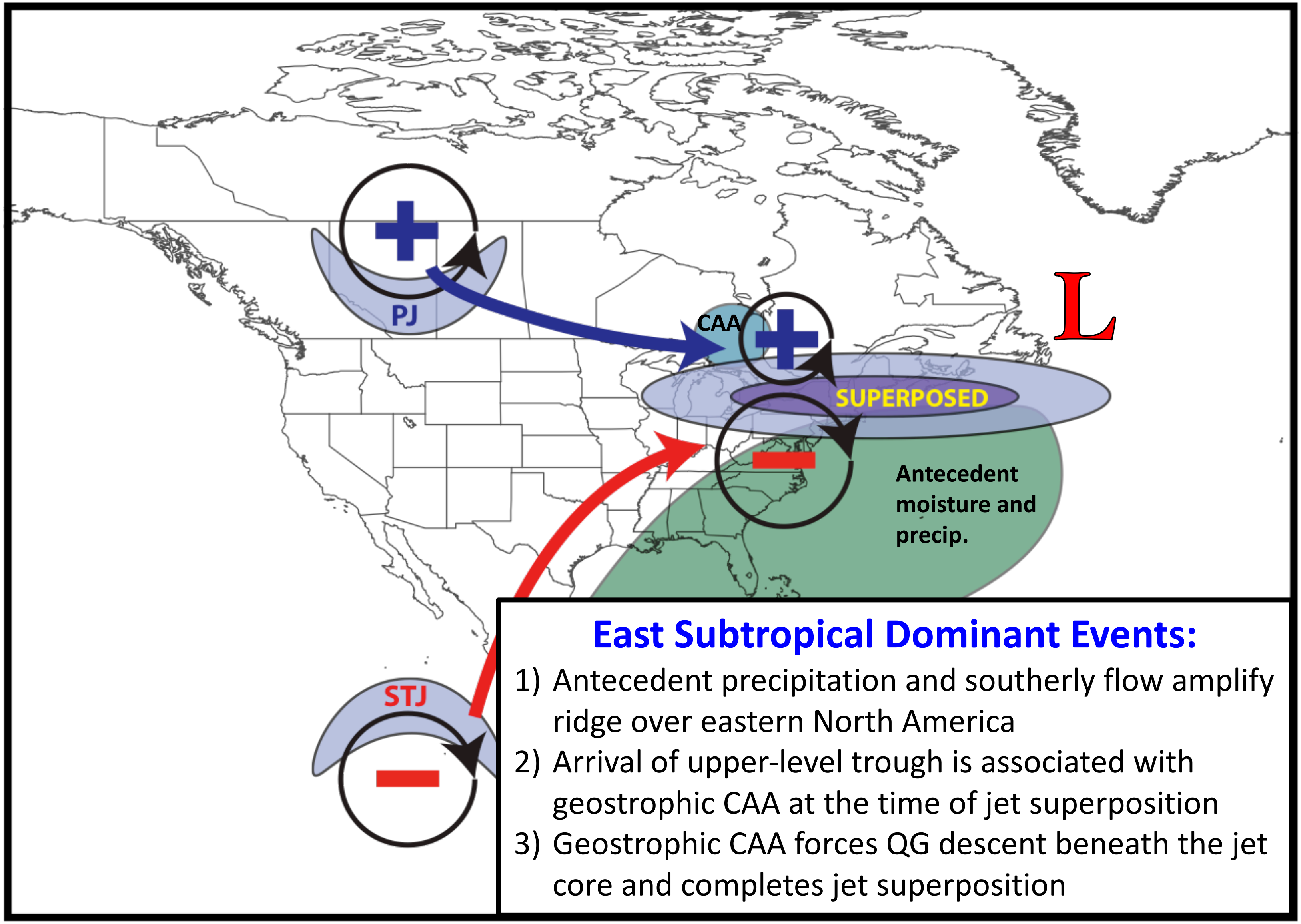


1a) Remote production of a cyclonic PV anomaly

1b) Remote production of an anticyclonic PV anomaly

East Subtropical Dominant Events:

# Summary



### East Subtropical Dominant Events:

1) Antecedent precipitation and southerly flow amplify ridge over eastern North America
2) Arrival of upper-level trough is associated with geostrophic CAA at the time of jet superposition
3) Geostrophic CAA forces QG descent beneath the jet core and completes jet superposition

# Future Work

- Apply piecewise PV inversion (e.g., Davis and Emanuel 1991) to quantify the influence that polar cyclonic and tropical anticyclonic PV anomalies have on deforming the tropopause during each type of superposition event.

- Examine the impact that each type of jet superposition event has on the evolution of the downstream large-scale flow pattern.

- Utilize numerical simulations of jet superposition events to examine the sensitivity of jet superposition to diabatic processes.

- Further illuminate the connection between jet superposition events and high-impact weather events (e.g., severe weather, cyclogenesis, floods).

# Supplementary Slides

# References

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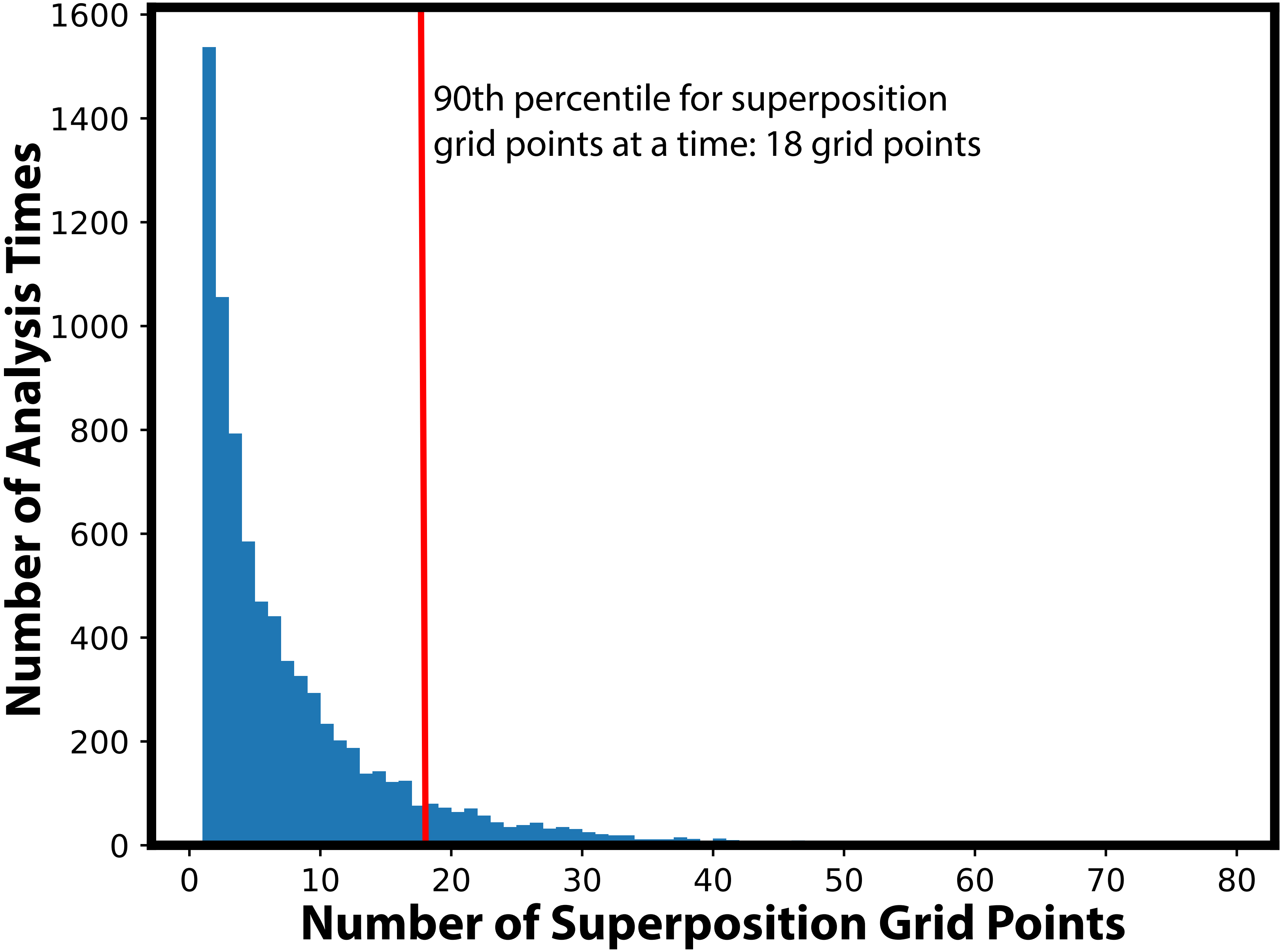
# Jet Superposition Event Identification

