Antecedent Synoptic Environments Conducive to North American Polar/Subtropical Jet Superposition Events

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Boulder, CO

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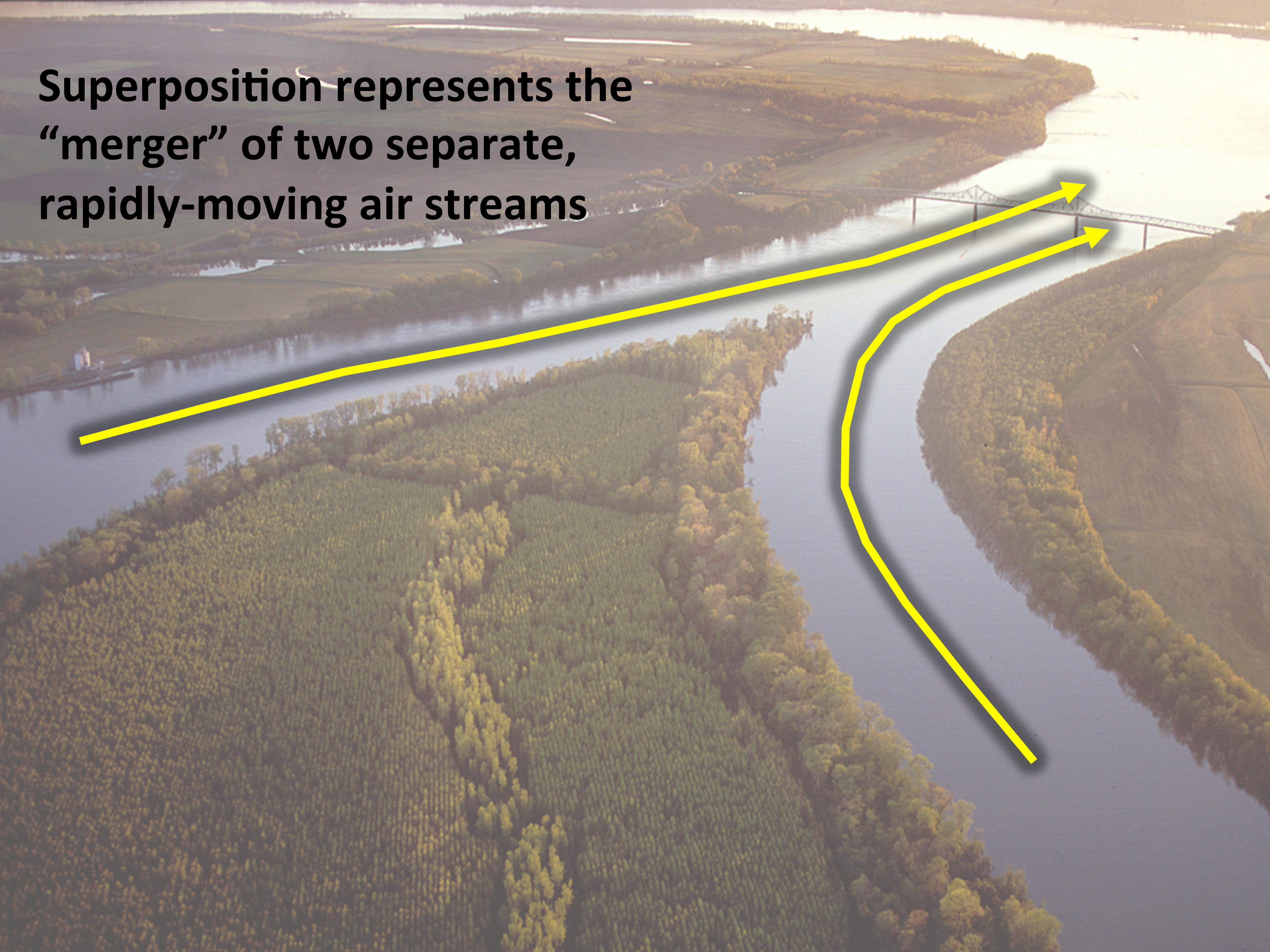
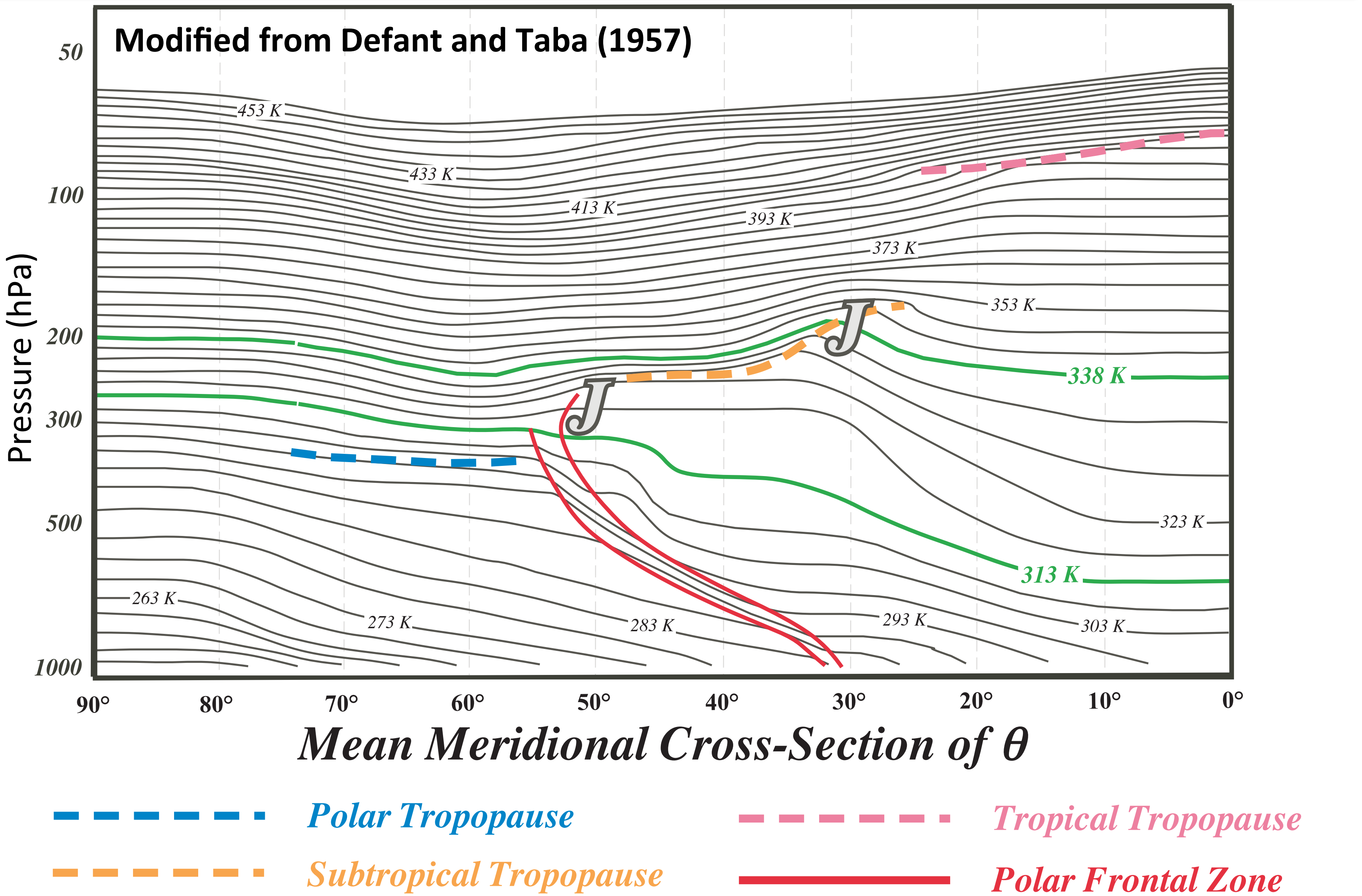
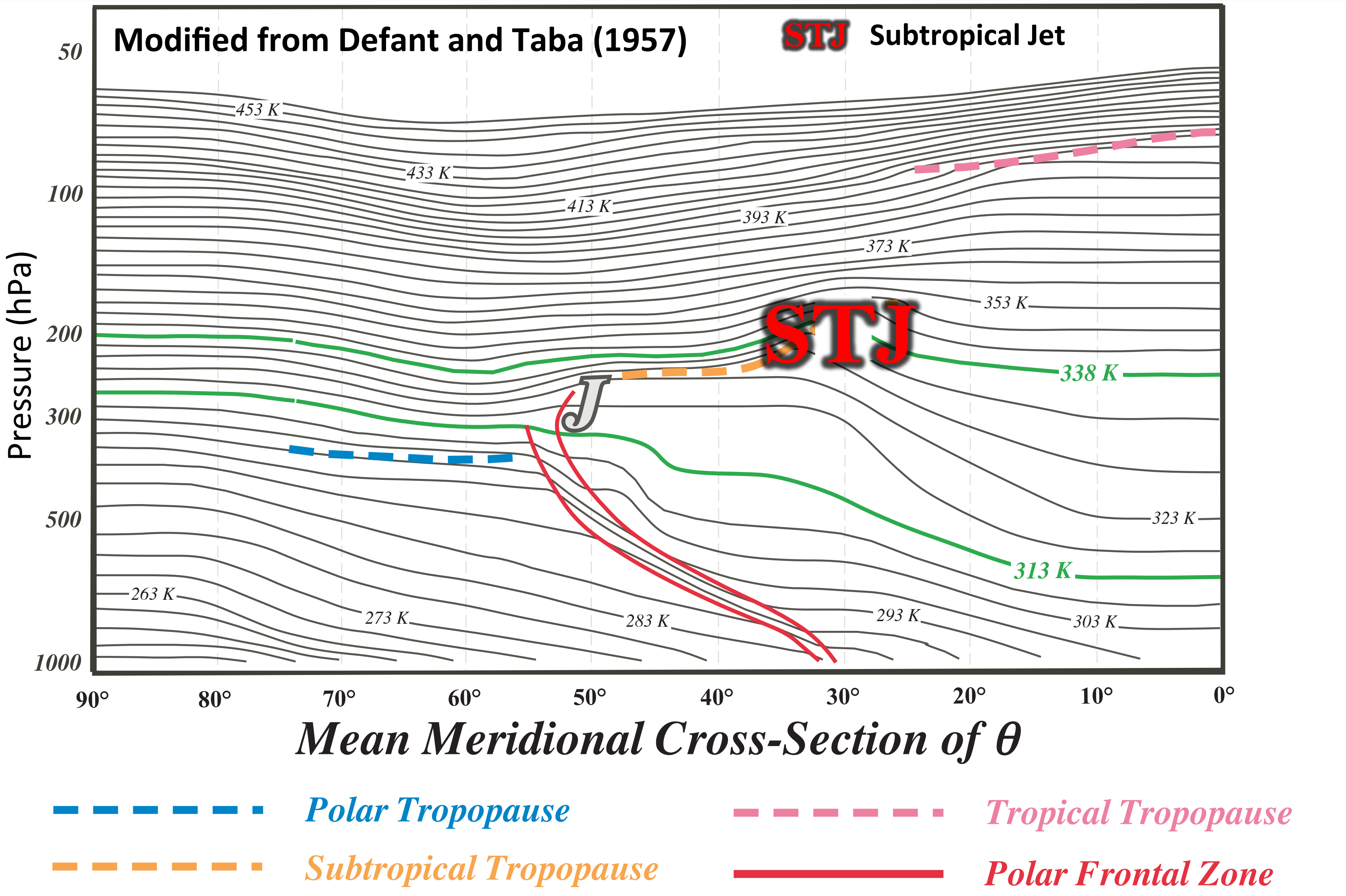

Superposition represents the
"merger" of two separate,
rapidly-moving air streams

Background


Modified from Defant and Taba (1957)
Pressure (hPa)
50
100
200
300
500
1000
453 K
433 K
413 K
393 K
373 K
353 K
338 K
323 K
313 K
303 K
293 K
283 K
273 K
263 K
J
J
90°
80°
70°
60°
50°
40°
30°
20°
10°
0°
Mean Meridional Cross-Section of θ
Polar Tropopause
Tropical Tropopause
Subtropical Tropopause
Polar Frontal Zone

Background



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STJ Subtropical Jet
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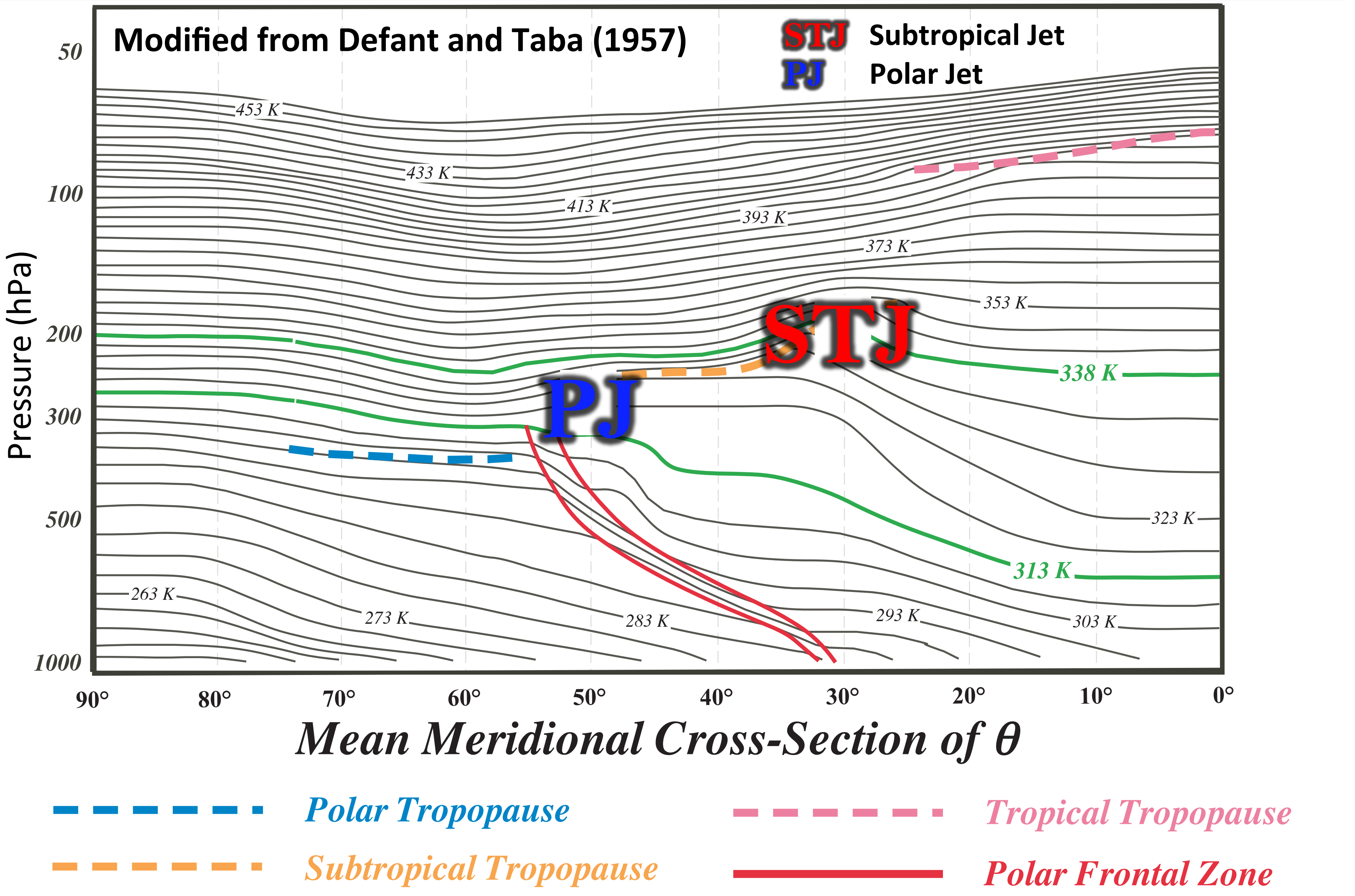

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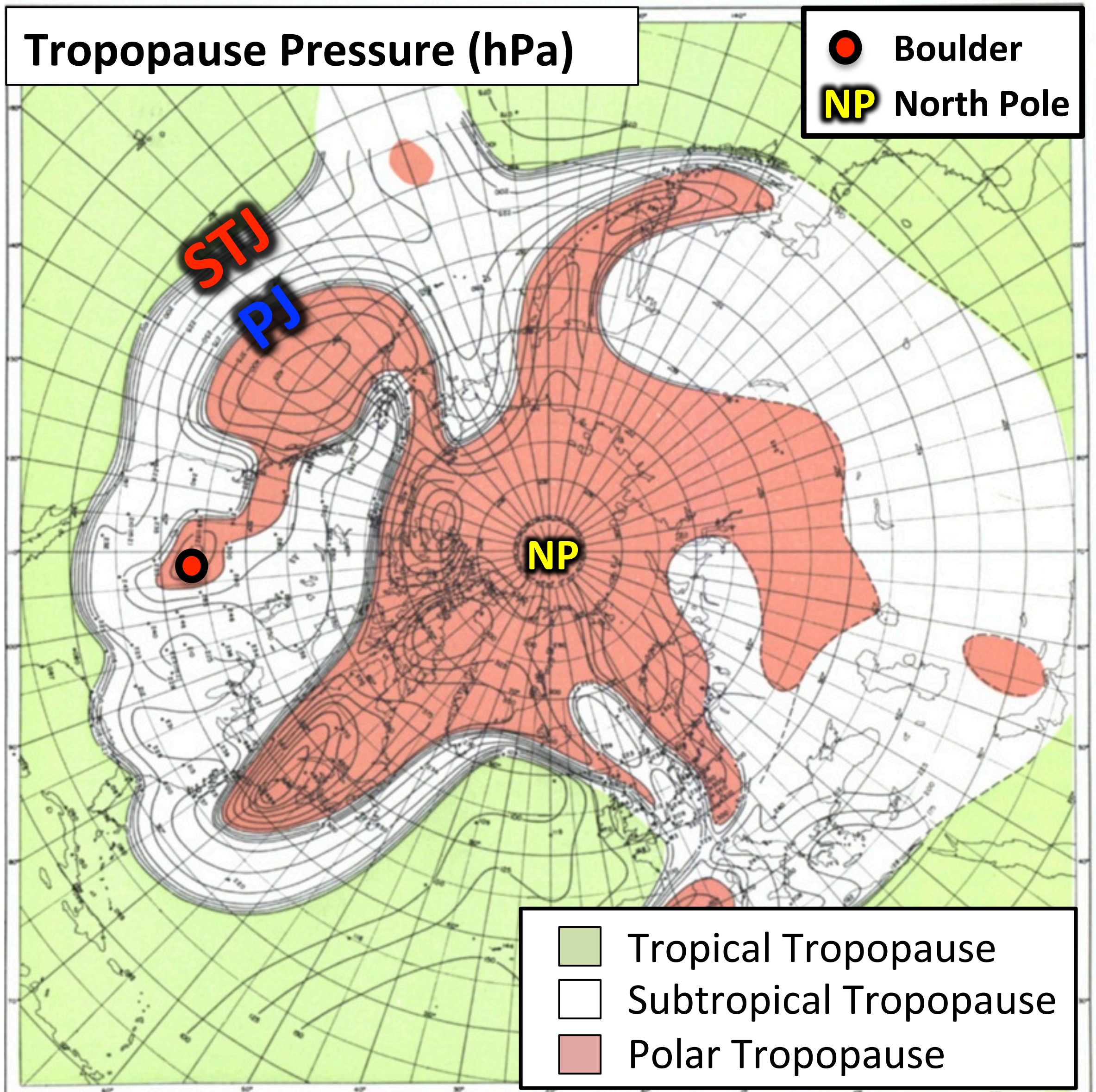

Maps of tropopause pressure help to identify the location of the jets.

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

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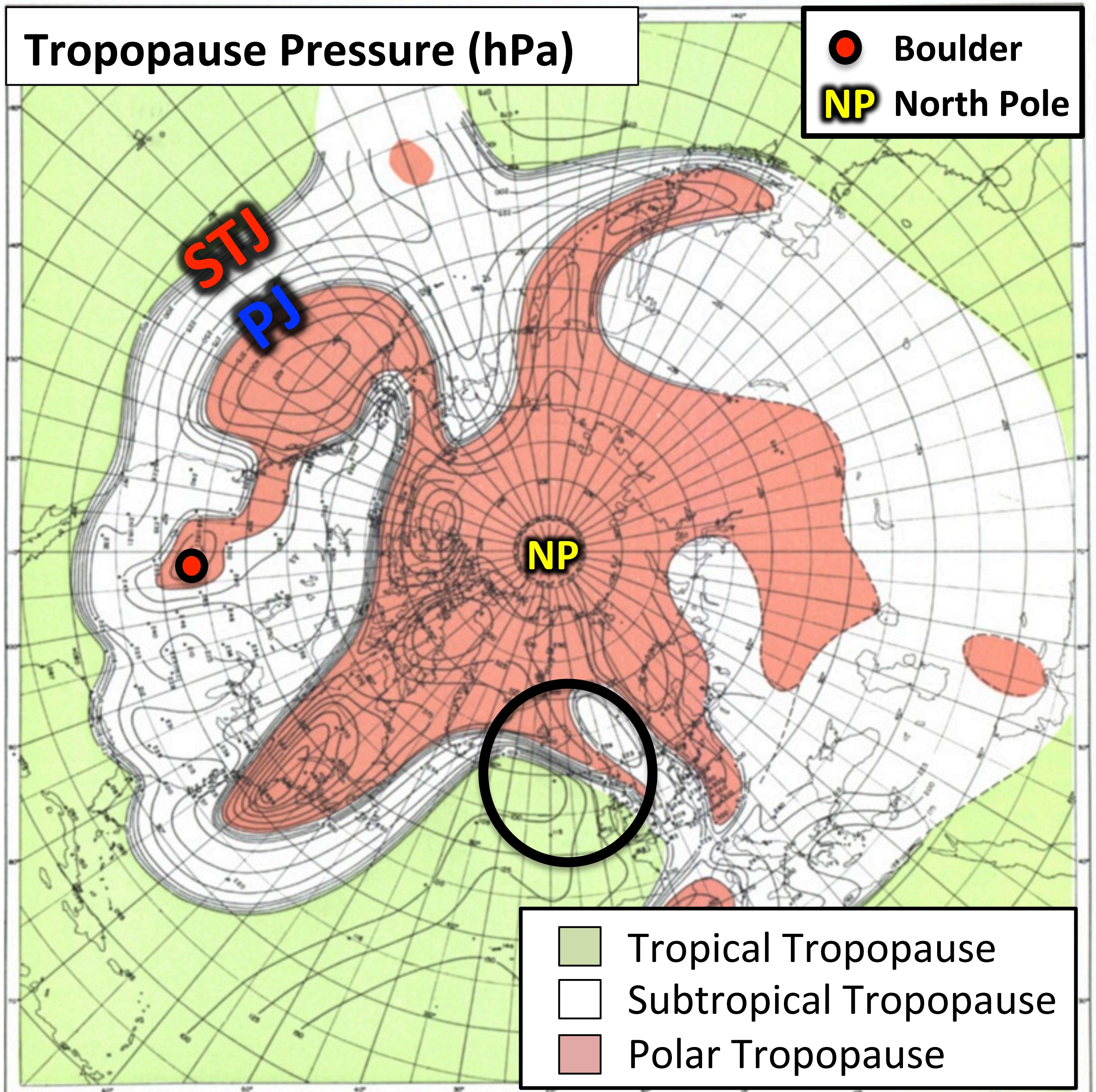

Maps of tropopause pressure help to identify the location of the jets.

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

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

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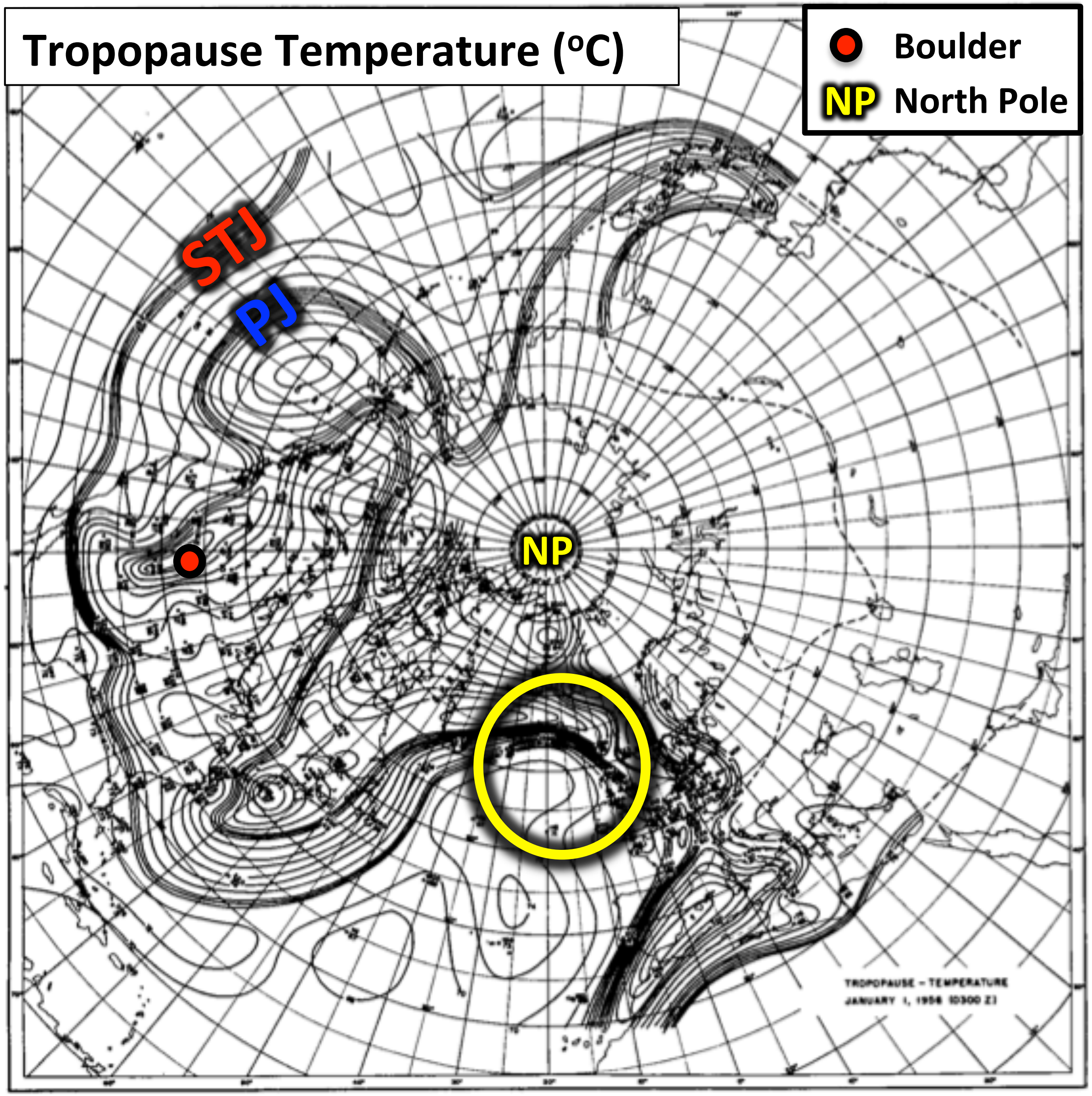
Background



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.

Modified from Defant and Taba (1957)

Background

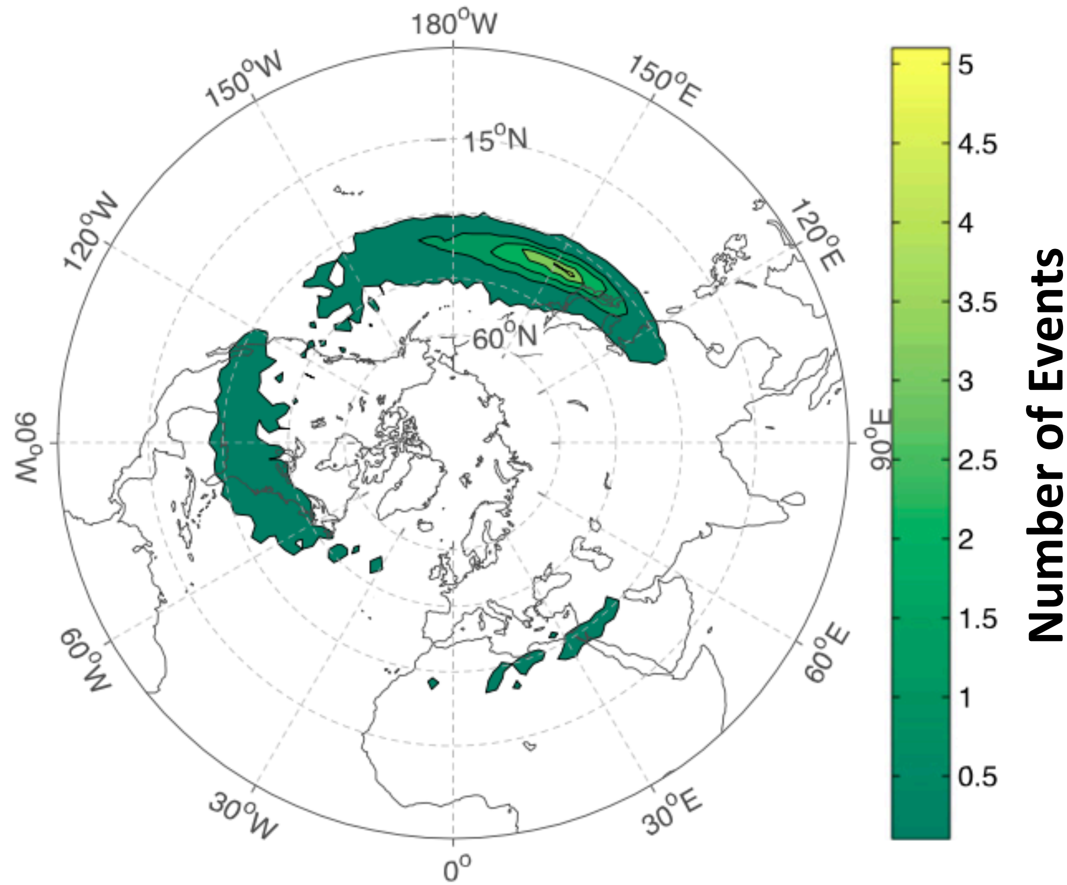
Christenson et al. (2017) highlight three locations that experience the greatest frequency of jet superpositions:

1) Western Pacific

2) North America

3) Northern Africa

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



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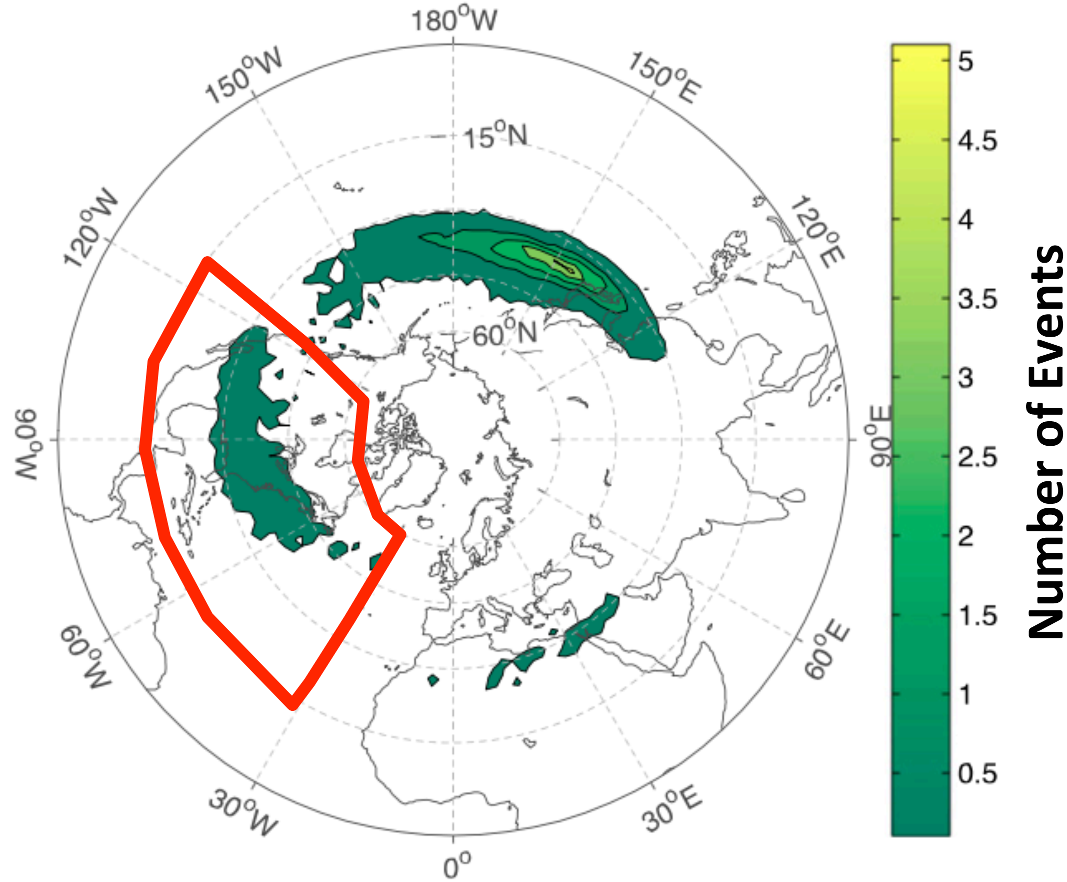
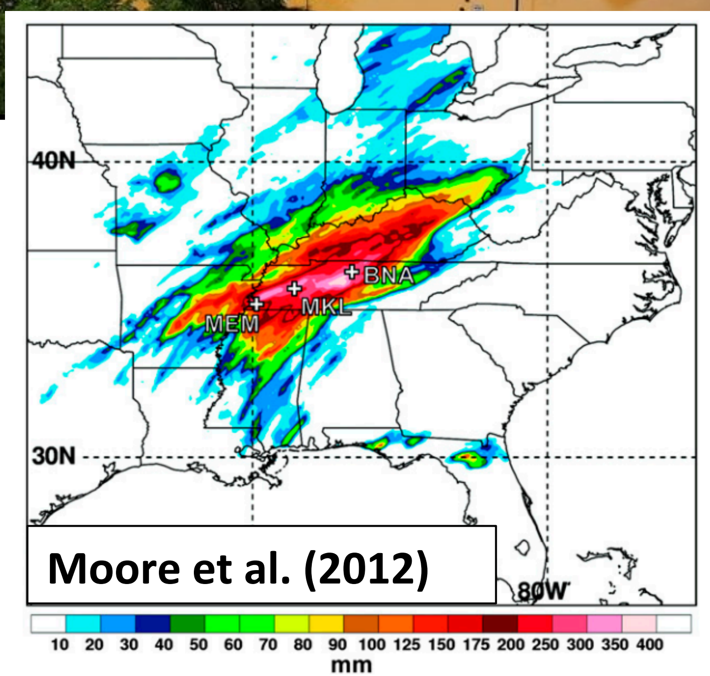


Christenson et al. (2017)

Jet Superpositions and High-Impact Weather

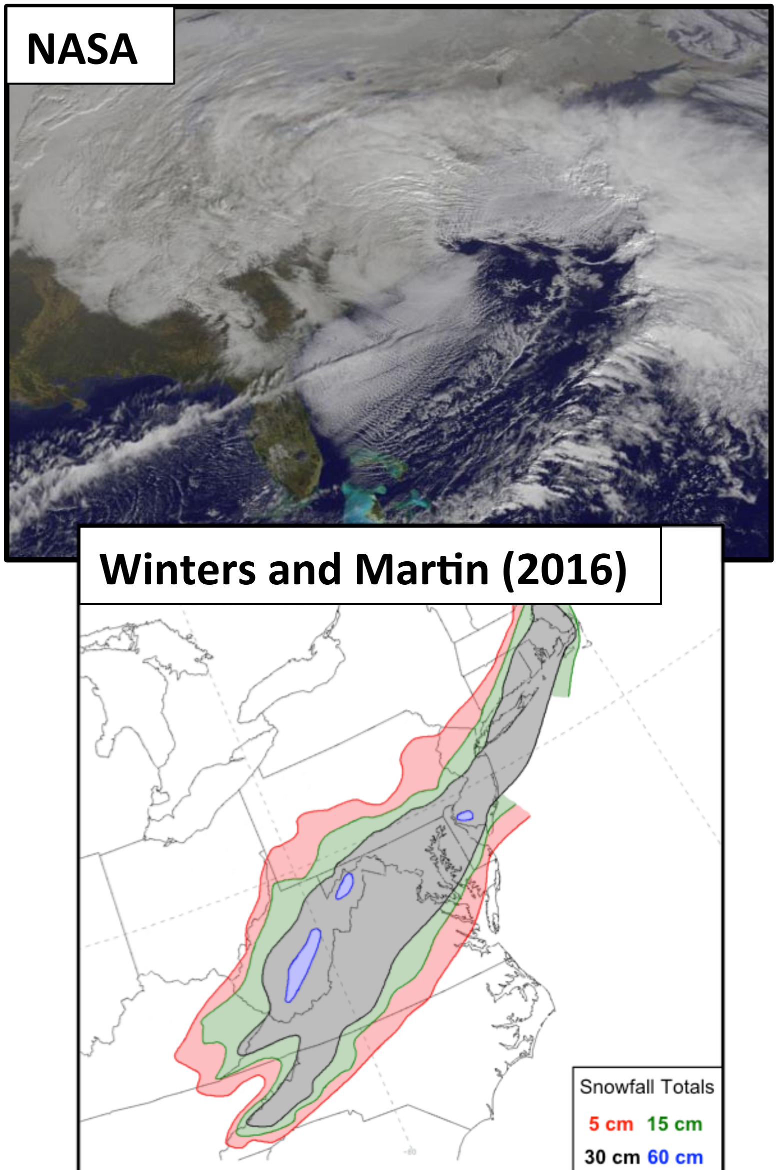


Jet superpositions can be an element of high-impact weather events

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



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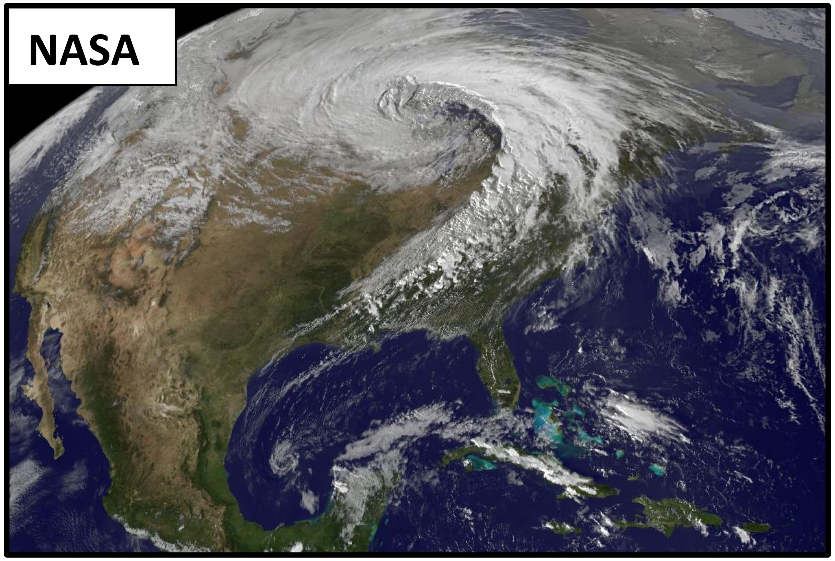

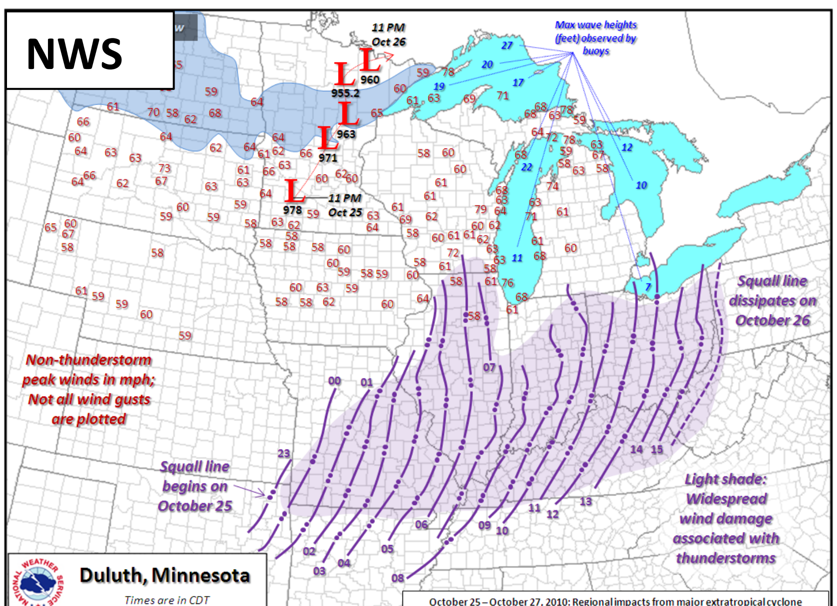

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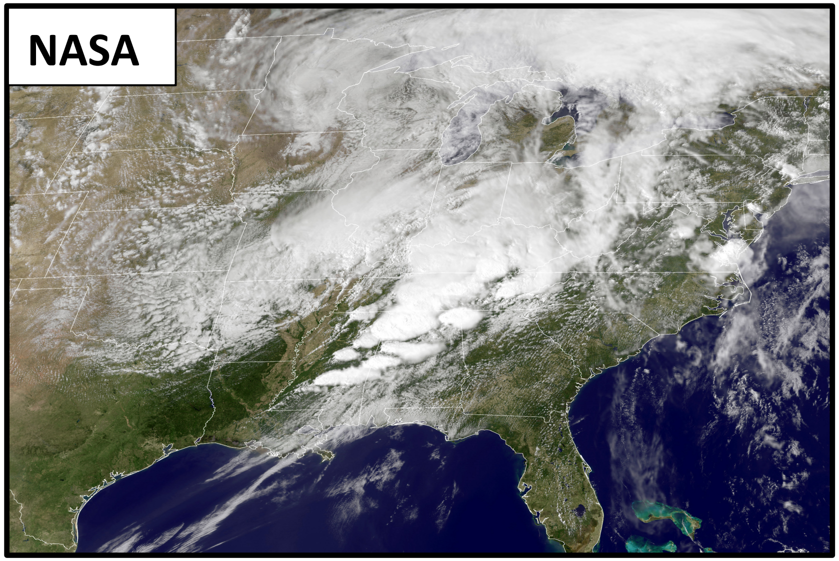
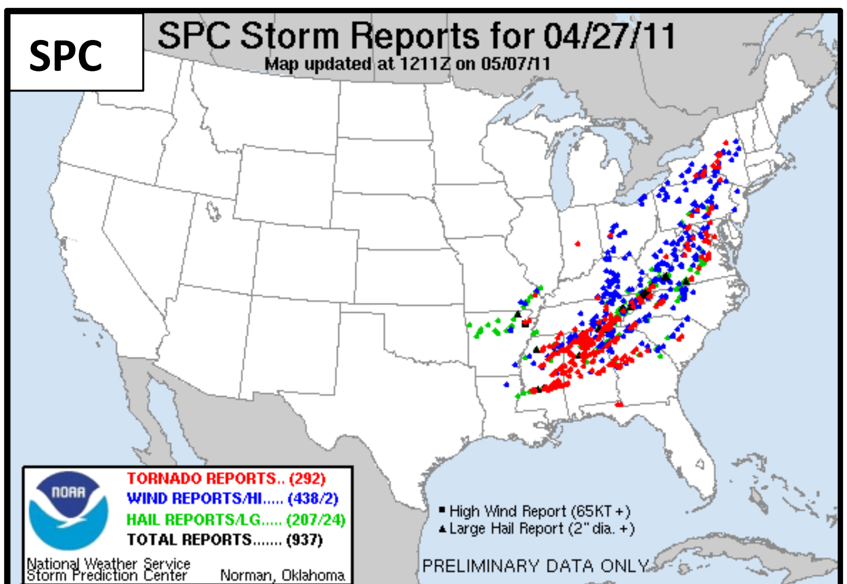
26 October 2010: Explosive Cyclogenesis Event

- Jet superposition over the West Pacific preceded the development of an intense Midwest U.S. cyclone.

Jet Superpositions and High-Impact Weather





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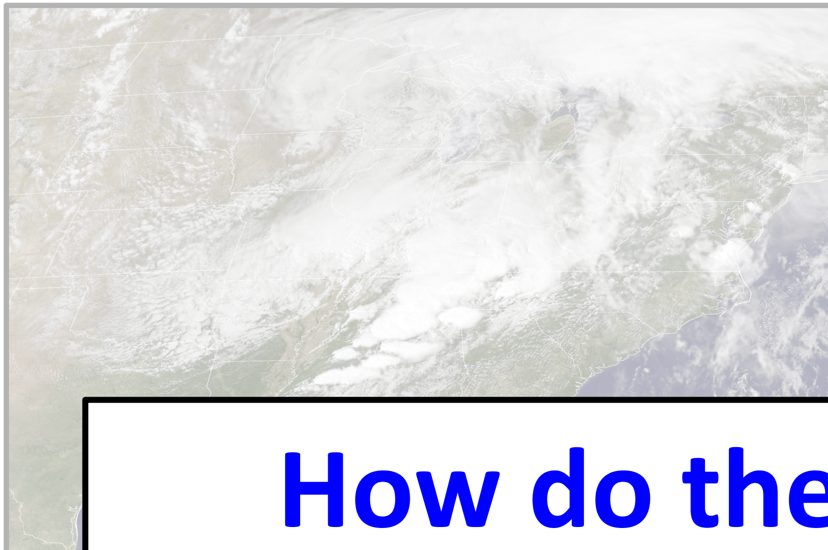
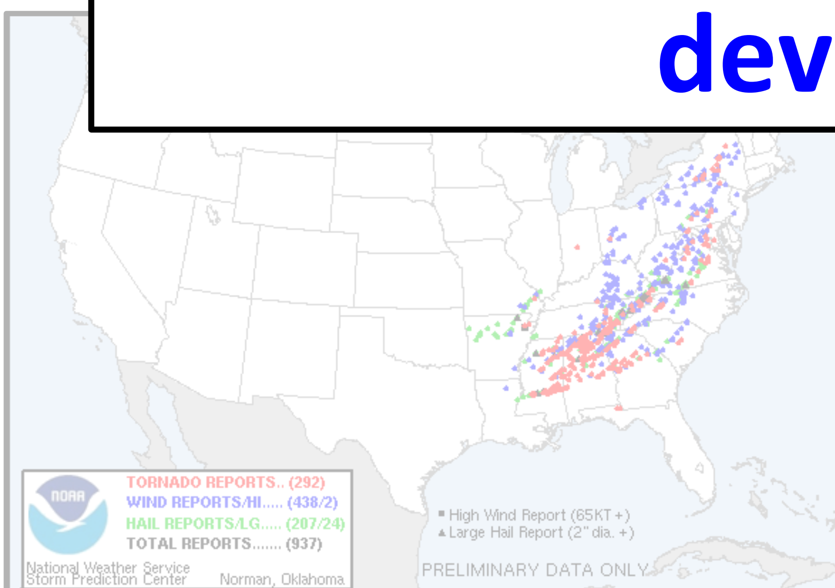
Jet Superpositions and High-Impact Weather





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

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How do these structures develop?