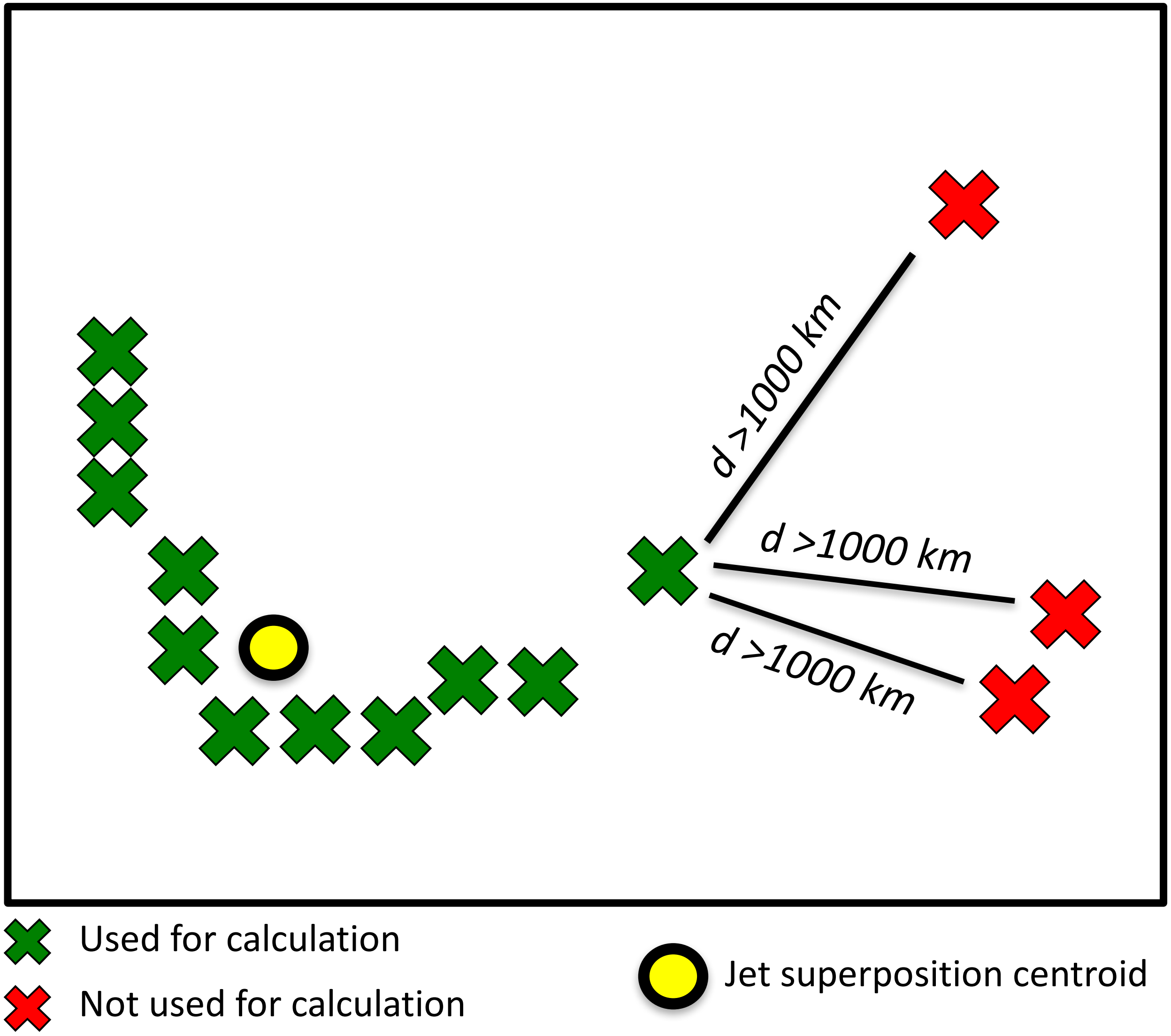


# Jet Superposition Event Identification

## Sample Jet Superposition Centroid Calculation

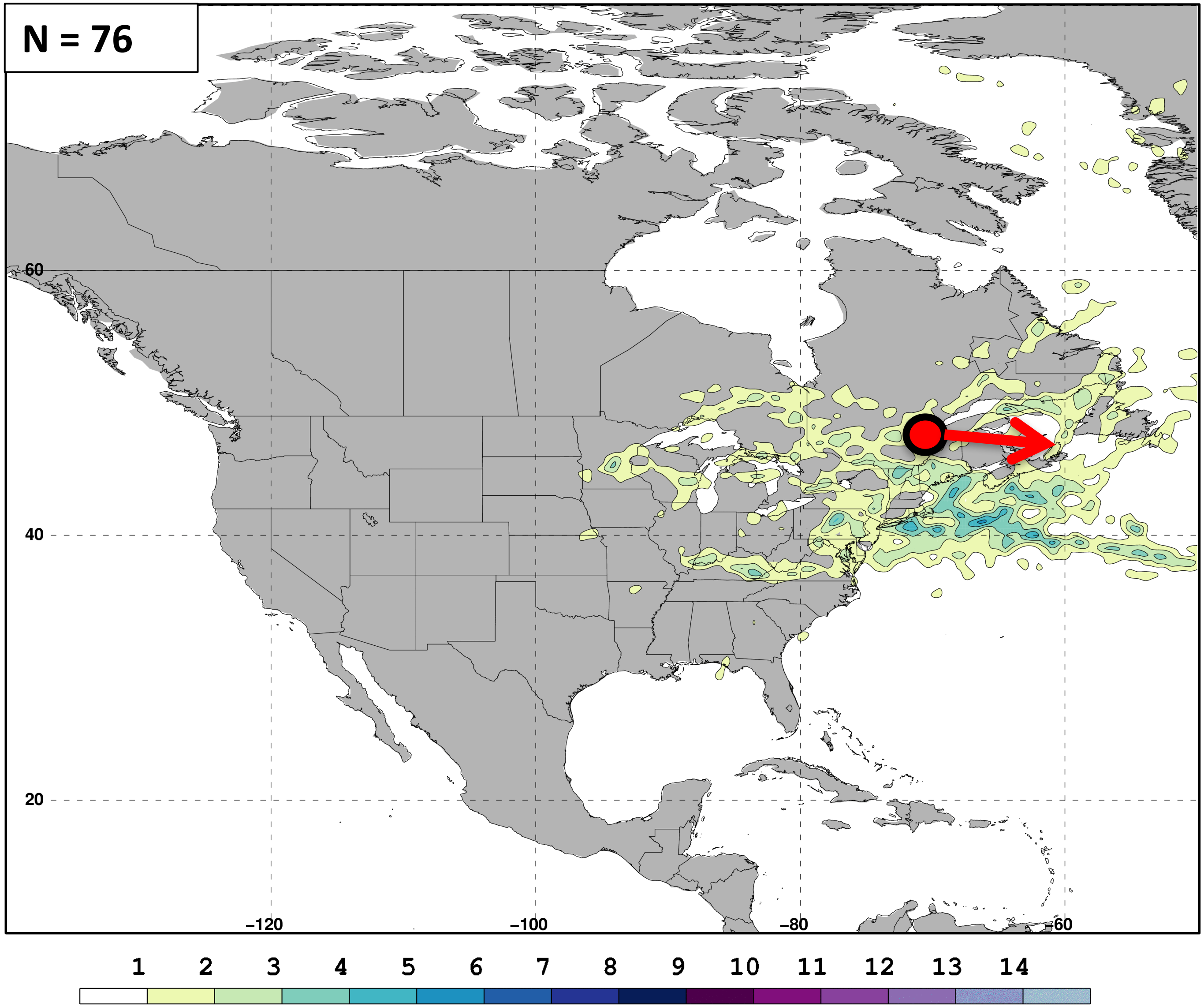
Calculated the centroid of each jet superposition based on all valid grid points at a particular analysis time.

To calculate the centroid, there must exist a group of 18 superposition grid points, of which no superposition grid point is >1000 km away from another superposition grid point.