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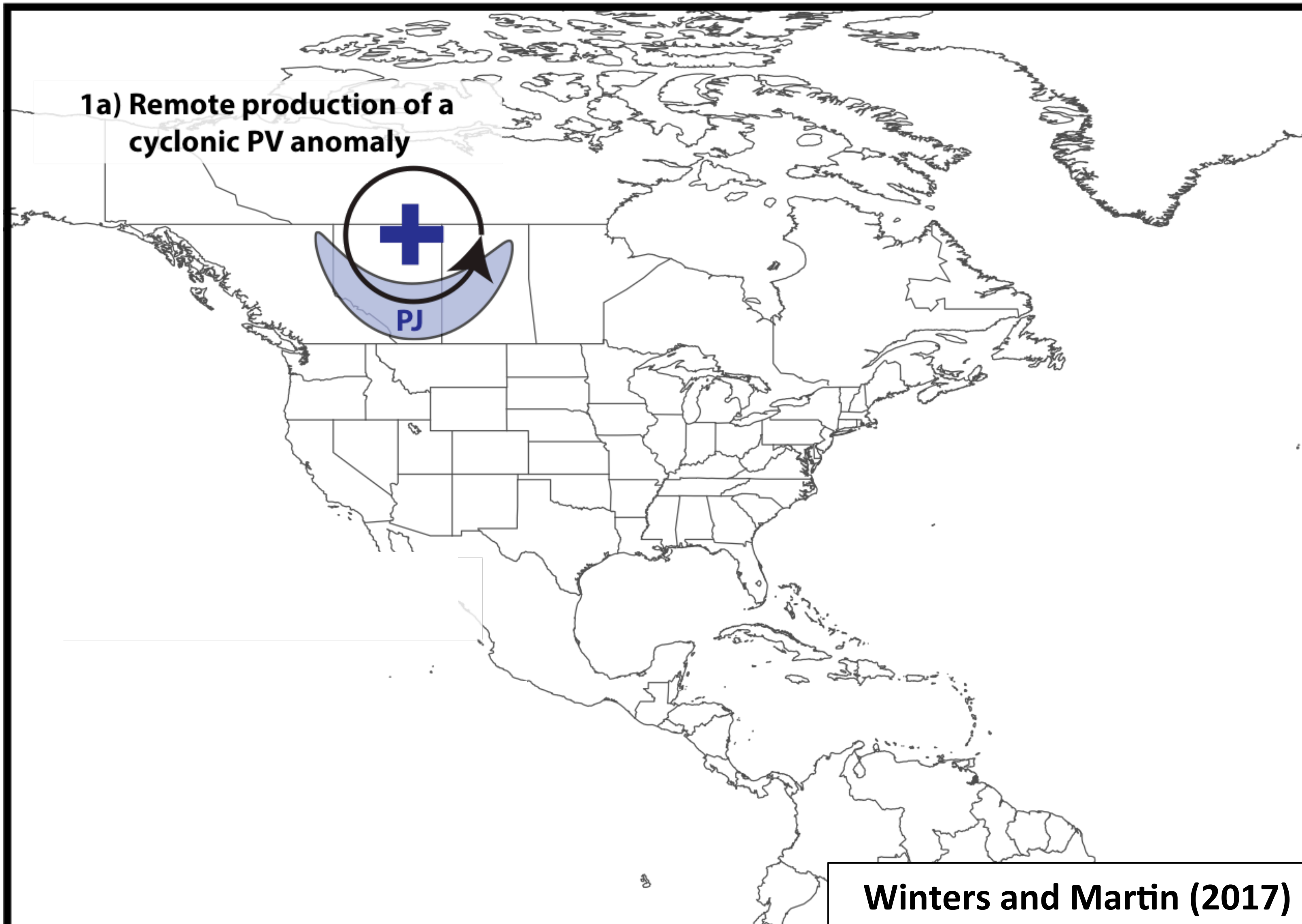
Jet Superposition Conceptual Model



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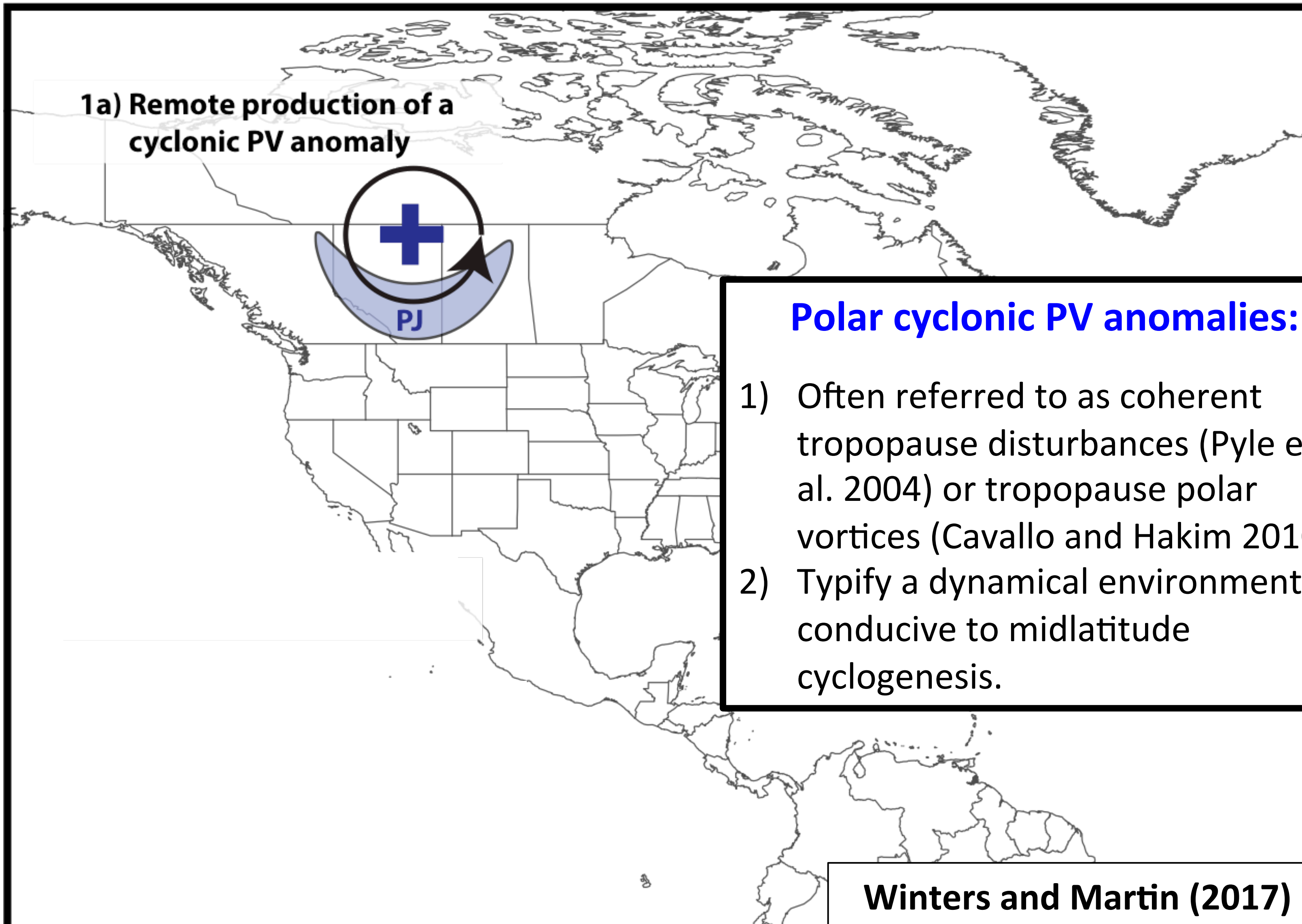
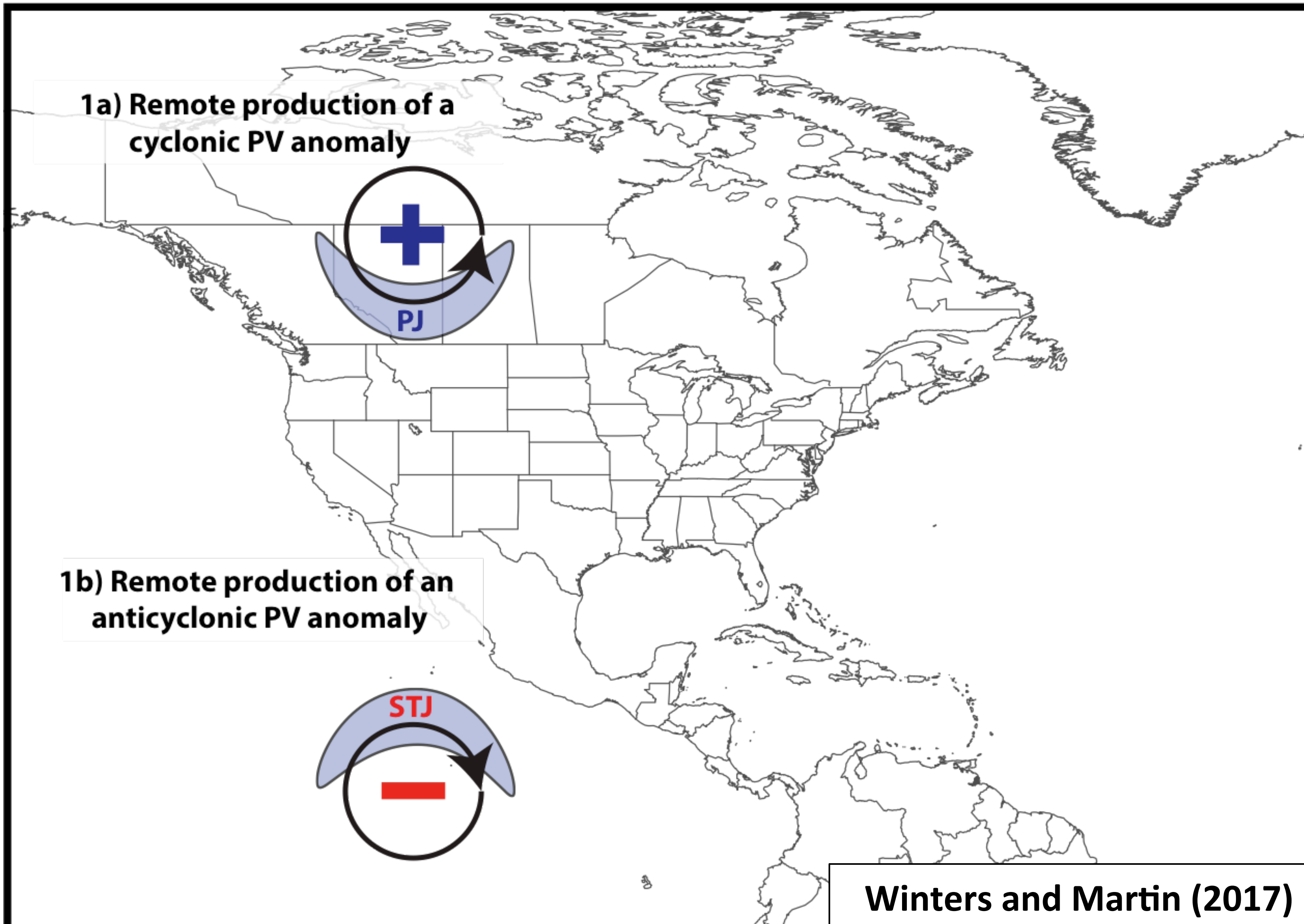


Polar cyclonic PV anomalies:

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.

Jet Superposition Conceptual Model



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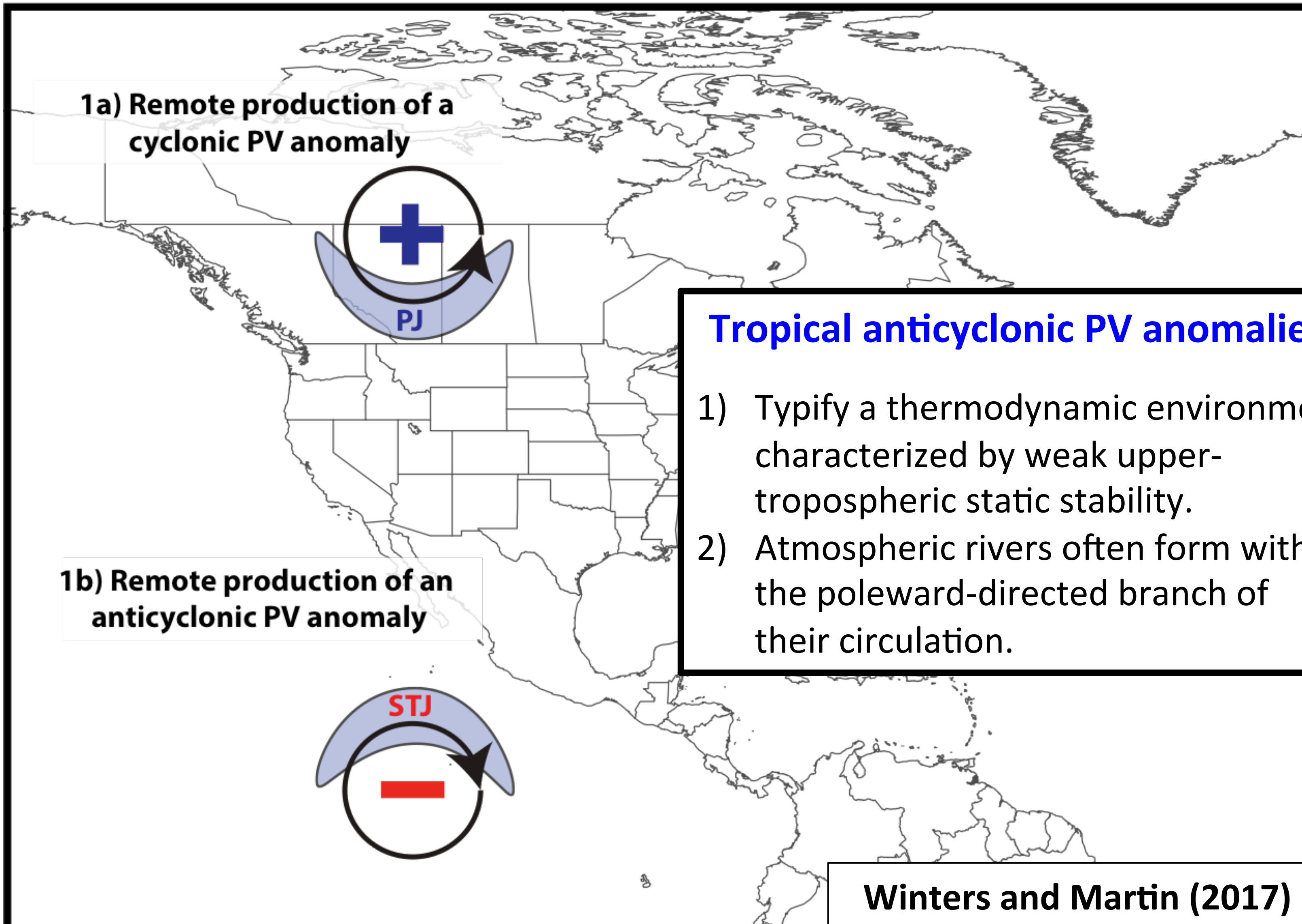

Tropical anticyclonic PV anomalies:

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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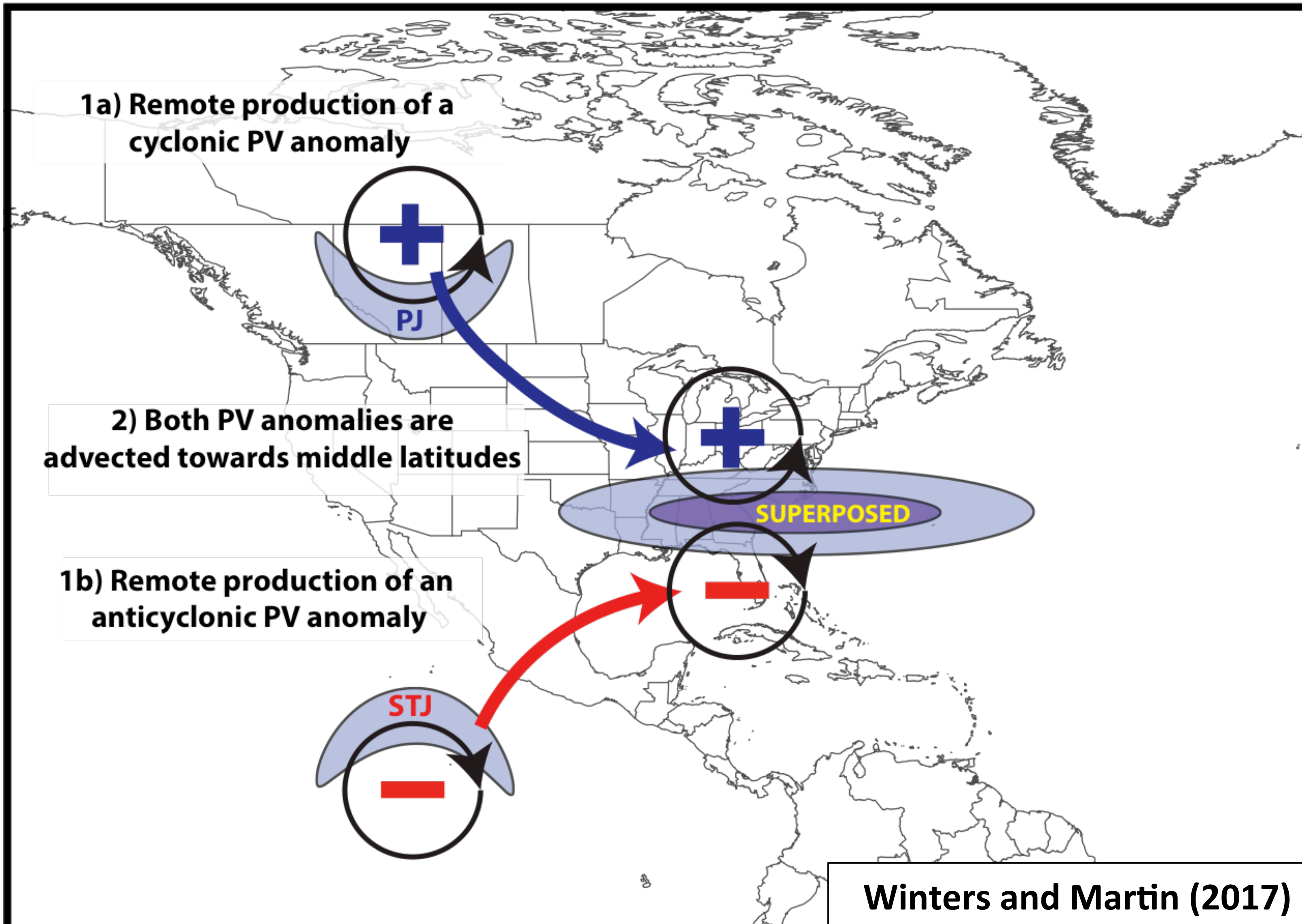

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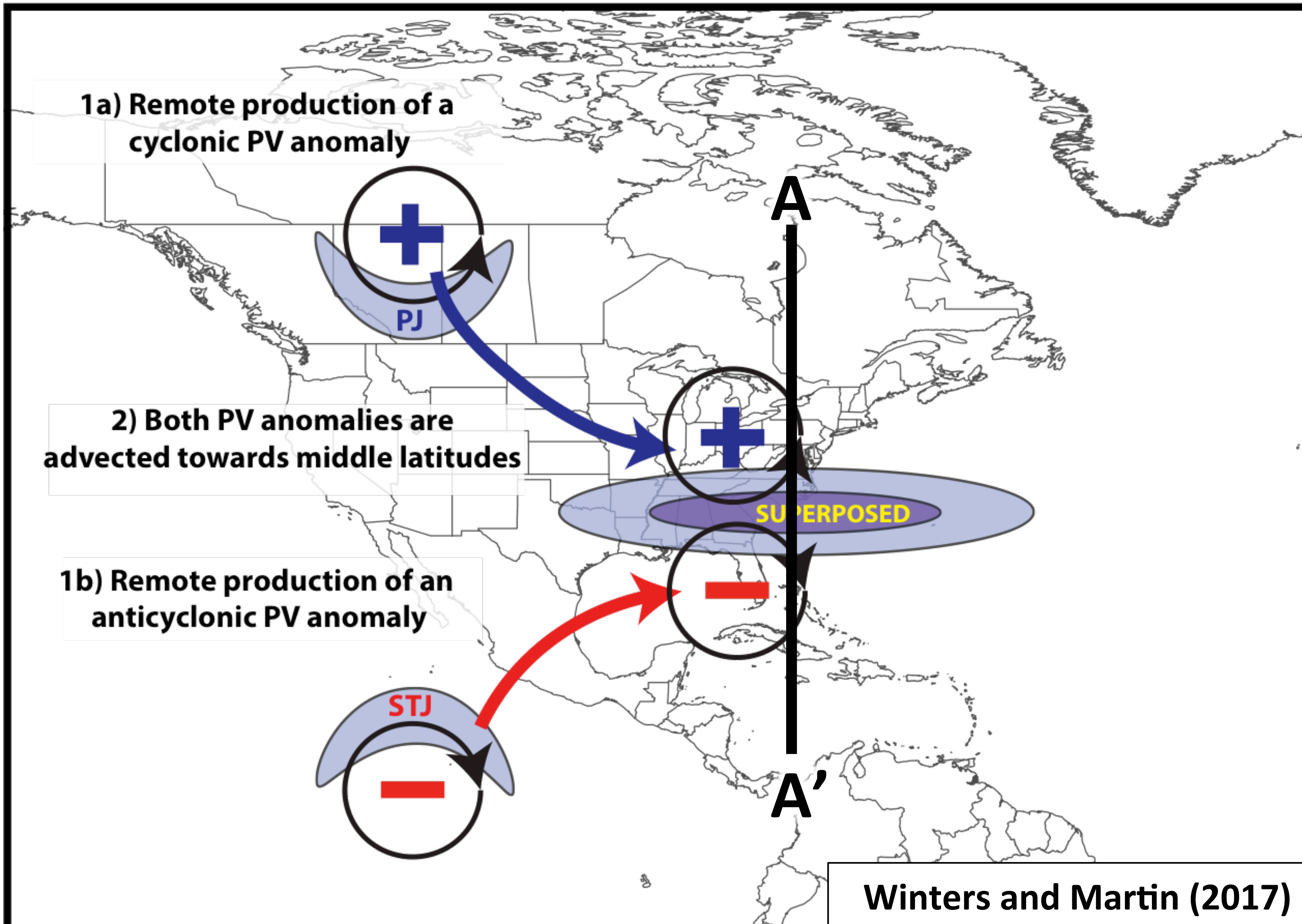

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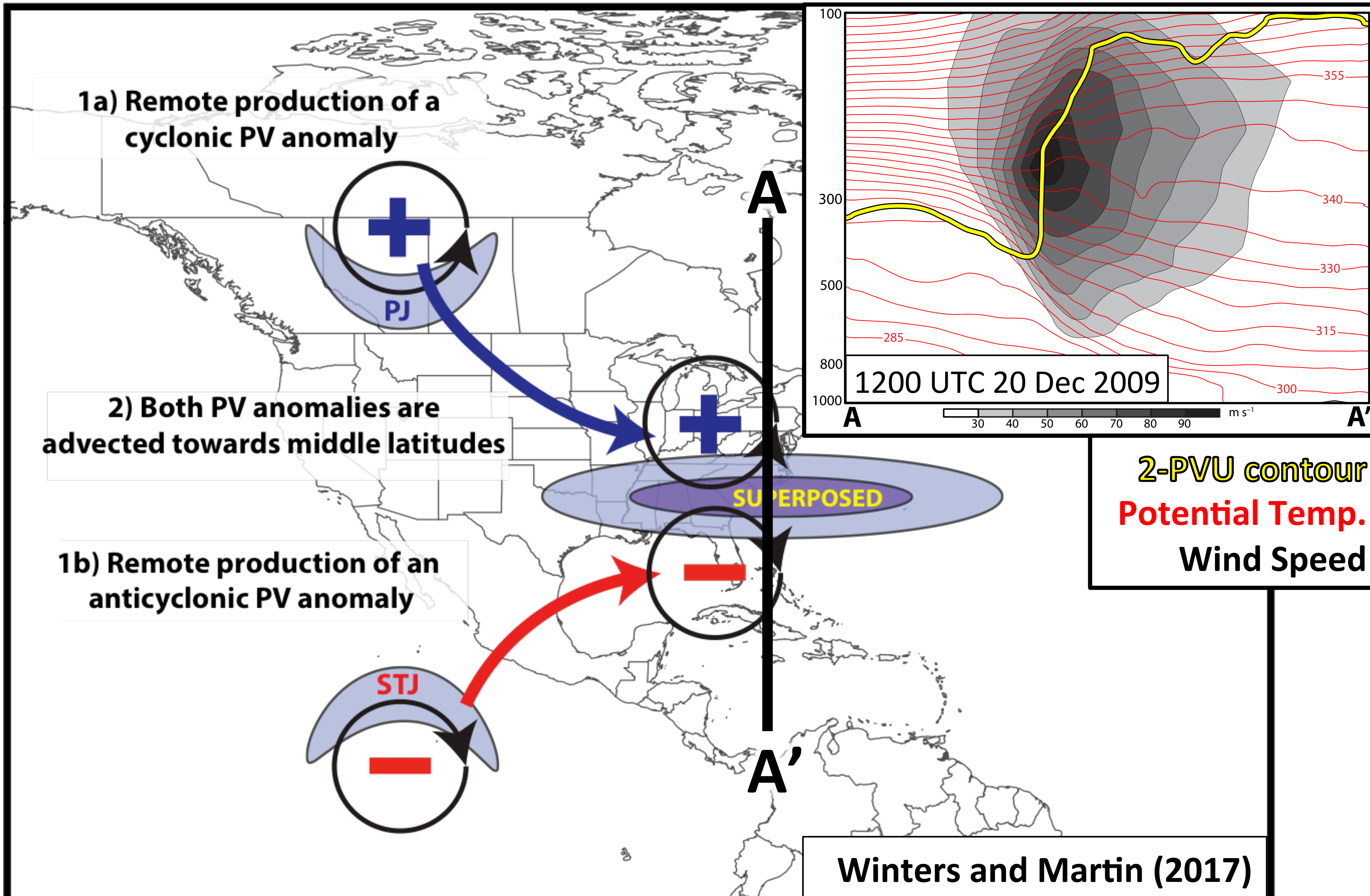

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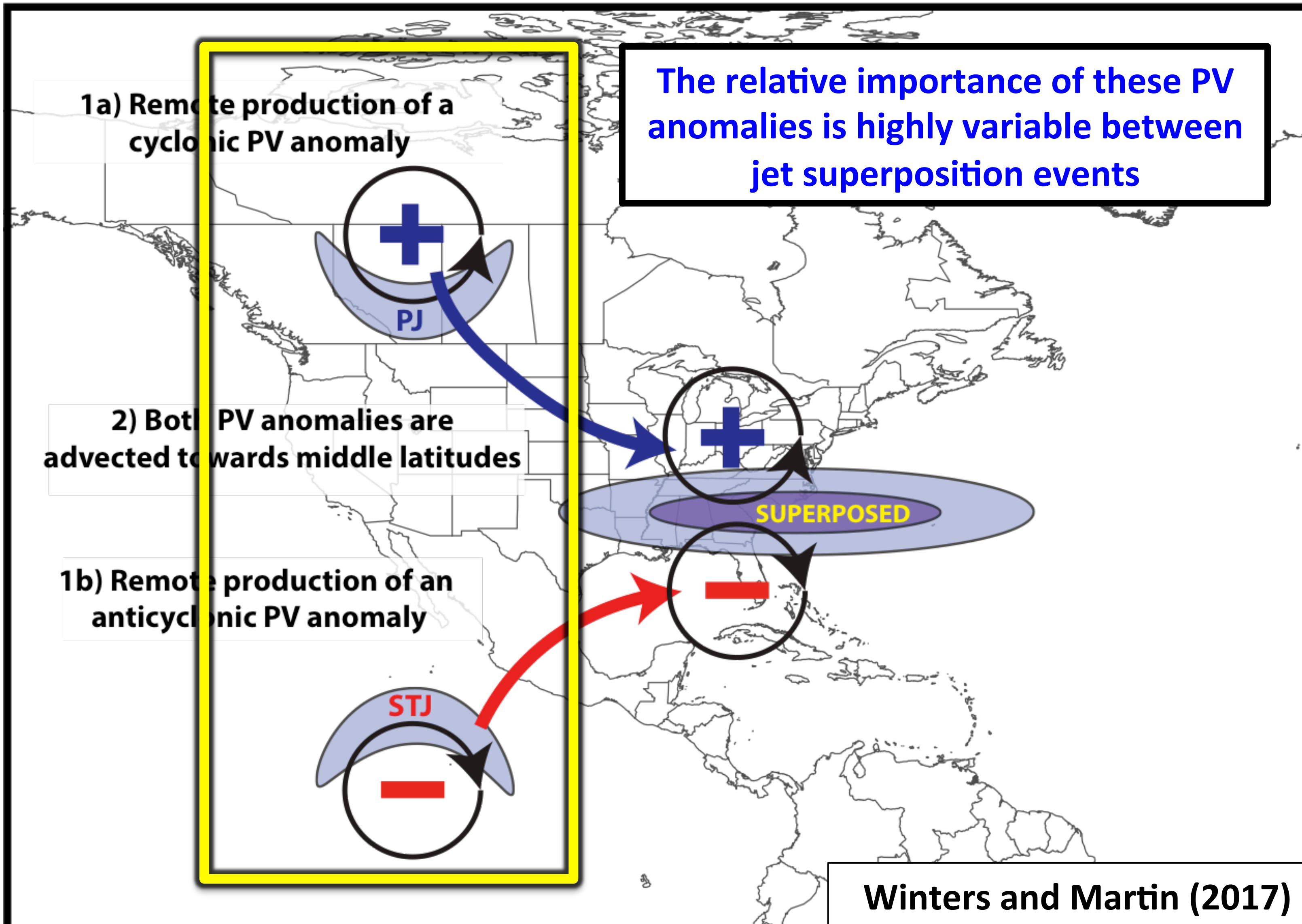

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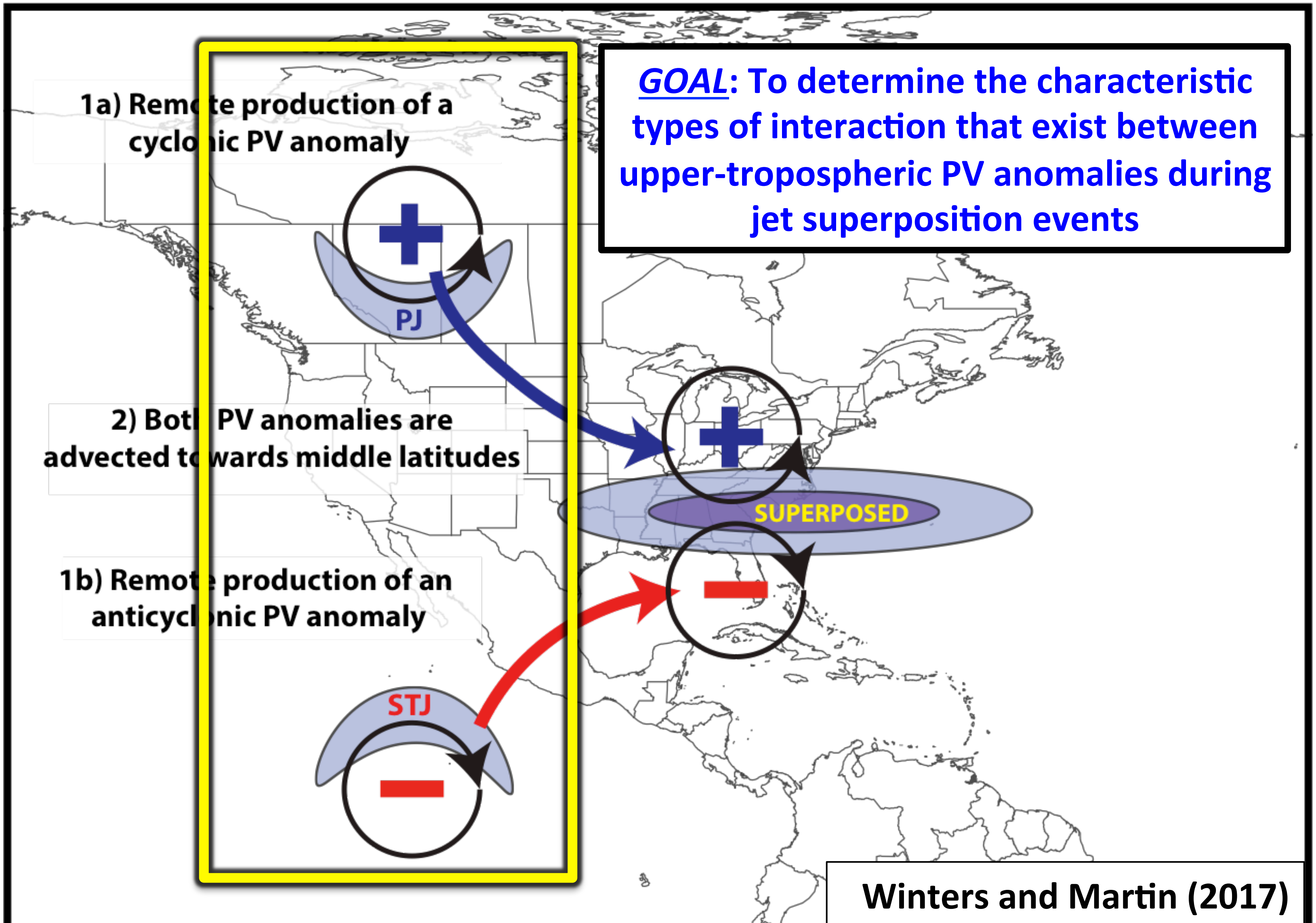
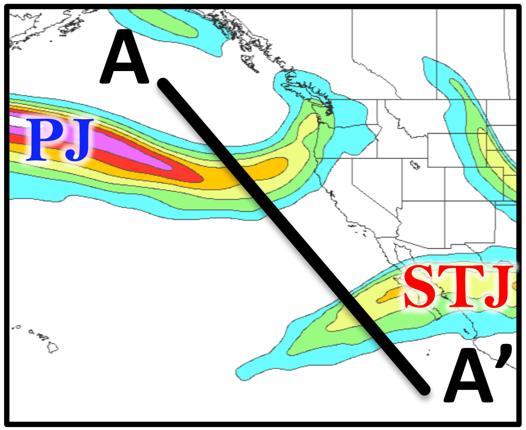


Jet Superposition Event Identification and Classification

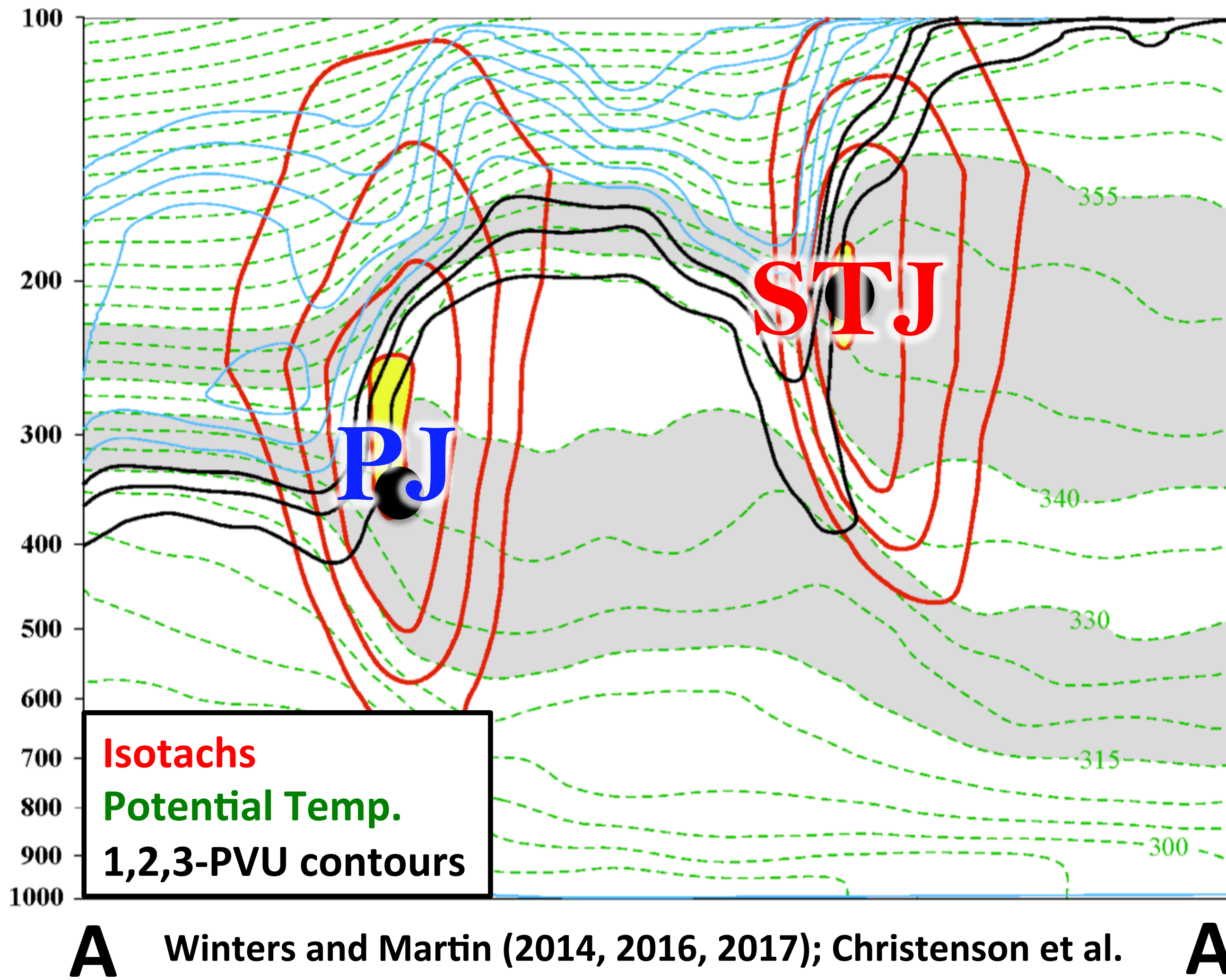
Jet Superposition Event Identification

0000 UTC 27 April 2010



250-hPa wind speed

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



Winters and Martin (2014, 2016, 2017); Christenson et al. (2017); Handlos and Martin (2016)

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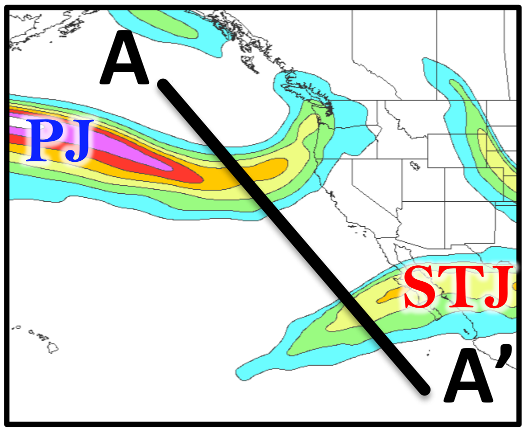

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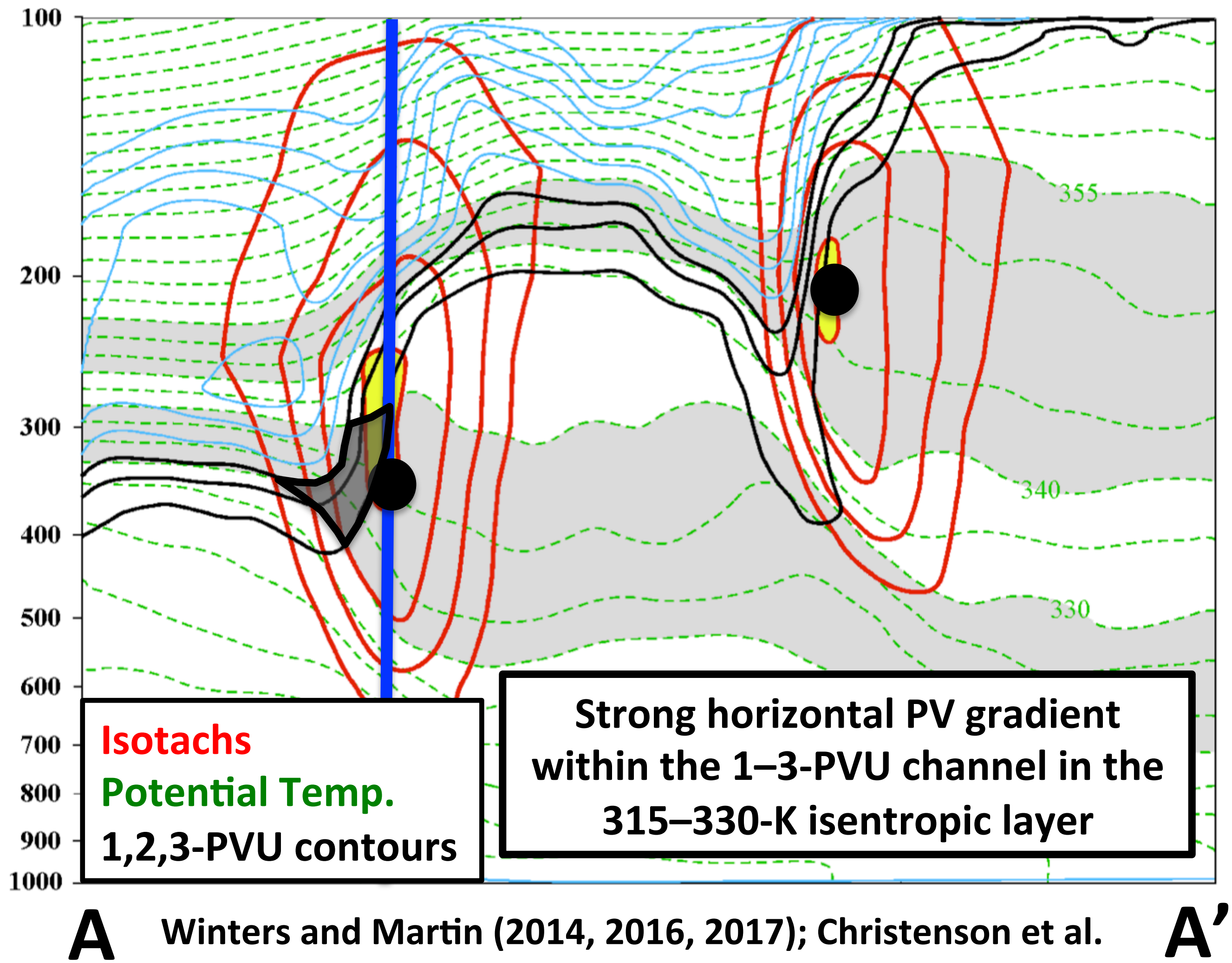

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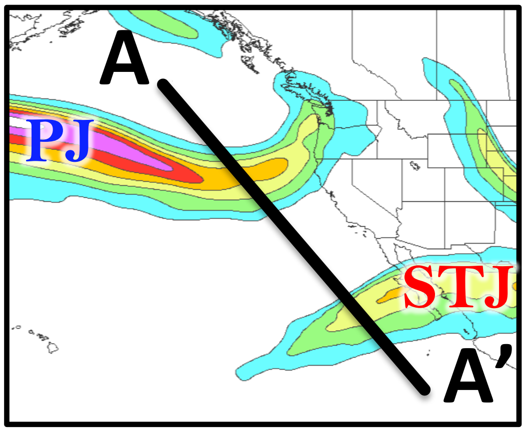

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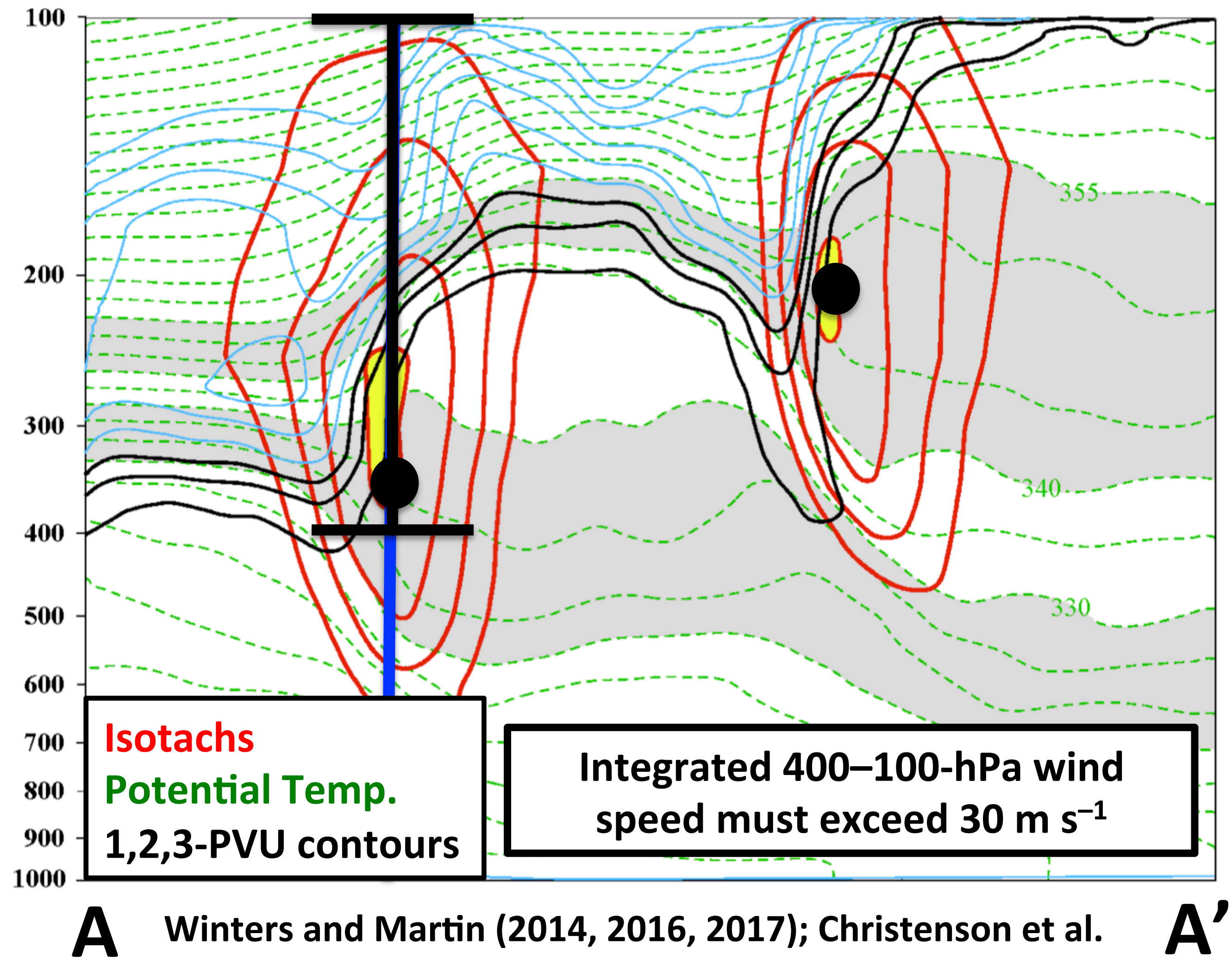

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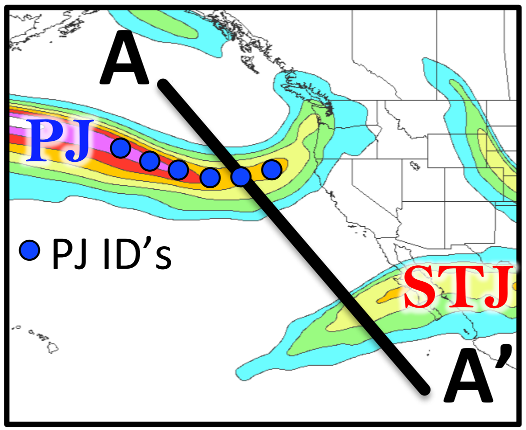

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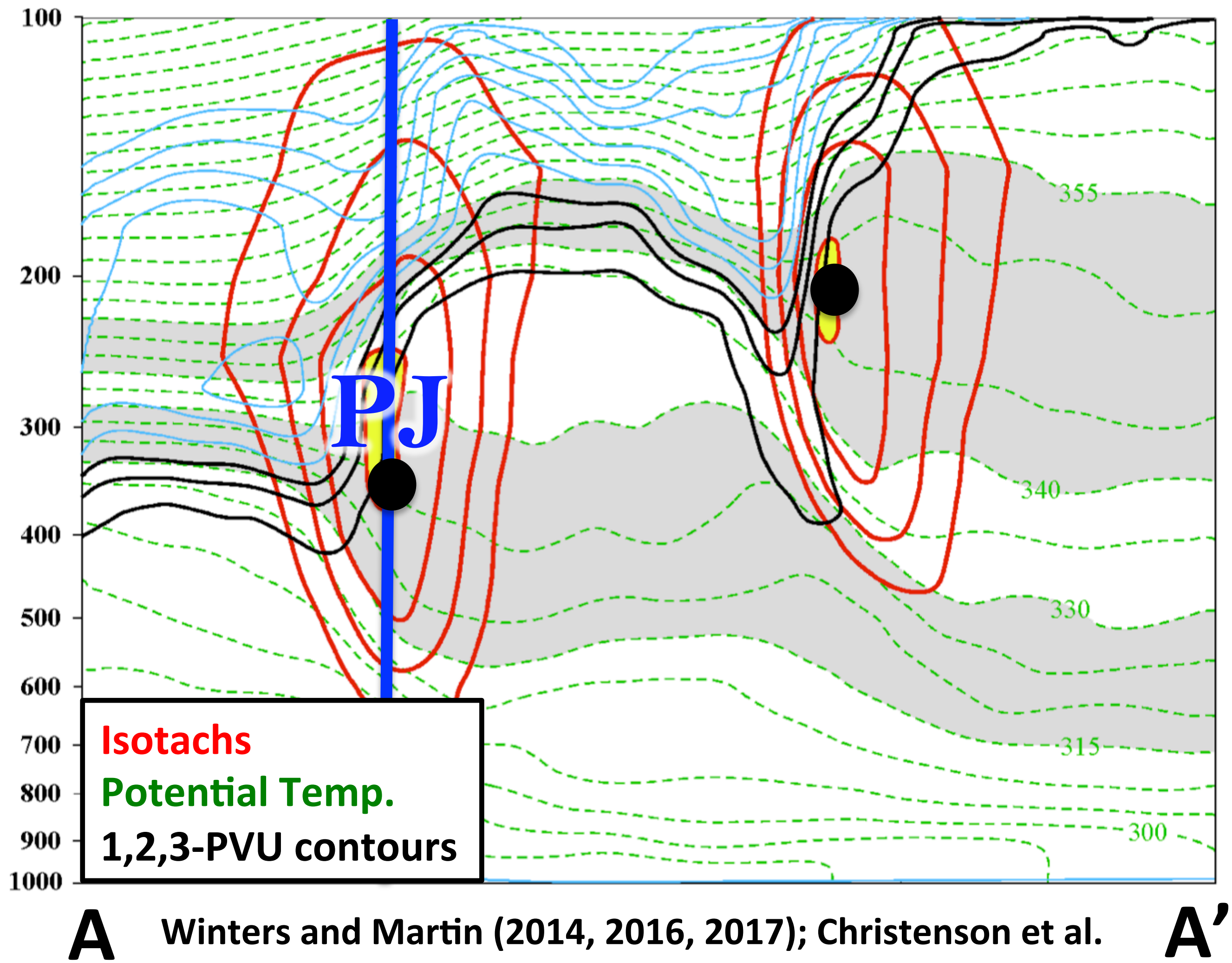

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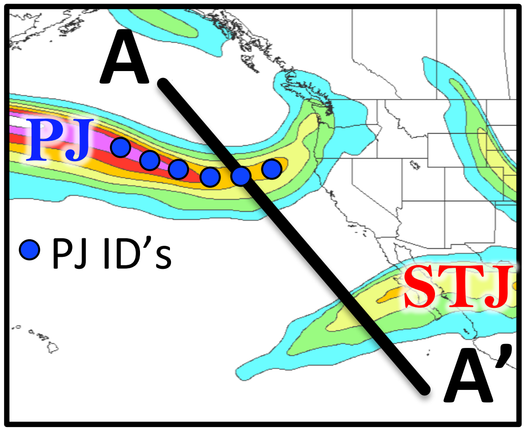

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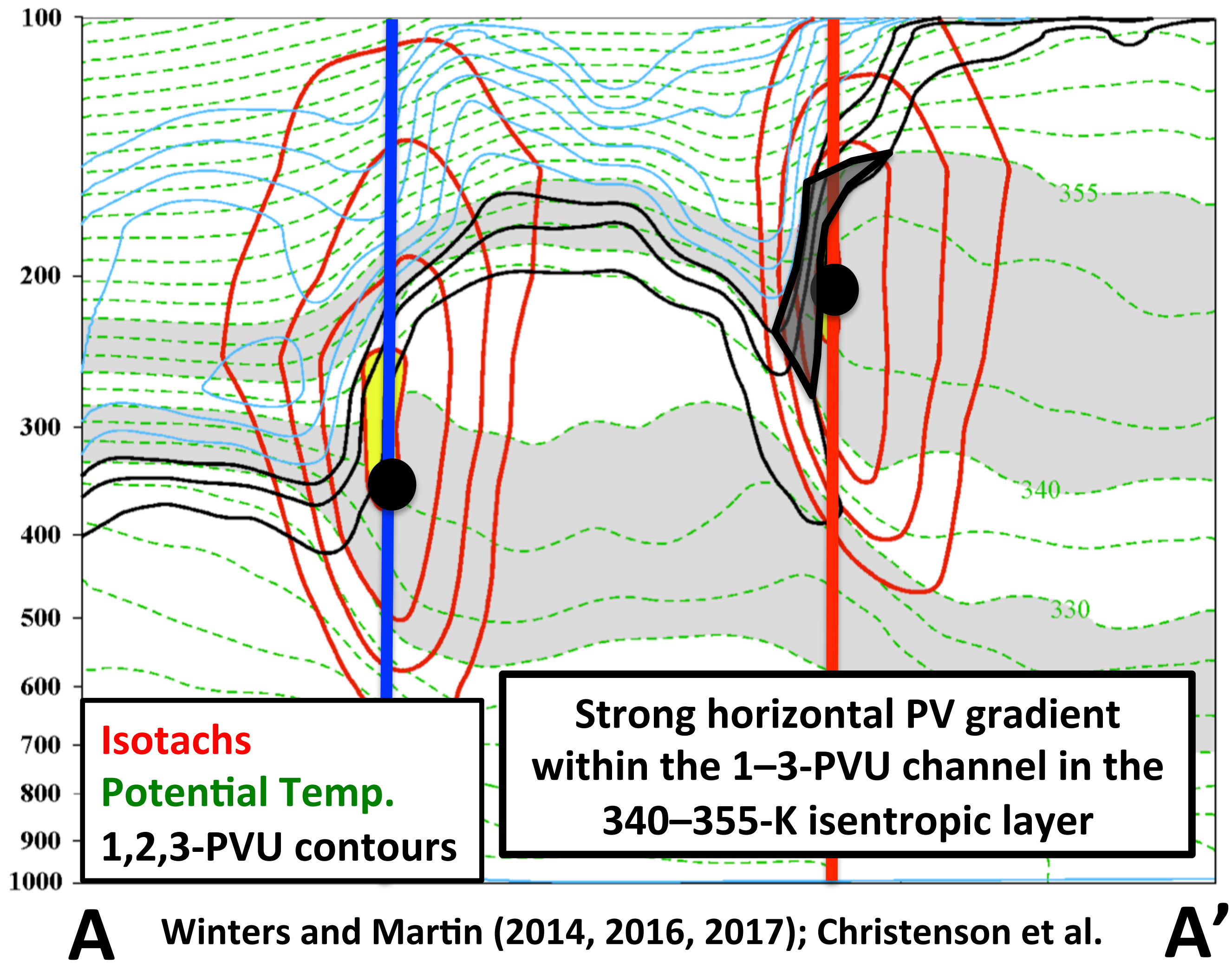

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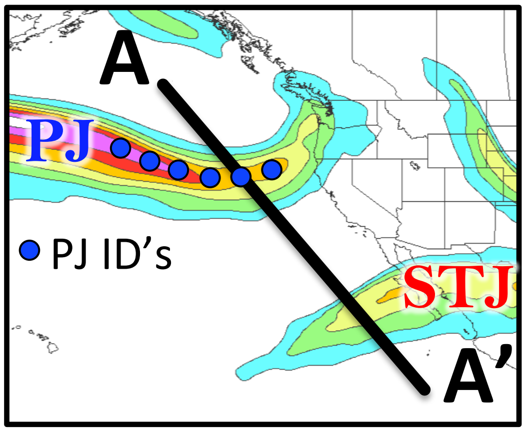

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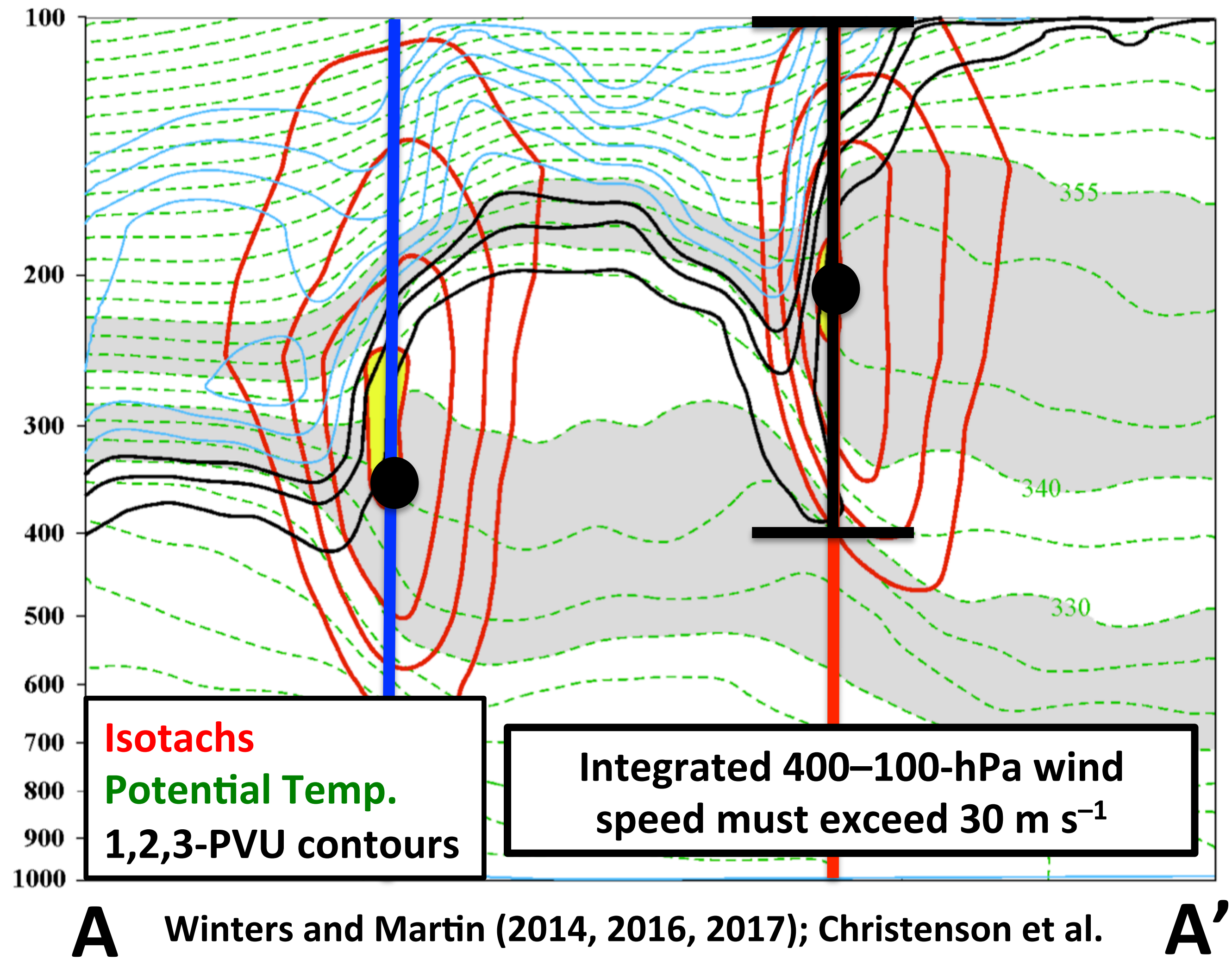

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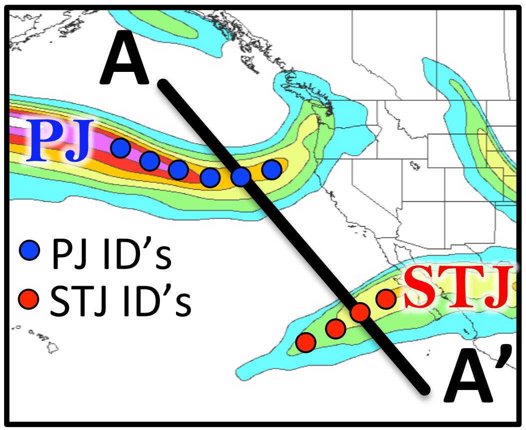

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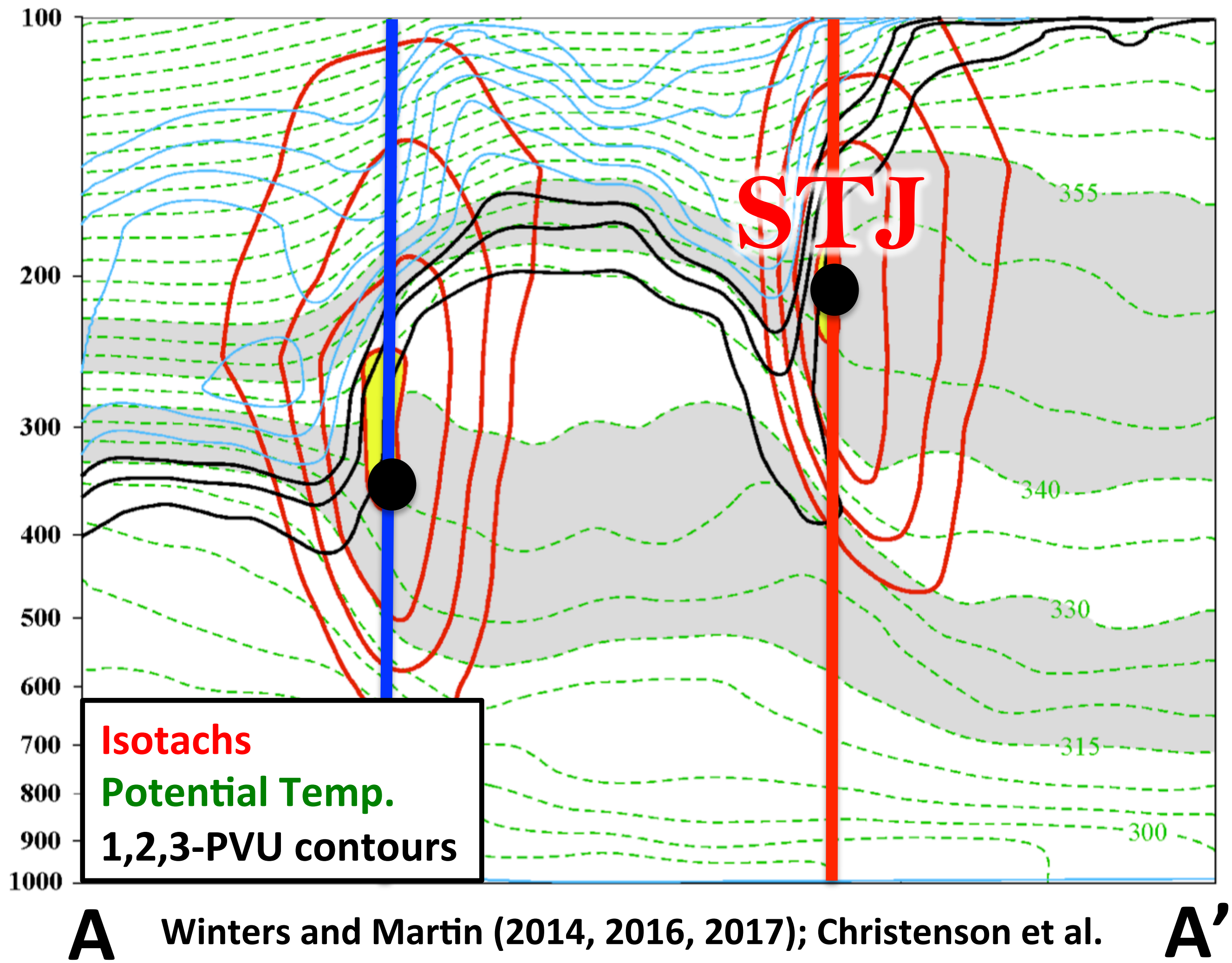

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Jet Superposition Event Identification

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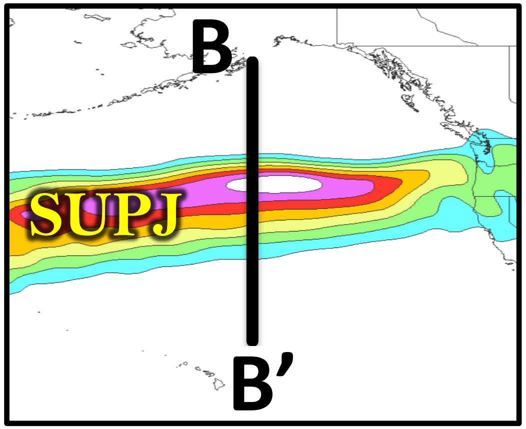

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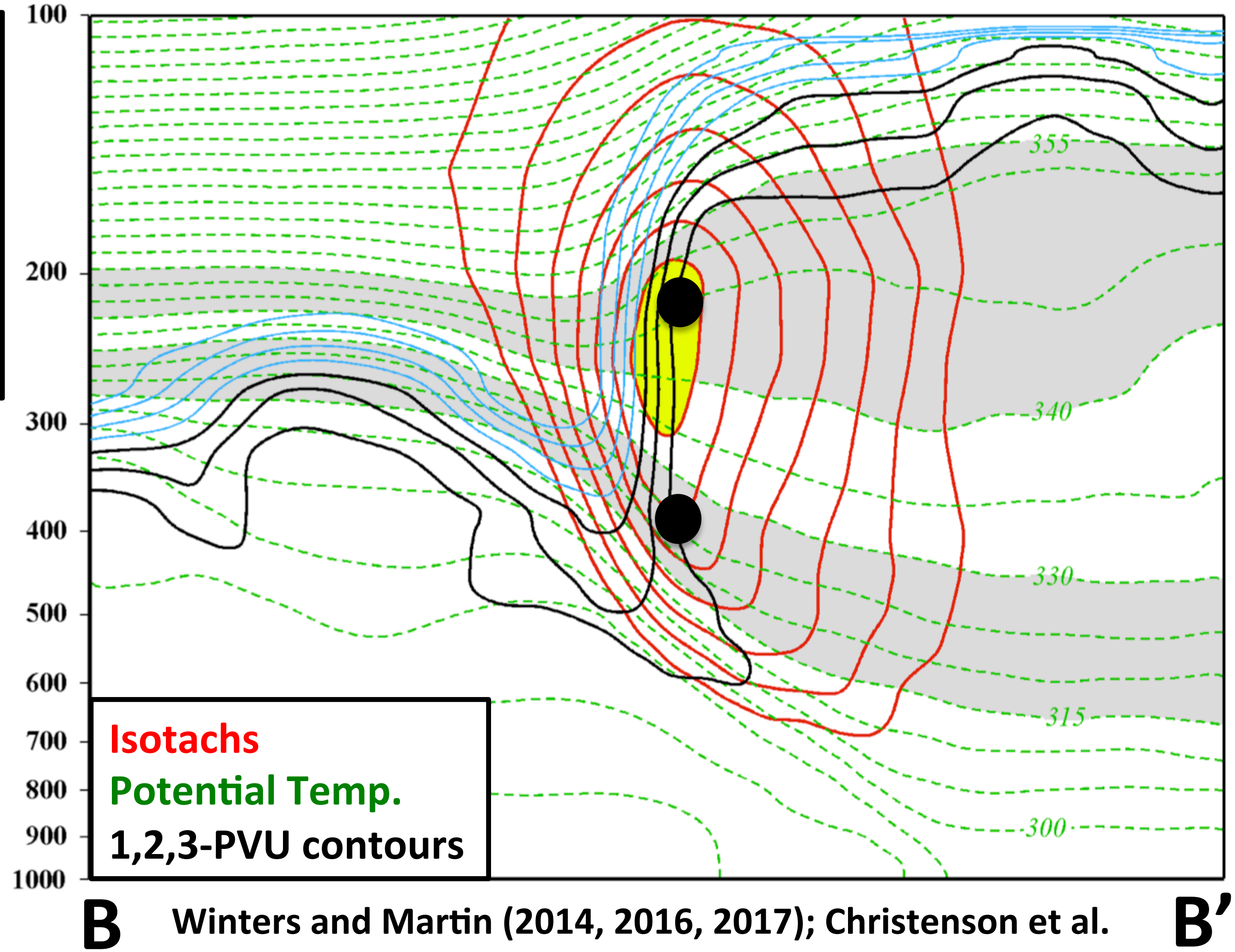

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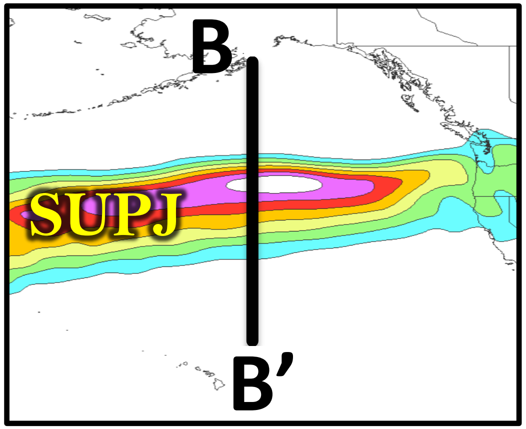

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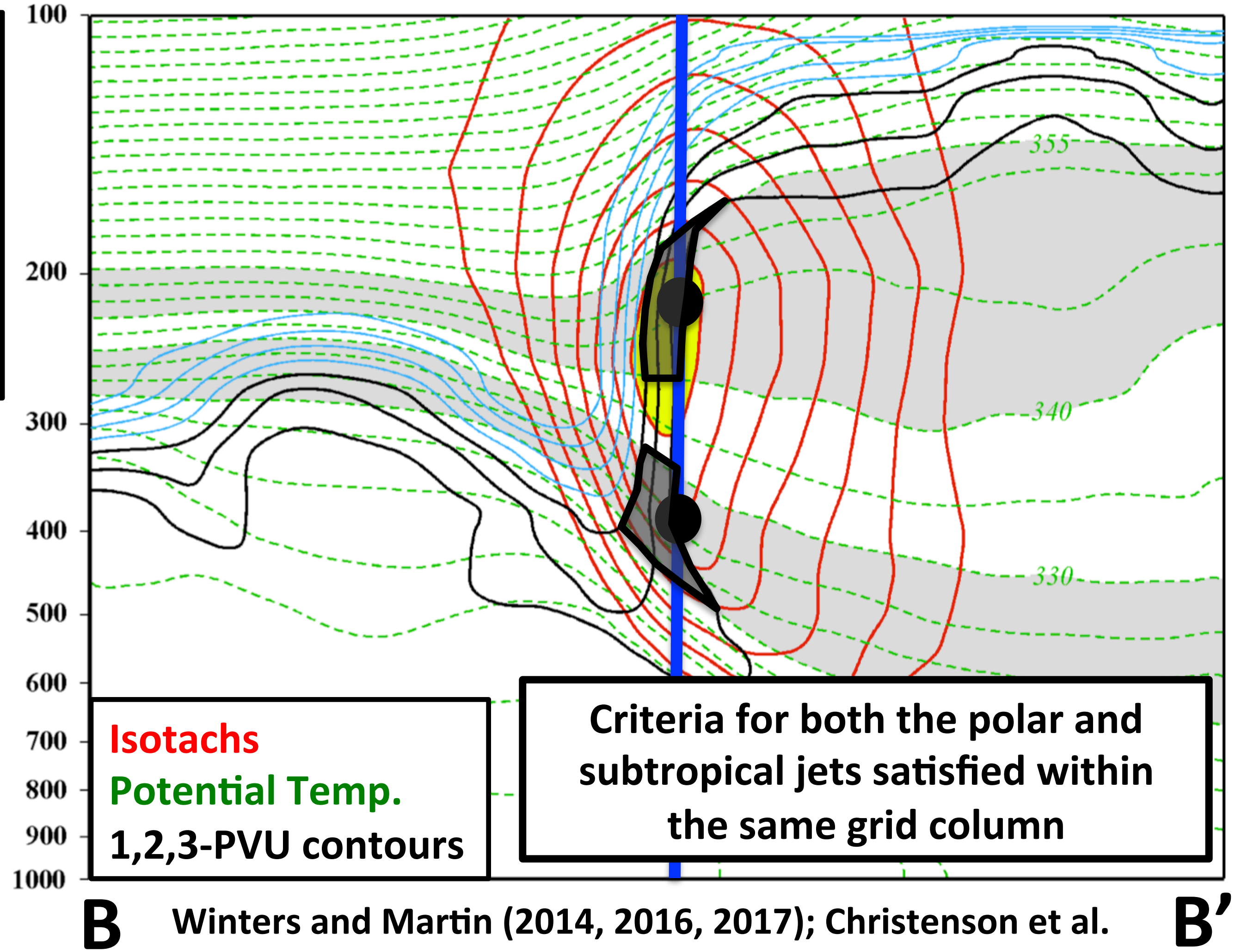

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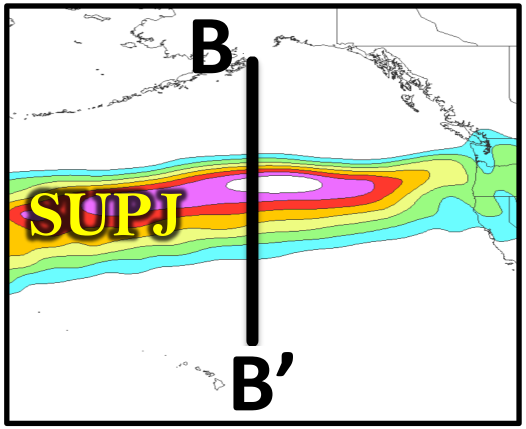

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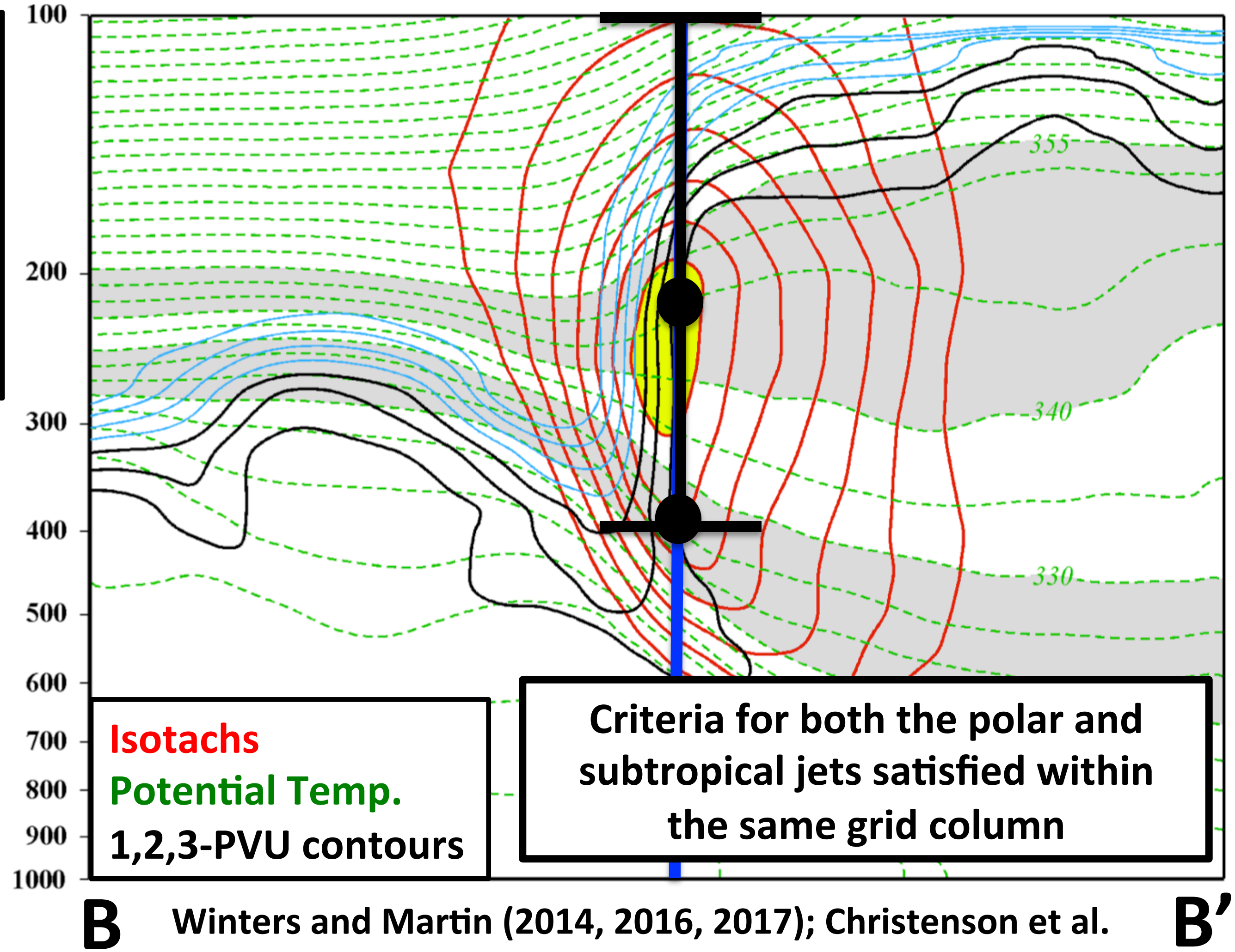

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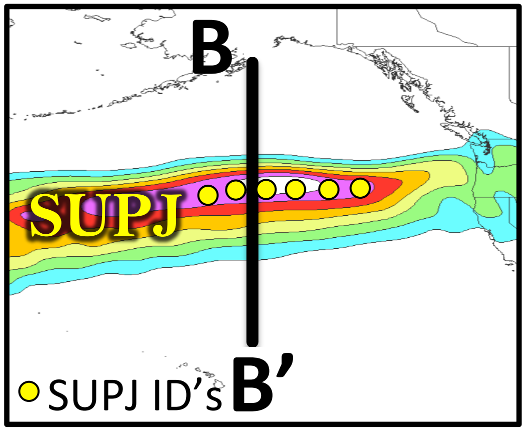

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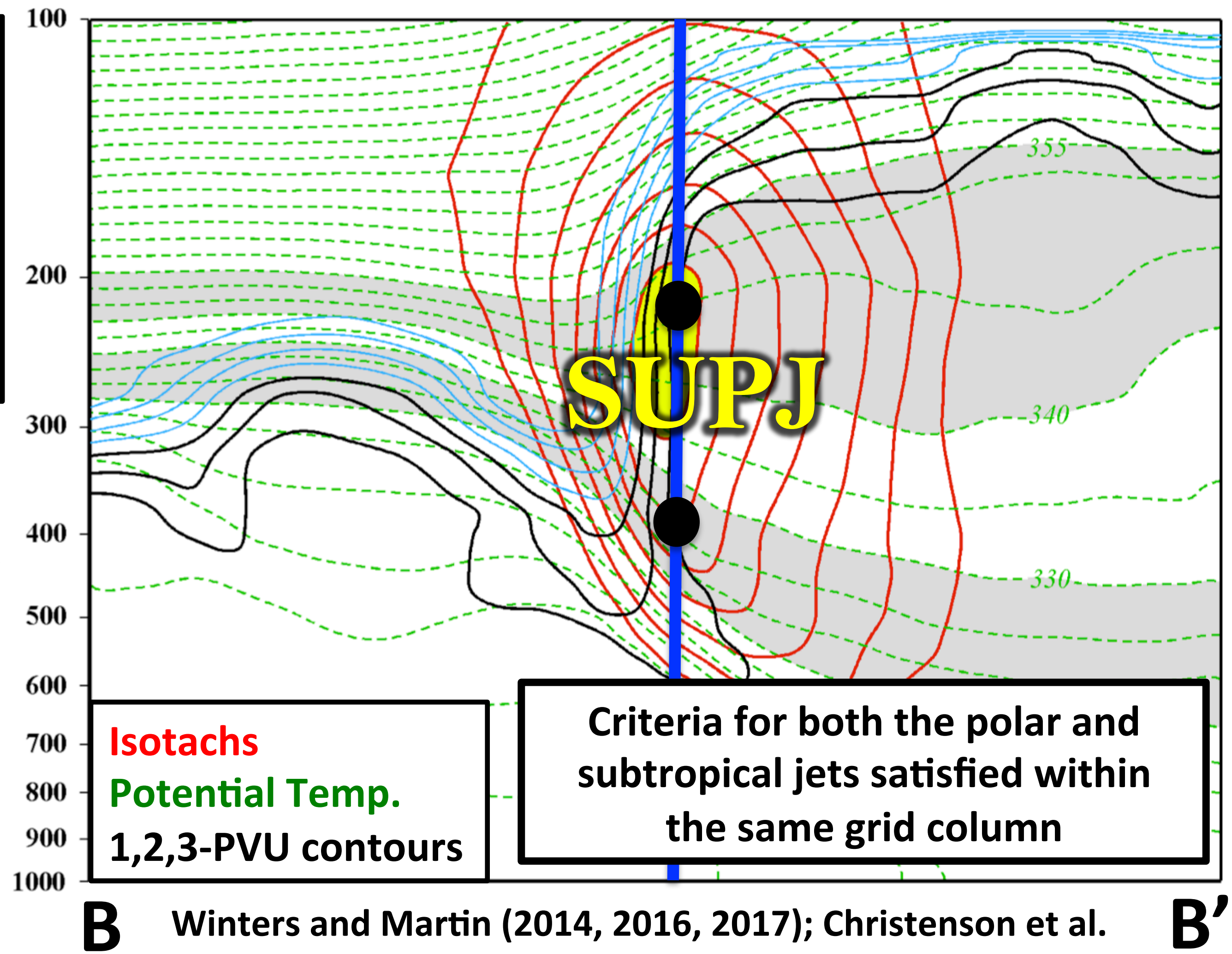

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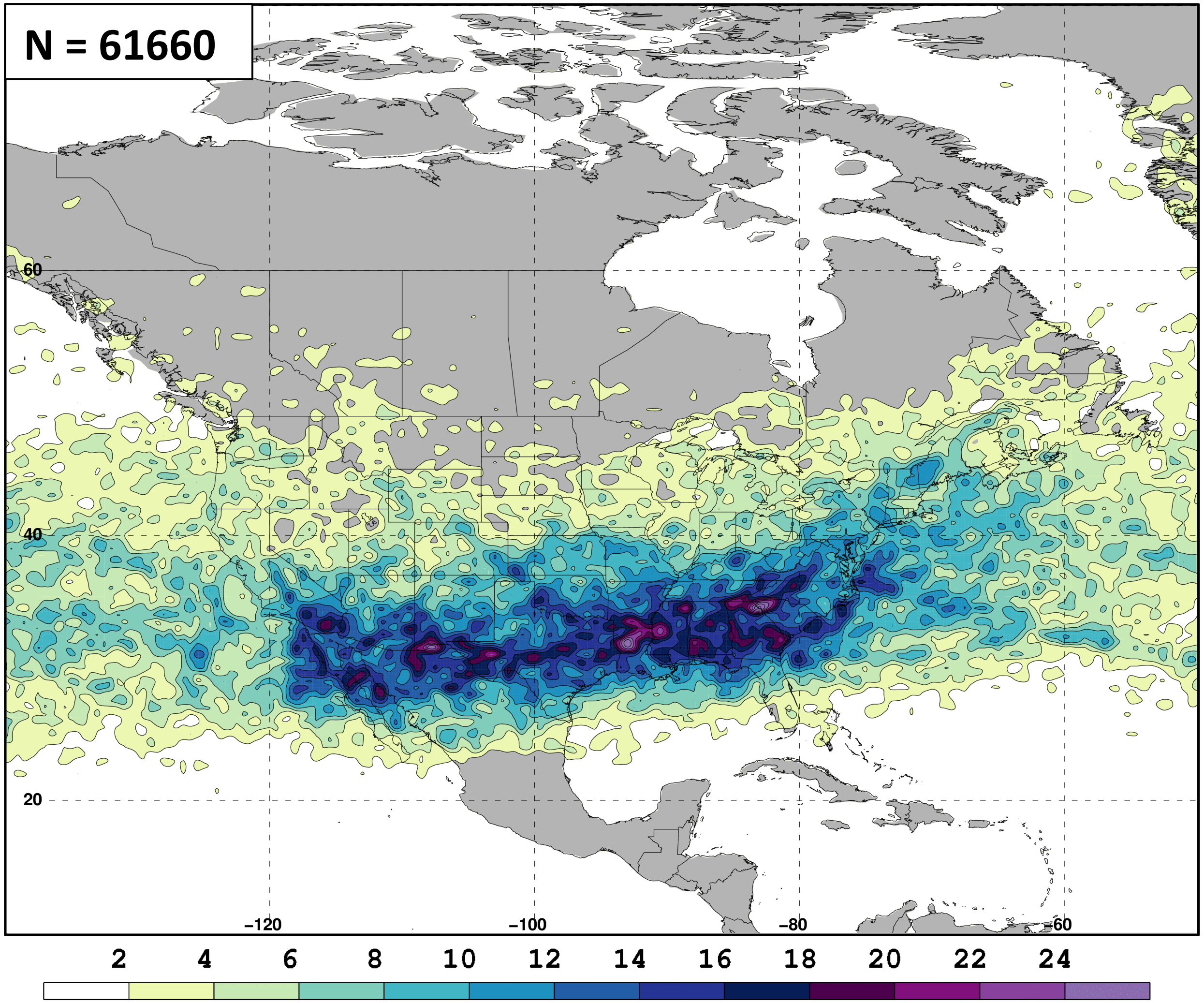
Jet Superposition Event Identification

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

Jet Superposition Frequency – All Times



Jet Superposition Event Identification

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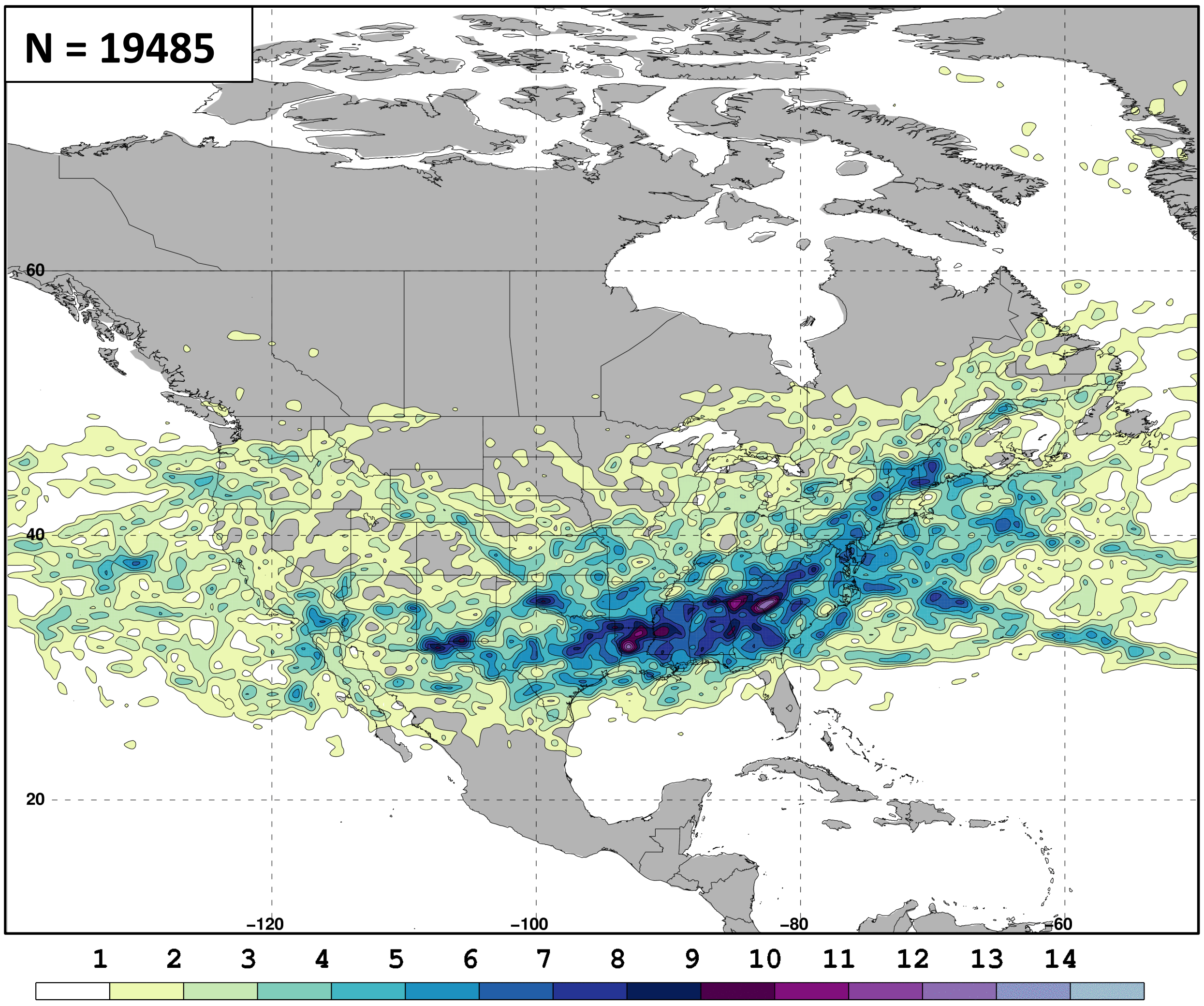
2. Retained analysis times that rank in the top 10% in terms the number of grid points characterized by a jet superposition.

Jet Superposition Frequency – Top 10% Times



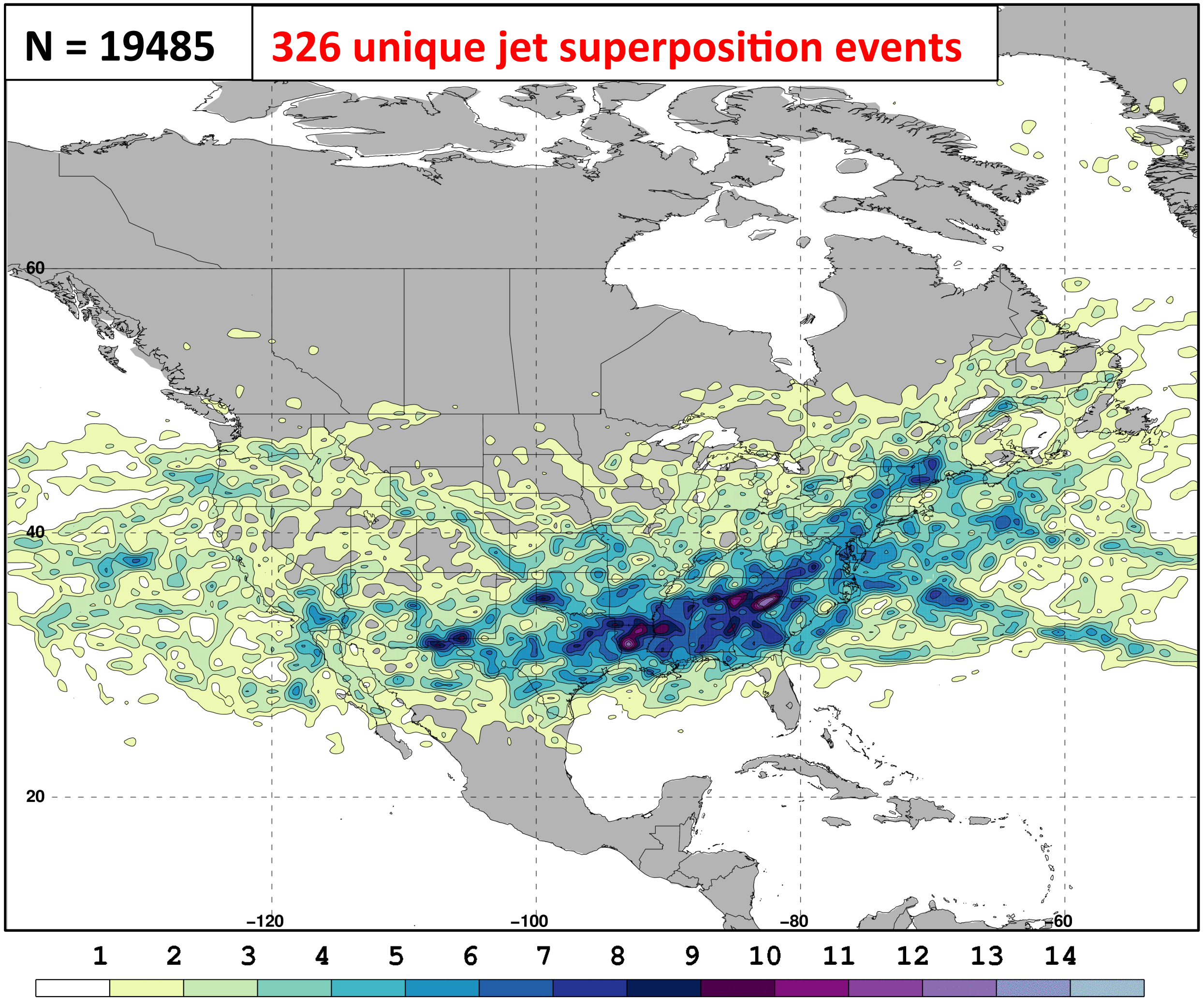
Jet Superposition Event Identification

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.

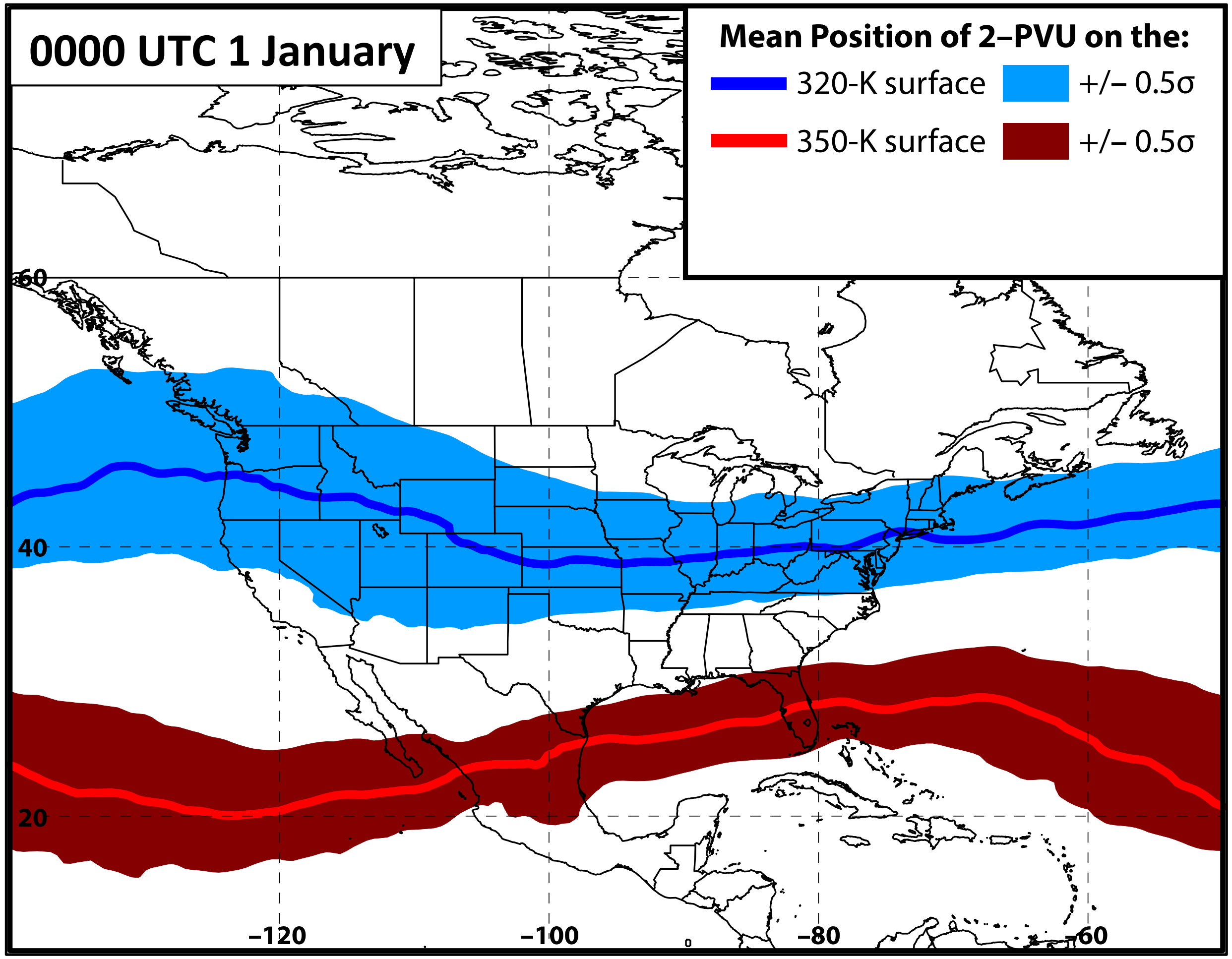
3. Filtered retained analysis times to group together jet superpositions that are < 30 h and < 1500 km apart.