# Jet Superposition Event Identification

**Frequency of East Subtropical Dominant Jet Superposition Events**



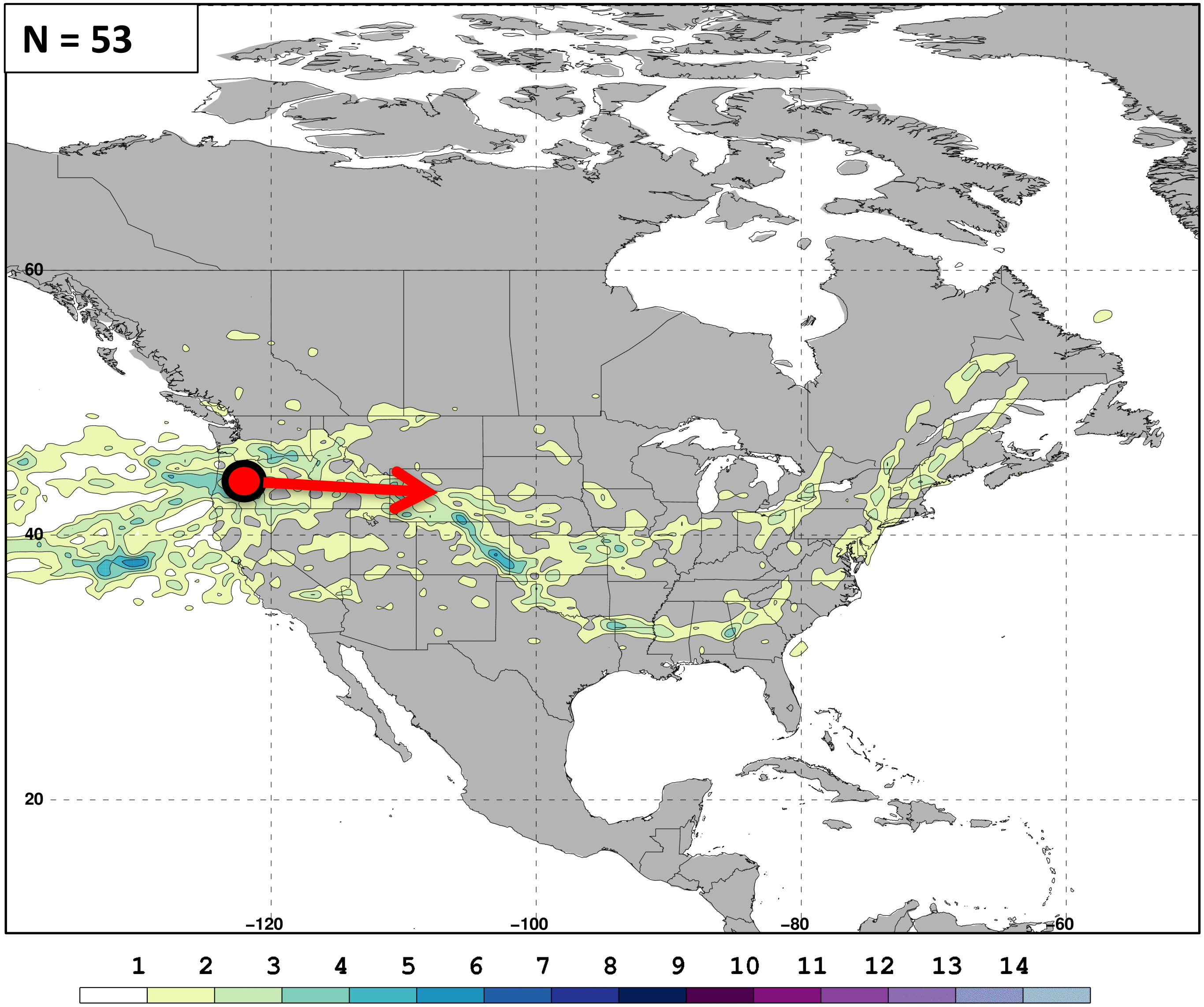
**Legend**

● Centroid of all events

→ Composite movement of superposition

# Jet Superposition Event Identification