Jet Superposition Frequency – Top 10% Times



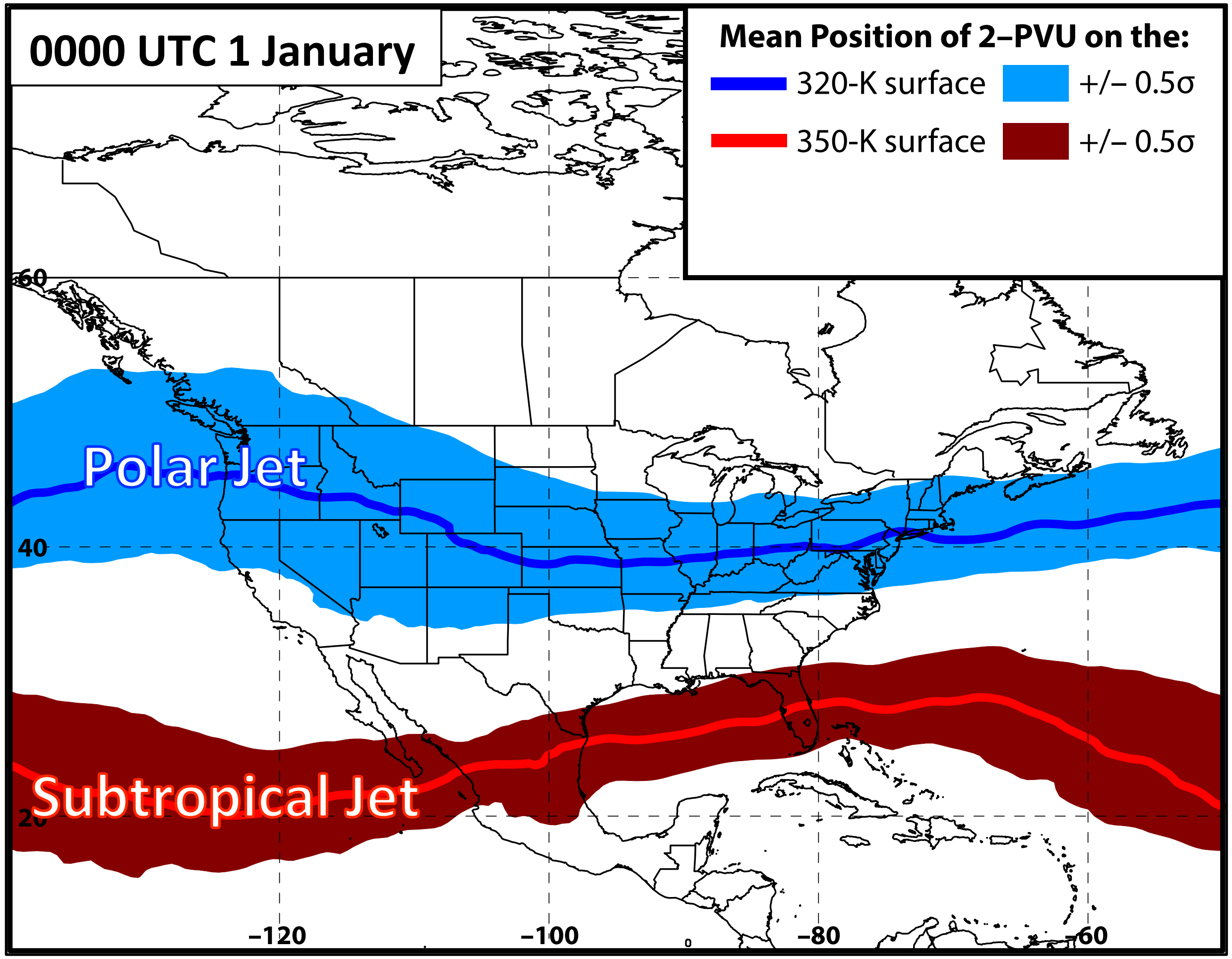
Jet Superposition Event Classification

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.



Jet Superposition Event Classification

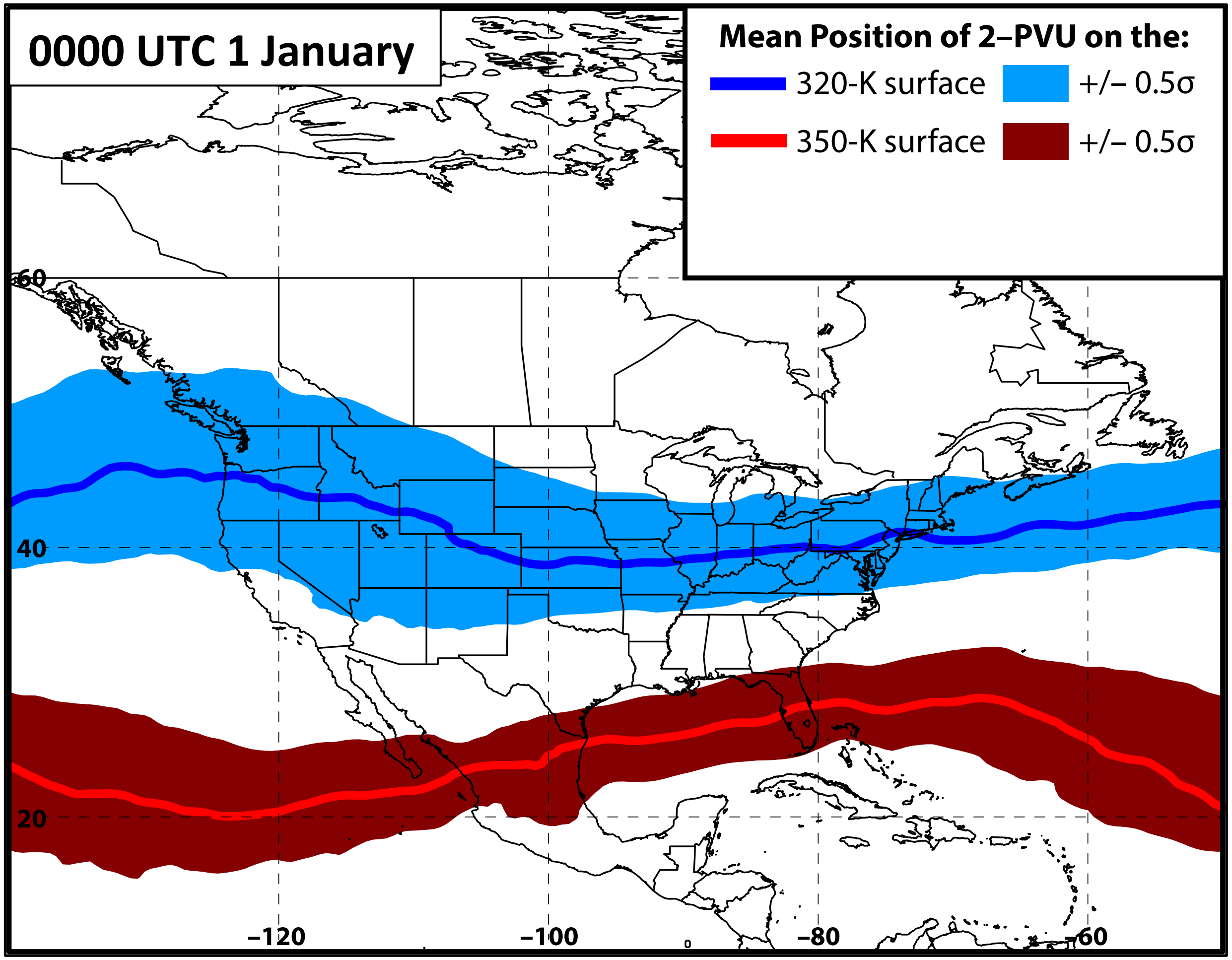
1. Determined the mean position of the 2-PVU contour on the 320-K and 350-K surfaces at each analysis time in the CFSR.



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.



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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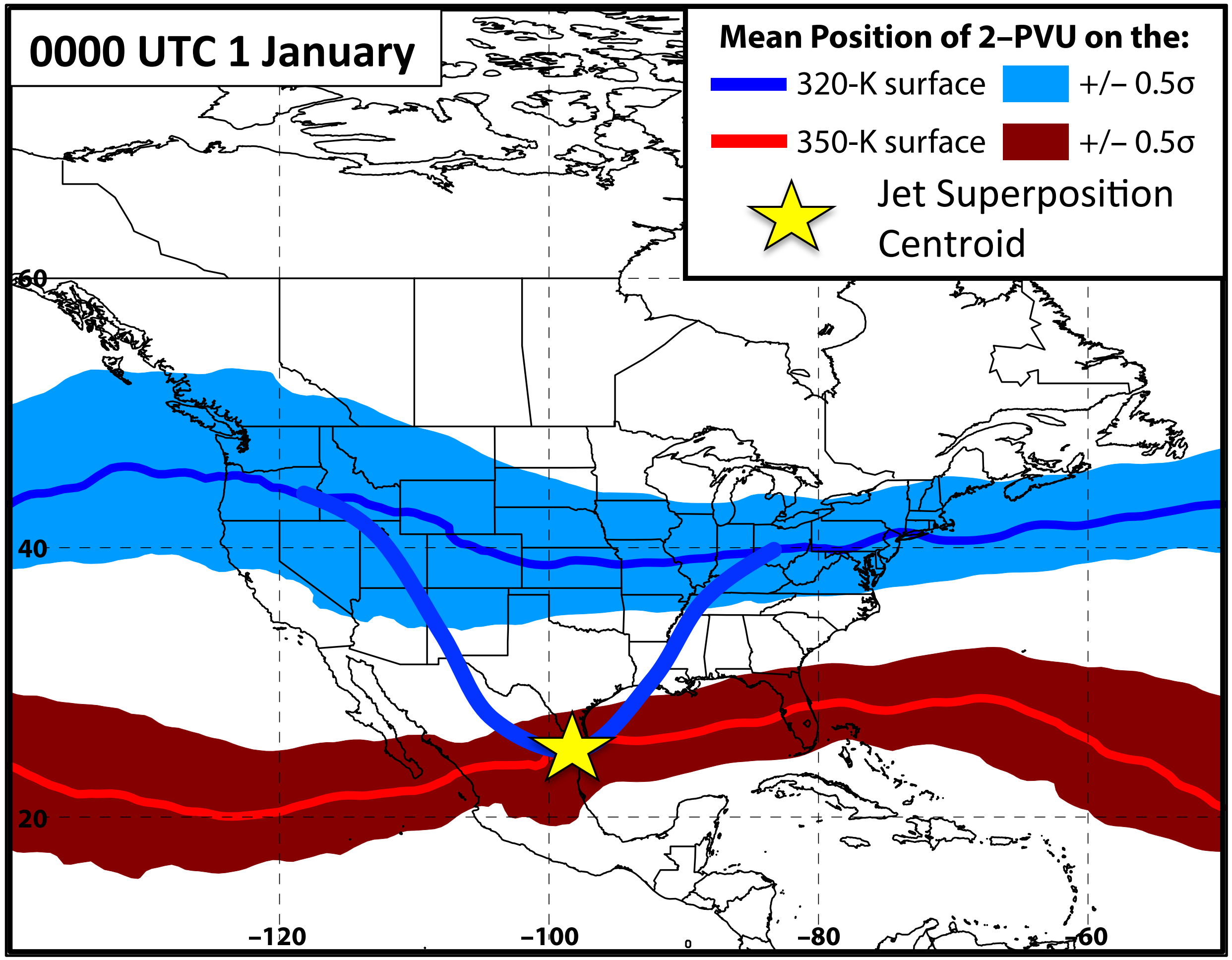
- **Polar Dominant**

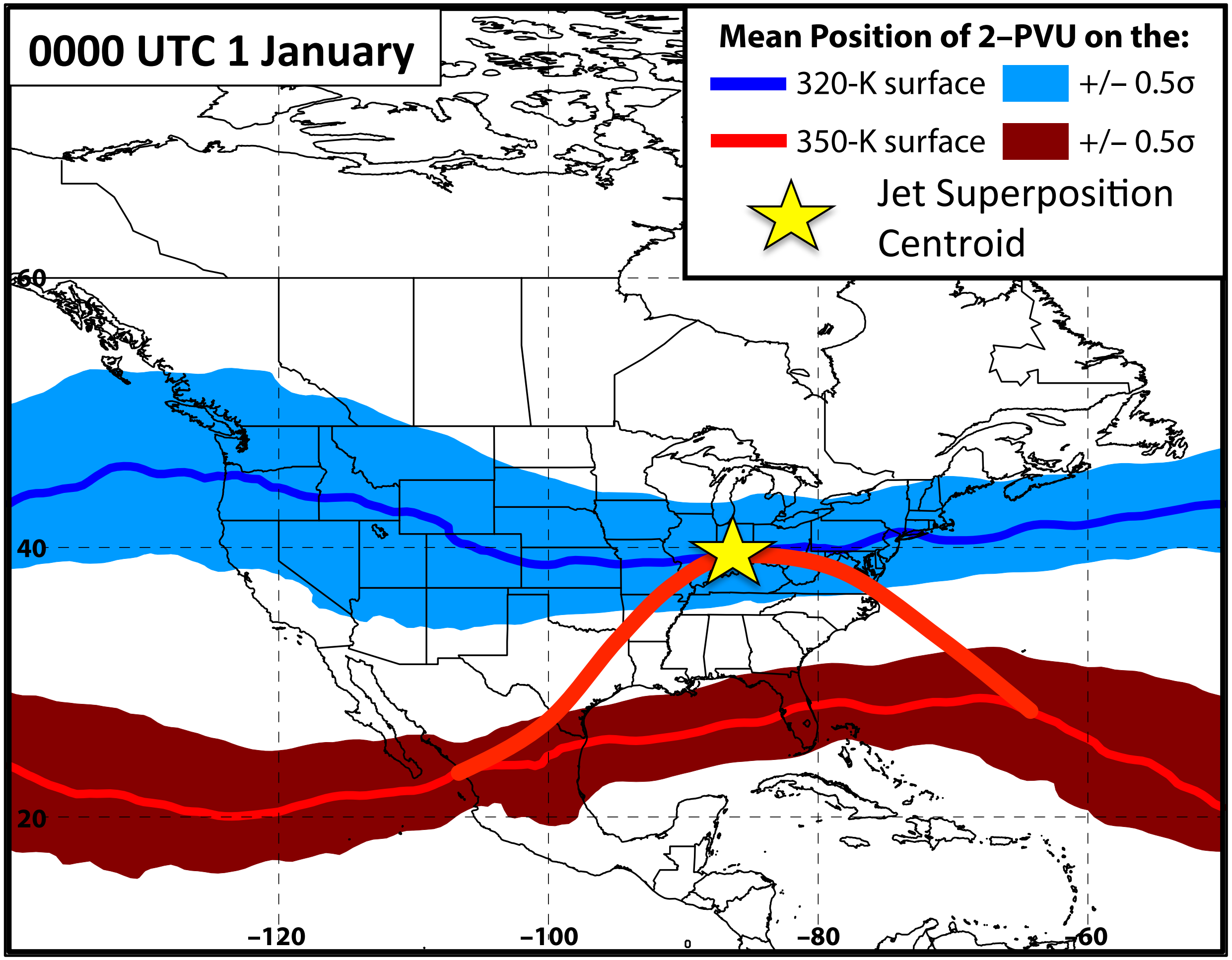


Jet Superposition Event Classification

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**

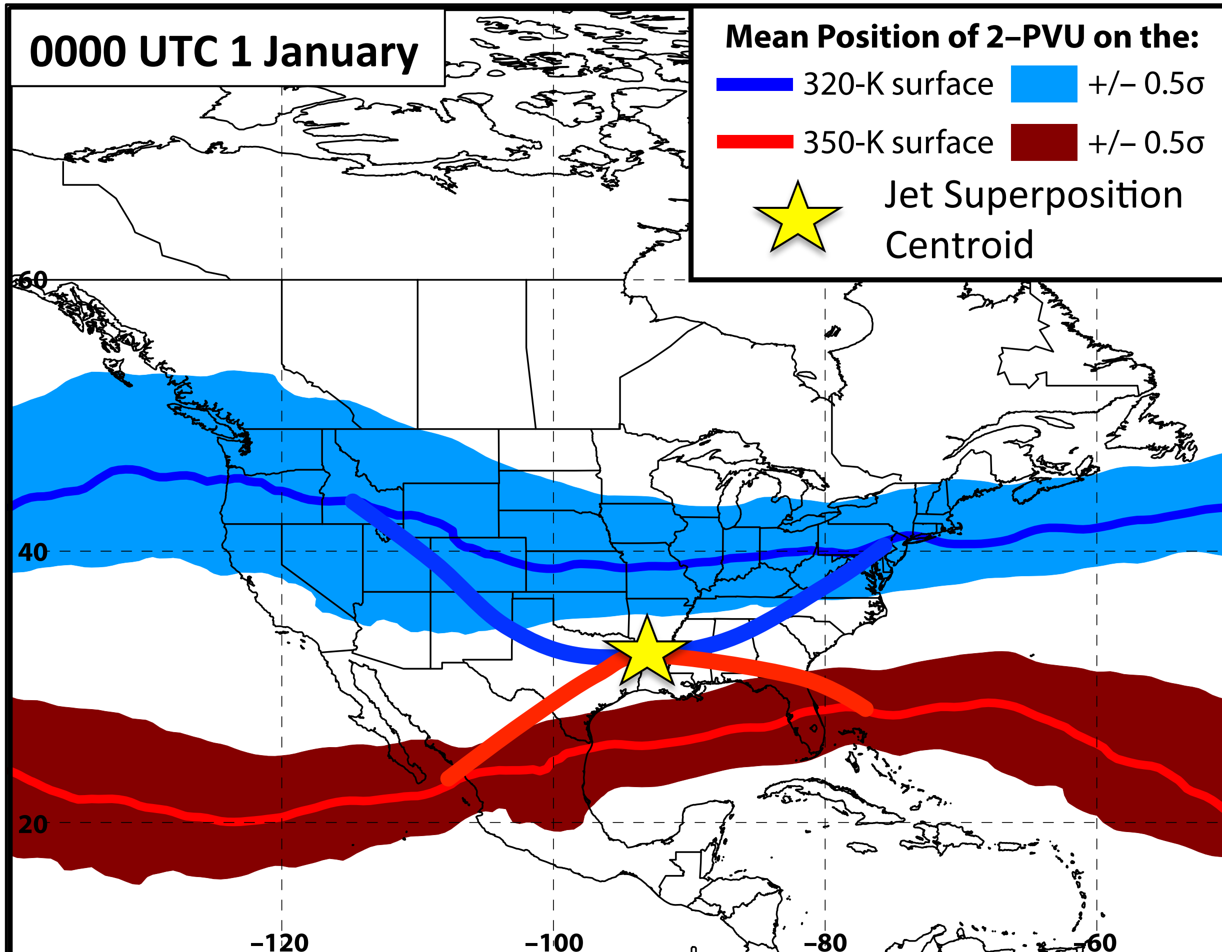


Jet Superposition Event Classification

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.

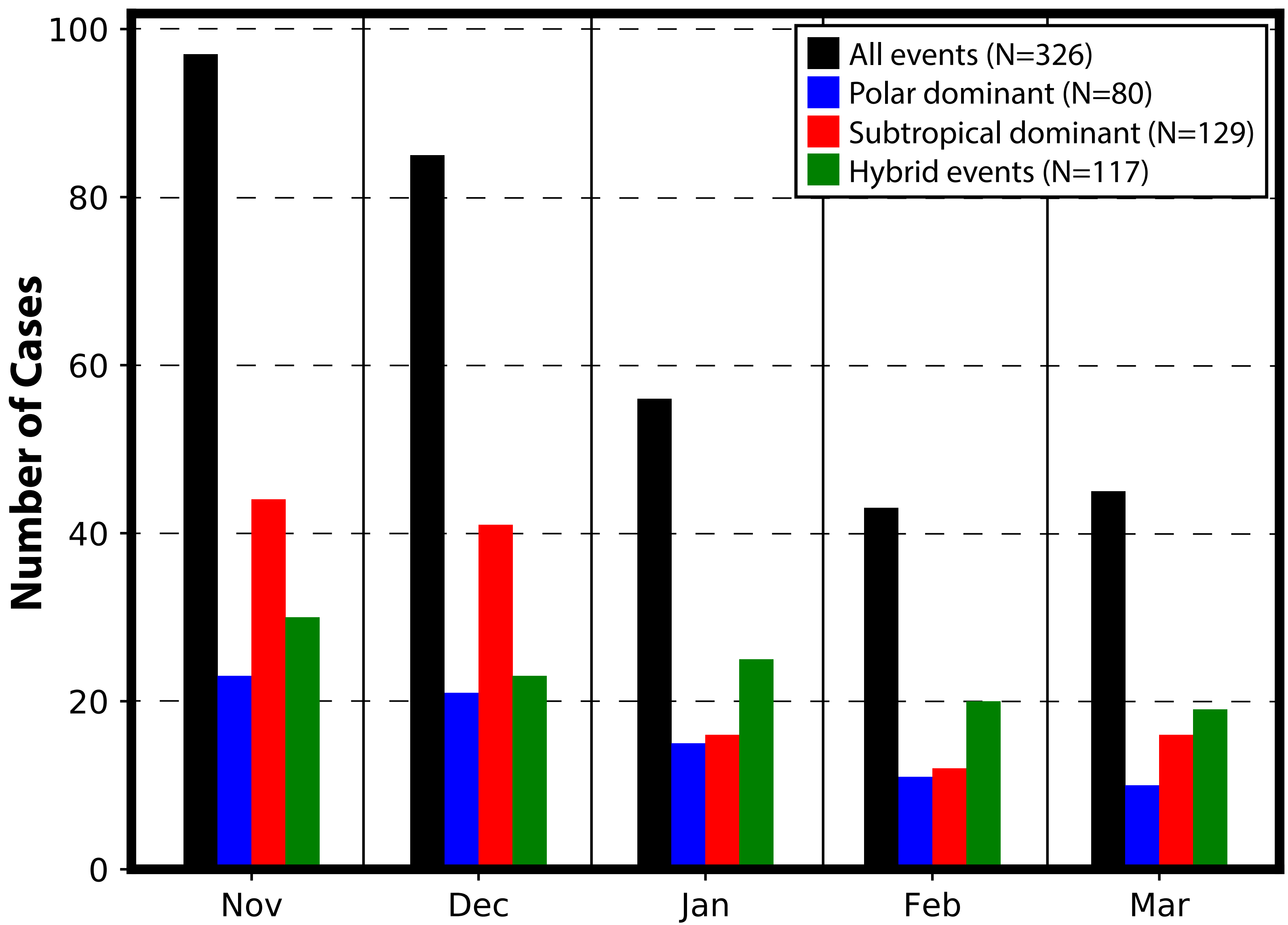
2. Compared the position of the jet superposition centroid at the start of each event against the climatological position of the 2-PVU contour.

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

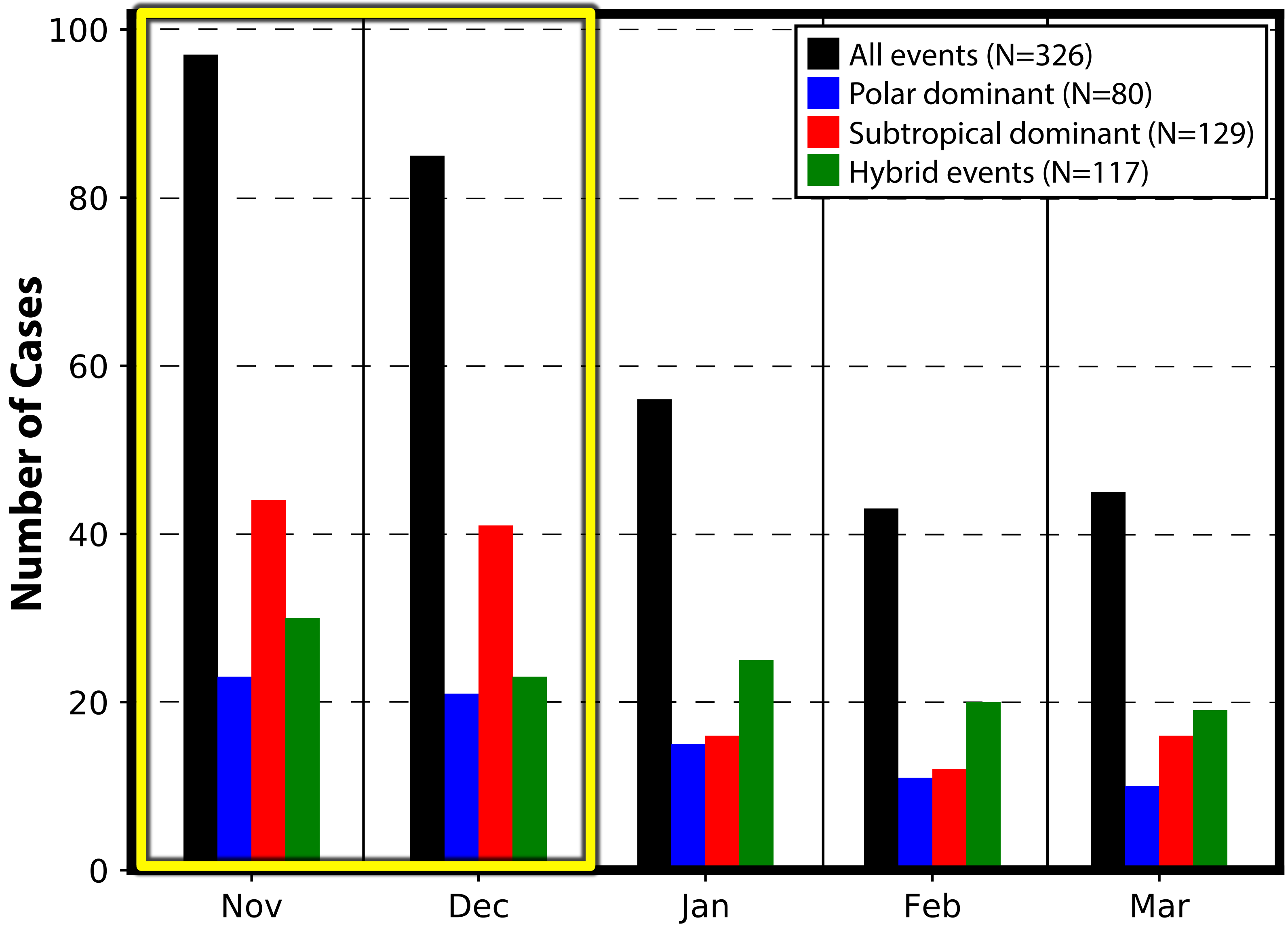


Climatological Characteristics of Jet Superposition Events

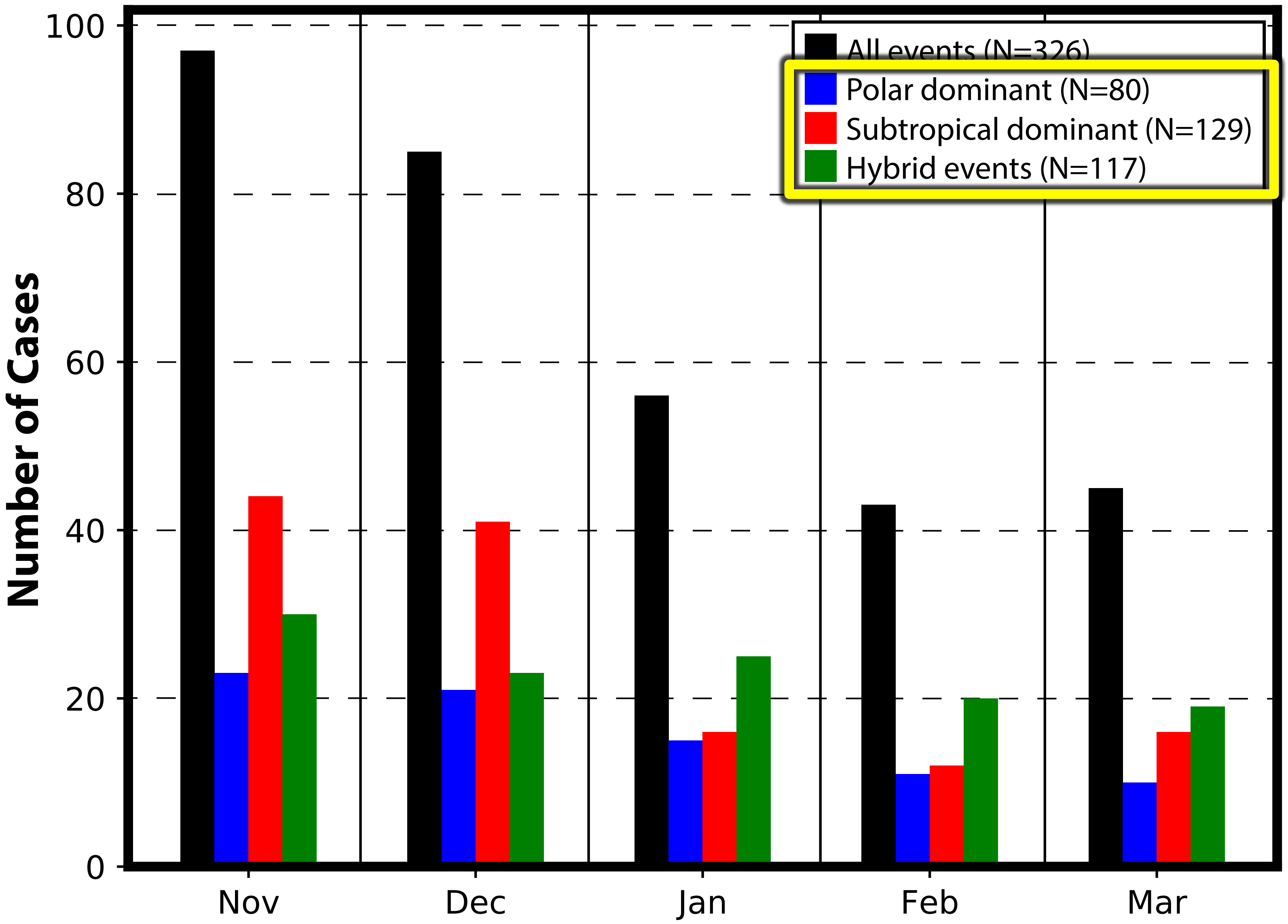
Jet Superposition Event Characteristics



Jet Superposition Event Characteristics

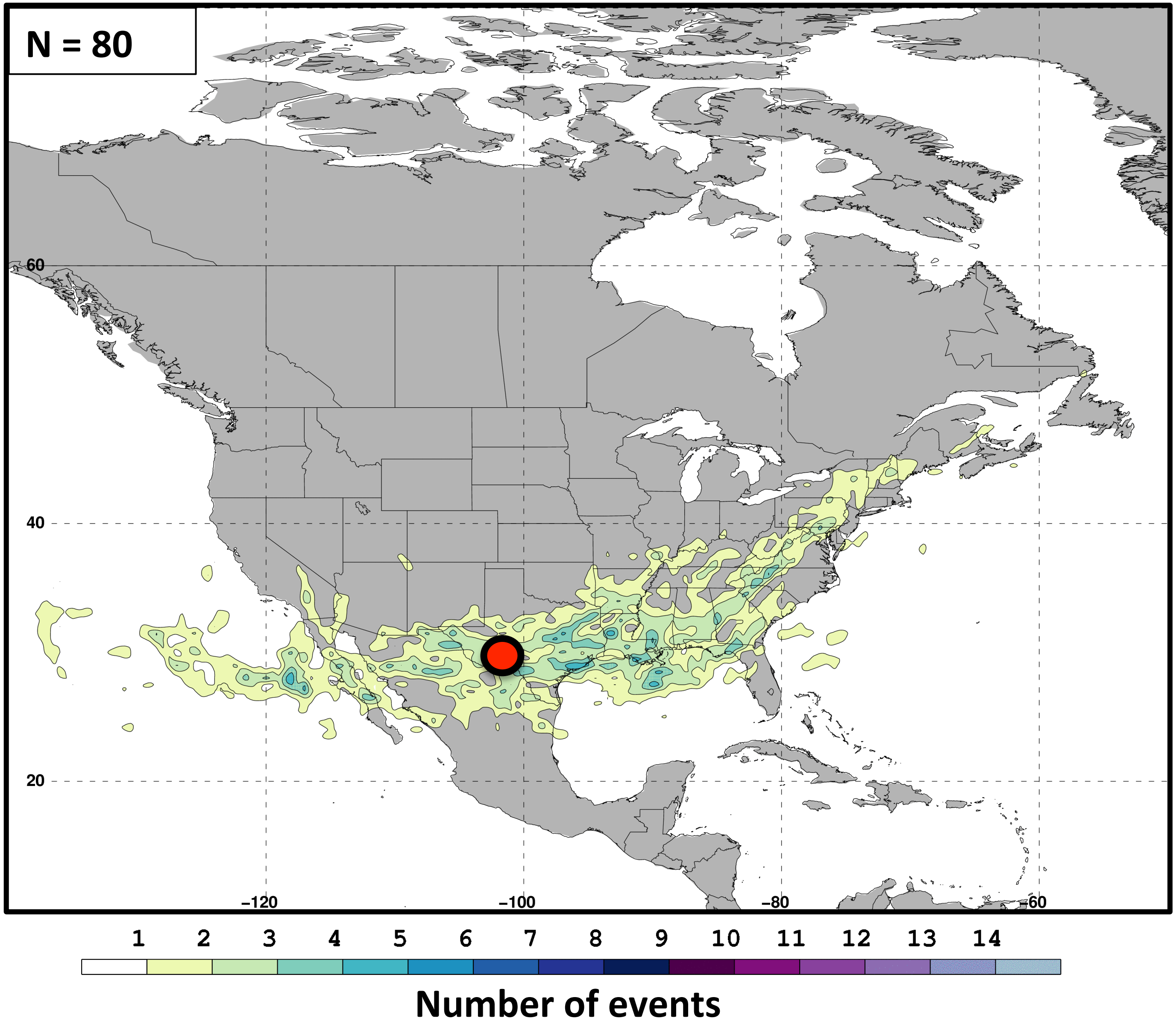


Jet Superposition Event Characteristics



Jet Superposition Event Characteristics

Frequency of
Polar Dominant
Jet
Superposition
Events

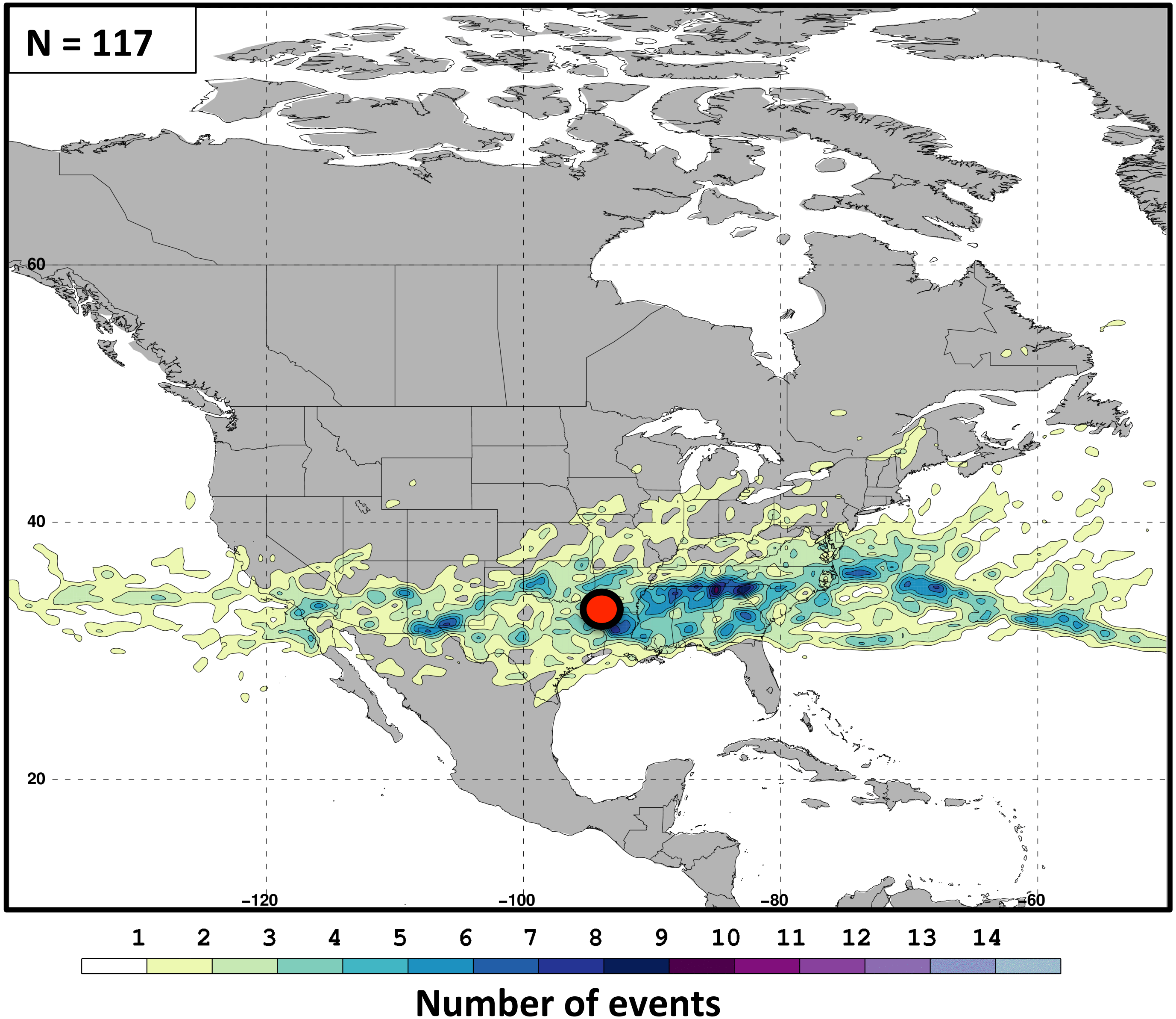


Legend

Avg. Location of Superposition

Jet Superposition Event Characteristics

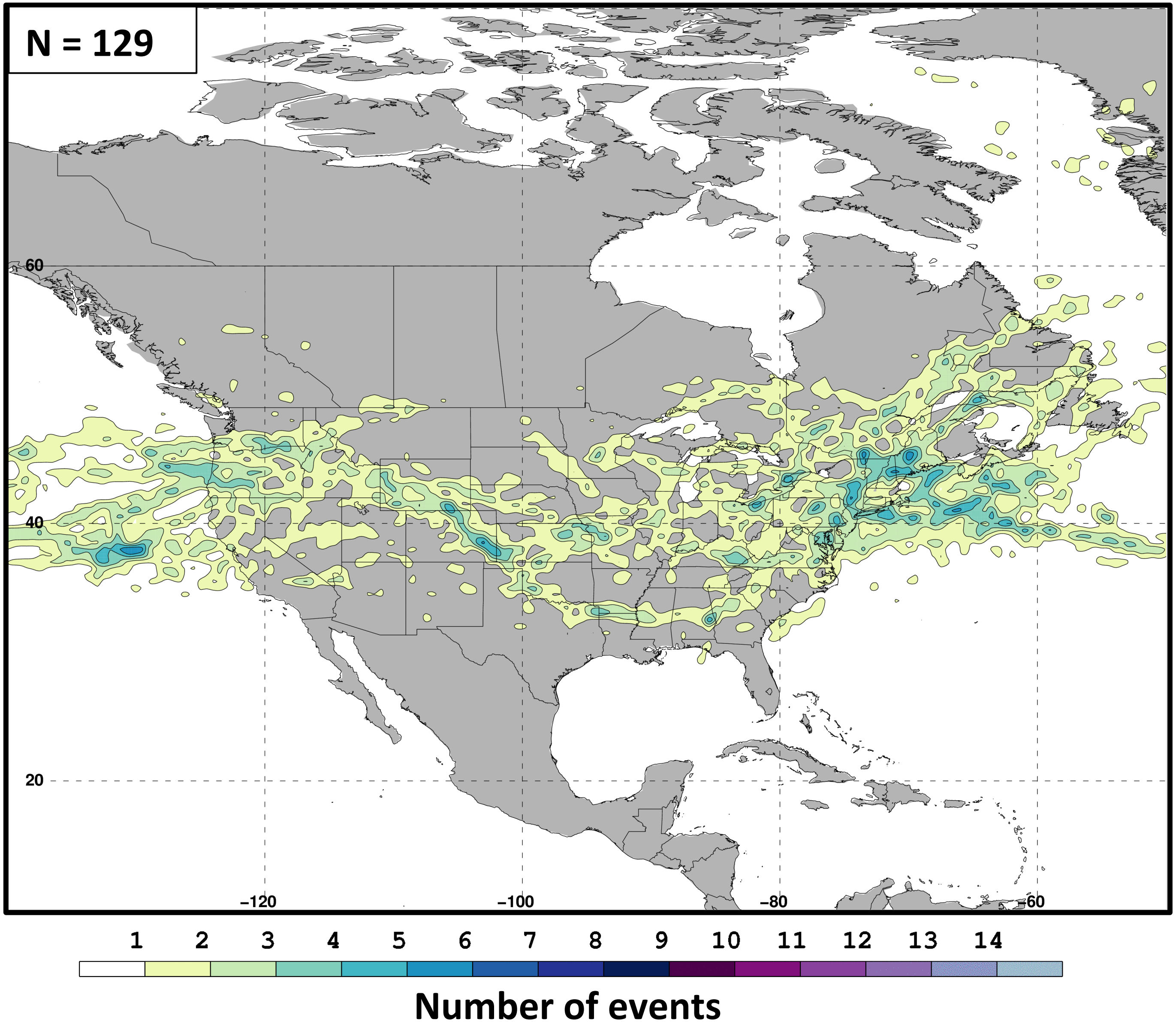
Frequency of
Hybrid
Jet
Superposition
Events



Legend
● Avg. Location of Superposition

Jet Superposition Event Characteristics

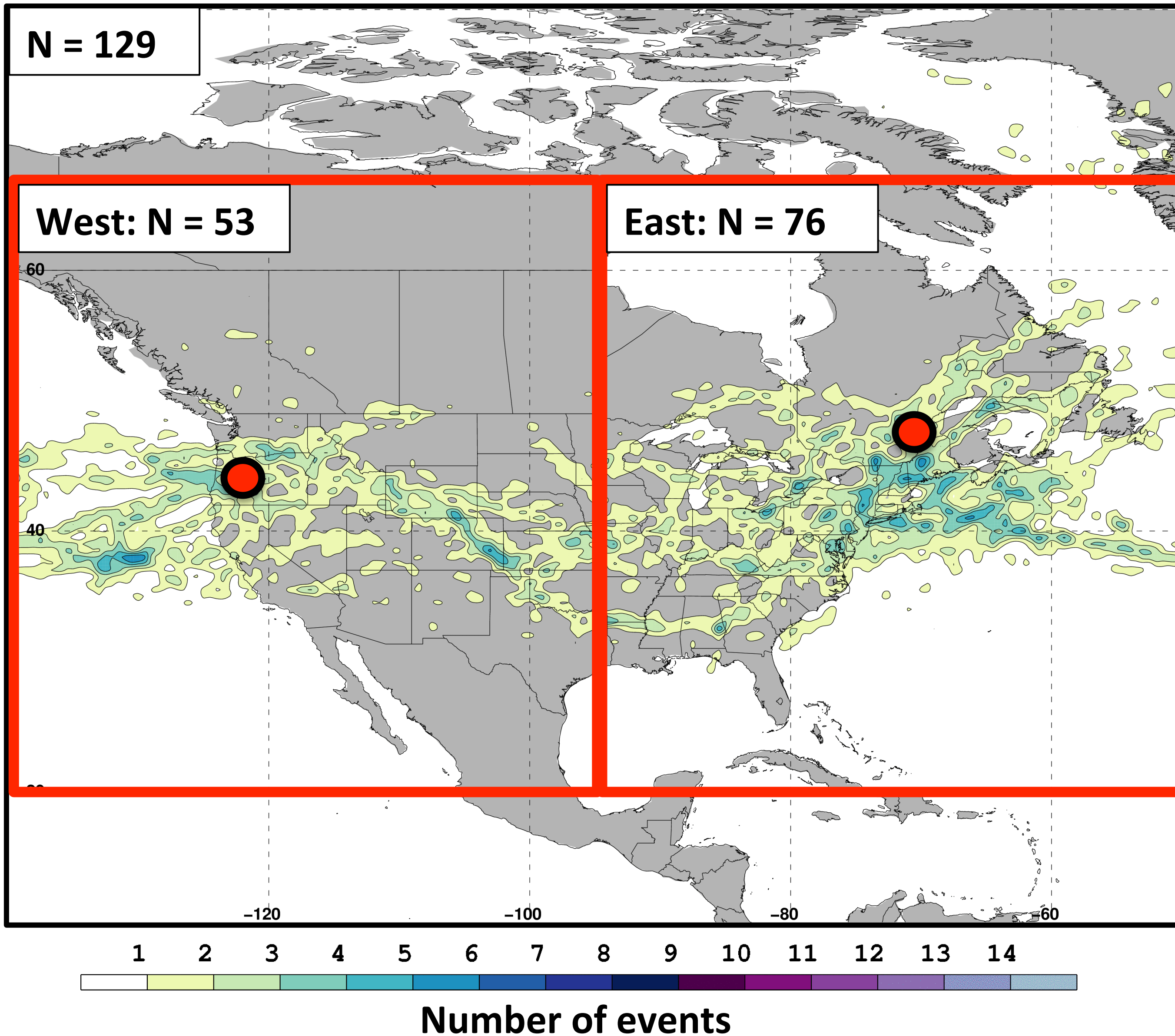
Frequency of Subtropical Dominant Jet Superposition Events