## Frequency of West Subtropical Dominant Jet Superposition Events

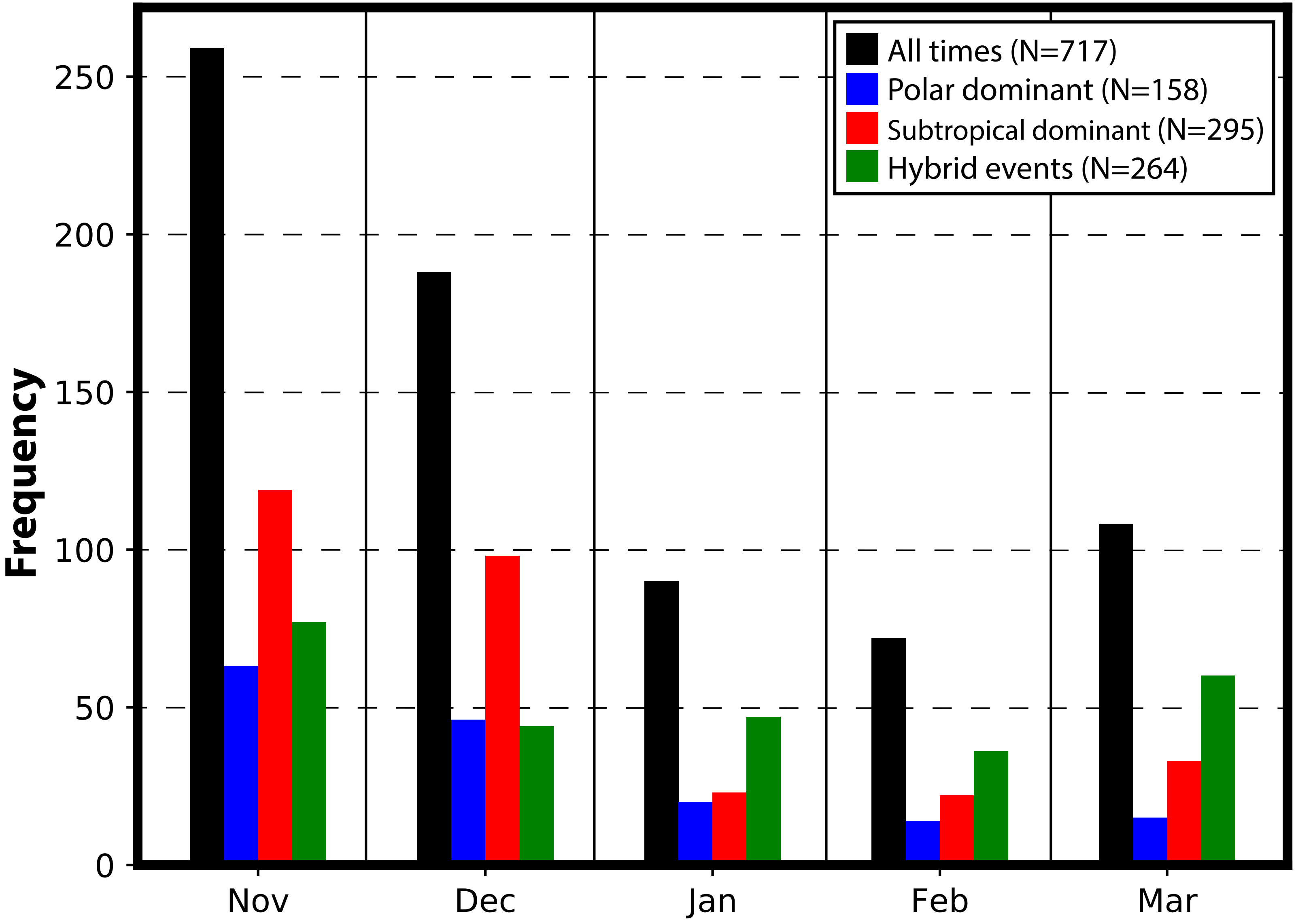


**Legend**

● Centroid of all events

→ Composite movement of superposition

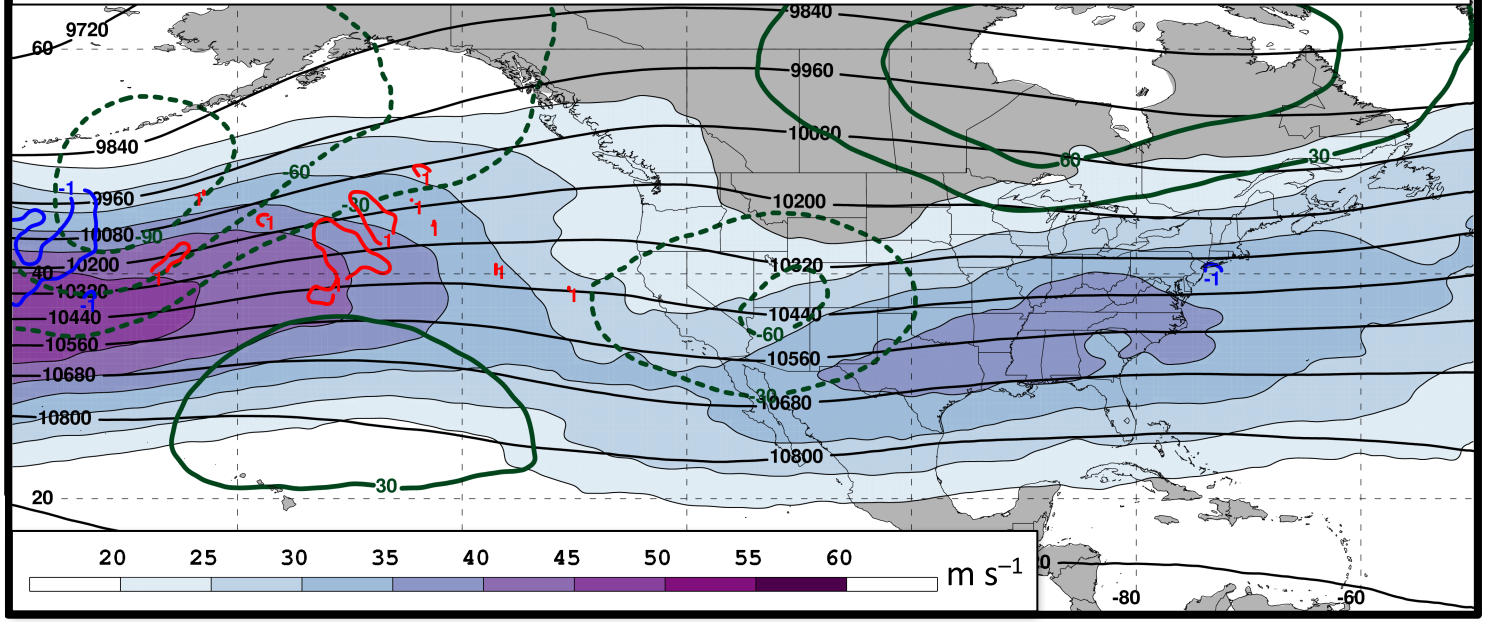
# Jet Superposition Event Classification