Legend
● Avg. Location of Superposition

Jet Superposition Event Characteristics

Frequency of Subtropical Dominant Jet Superposition Events



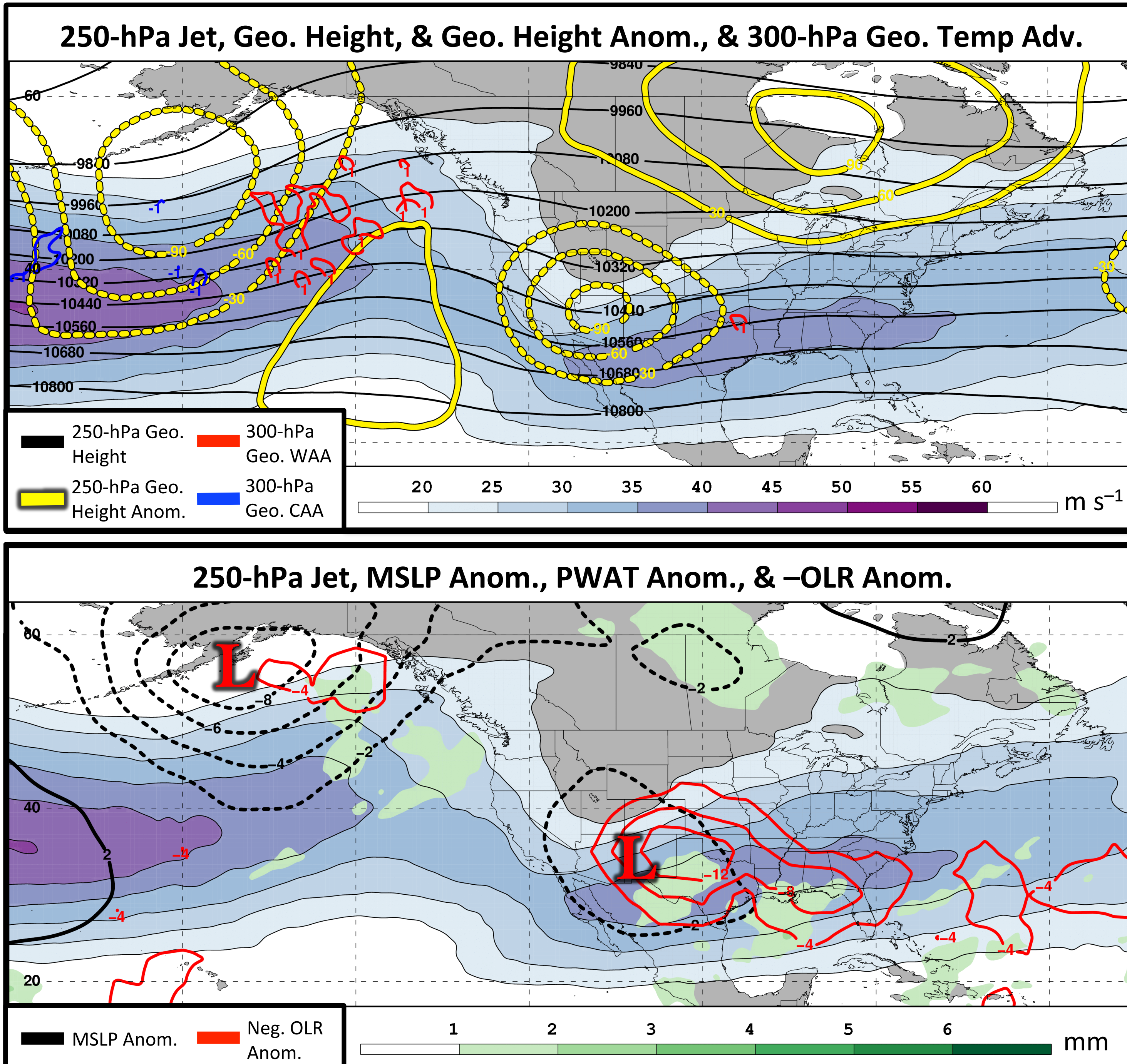
Legend
Avg. Location of Superposition

Jet Superposition Event Composites:

Polar Dominant
vs.
East Subtropical Dominant

Polar Dominant Jet Superposition Events

2 Days Prior to Jet Superposition

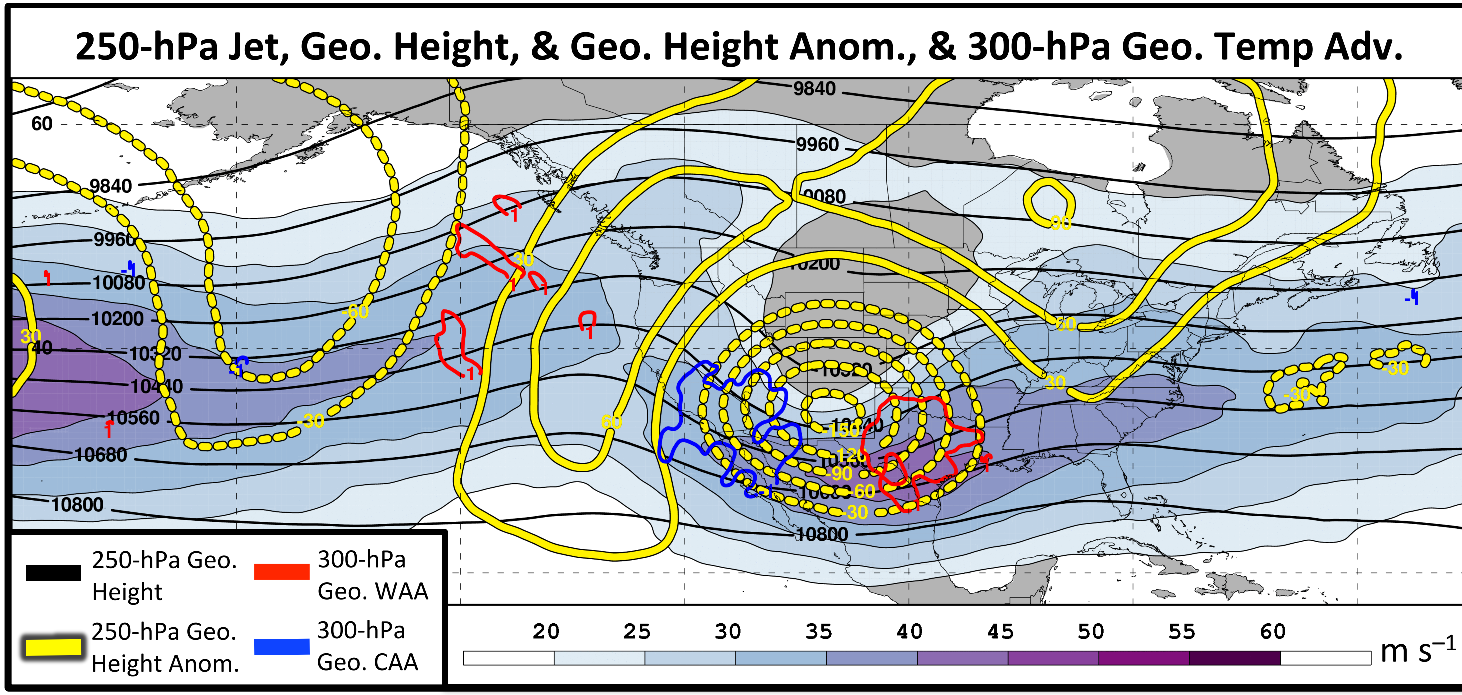


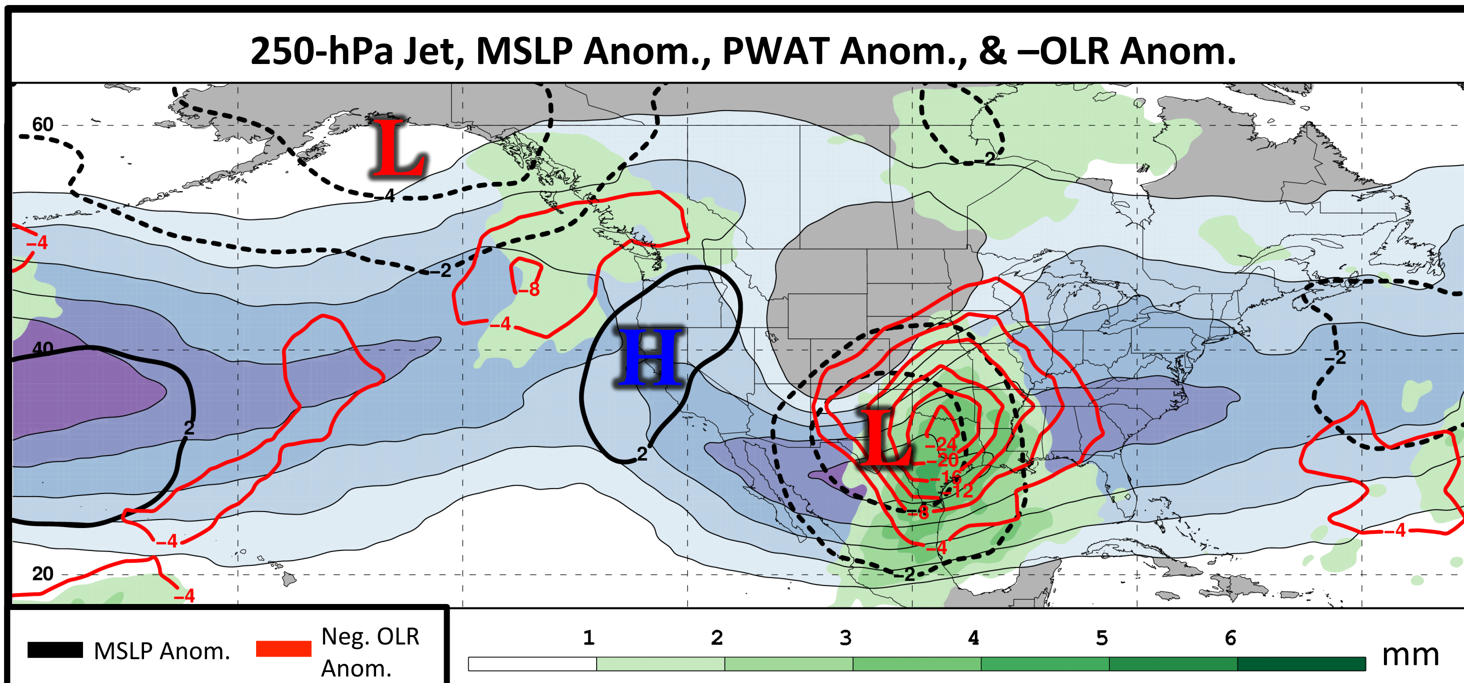
N=80

Polar Dominant Jet Superposition Events

1 Day Prior to Jet Superposition

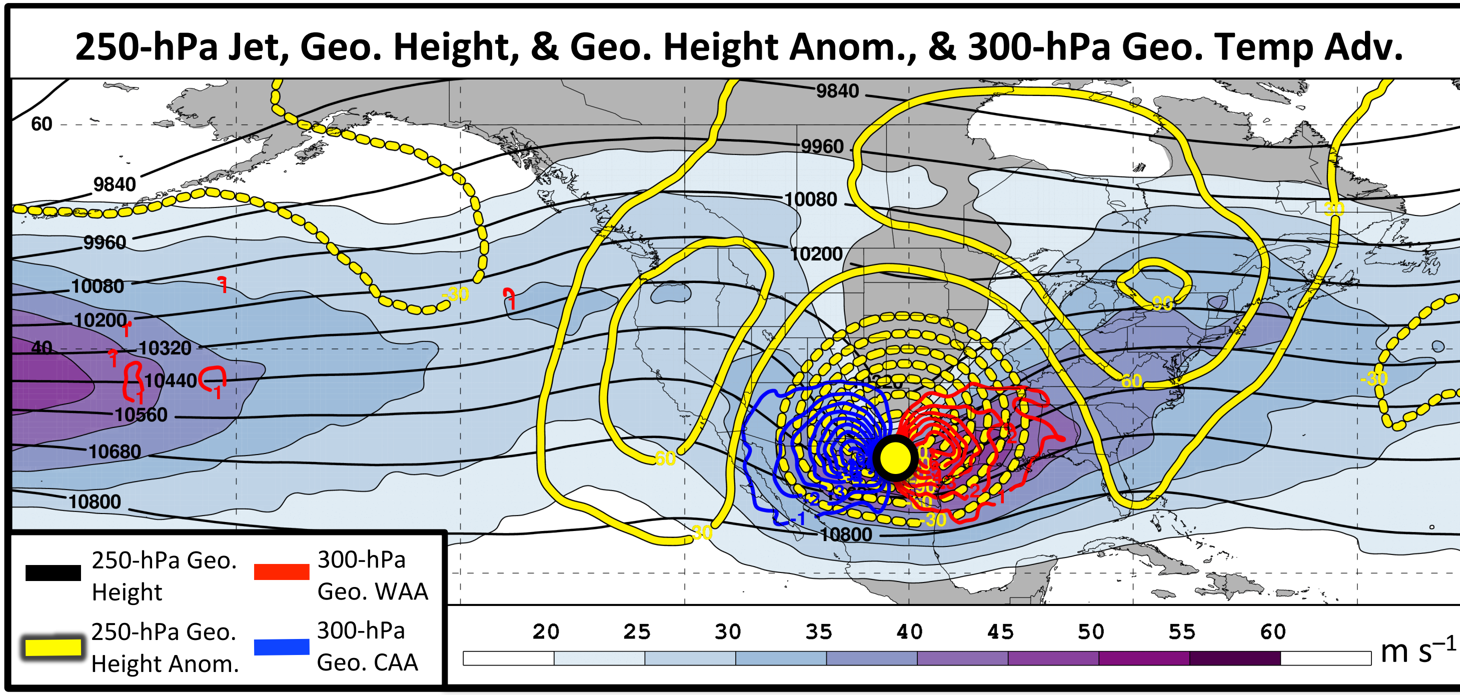
N=80

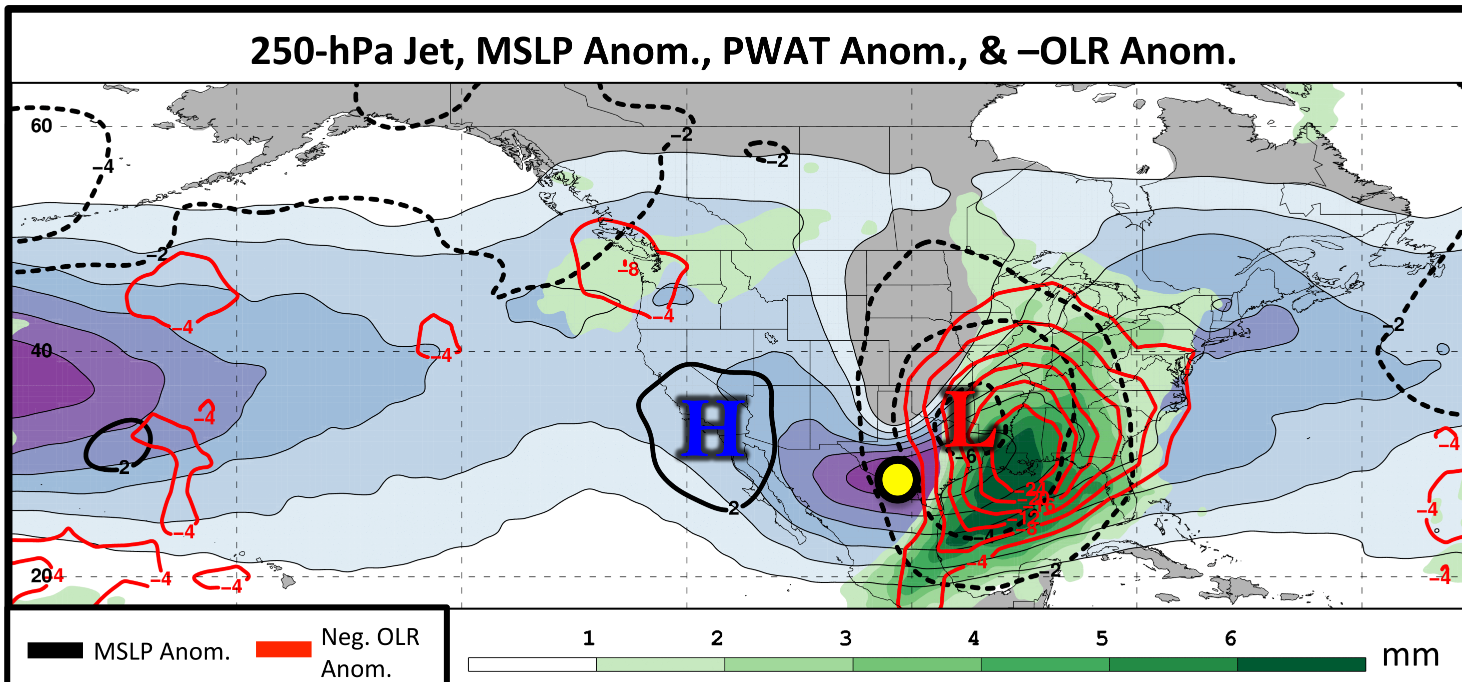




Polar Dominant Jet Superposition Events

0 Days Prior to Jet Superposition



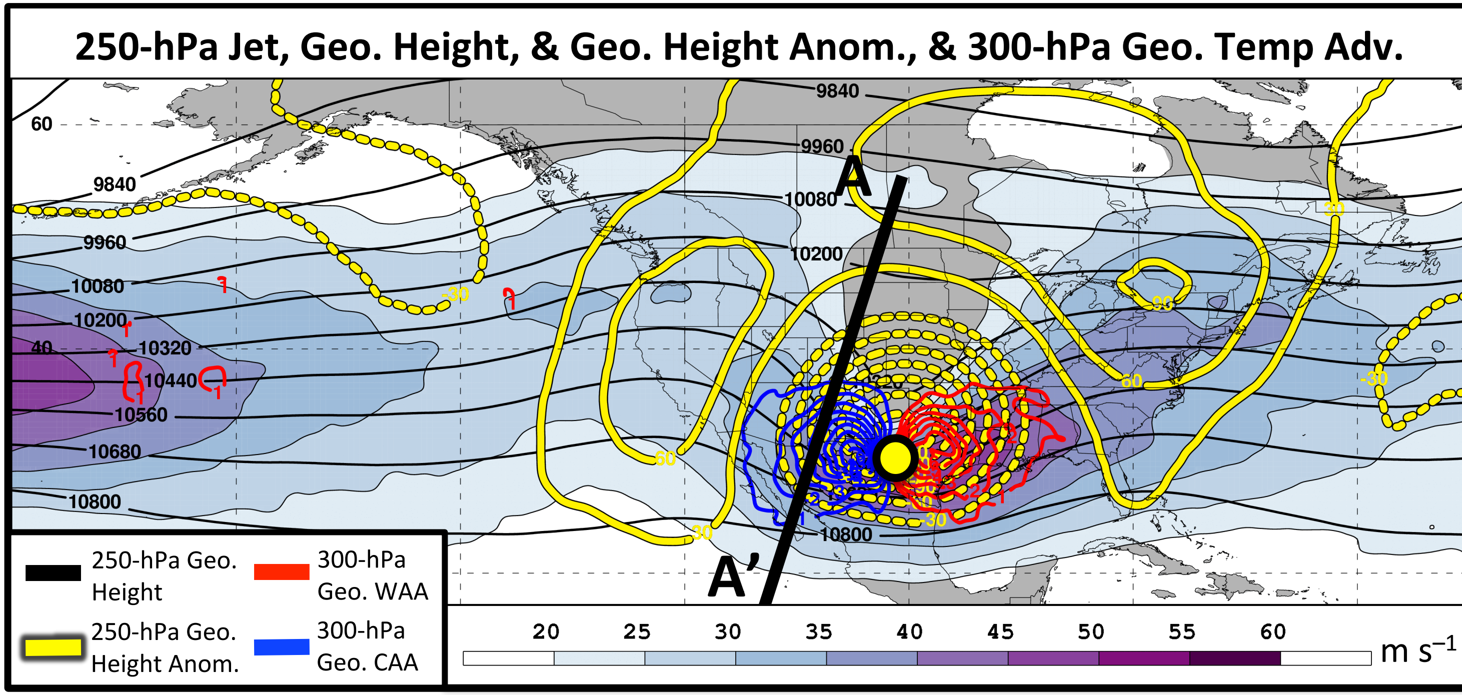


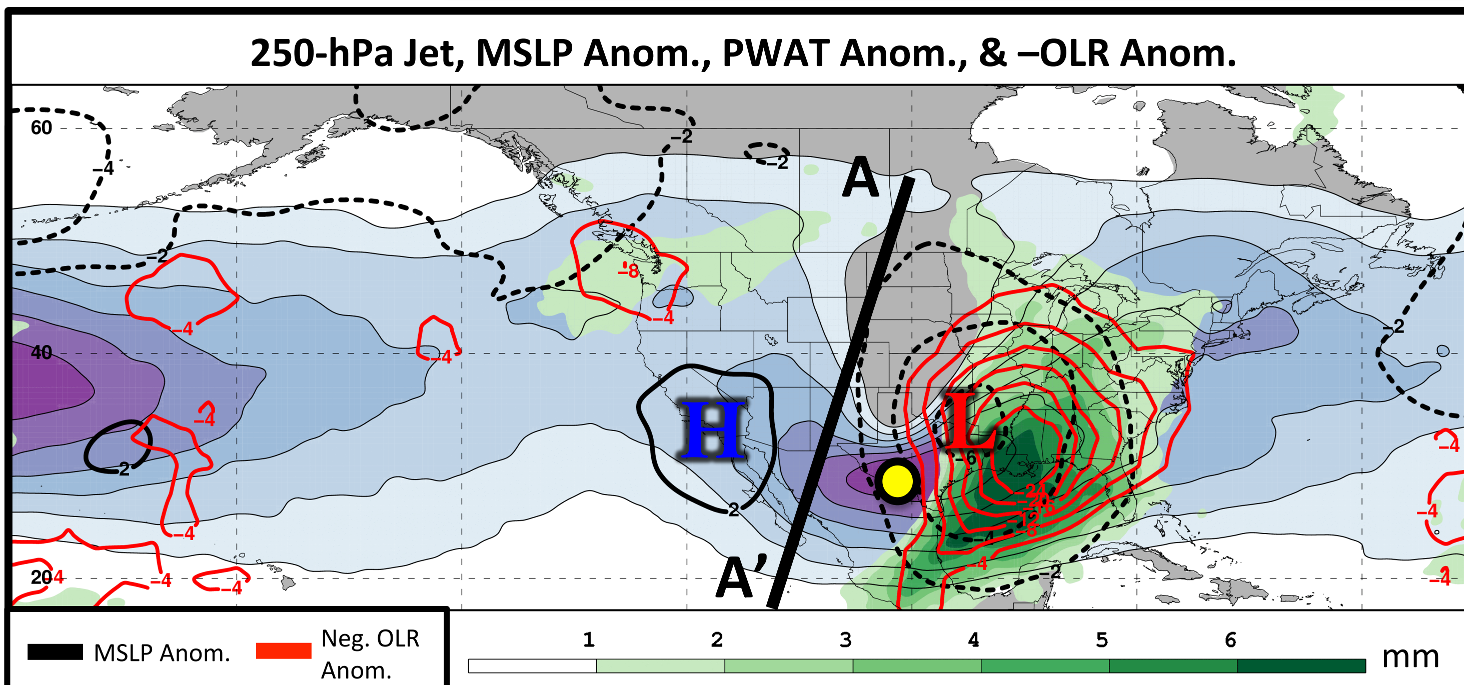
Average Location of Superposition

N=80

Polar Dominant Jet Superposition Events

0 Days Prior to Jet Superposition

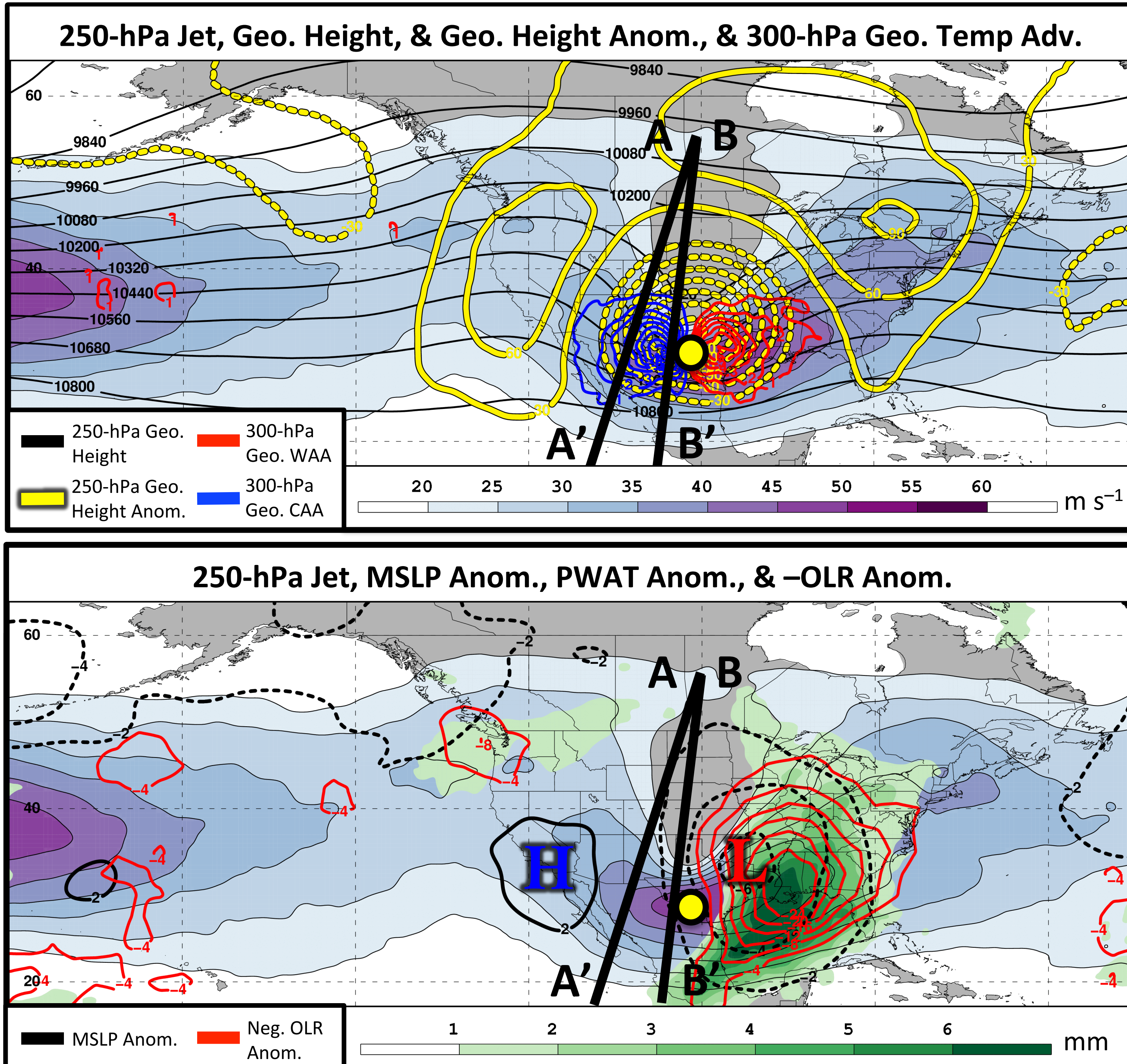




Average Location of Superposition

N=80

Polar Dominant Jet Superposition Events

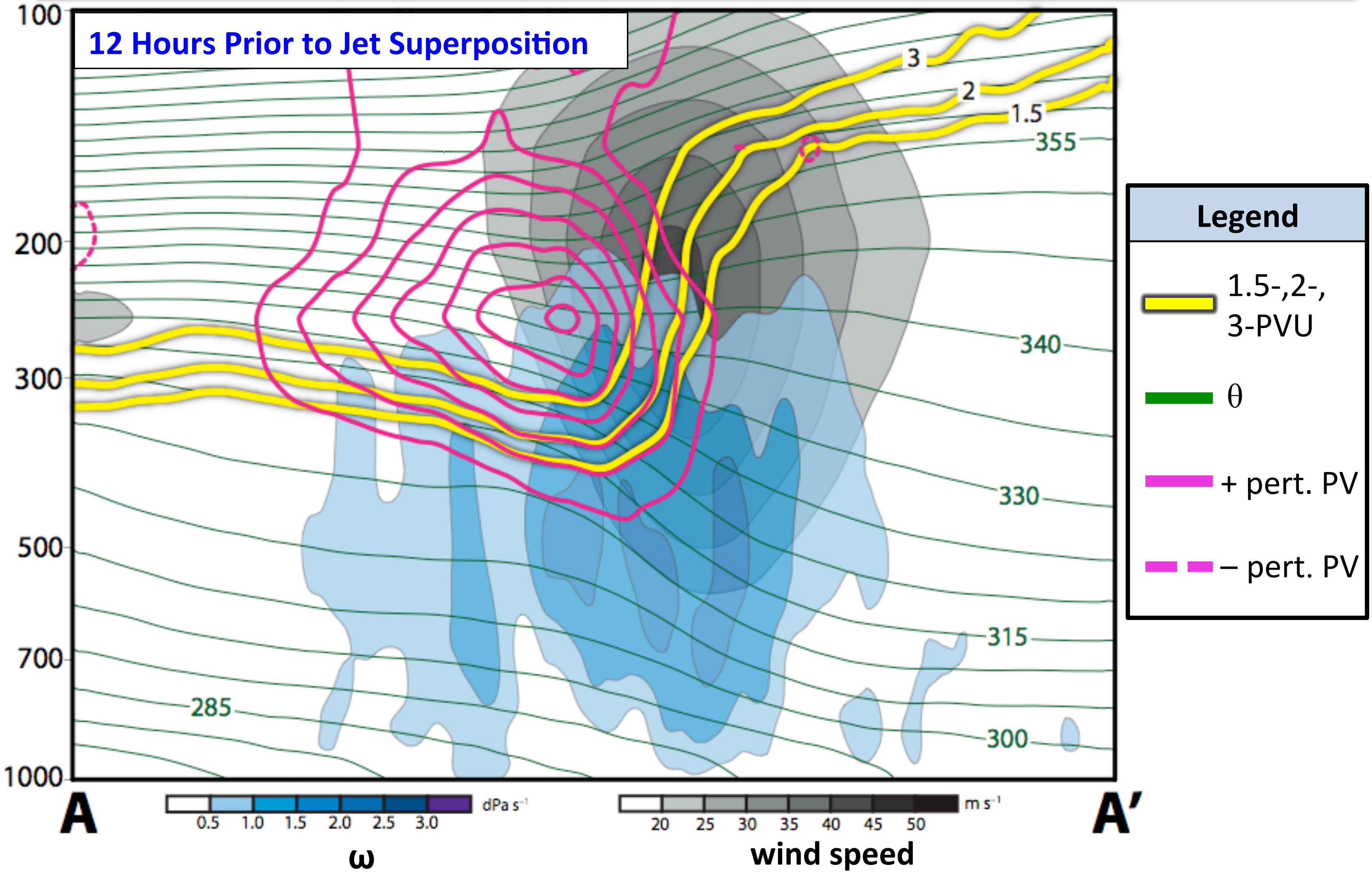


0 Days Prior to Jet Superposition

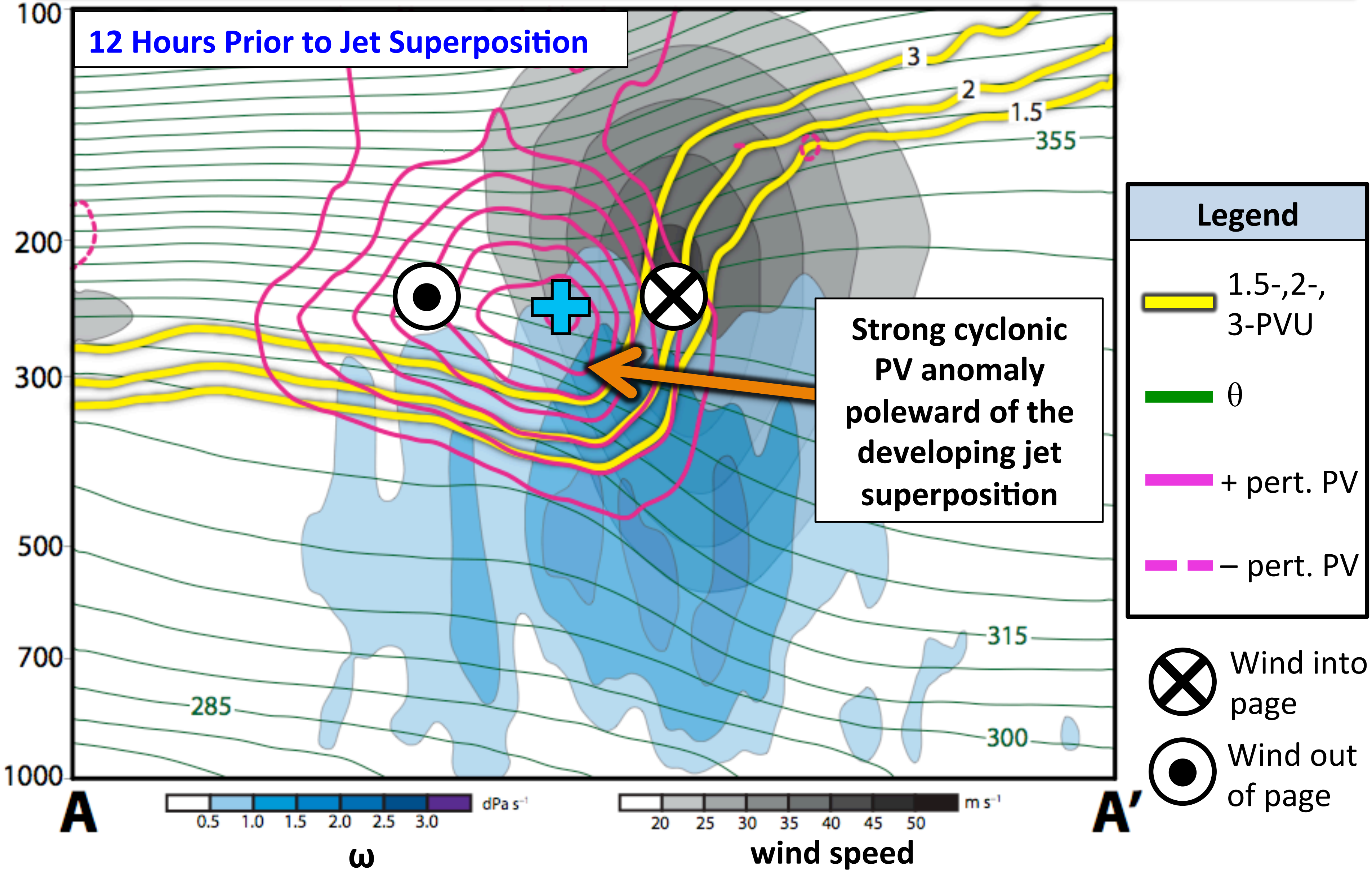
Average Location of Superposition

N=80

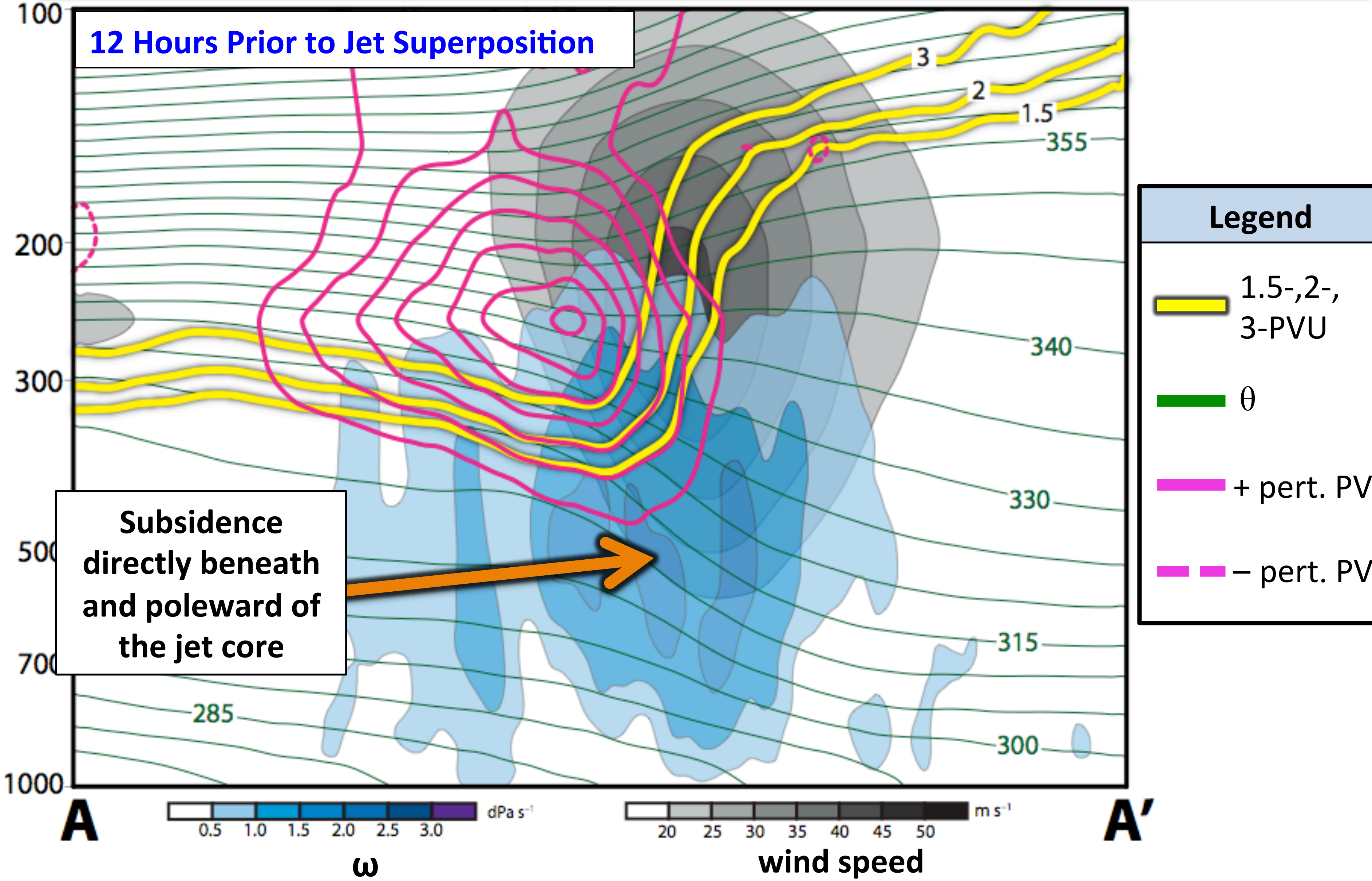
Polar Dominant Jet Superposition Events



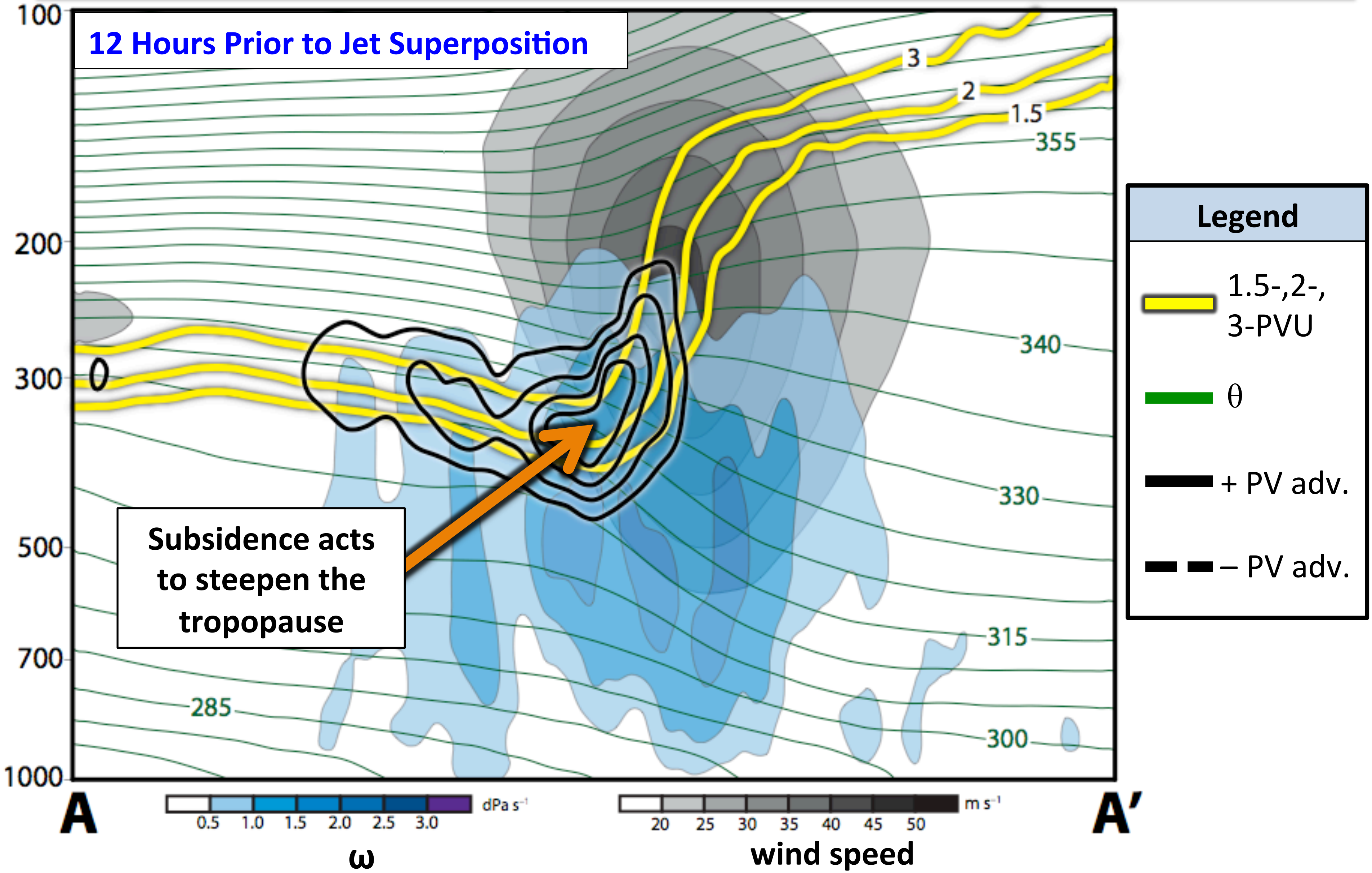
Polar Dominant Jet Superposition Events



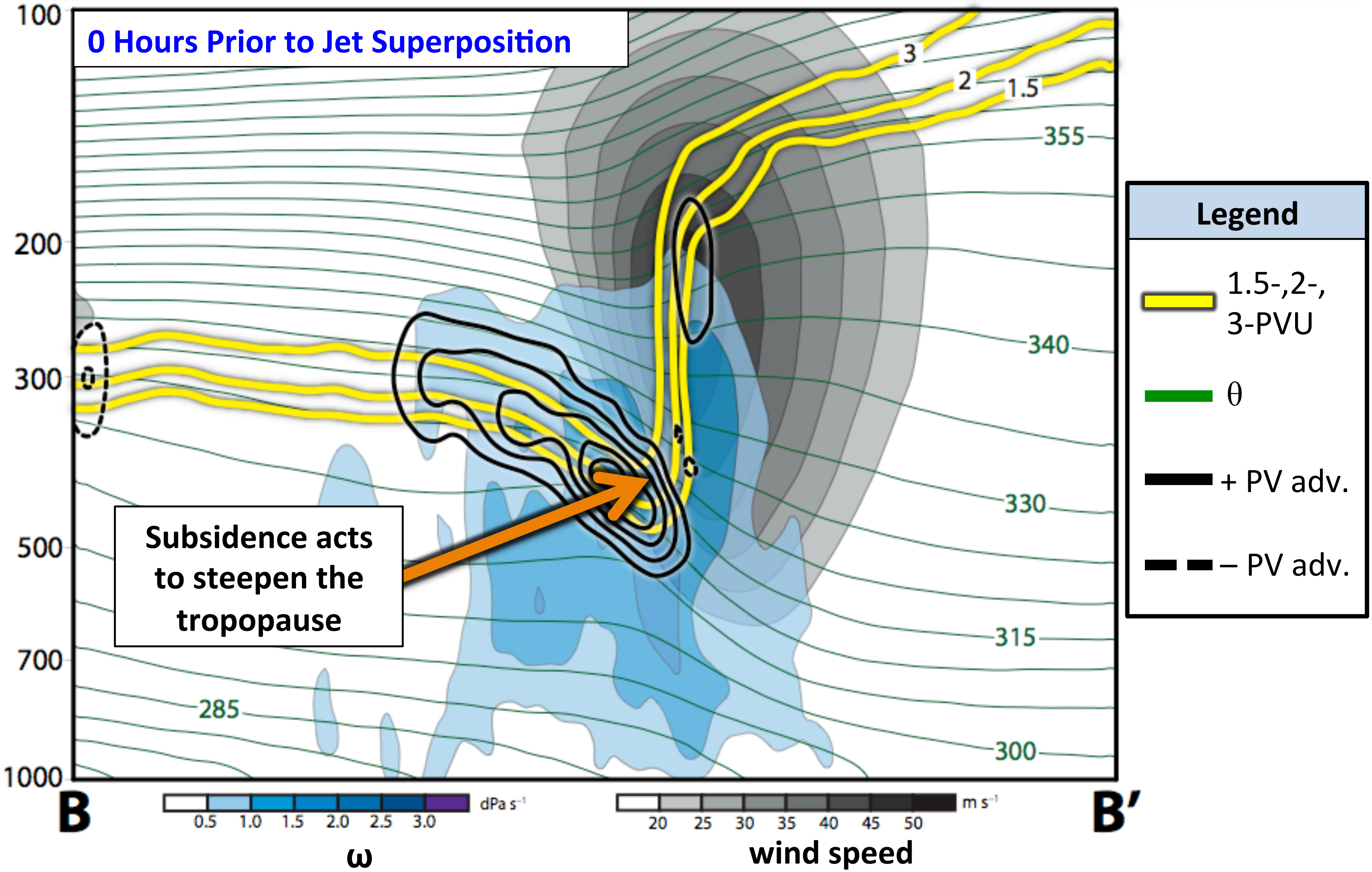
Polar Dominant Jet Superposition Events



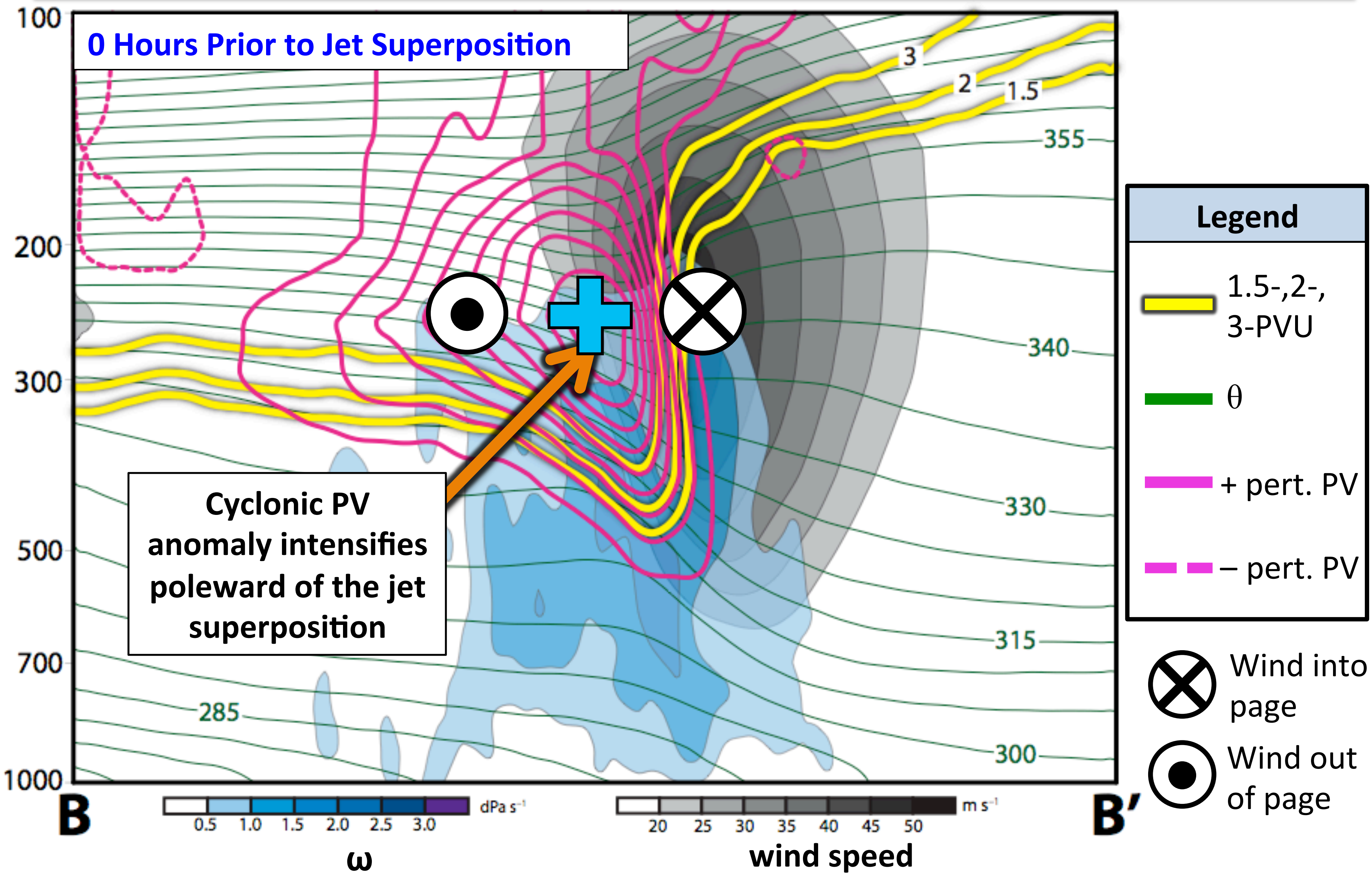
Polar Dominant Jet Superposition Events



Polar Dominant Jet Superposition Events



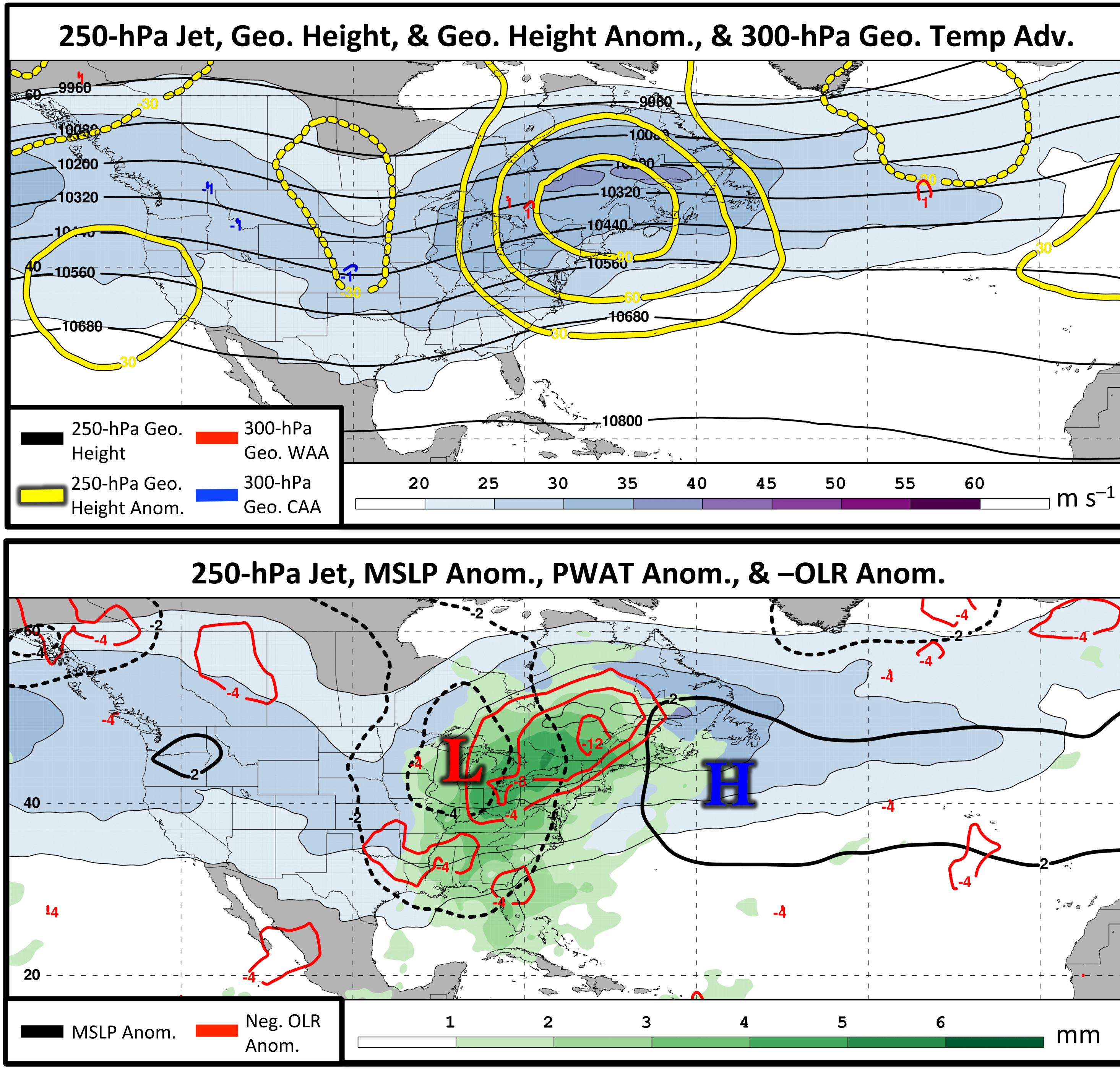
Polar Dominant Jet Superposition Events



E. Subtropical Dominant Jet Superposition Events

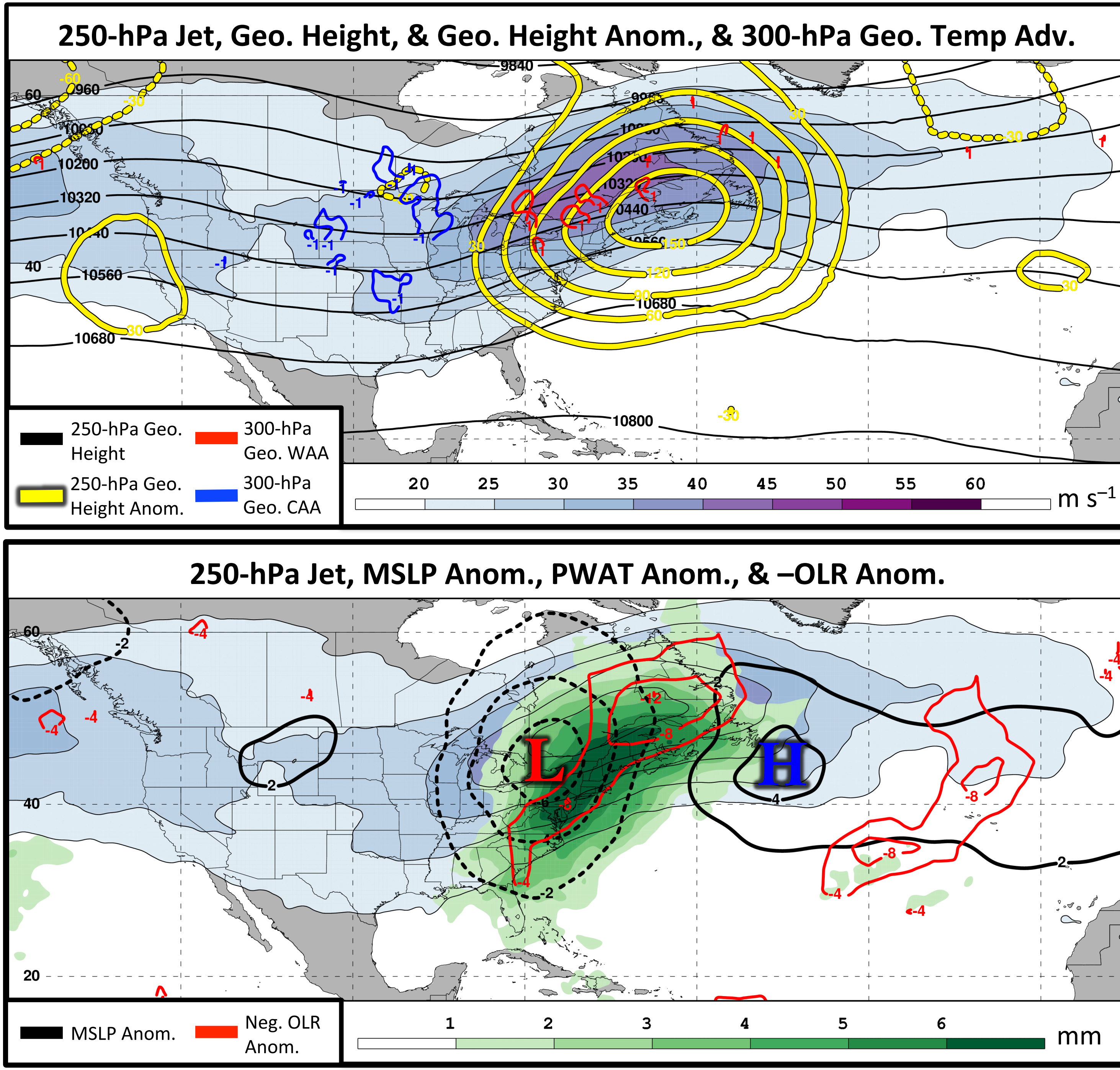
2 Days Prior to Jet Superposition

N=76



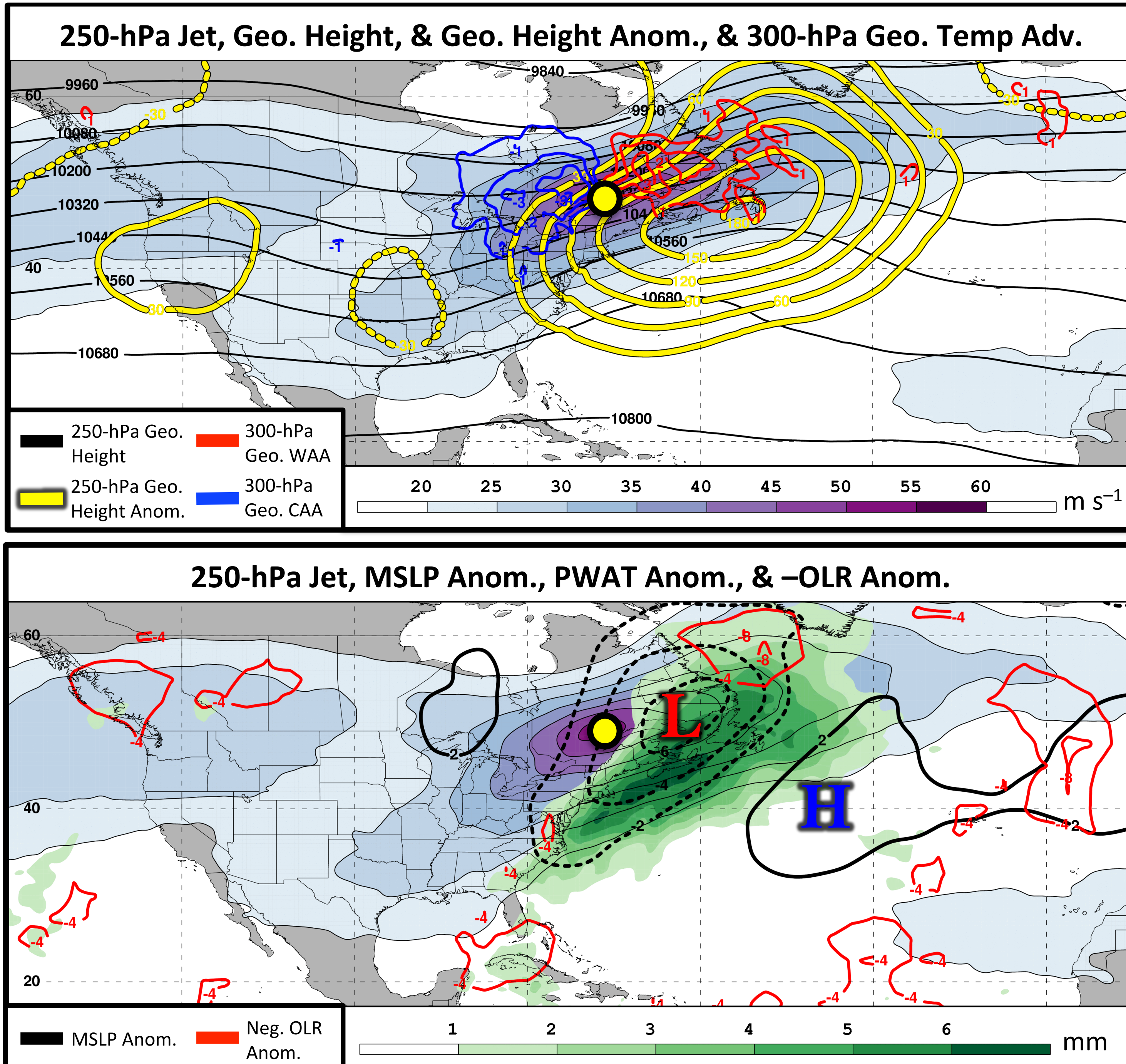
E. Subtropical Dominant Jet Superposition Events

1 Day Prior to Jet Superposition



N=76

E. Subtropical Dominant Jet Superposition Events



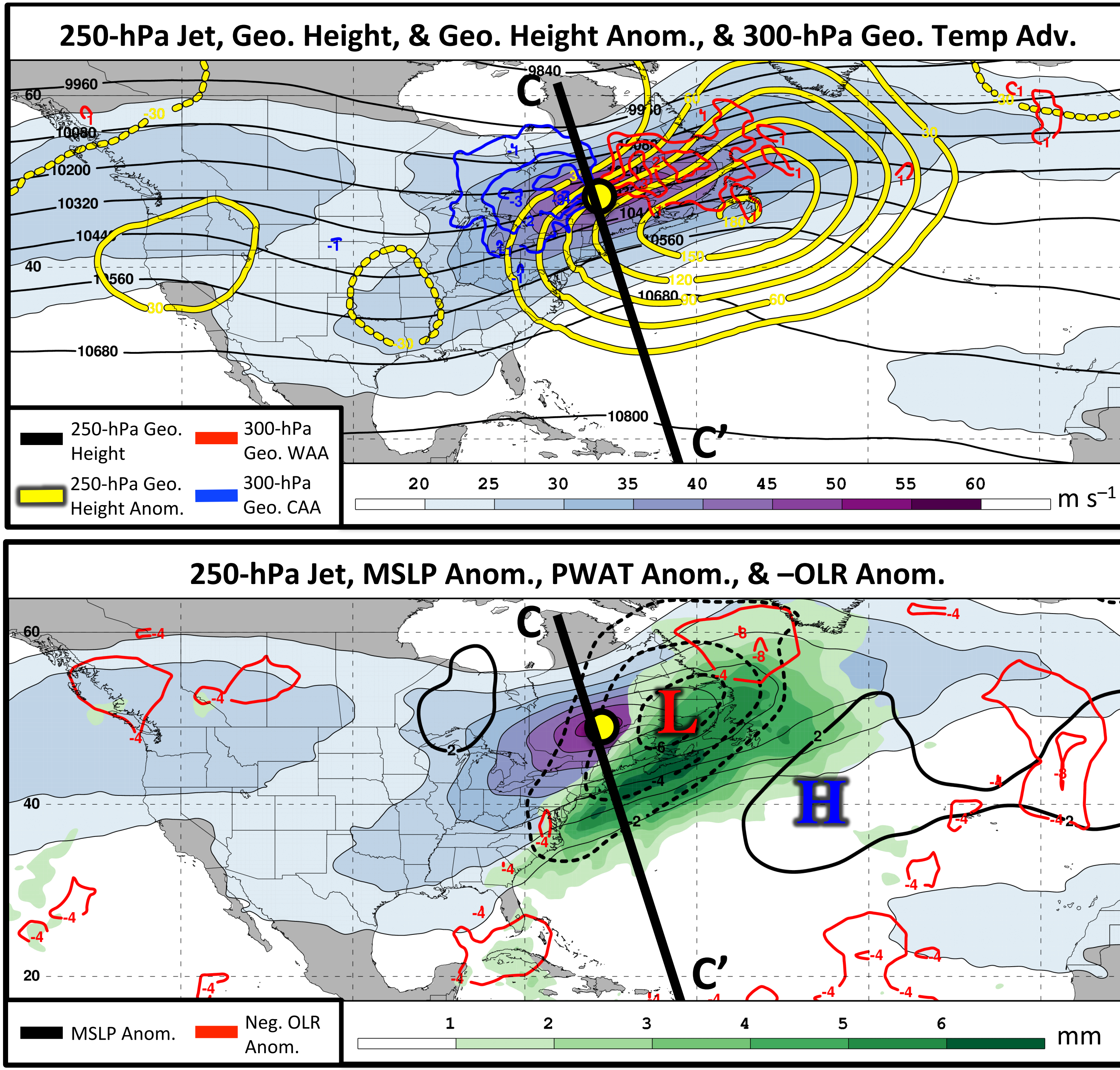
0 Days Prior to Jet Superposition

Average Location of Superposition

N=76

E. Subtropical Dominant Jet Superposition Events

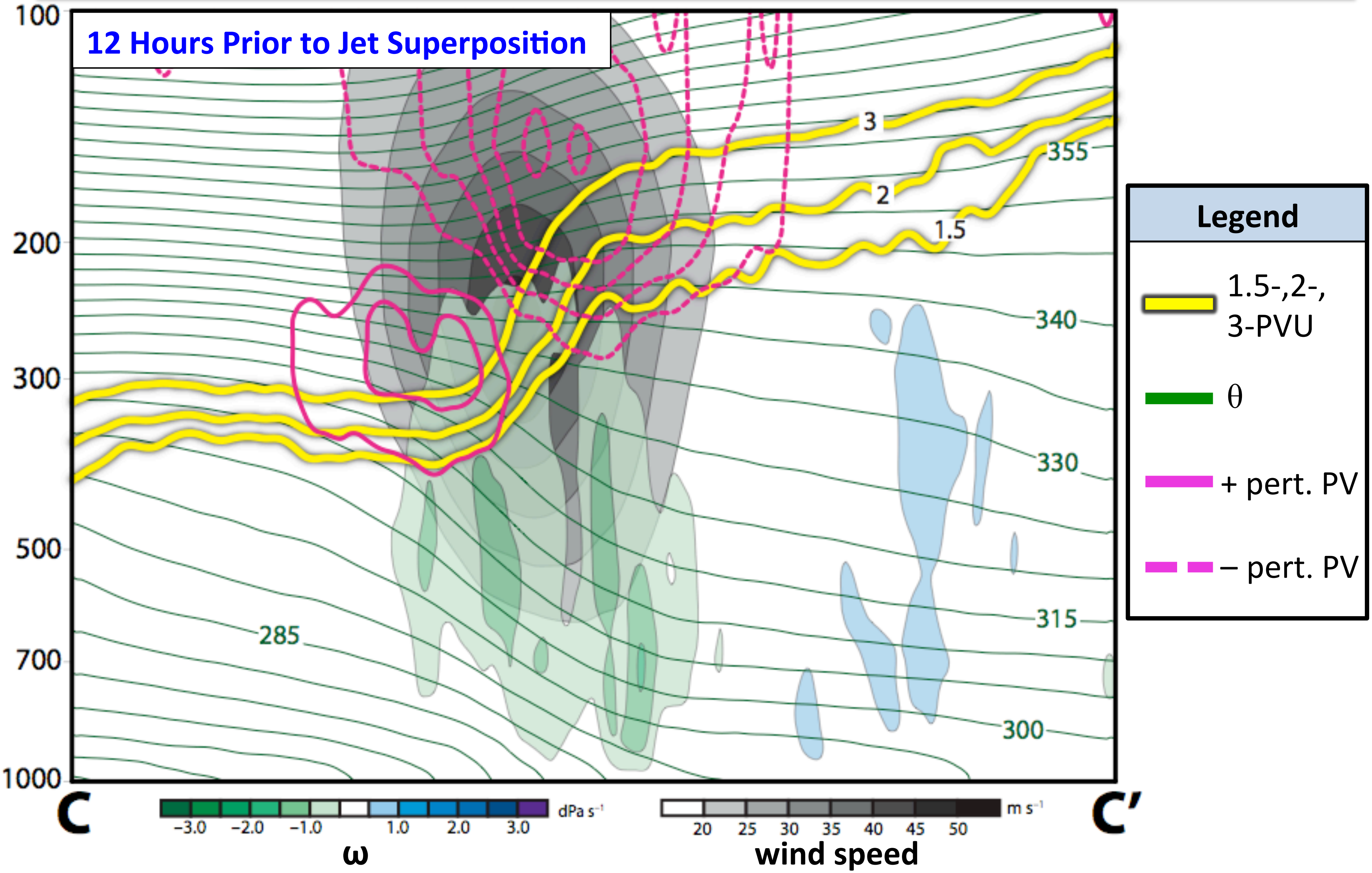
0 Days Prior to Jet Superposition



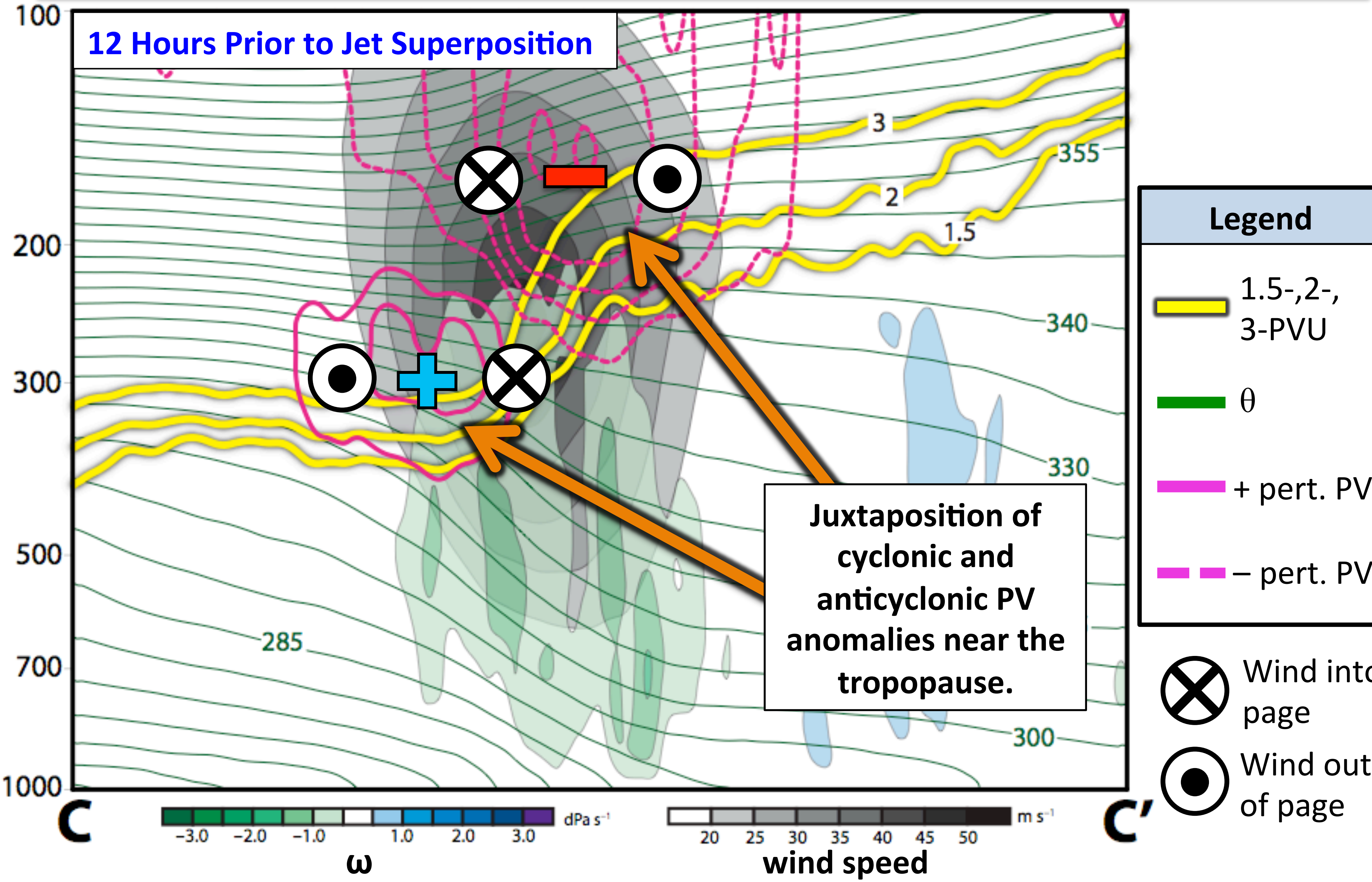
Average Location of Superposition

N=76

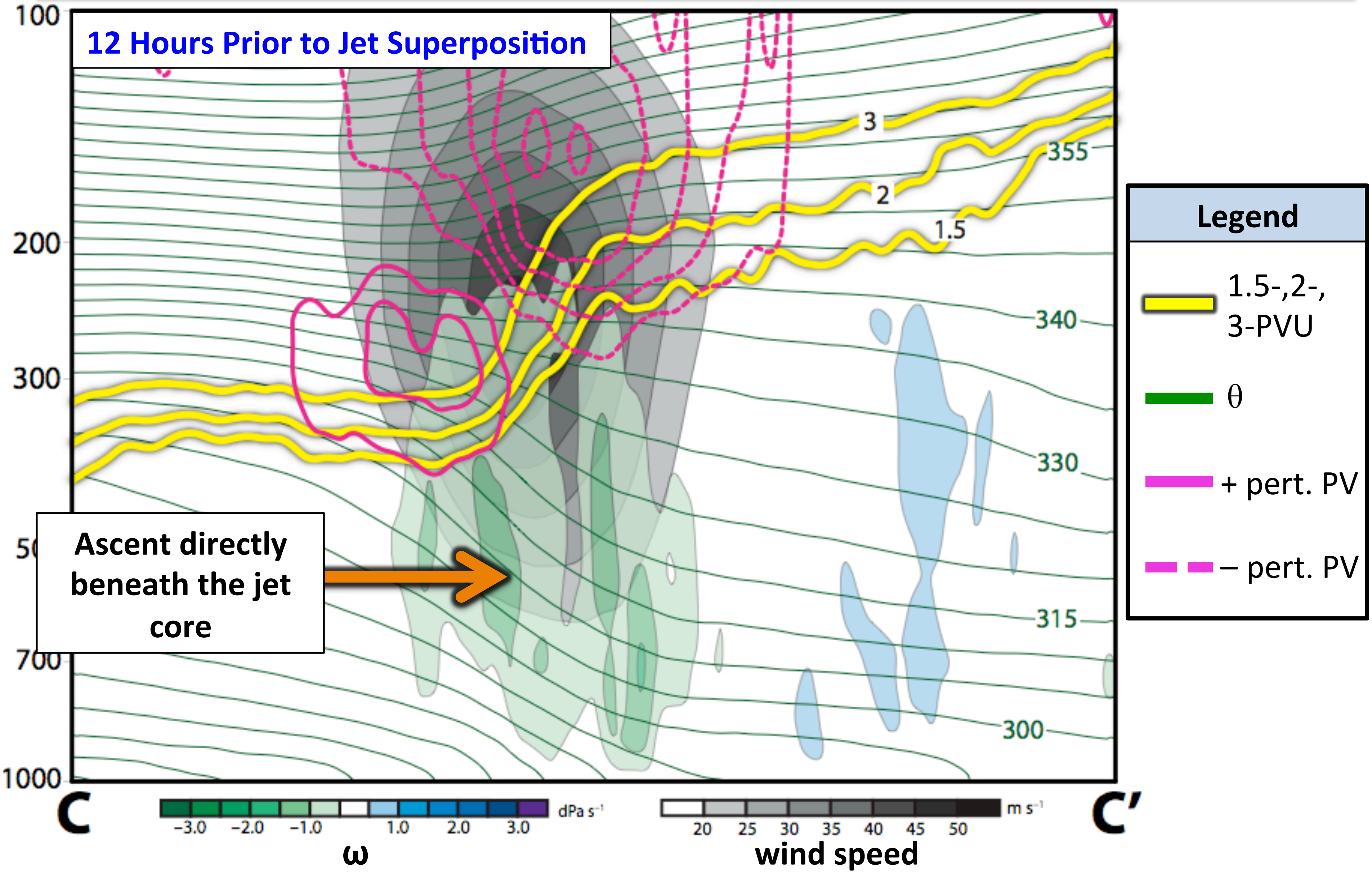
E. Subtropical Dominant Jet Superposition Events



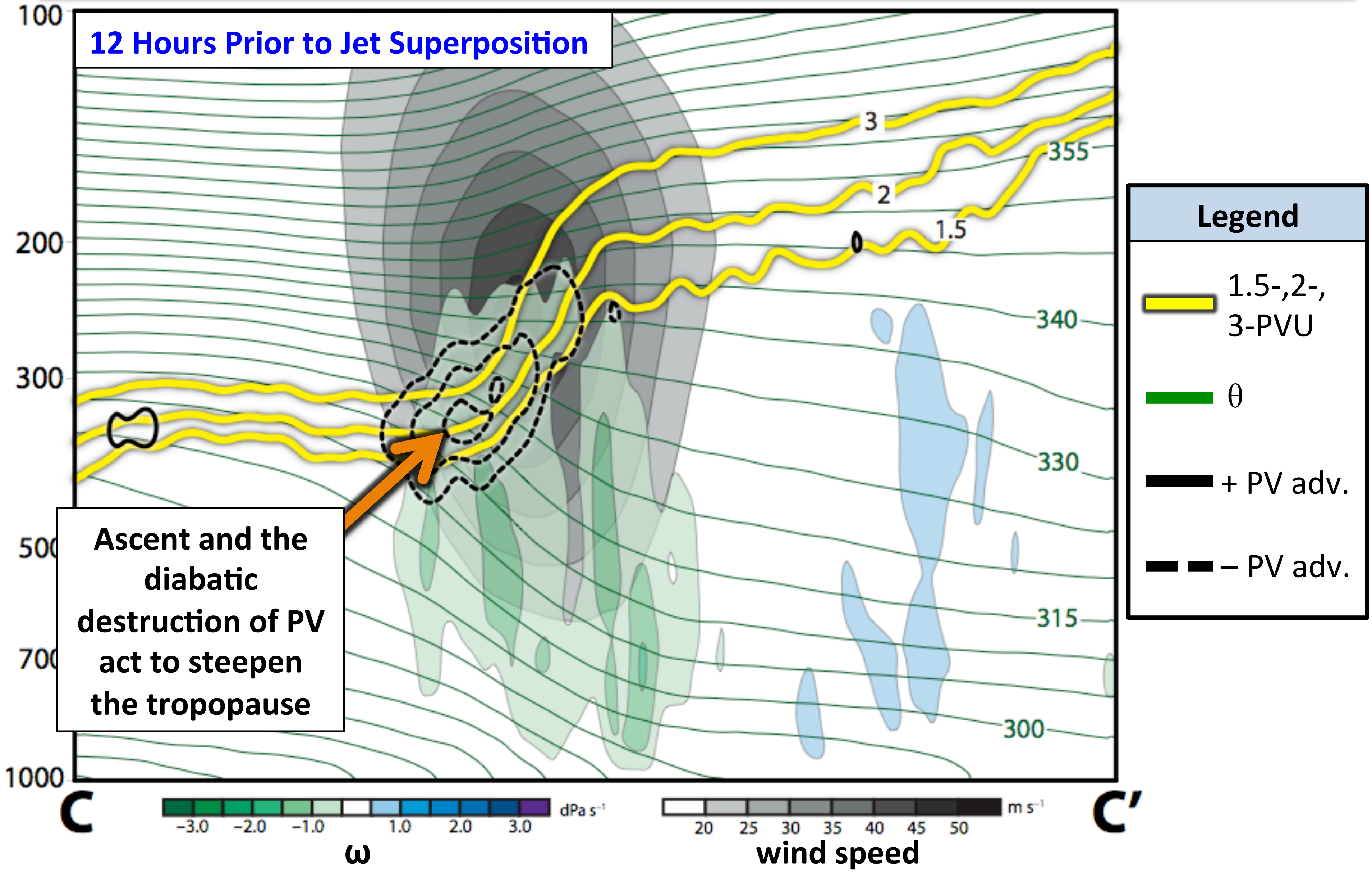
E. Subtropical Dominant Jet Superposition Events



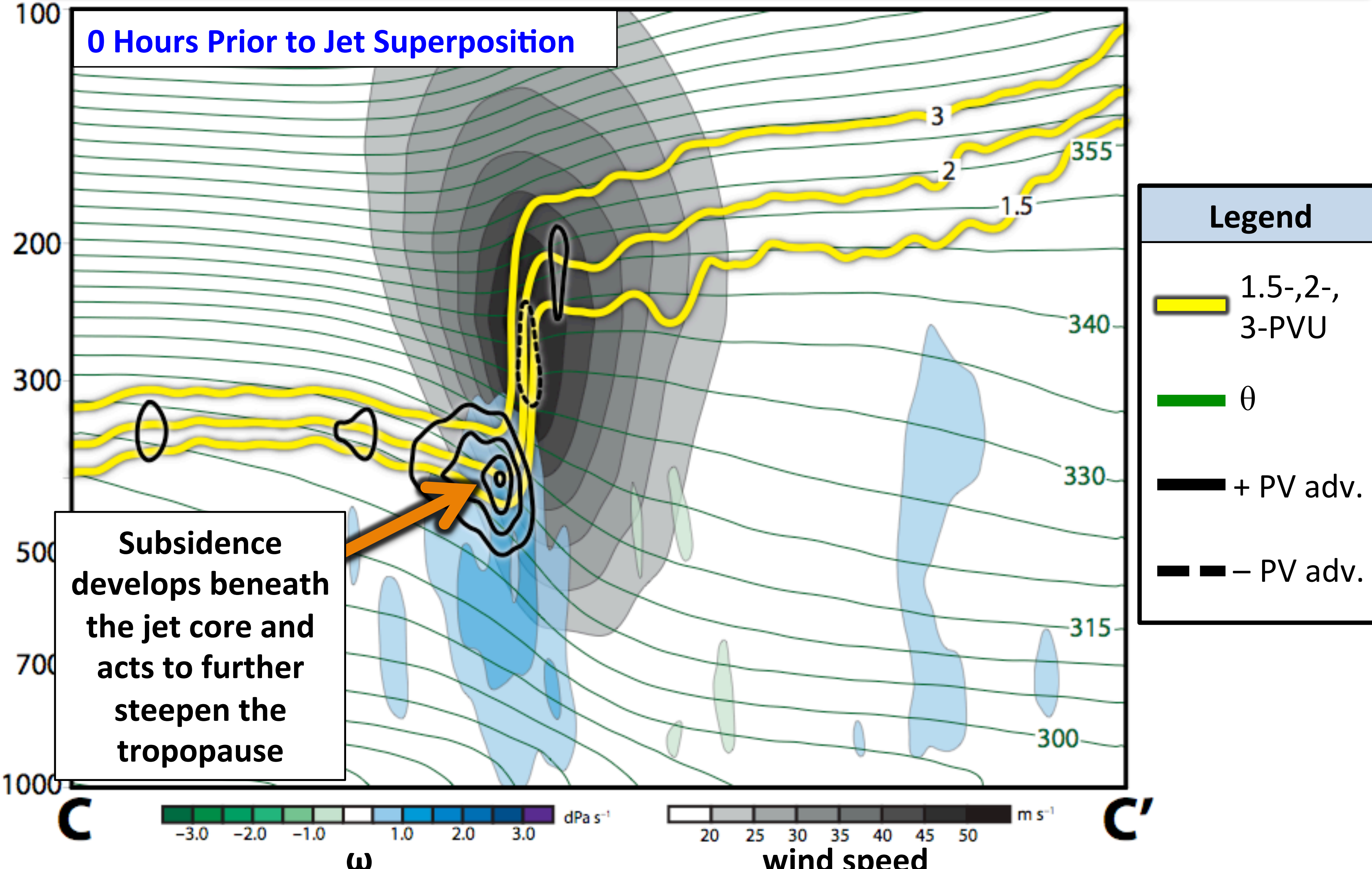
E. Subtropical Dominant Jet Superposition Events



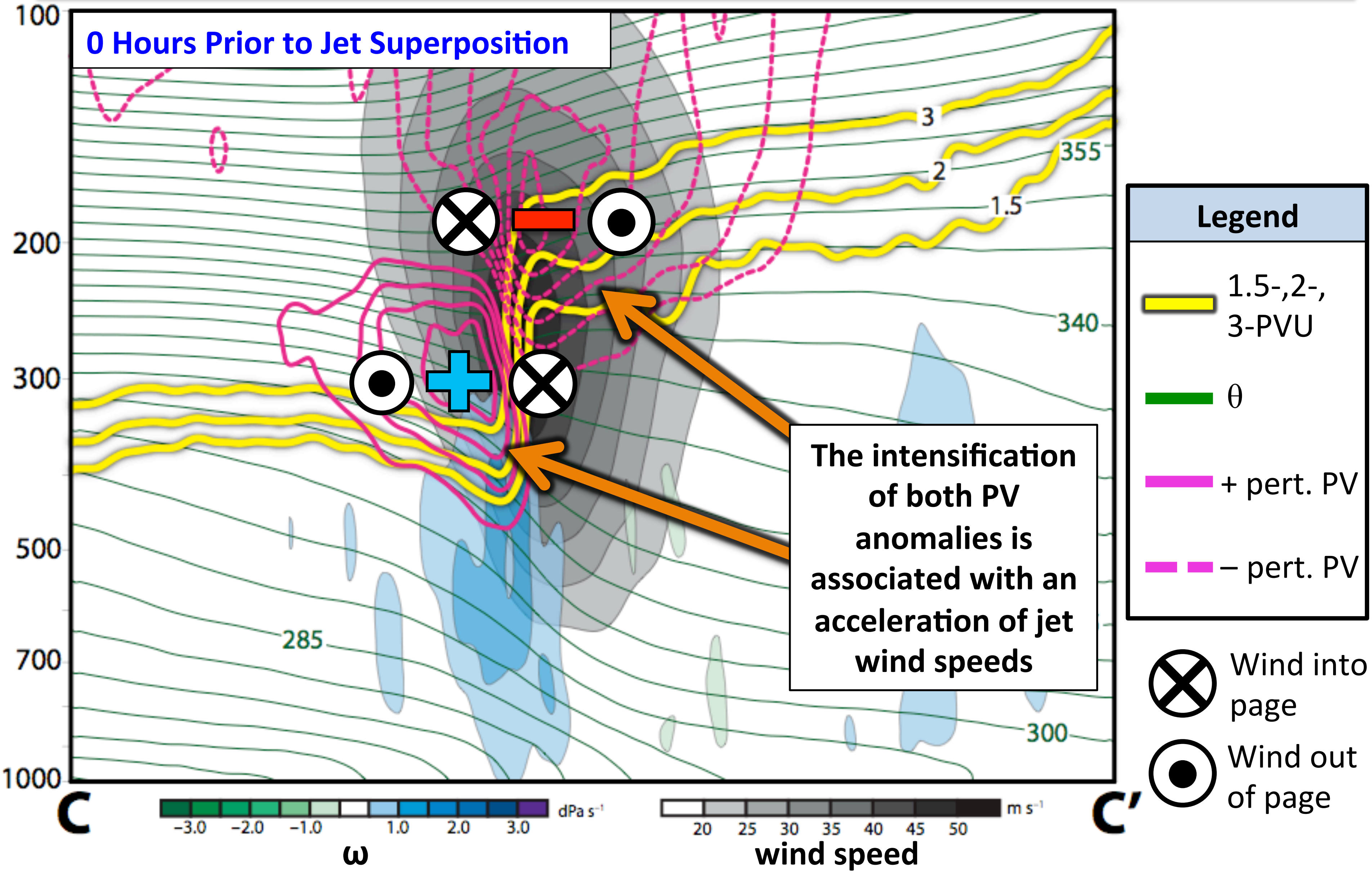
E. Subtropical Dominant Jet Superposition Events



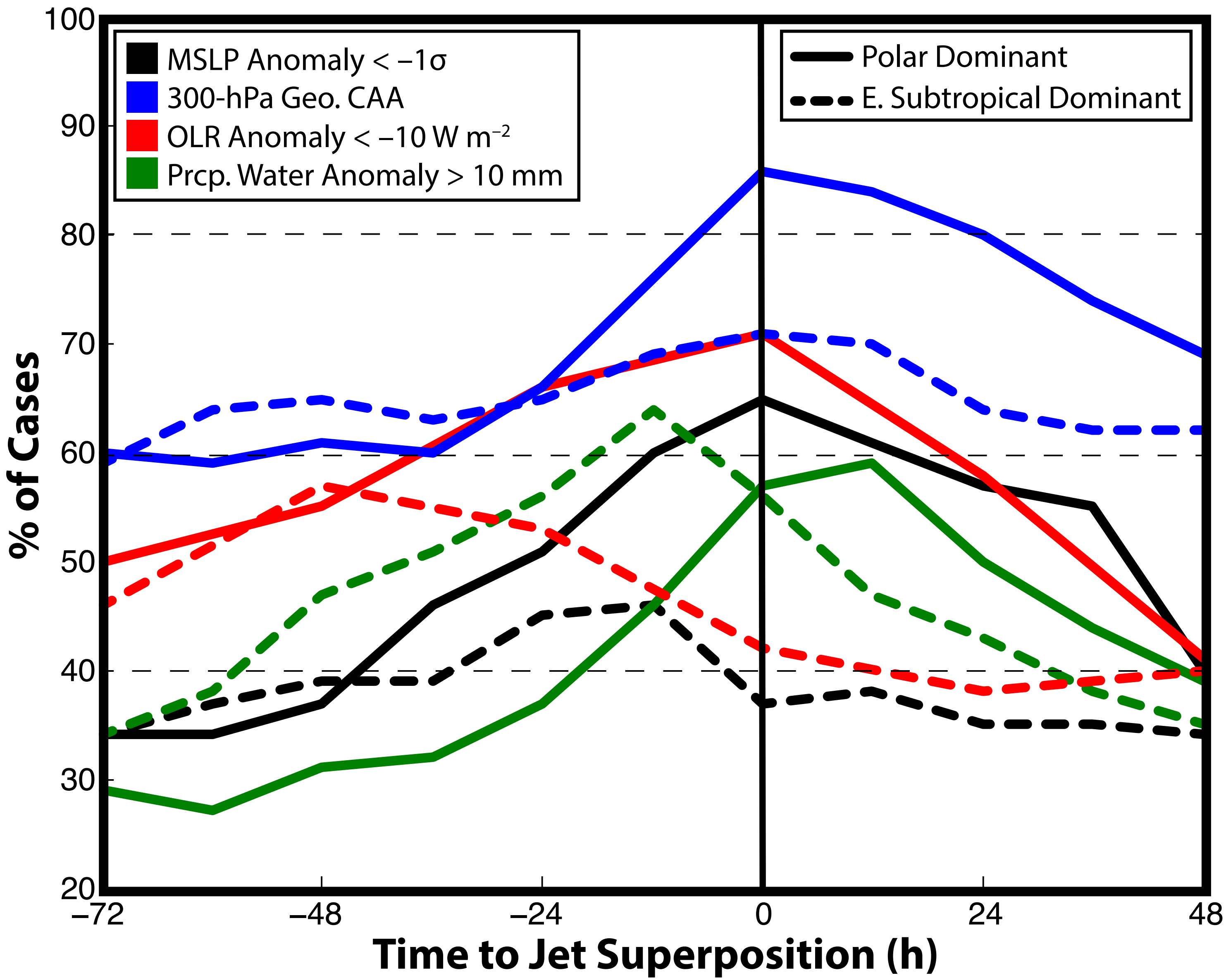
E. Subtropical Dominant Jet Superposition Events



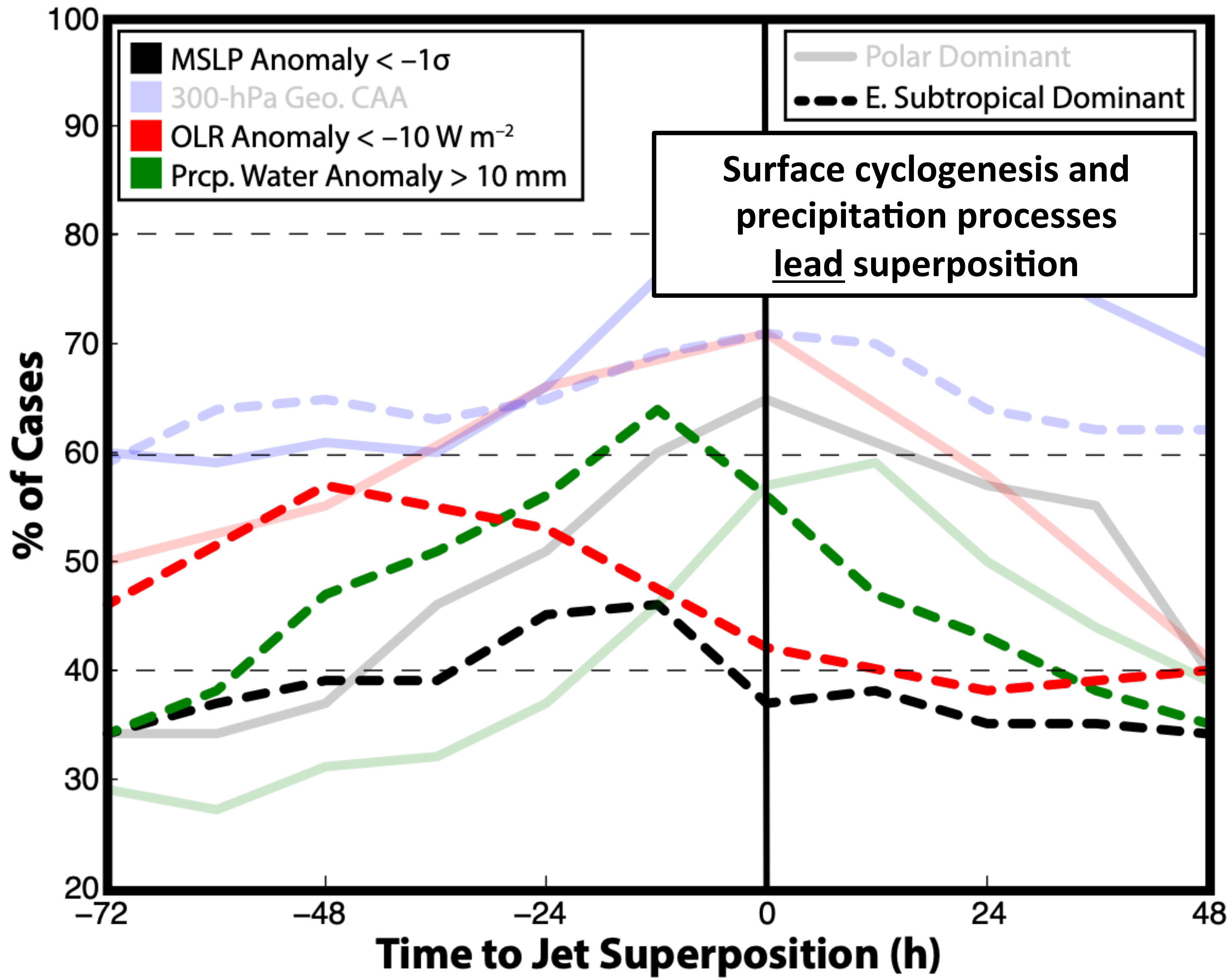
E. Subtropical Dominant Jet Superposition Events



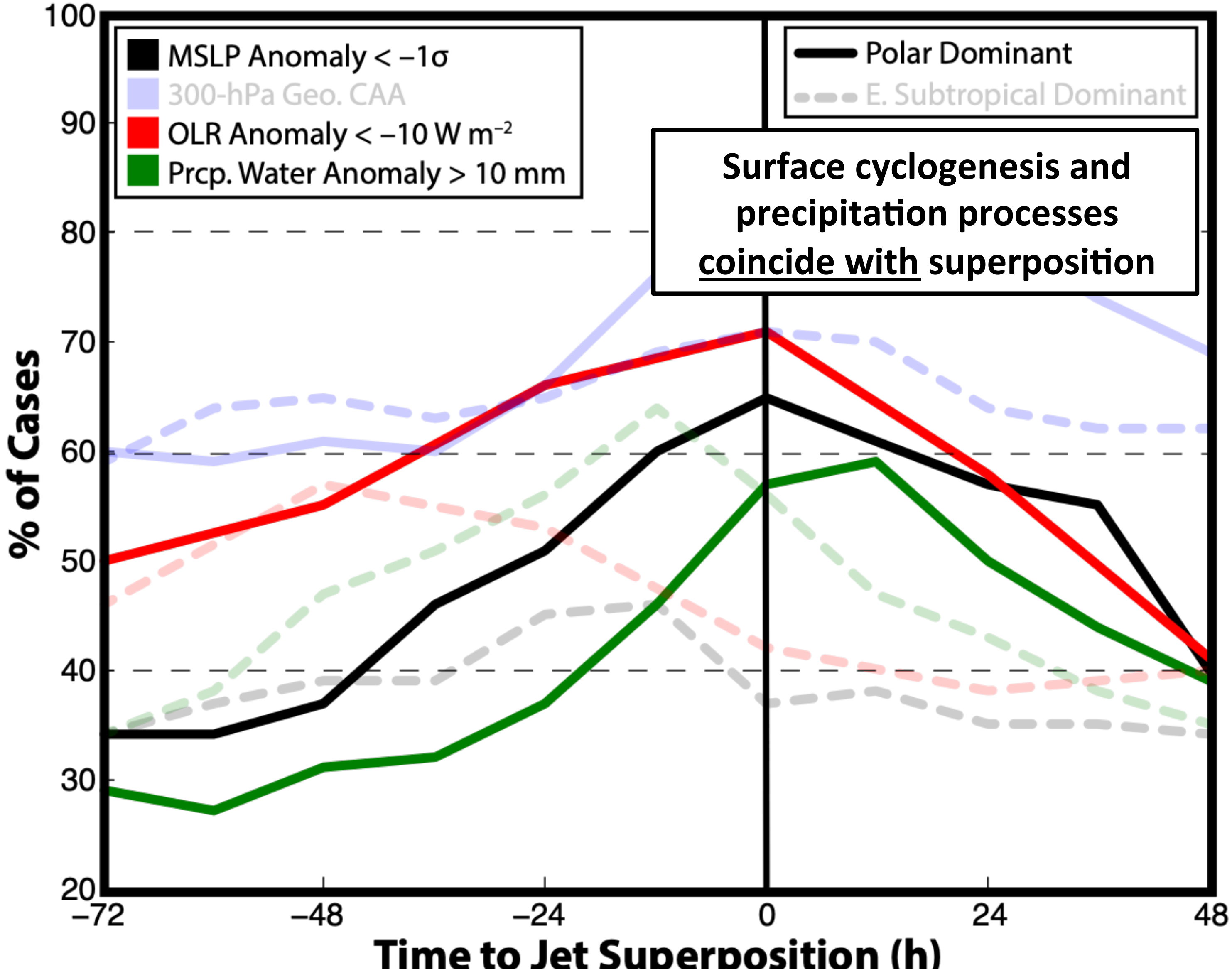
Jet Superposition Event Composites



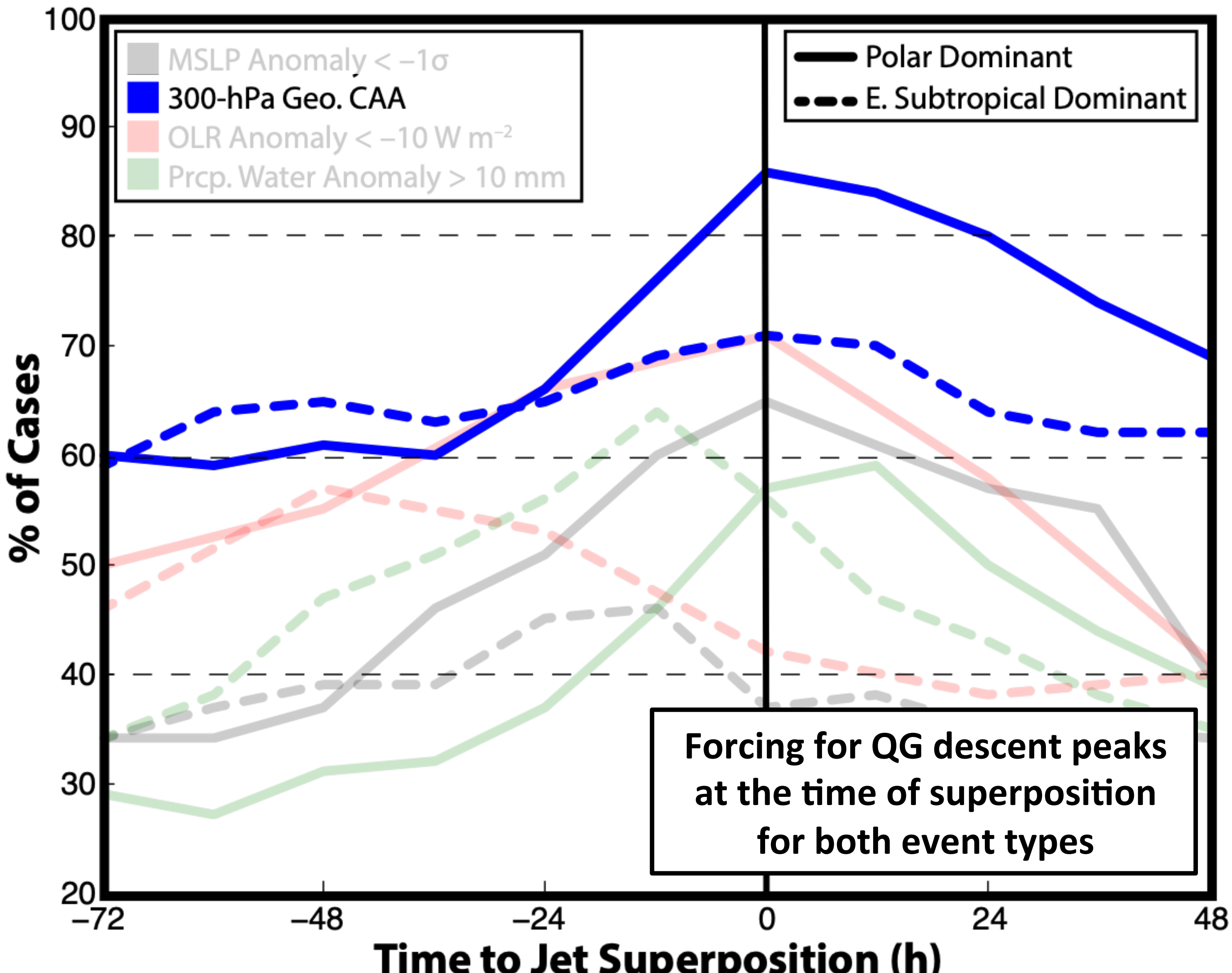
Jet Superposition Event Composites



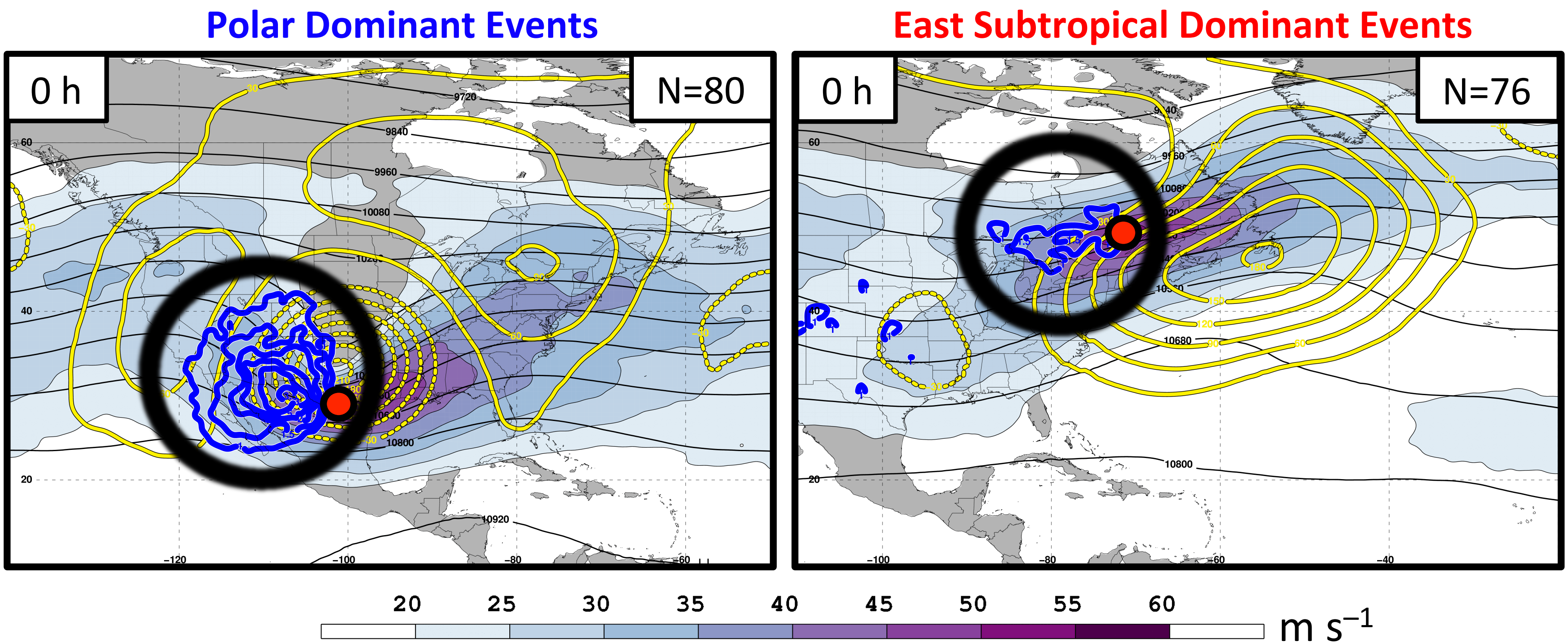
Jet Superposition Event Composites



Jet Superposition Event Composites



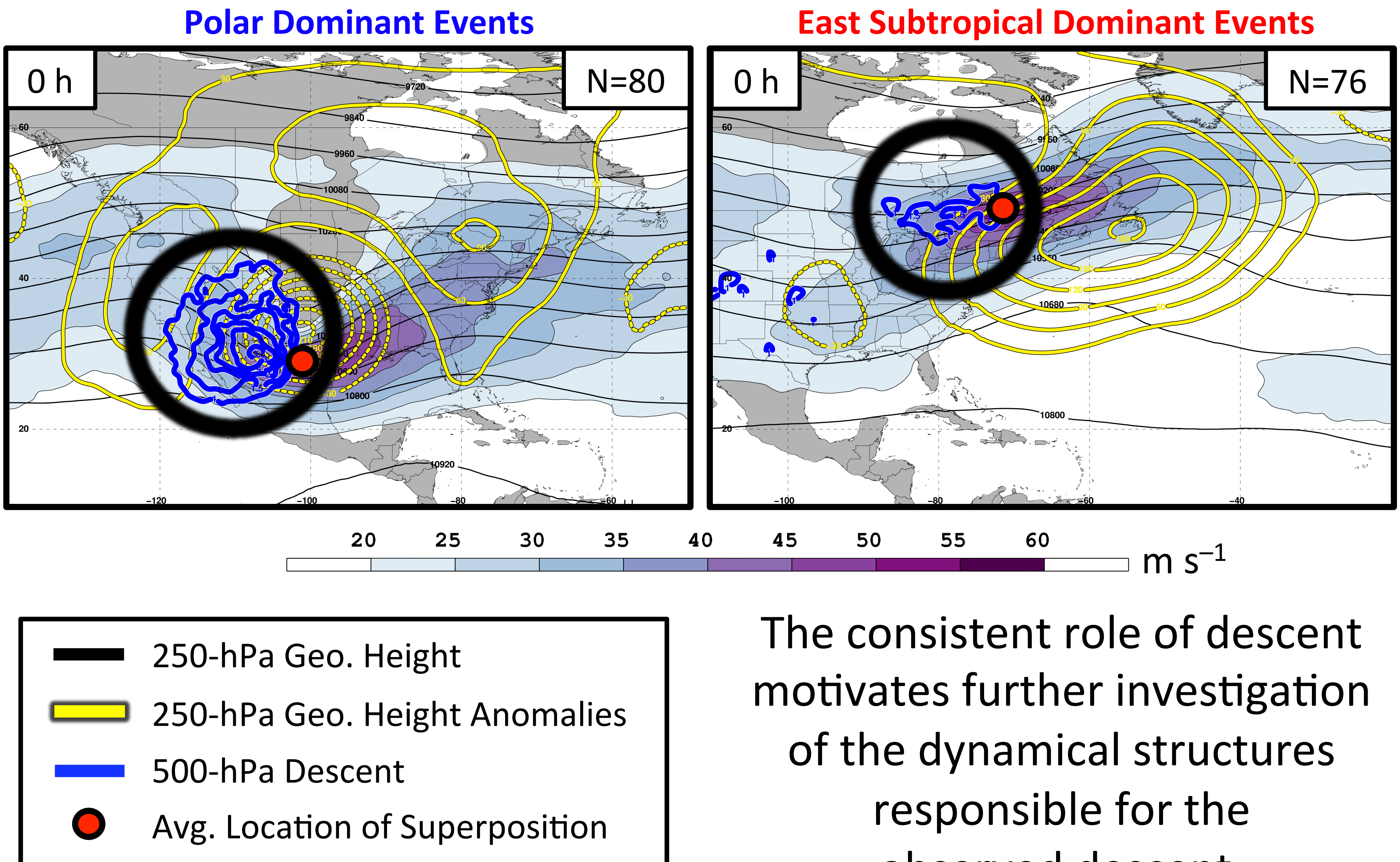
The Consistent Role of Descent



- 250-hPa Geo. Height
- 250-hPa Geo. Height Anomalies
- 500-hPa Descent
- Avg. Location of Superposition

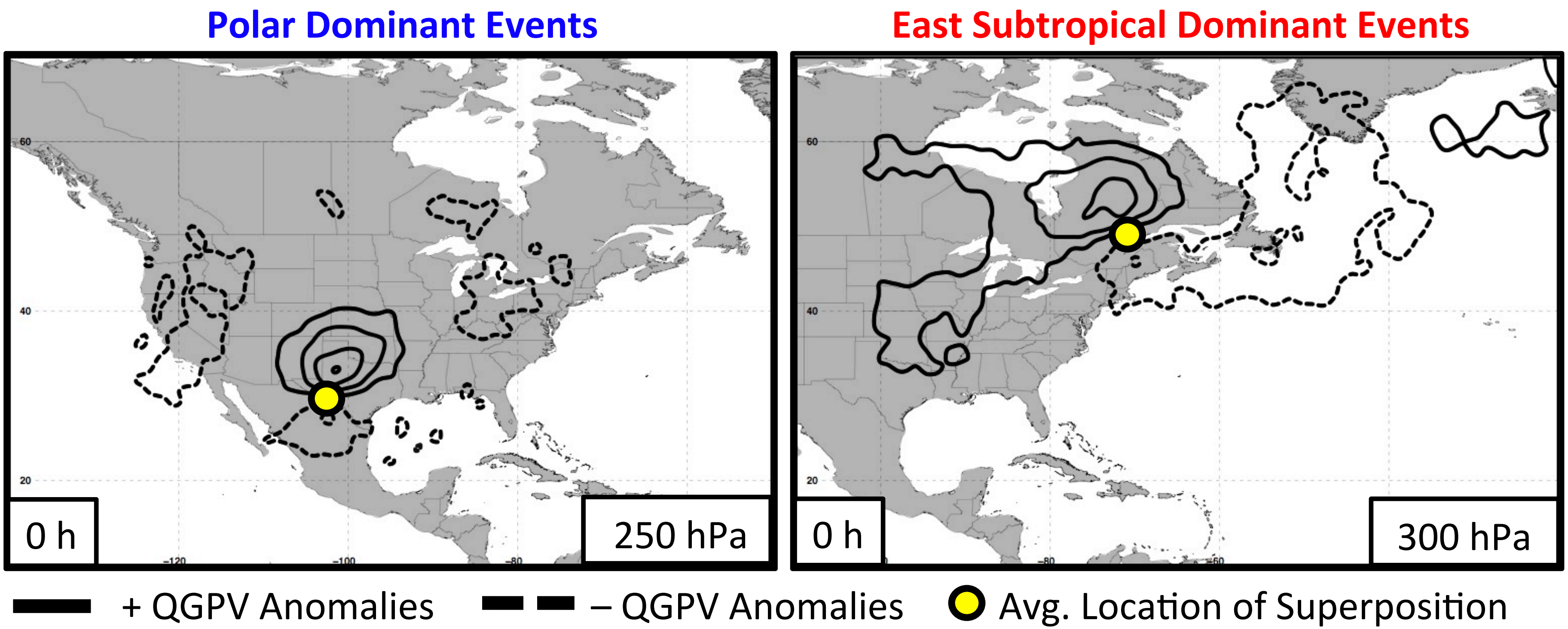
Descent within the jet-entrance region is a common element among the jet superposition event composites.

The Consistent Role of Descent



The consistent role of descent motivates further investigation of the dynamical structures responsible for the observed descent.

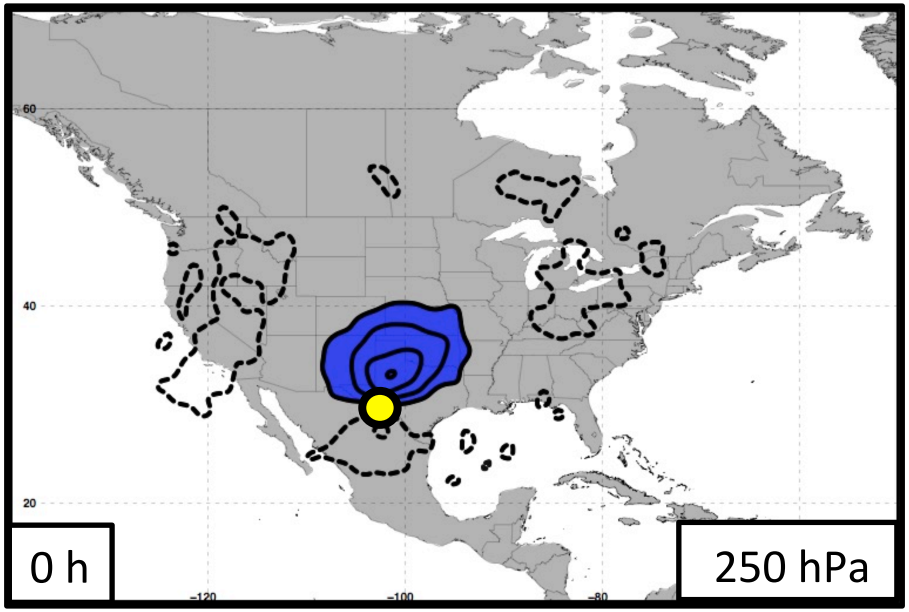
The Consistent Role of Descent



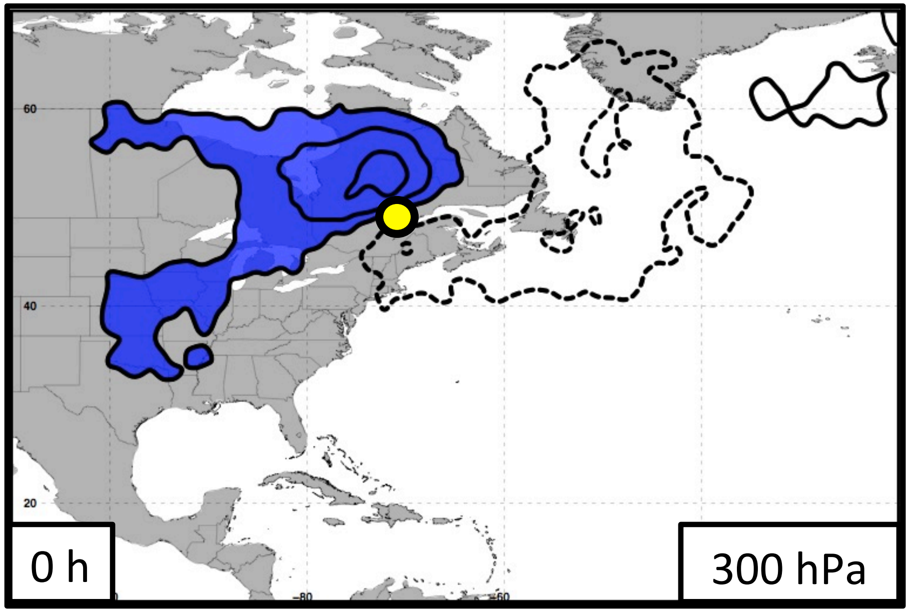
The descent characterizing each jet superposition event composite is examined further by isolating quasi-geostrophic (QG) PV anomalies in the vicinity of the jet superposition.

The Consistent Role of Descent

Polar Dominant Events



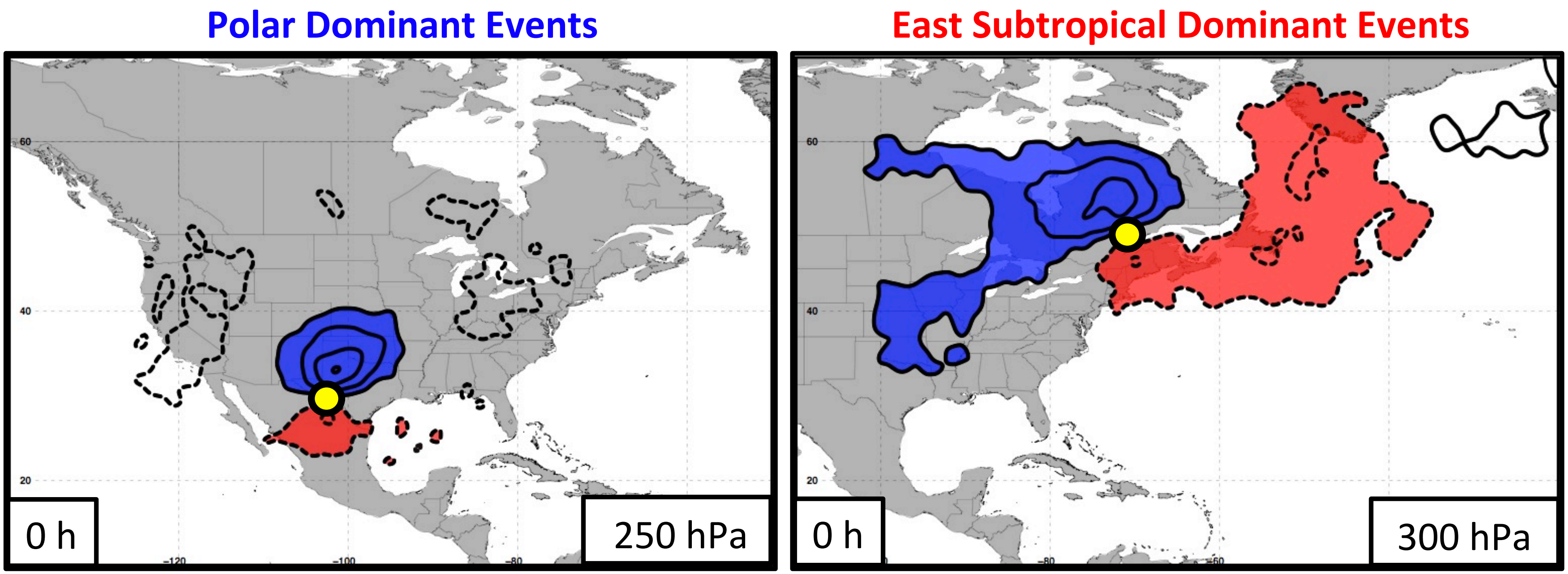
East Subtropical Dominant Events



Polar Cyclonic QGPV Anomalies

Avg. Location of Superposition

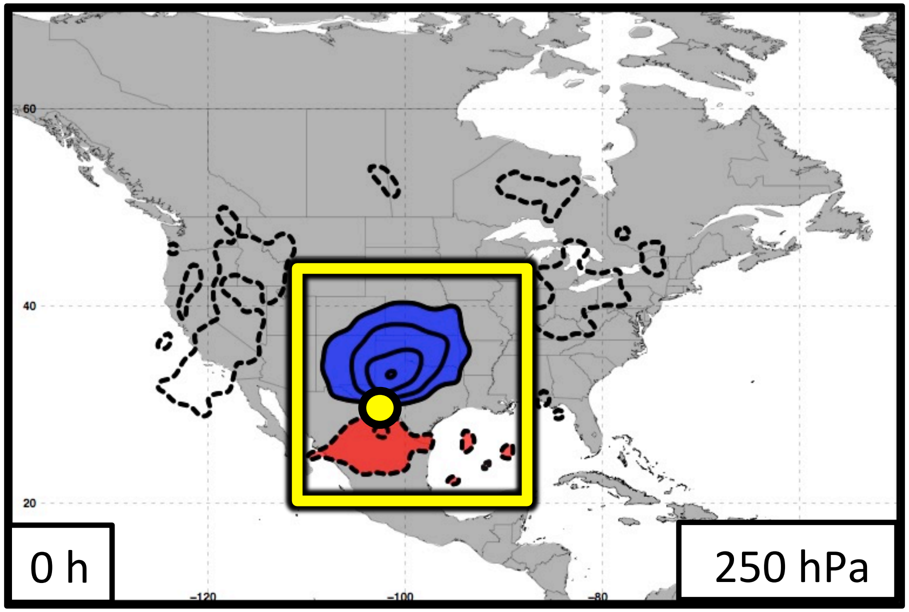
The Consistent Role of Descent



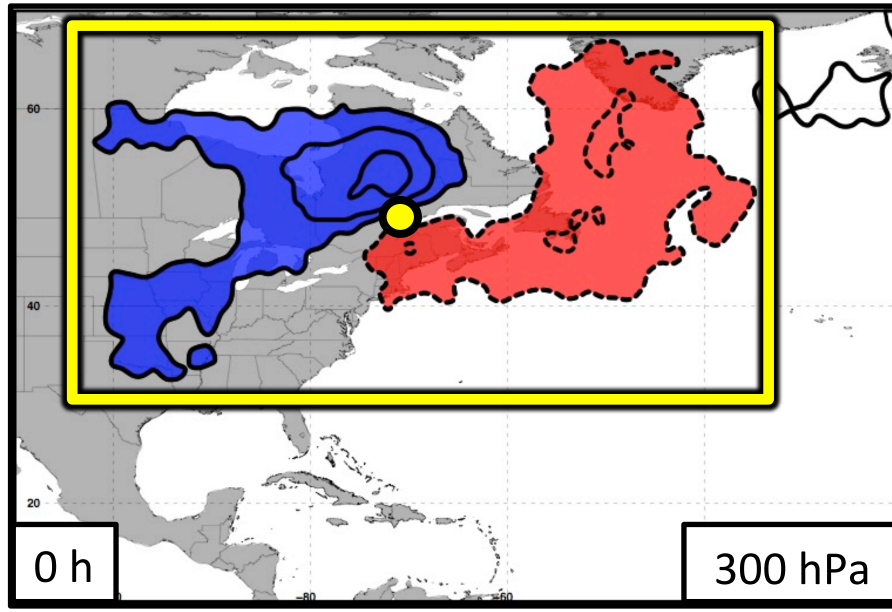
Polar Cyclonic QGPV Anomalies
Tropical Anticyclonic QGPV Anomalies
Avg. Location of Superposition

The Consistent Role of Descent

Polar Dominant Events

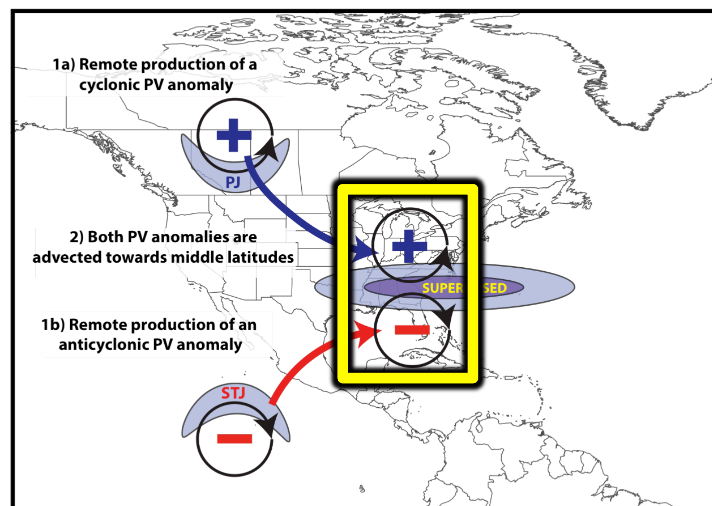


East Subtropical Dominant Events

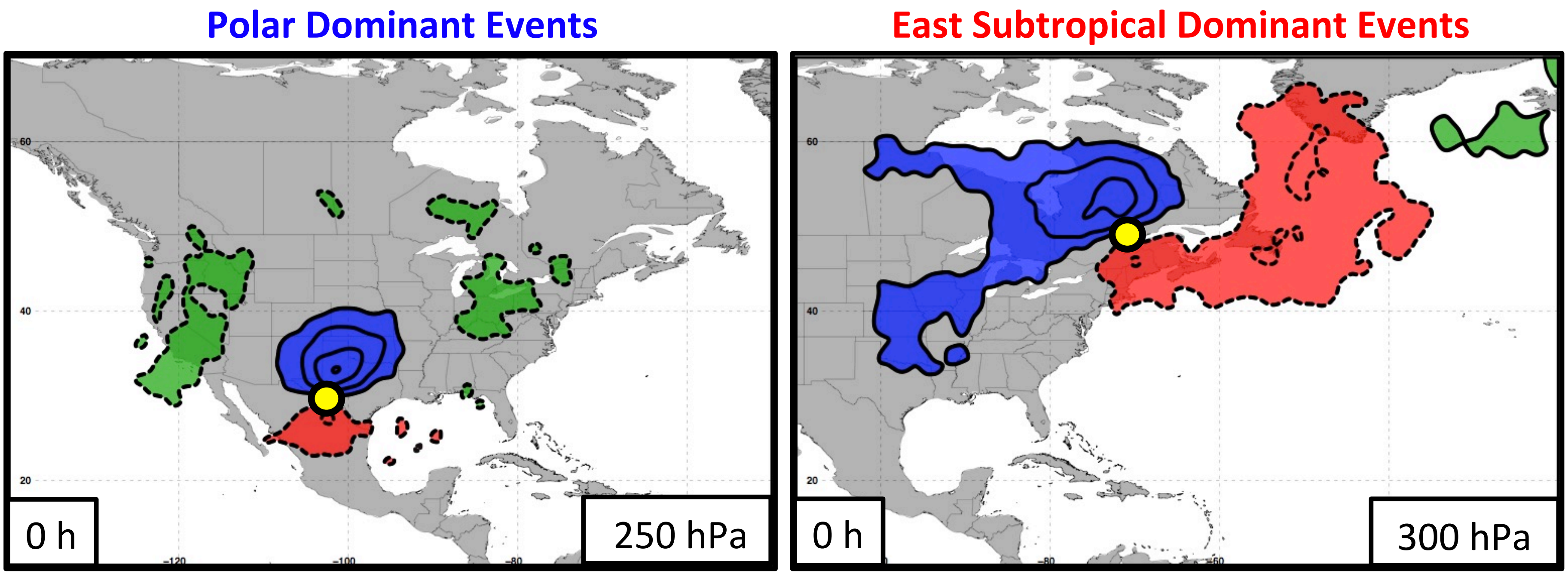


Polar Cyclonic QGPV Anomalies
Tropical Anticyclonic QGPV Anomalies

Avg. Location of Superposition



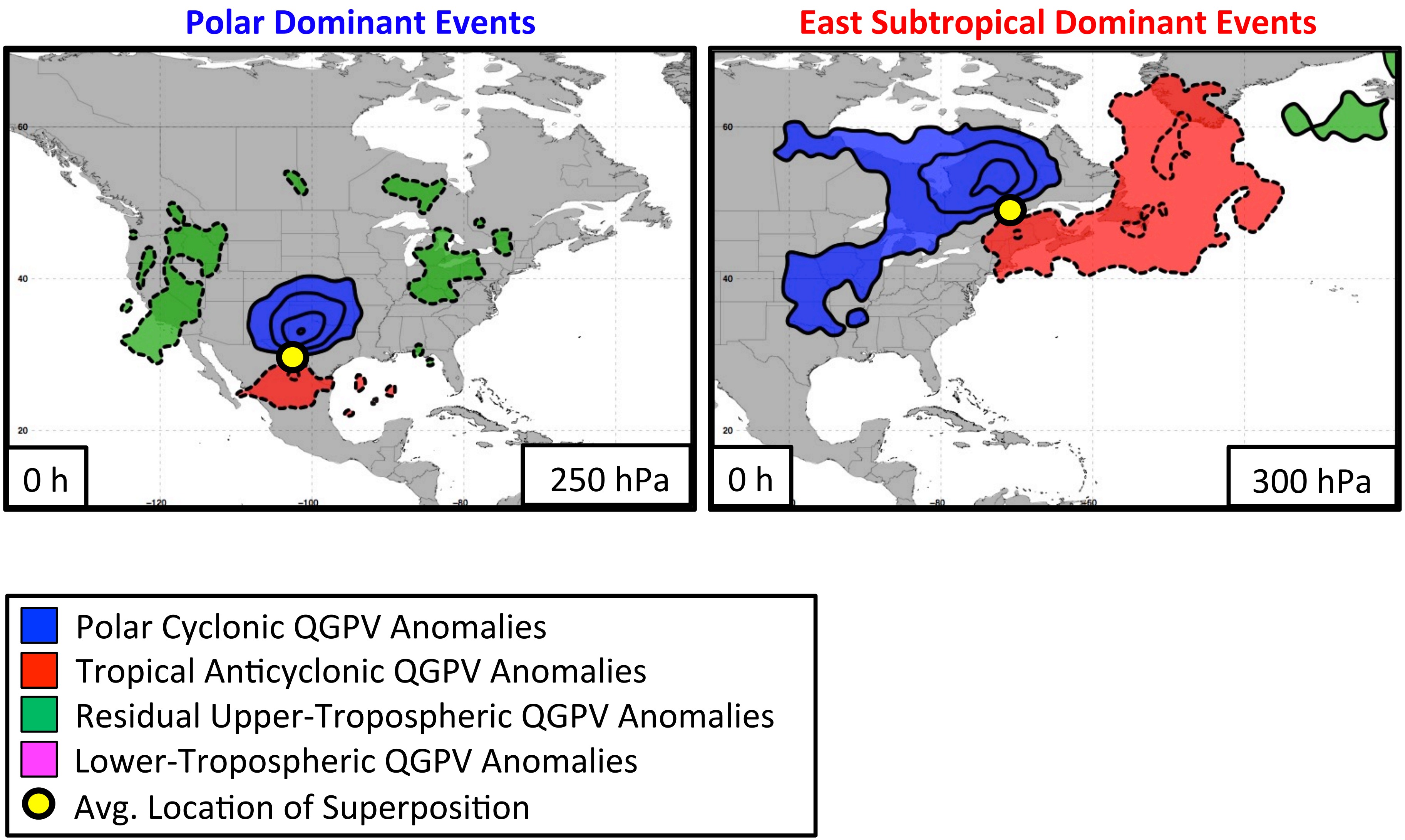
The Consistent Role of Descent



Polar Cyclonic QGPV Anomalies
Tropical Anticyclonic QGPV Anomalies
Residual Upper-Tropospheric QGPV Anomalies

Avg. Location of Superposition

The Consistent Role of Descent



The Consistent Role of Descent

Each category of QGPV anomalies (q') is inverted to determine its associated geopotential (ϕ') field:

$$q' = \frac{1}{f_0}\nabla^2\phi' + f_0\frac{\partial}{\partial p}\left(\frac{1}{\sigma_r}\frac{\partial\phi'}{\partial p}\right)$$

where

f_0 = Reference Coriolis Parameter
σ_r = Static Stability of the U.S. Std. Atm.

The Consistent Role of Descent

Each category of QGPV anomalies (q') is inverted to determine its associated geopotential (ϕ') field:

$$q' = \frac{1}{f_0}\nabla^2\phi' + f_0\frac{\partial}{\partial p}\left(\frac{1}{\sigma_r}\frac{\partial\phi'}{\partial p}\right)$$

where f_0 = *Reference Coriolis Parameter*
σ_r = *Static Stability of the U.S. Std. Atm.*

The geopotential fields and the composite temperature (T) field are used to determine the QG vertical motion (ω) associated with each category of QGPV:

$$\sigma_r\nabla^2\omega + f_0^2\frac{\partial^2\omega}{\partial p^2} = -2\nabla\cdot\vec{Q}$$

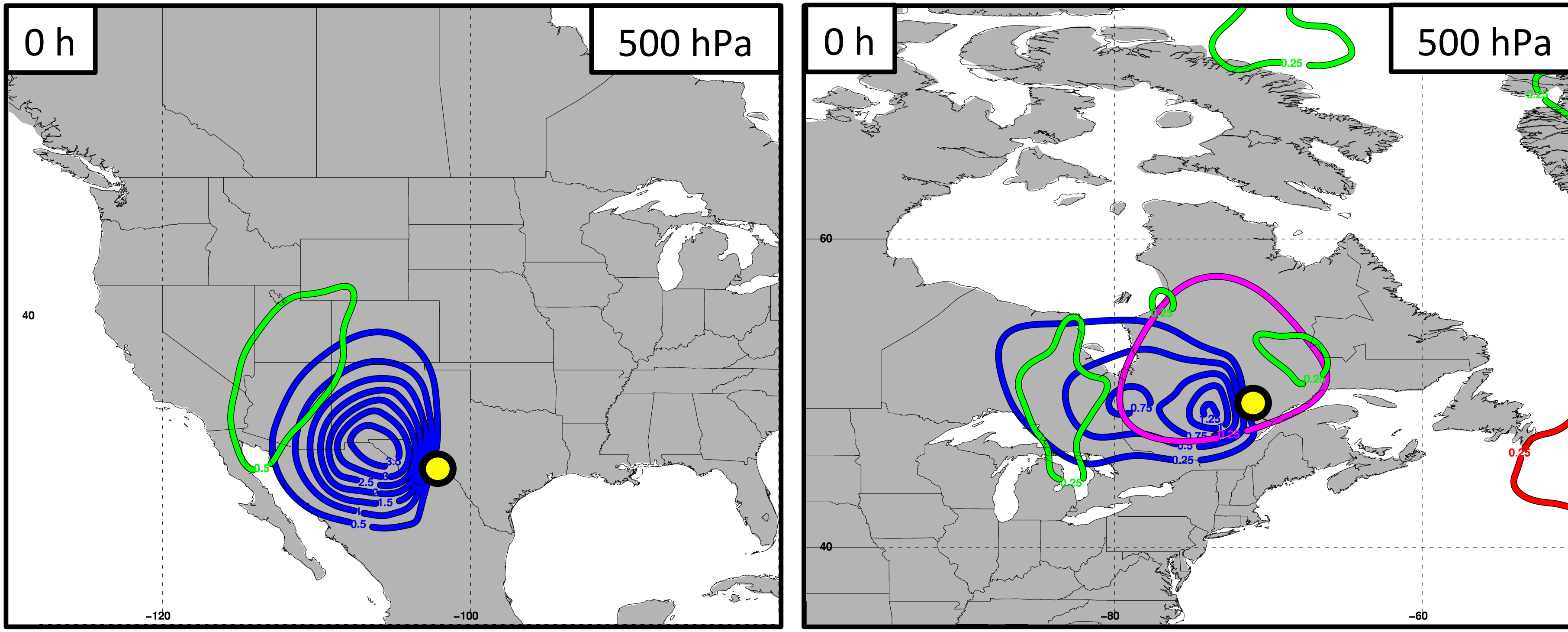
where

$$\vec{V_g'} = -(1/f_0)(\hat{k}\times\nabla\phi')$$

$$\vec{Q} = -\frac{R}{p}\left[\left(\frac{\partial\vec{V_g'}}{\partial x}\cdot\nabla T\right),\left(\frac{\partial\vec{V_g'}}{\partial y}\cdot\nabla T\right)\right]$$

The Consistent Role of Descent

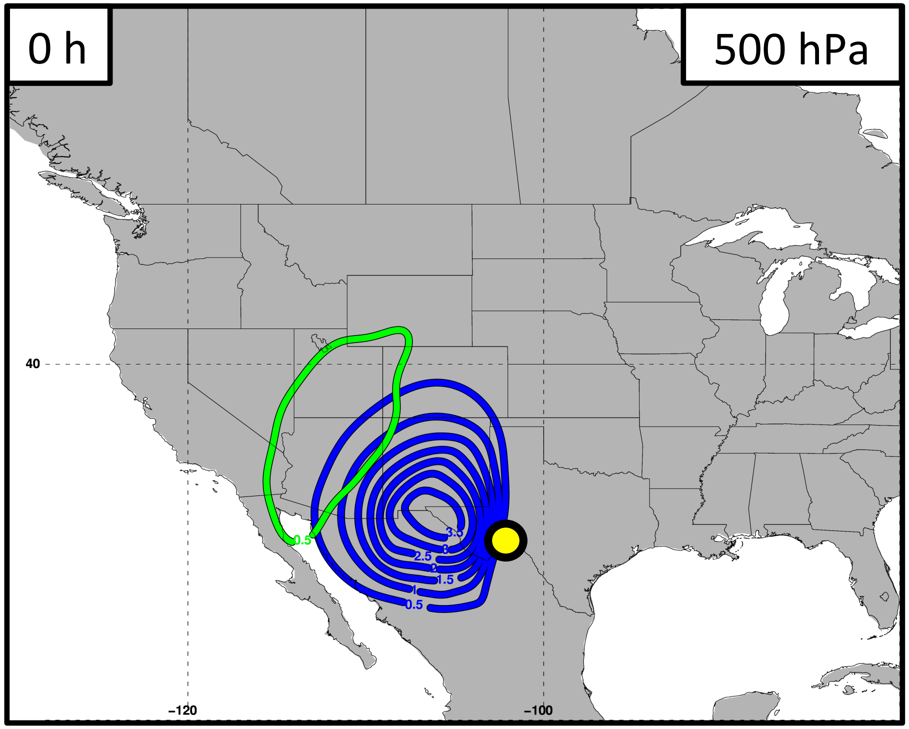
Polar Dominant Events | **East Subtropical Dominant Events**



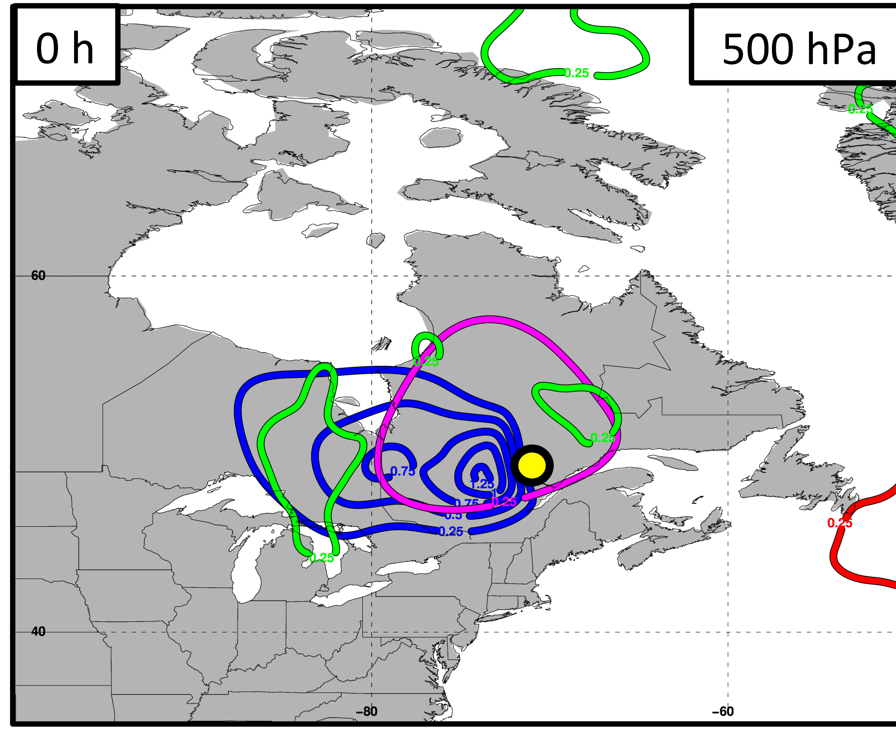
- Polar Cyclonic QGPV Anomalies
- Tropical Anticyclonic QGPV Anomalies
- Residual Upper-Tropospheric QGPV Anomalies
- Lower-Tropospheric QGPV Anomalies
- Avg. Location of Superposition

The Consistent Role of Descent

Polar Dominant Events



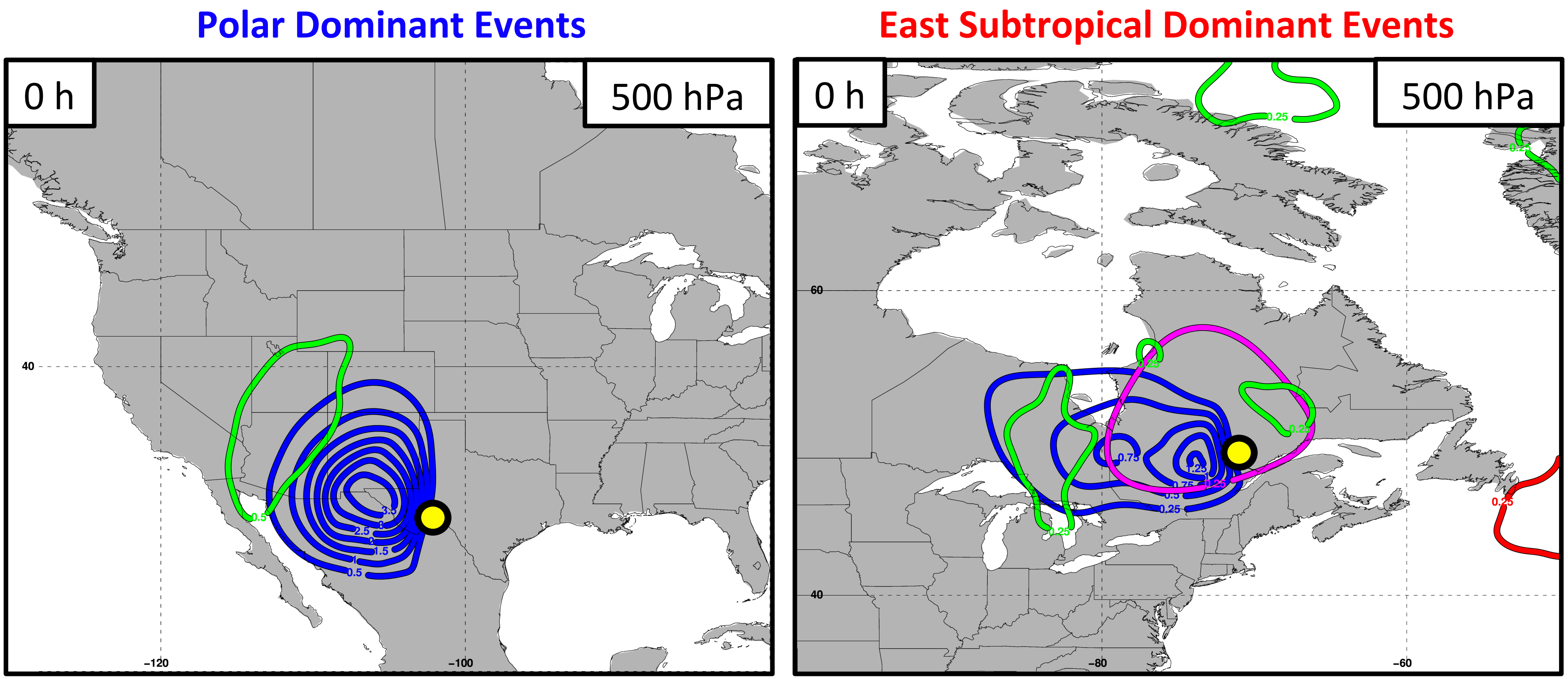
East Subtropical Dominant Events



- Polar Cyclonic QGPV Anomalies
- Tropical Anticyclonic QGPV Anomalies
- Residual Upper-Tropospheric QGPV Anomalies
- Lower-Tropospheric QGPV Anomalies
- Avg. Location of Superposition

Descent is primarily associated with polar cyclonic QGPV anomalies.