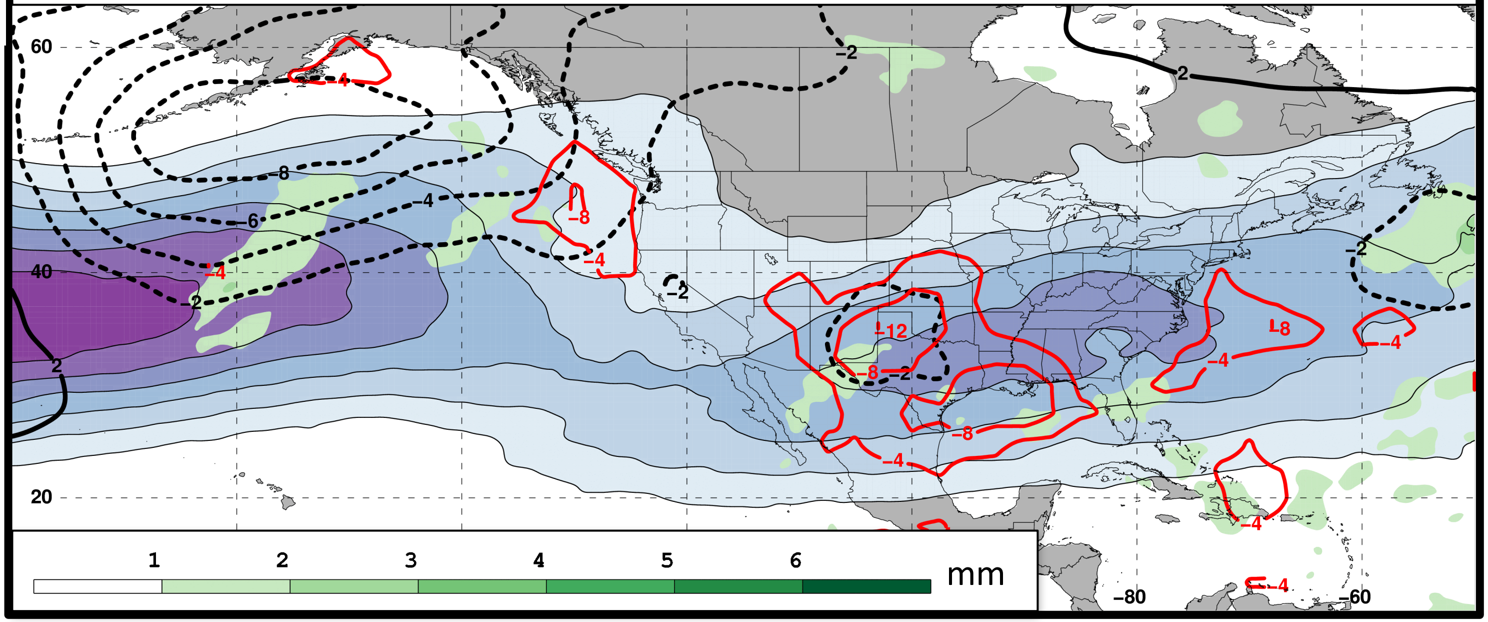
# Polar Dominant Jet Superposition Events

**3 Days Prior to Jet Superposition**

**250-hPa Jet, Geo. Height, & Geo. Height Anom., & 300-hPa Geo. Temp Adv.**



**250-hPa Jet, MSLP Anom., PWAT Anom., & OLR Anom.**



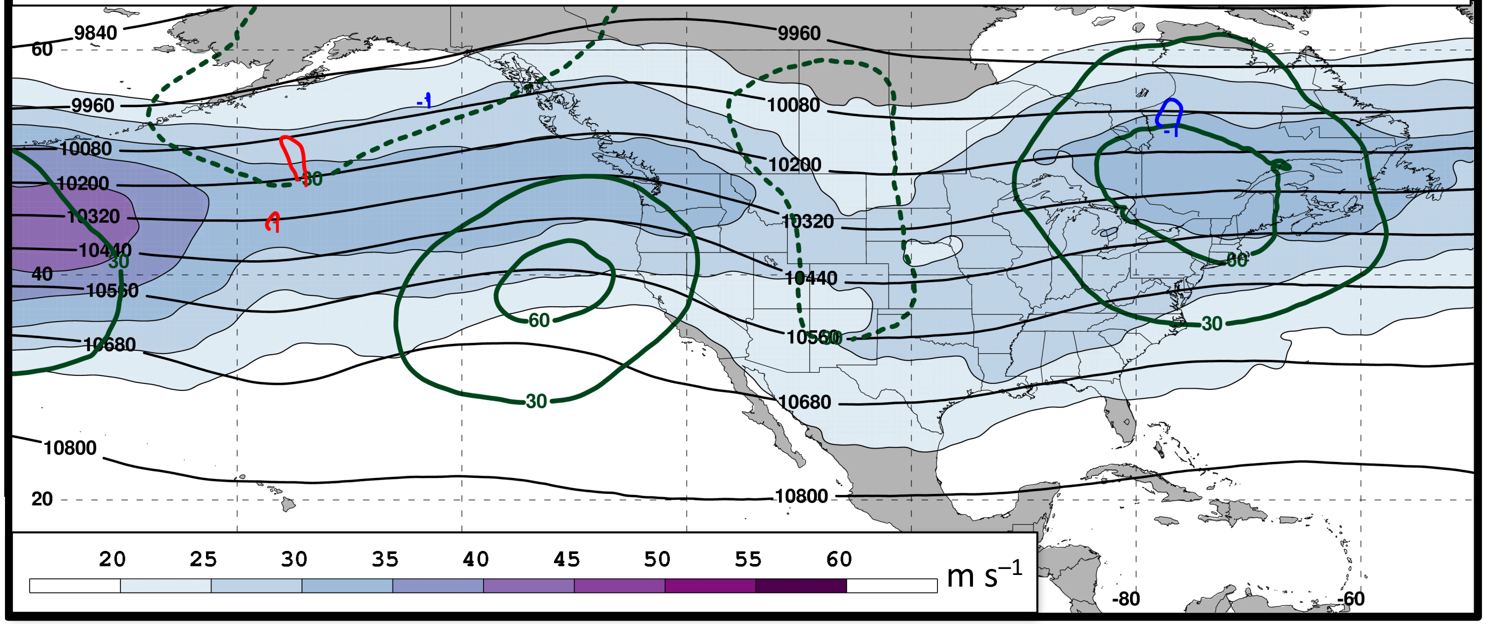
**N=80**

# E. Subtropical Dominant Jet Superposition Events

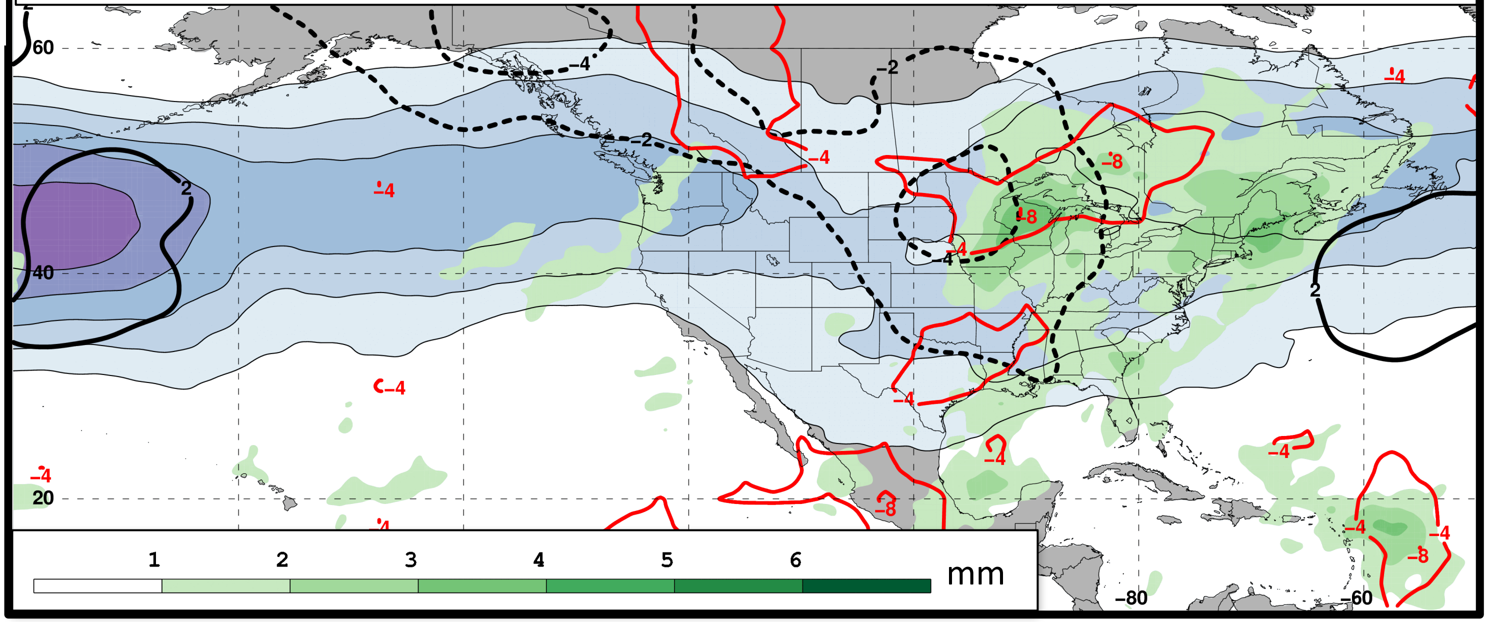
**3 Days Prior to Jet Superposition**

**N=76**

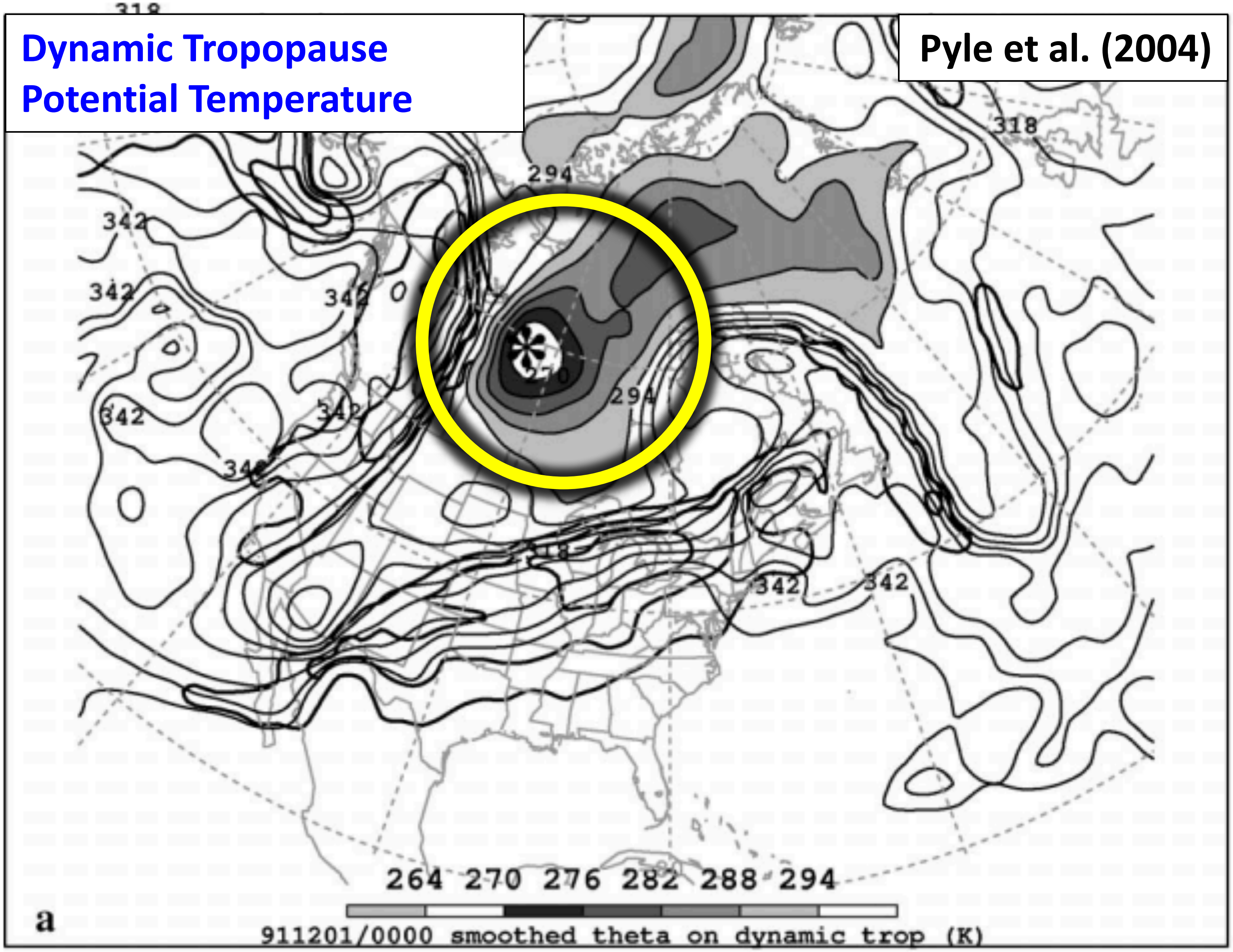
250-hPa Jet, Geo. Height, & Geo. Height Anom., & 300-hPa Geo. Temp Adv.



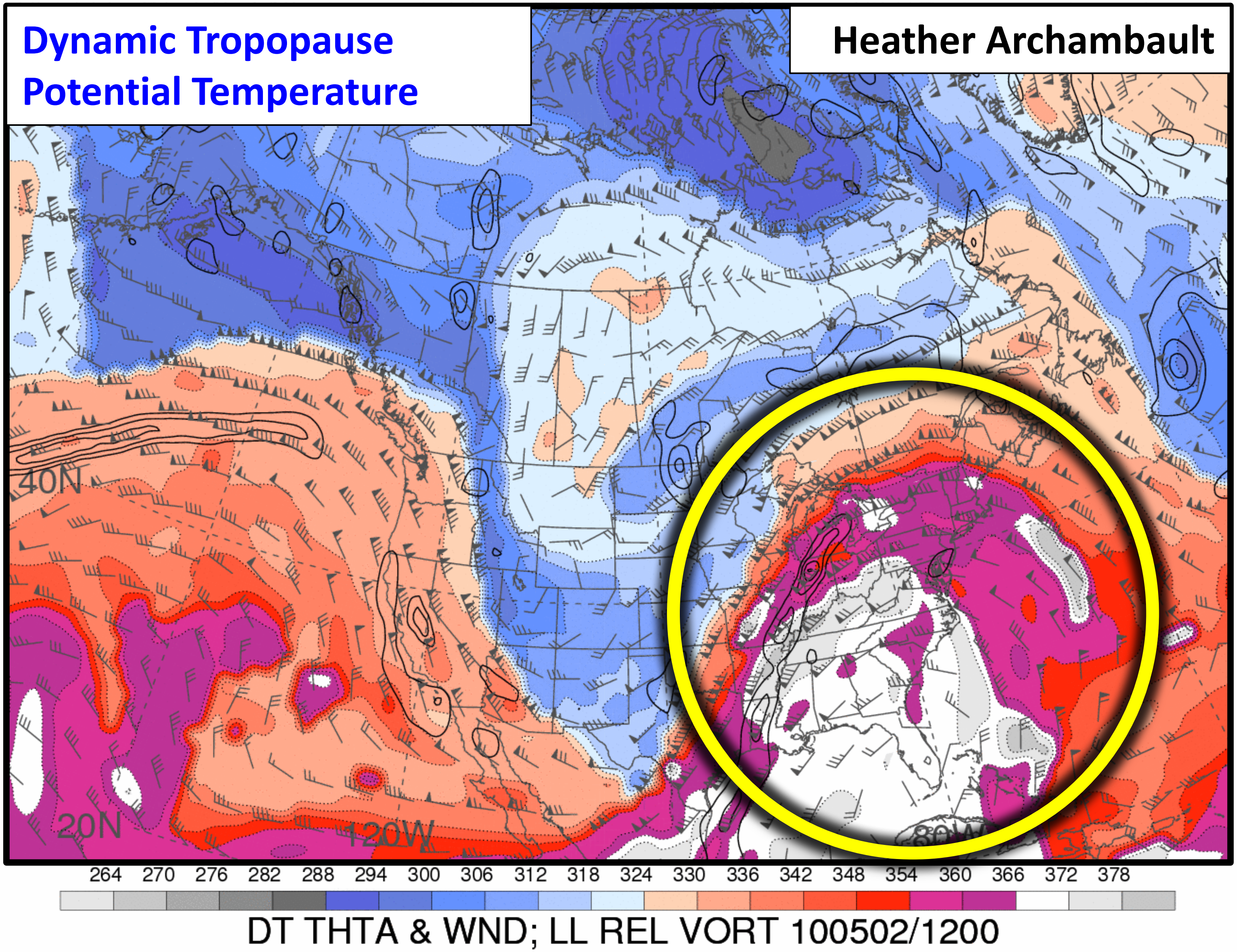
250-hPa Jet, MSLP Anom., PWAT Anom., & OLR Anom.



# Jet Superposition Conceptual Model



# Jet Superposition Conceptual Model



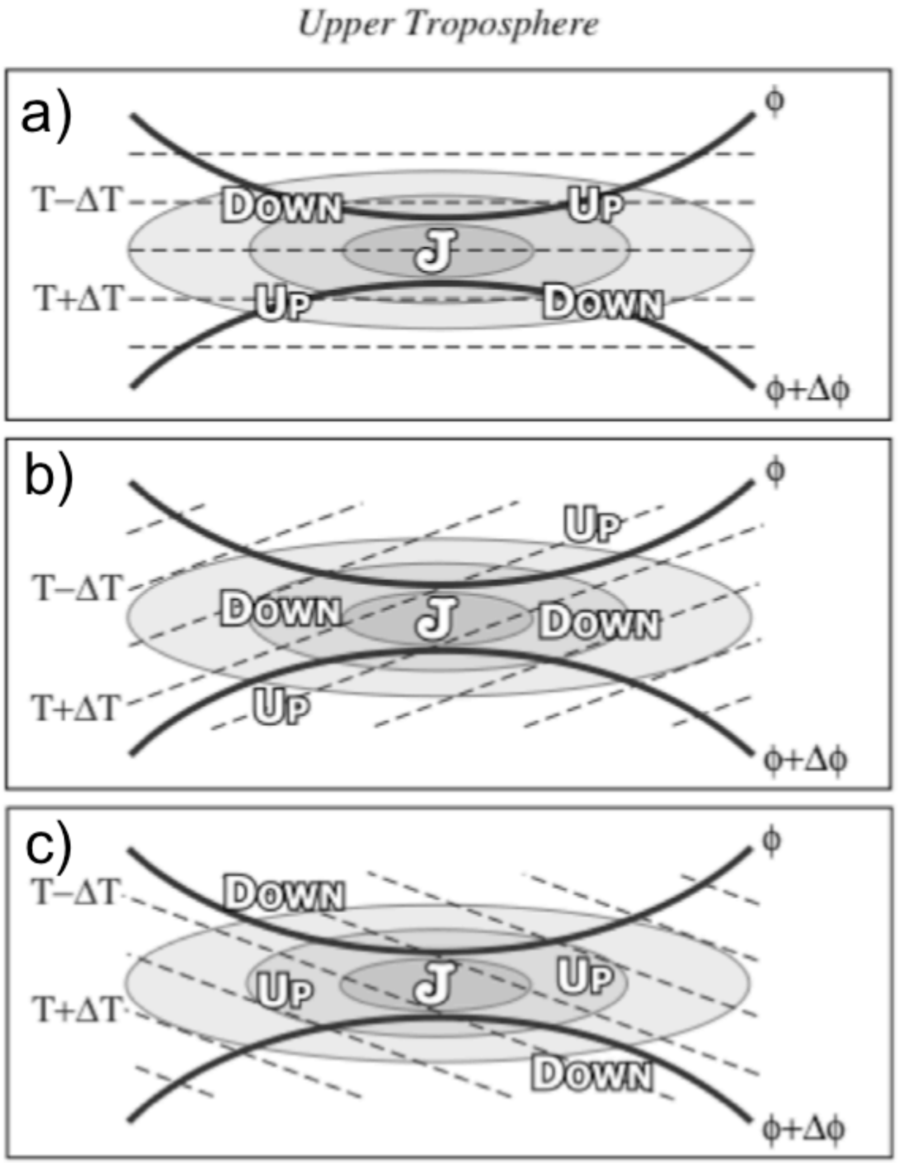
# Ageostrophic Transverse Jet Circulations

Traditional four-quadrant model

**Geo. cold-air advection (CAA)** along the jet axis promotes **subsidence** through the jet core

**Geo. warm-air advection (WAA)** along the jet axis promotes **ascent** through the jet core

**Lang and Martin (2012)**



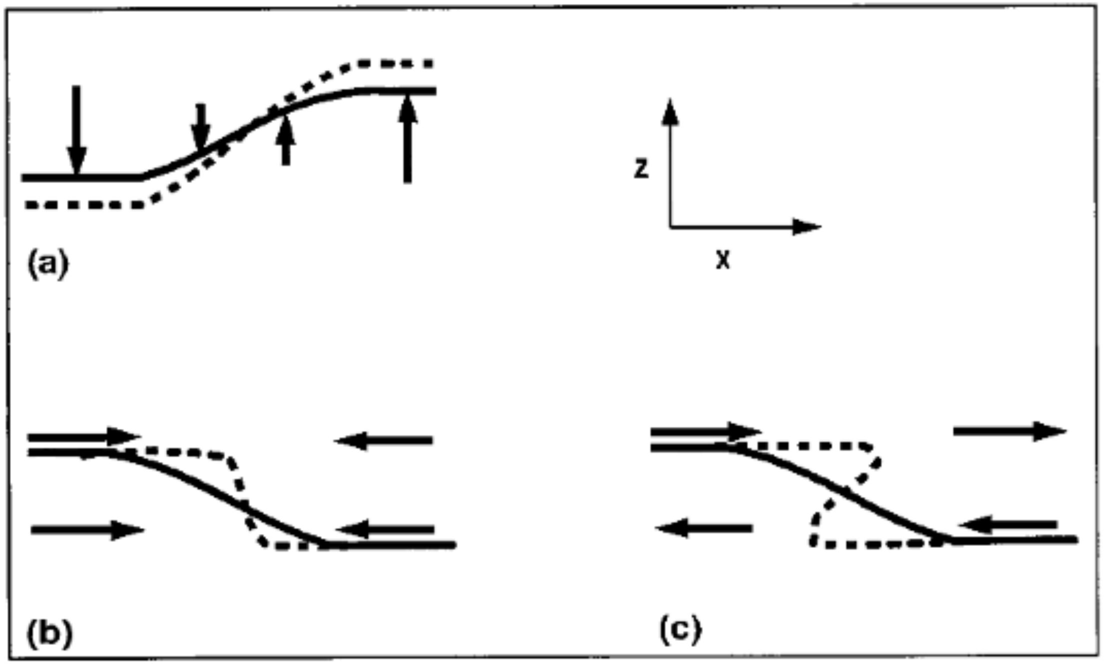
# Background

**Insight into how the tropopause can be restructured from a PV perspective can be found by consulting Wandishin et al. (2000)**

Two processes can account for "foldogenesis":

1) **Differential vertical motions** can vertically steepen the tropopause.

2) **Convergence** or a **vertical shear** can produce a differential horizontal advection of the tropopause surface.



Wandishin et al. 2000

These same mechanisms are also likely to play an important role in superpositions.

# Background

**Christenson et al. (2017)**

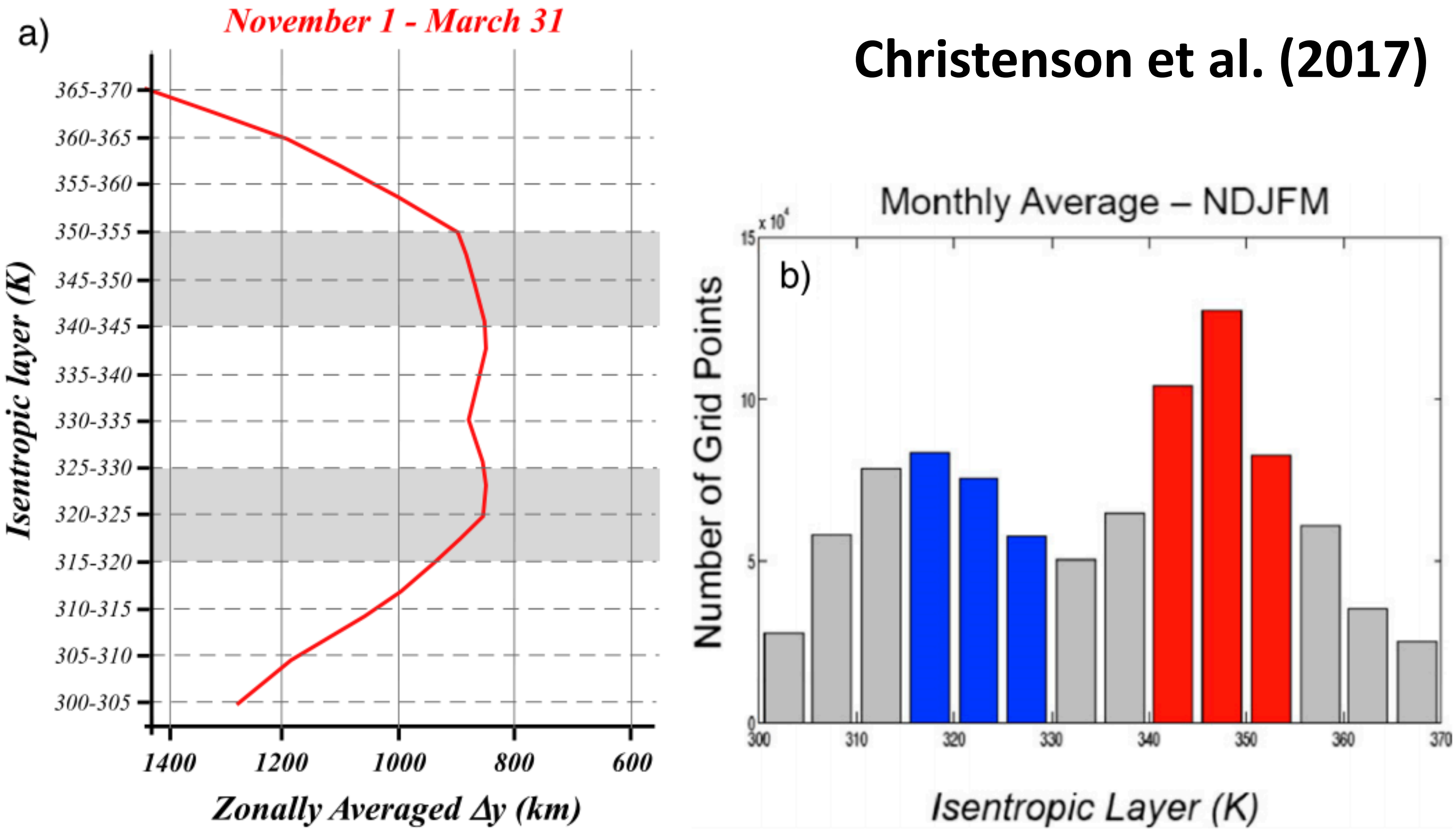


FIG. 2. (a) Cold season average of zonally averaged $\Delta y$ (km) for 5-K isentropic layers ranging from 300–305 to 365–370 K. The 315–330- and 340–355-K layers are highlighted in light gray shading. (b) The average frequency of occurrence of grid points with a maximum wind speed value within the 5-K isentropic layers along the abscissa per cold season. The 315–330- and 340–355-K layers are shaded in blue and red, respectively.