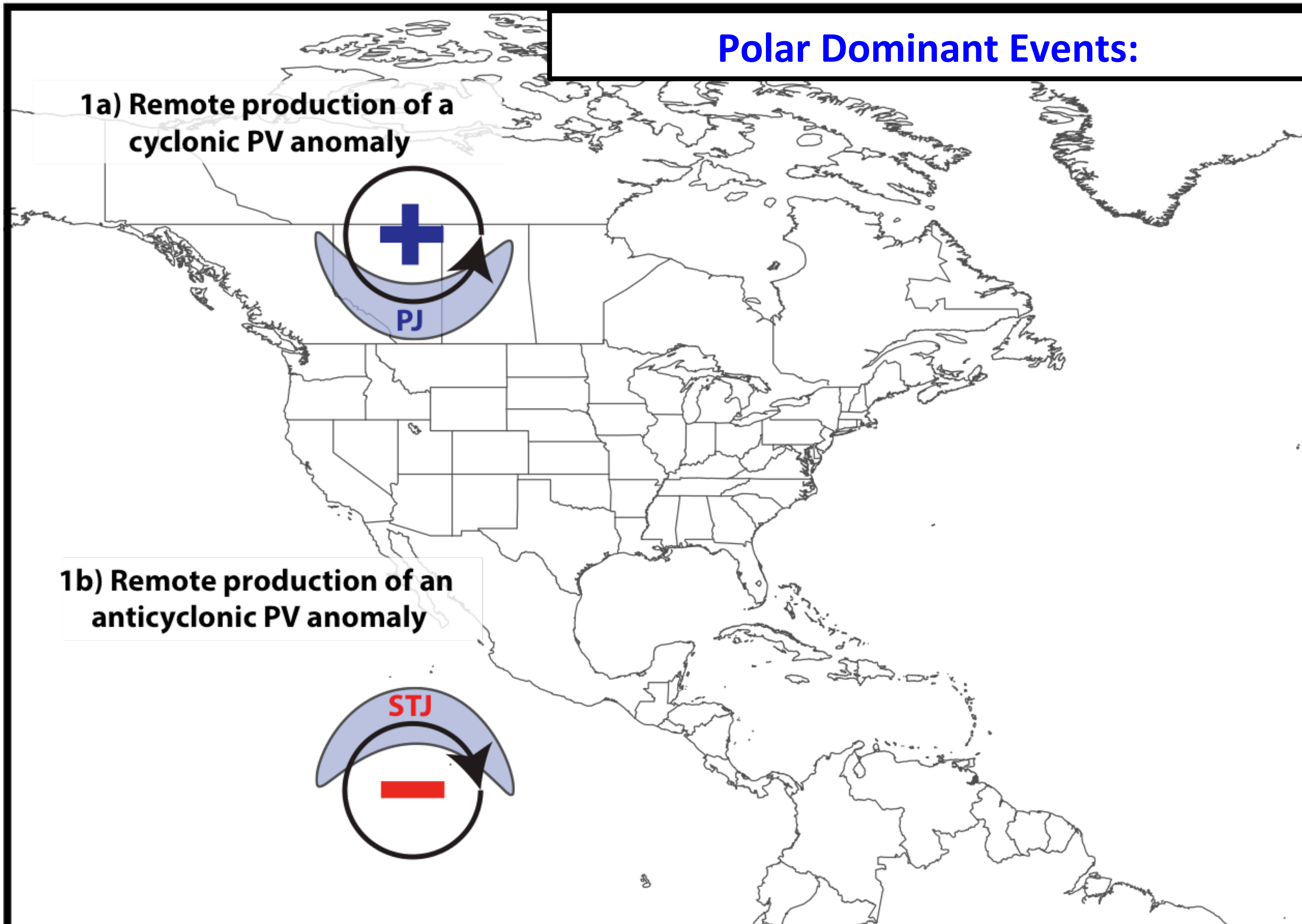
The Consistent Role of Descent



- Polar Cyclonic QGPV Anomalies
- Tropical Anticyclonic QGPV Anomalies
- Residual Upper-Tropospheric QGPV Anomalies
- Lower-Tropospheric QGPV Anomalies
- Avg. Location of Superposition

Polar cyclonic QGPV anomalies play a critical role during jet superpositions.

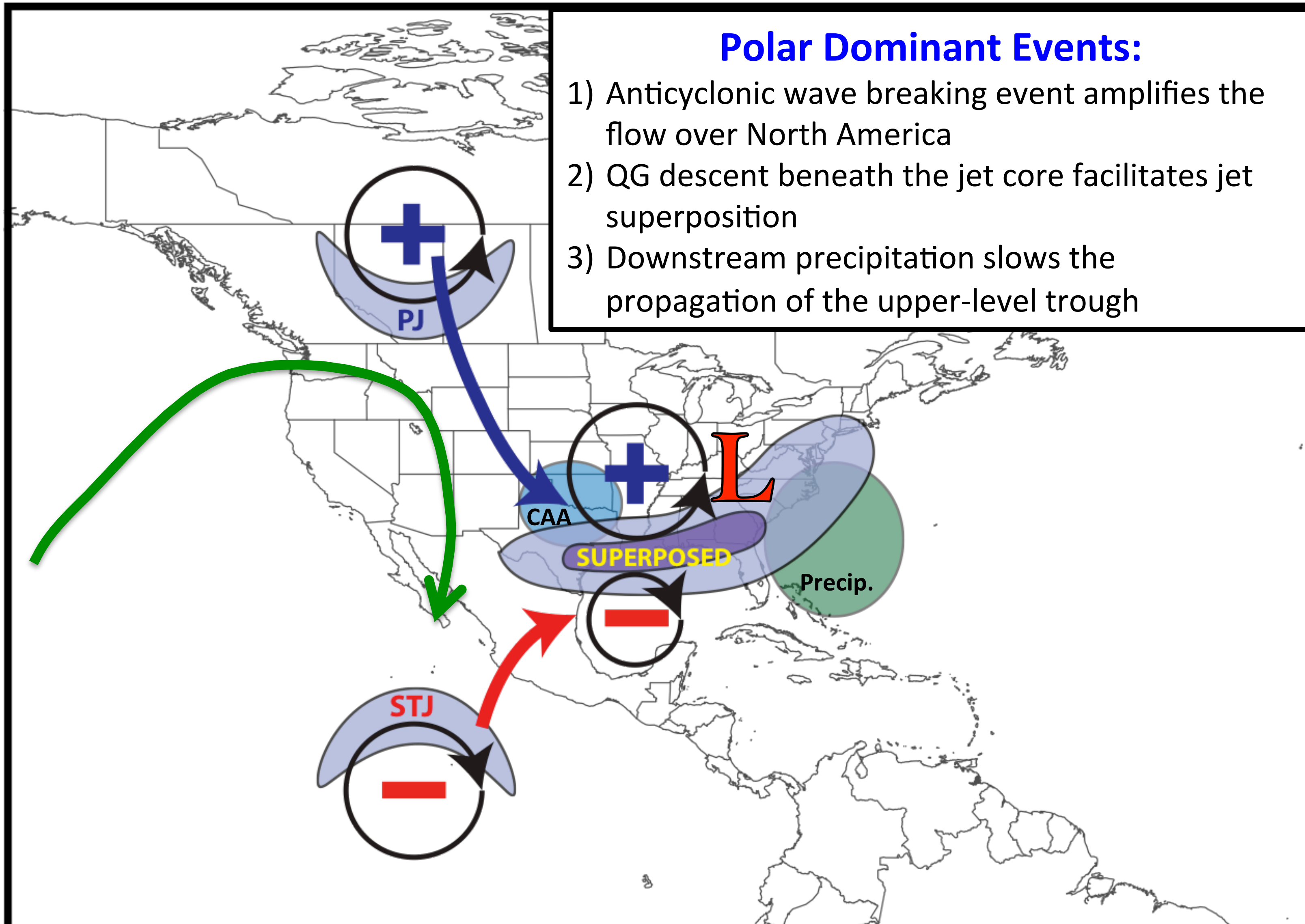
Summary


Polar Dominant Events:
1a) Remote production of a cyclonic PV anomaly
PJ
1b) Remote production of an anticyclonic PV anomaly
STJ

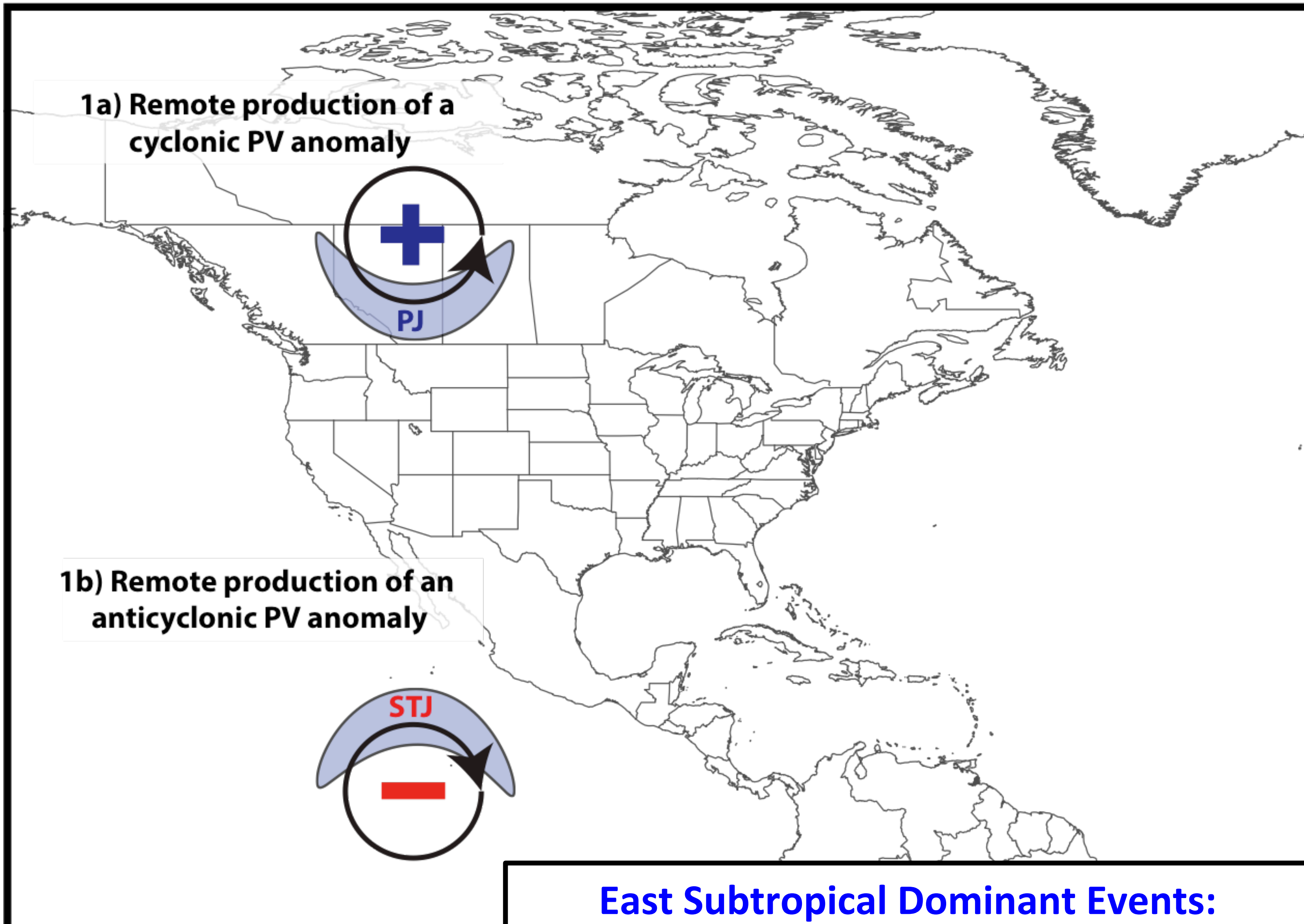
Summary

Polar Dominant Events:

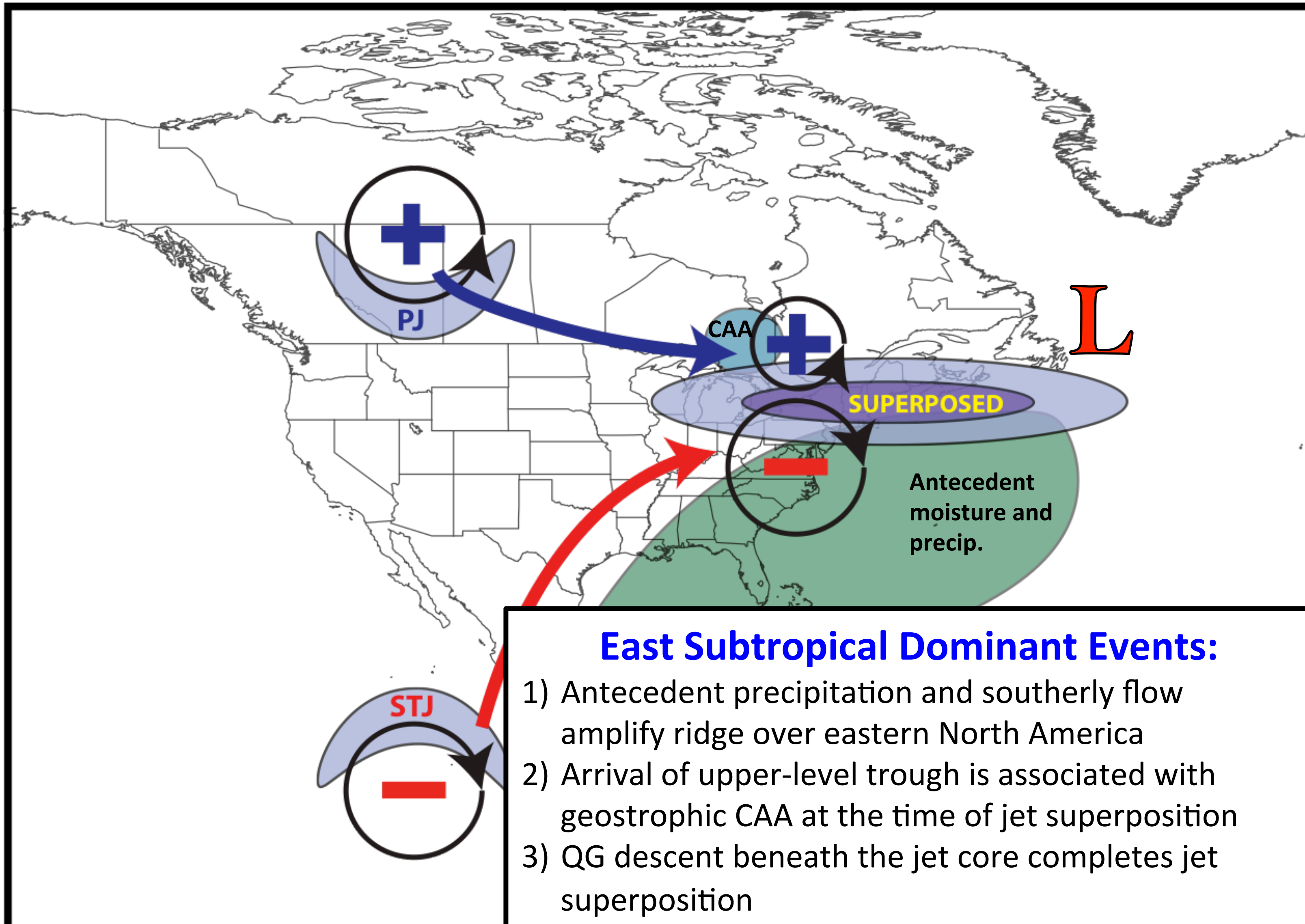
1) Anticyclonic wave breaking event amplifies the flow over North America
2) QG descent beneath the jet core facilitates jet superposition
3) Downstream precipitation slows the propagation of the upper-level trough



Summary


1a) Remote production of a cyclonic PV anomaly
PJ
1b) Remote production of an anticyclonic PV anomaly
STJ
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) QG descent beneath the jet core completes jet superposition

Future Work

- Examine the impact that each type of jet superposition event has on the evolution of the downstream large-scale flow pattern.
- Decipher the relationship between each type of jet superposition and the development of high-impact weather.
- Utilize numerical simulations of jet superposition events to examine the sensitivity of jet superposition to diabatic processes.
- Examine the frequency and characteristics of jet superposition events within future climate scenarios.

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Supplementary Slides

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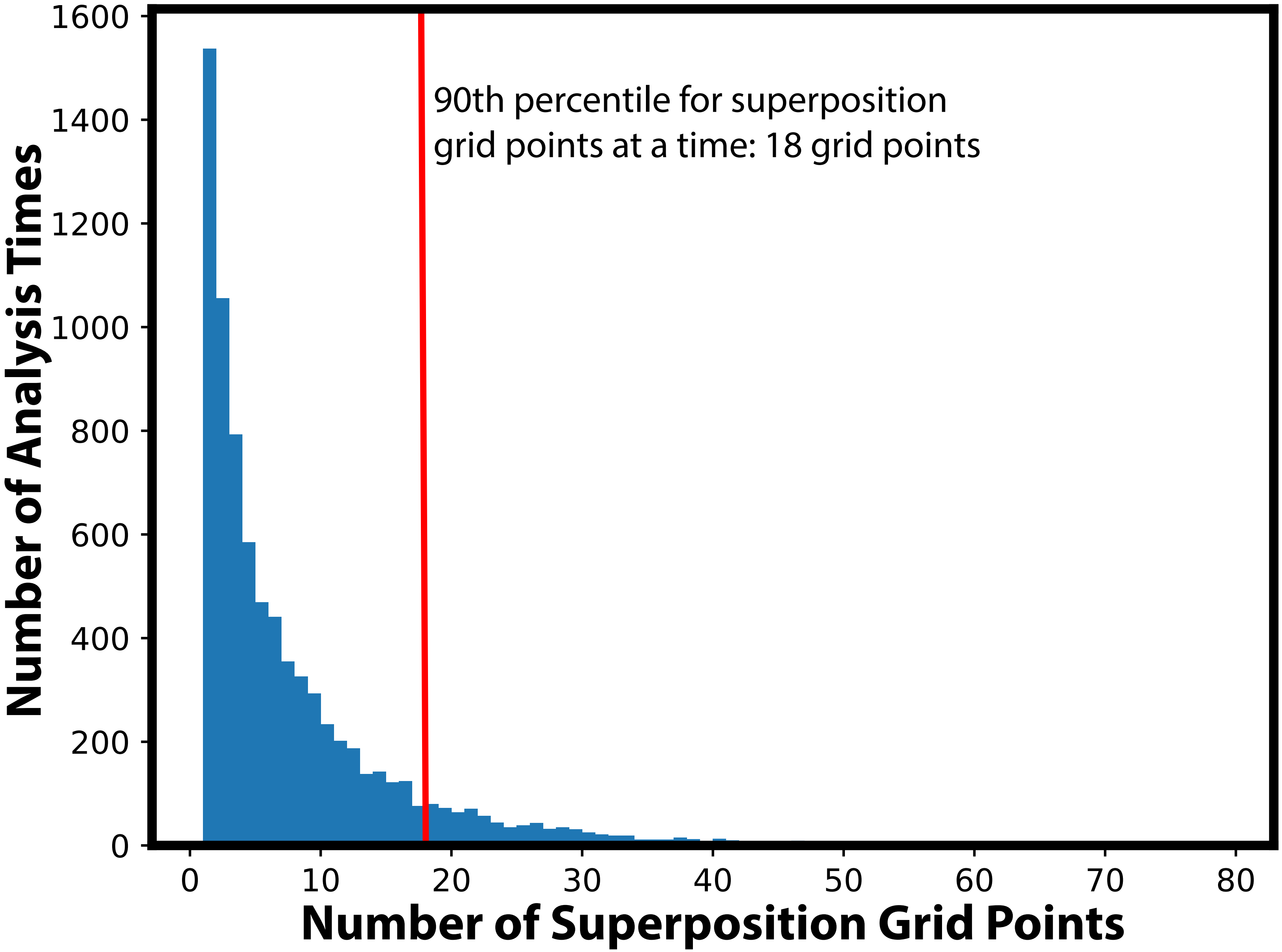
Jet Superposition Event Identification

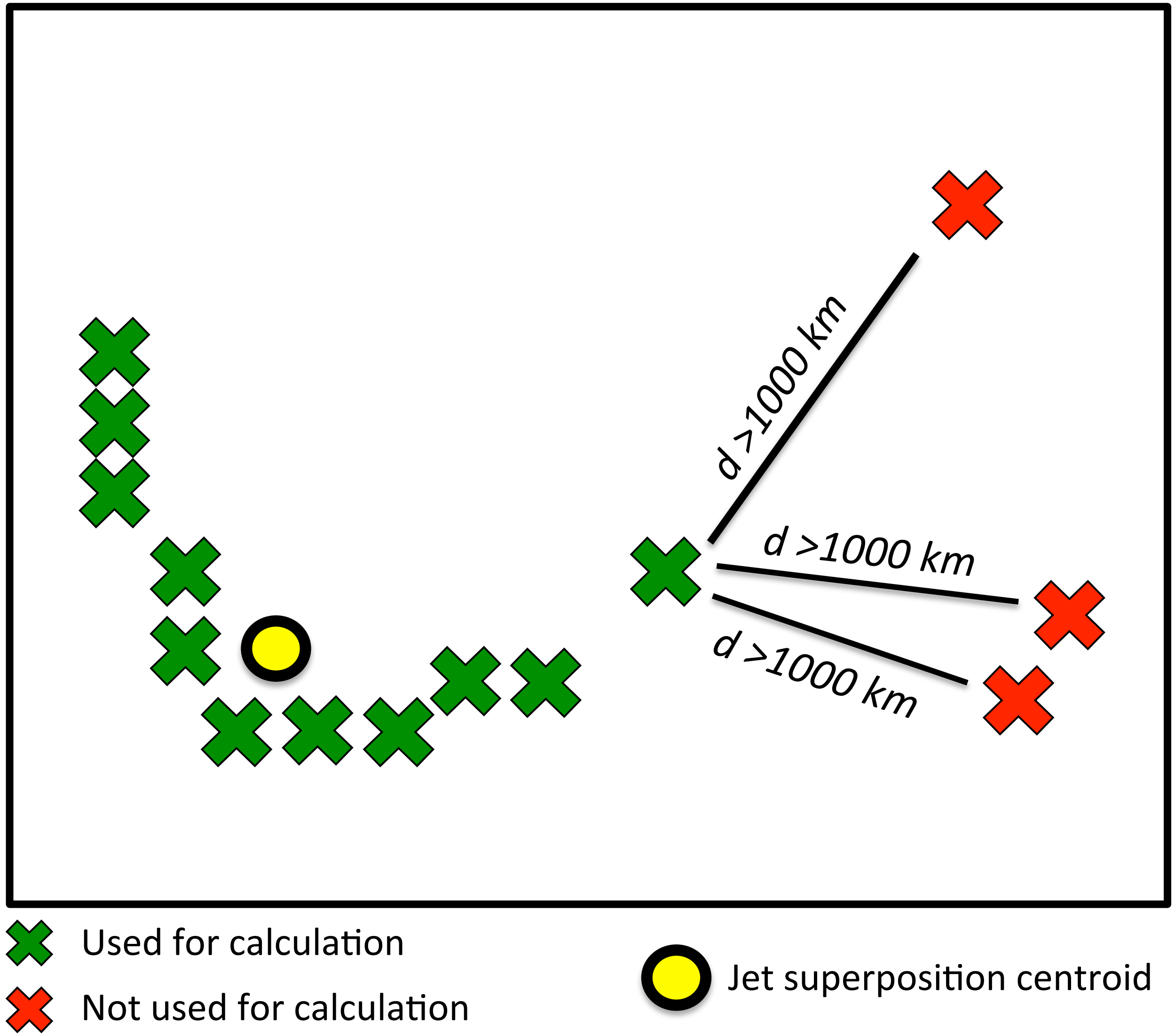


Jet Superposition Event Identification

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

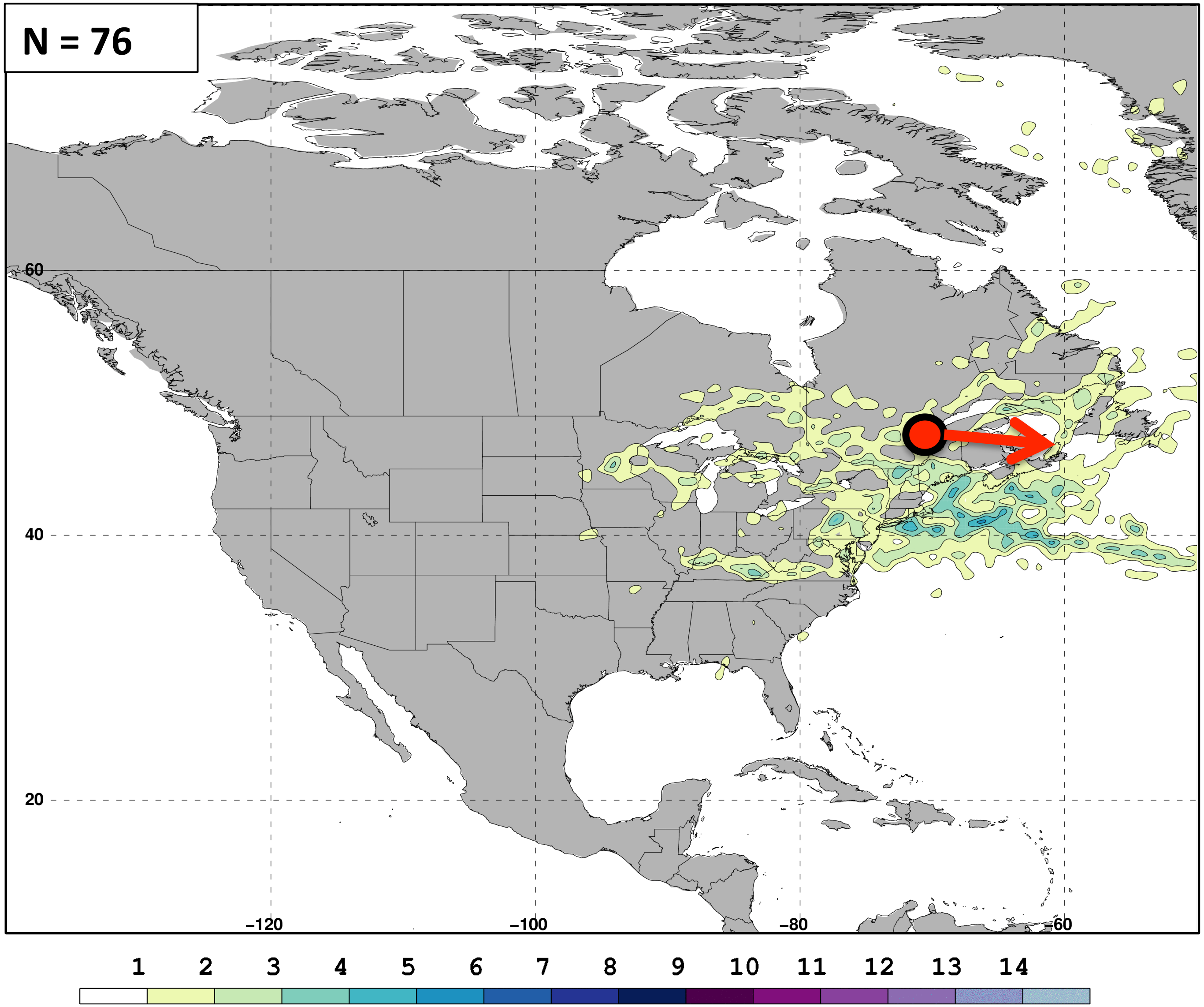
To calculate the centroid, there must exist a group of 18 superposition grid points, of which no superposition grid point is >1000 km away from another superposition grid point.

Sample Jet Superposition Centroid Calculation



Jet Superposition Event Identification

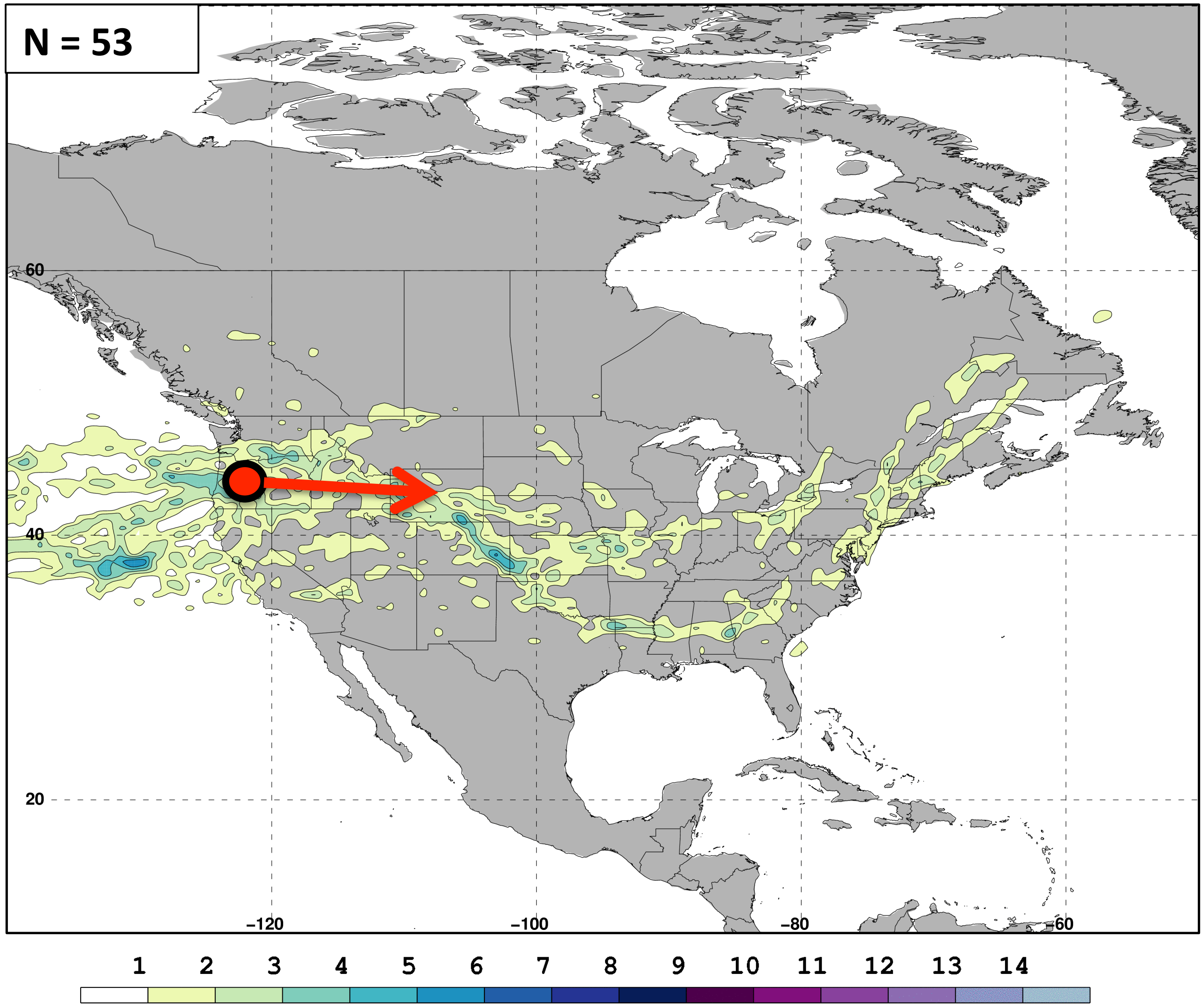
Frequency of East Subtropical Dominant Jet Superposition Events



Legend
Centroid of all events
Composite movement of superposition

Jet Superposition Event Identification

Frequency of West Subtropical Dominant Jet Superposition Events

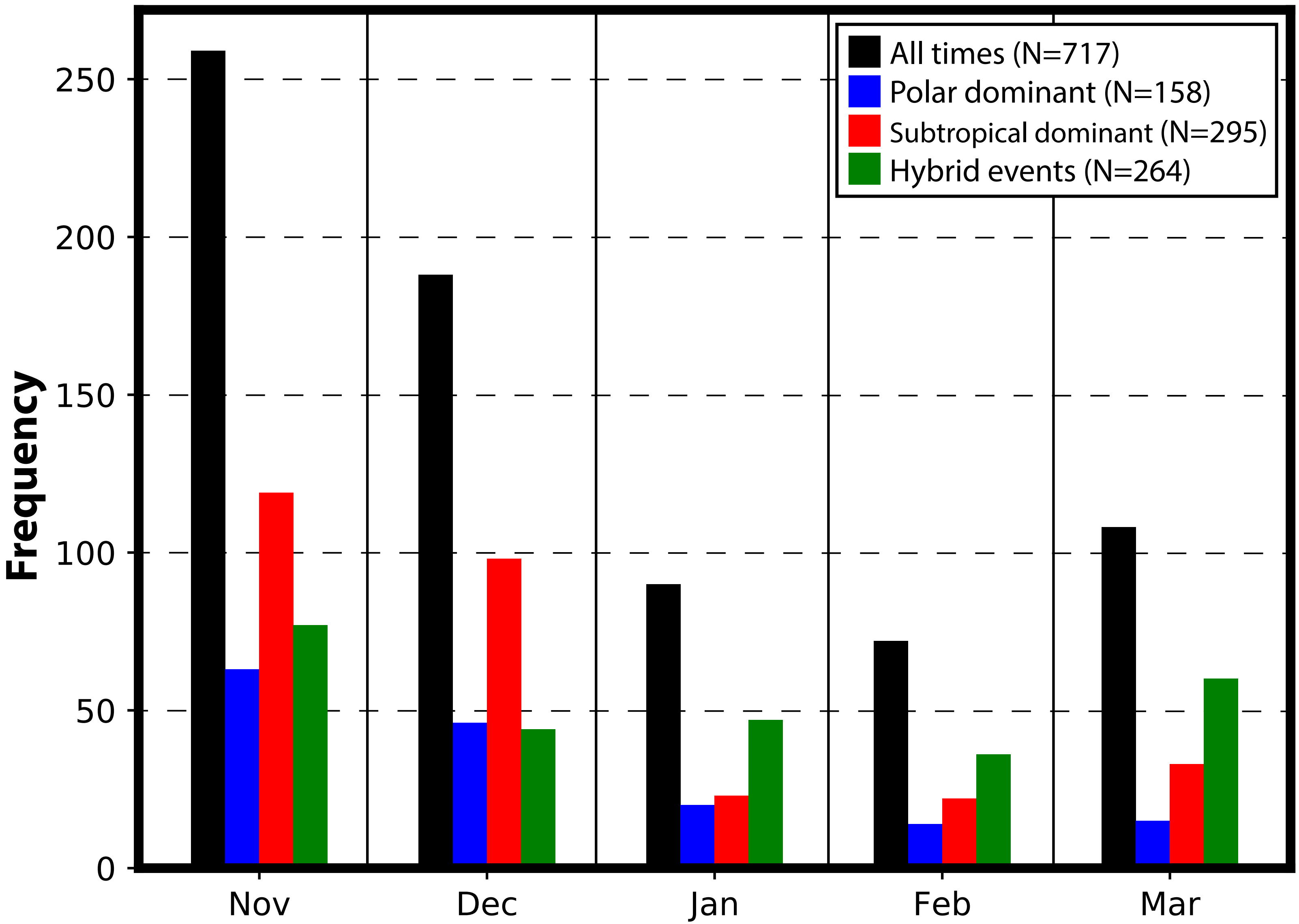


Legend

Centroid of all events

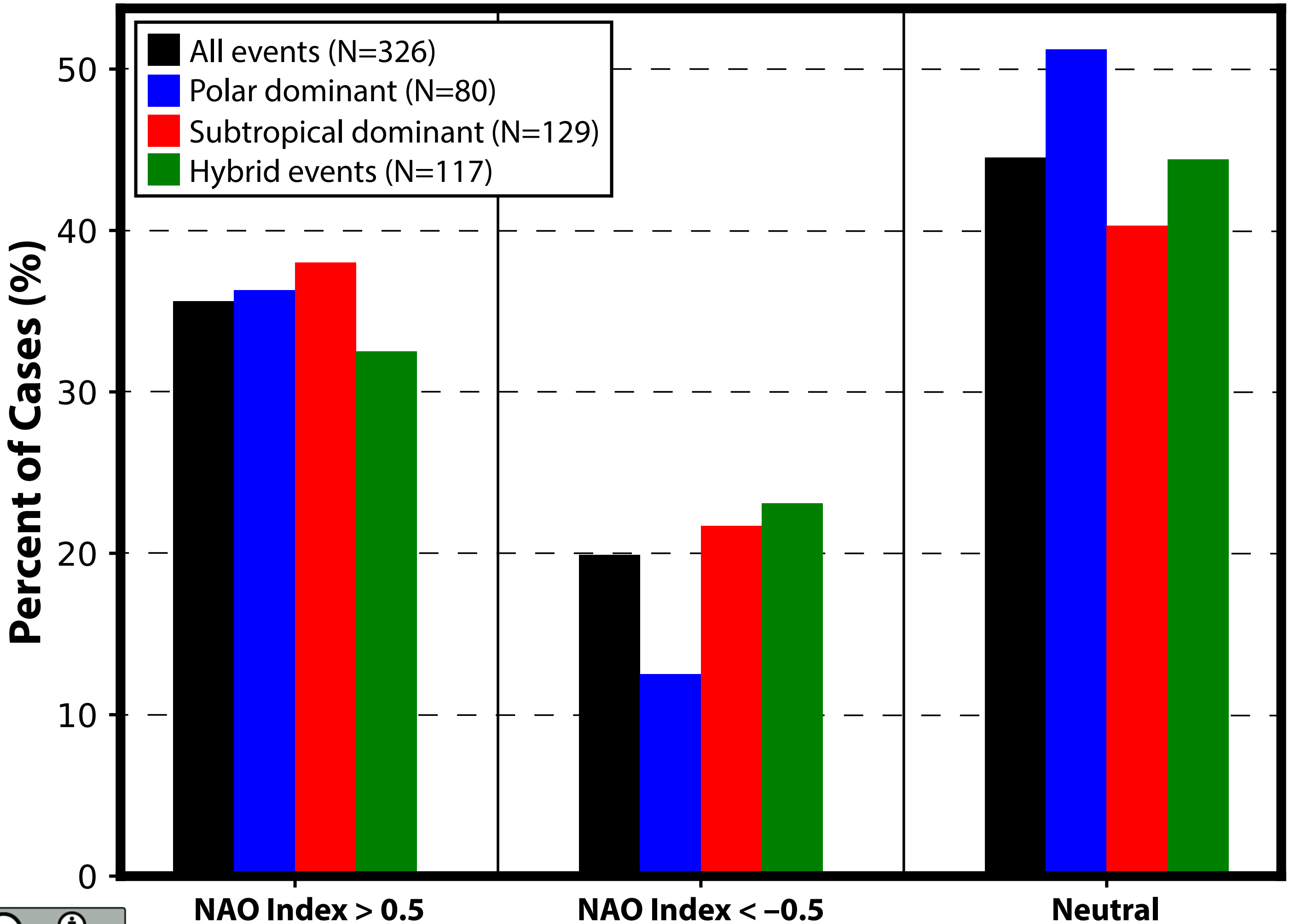
Composite movement of superposition

Jet Superposition Event Classification



Downstream Consequences

North Atlantic Oscillation: 5 Days After Jet Superposition



All Events ΔNAO
+0.11

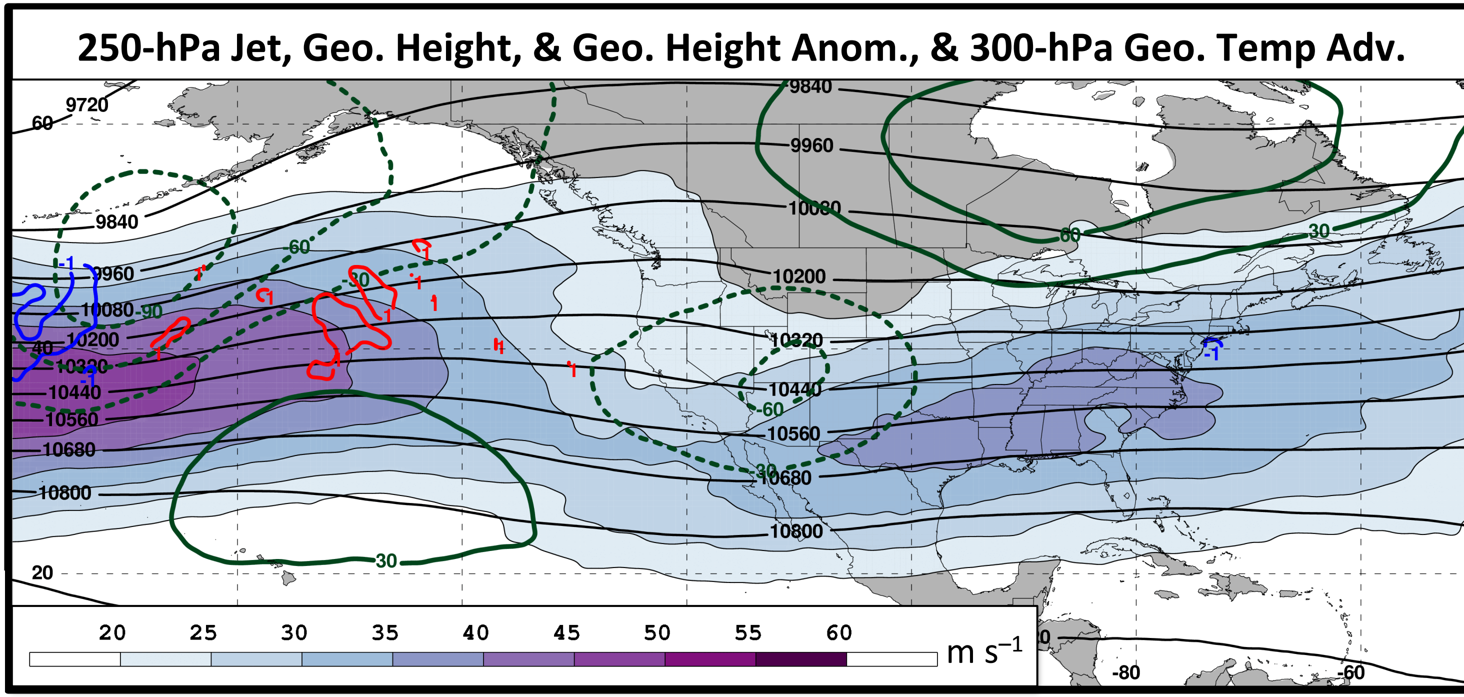
Ave. Polar Dominant ΔNAO
+0.15

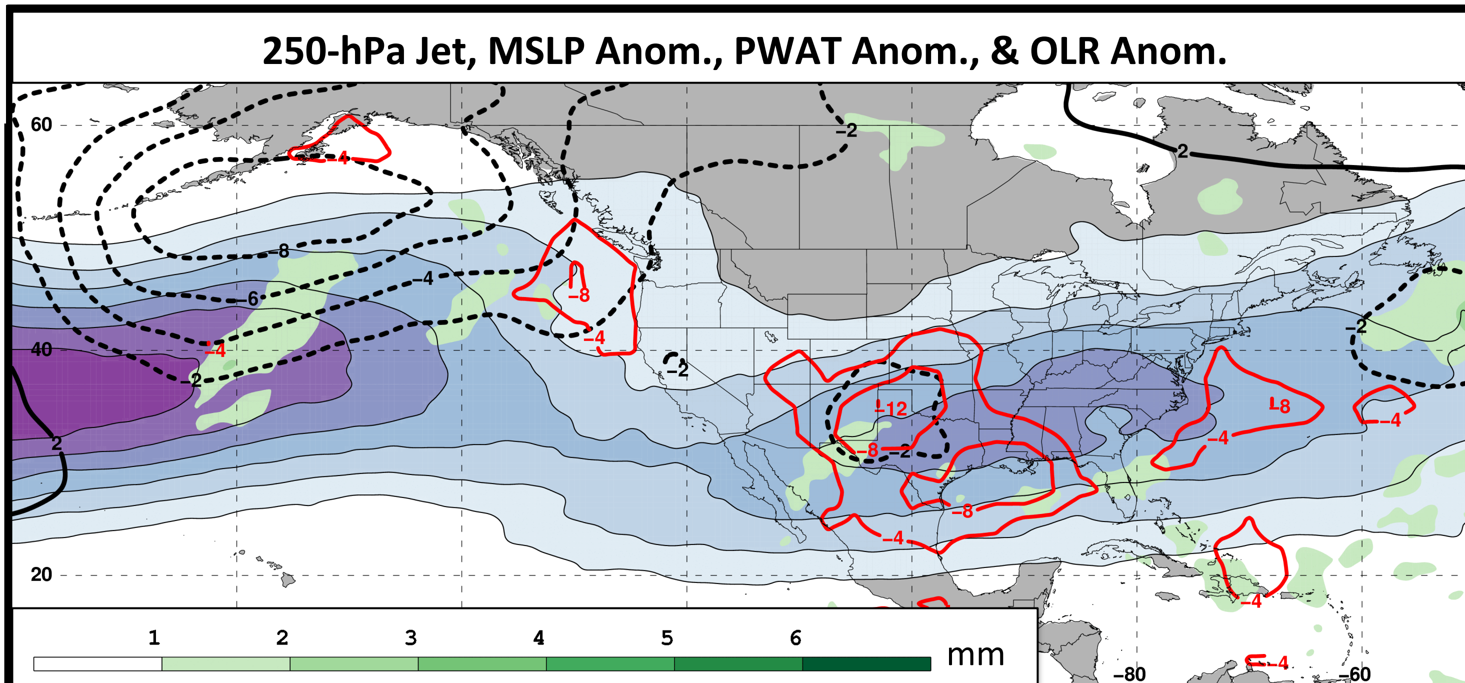
Ave. Subtropical Dominant ΔNAO
+0.13

Ave. Hybrid ΔNAO
+0.07

Polar Dominant Jet Superposition Events

3 Days Prior to Jet Superposition

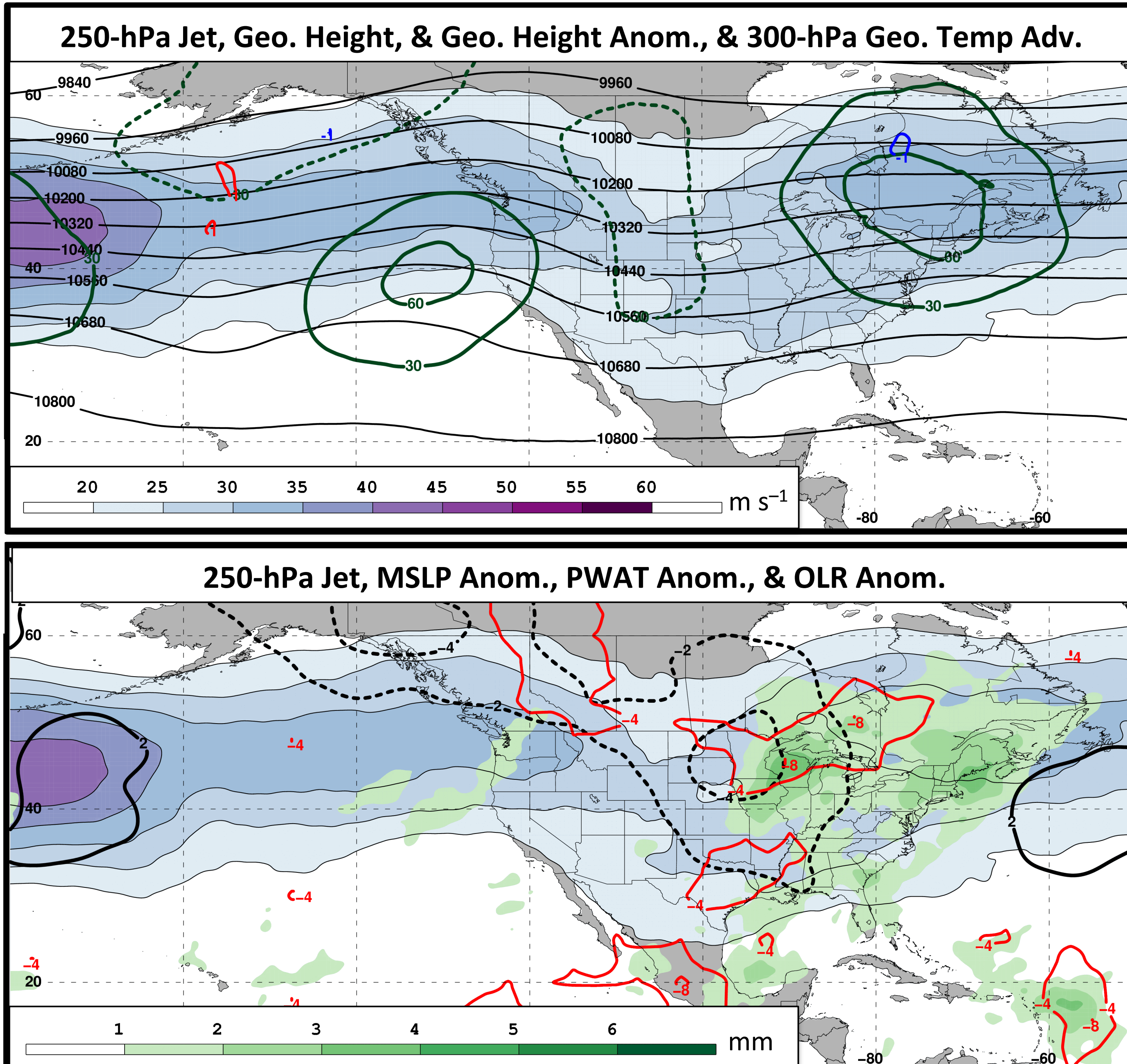




N=80

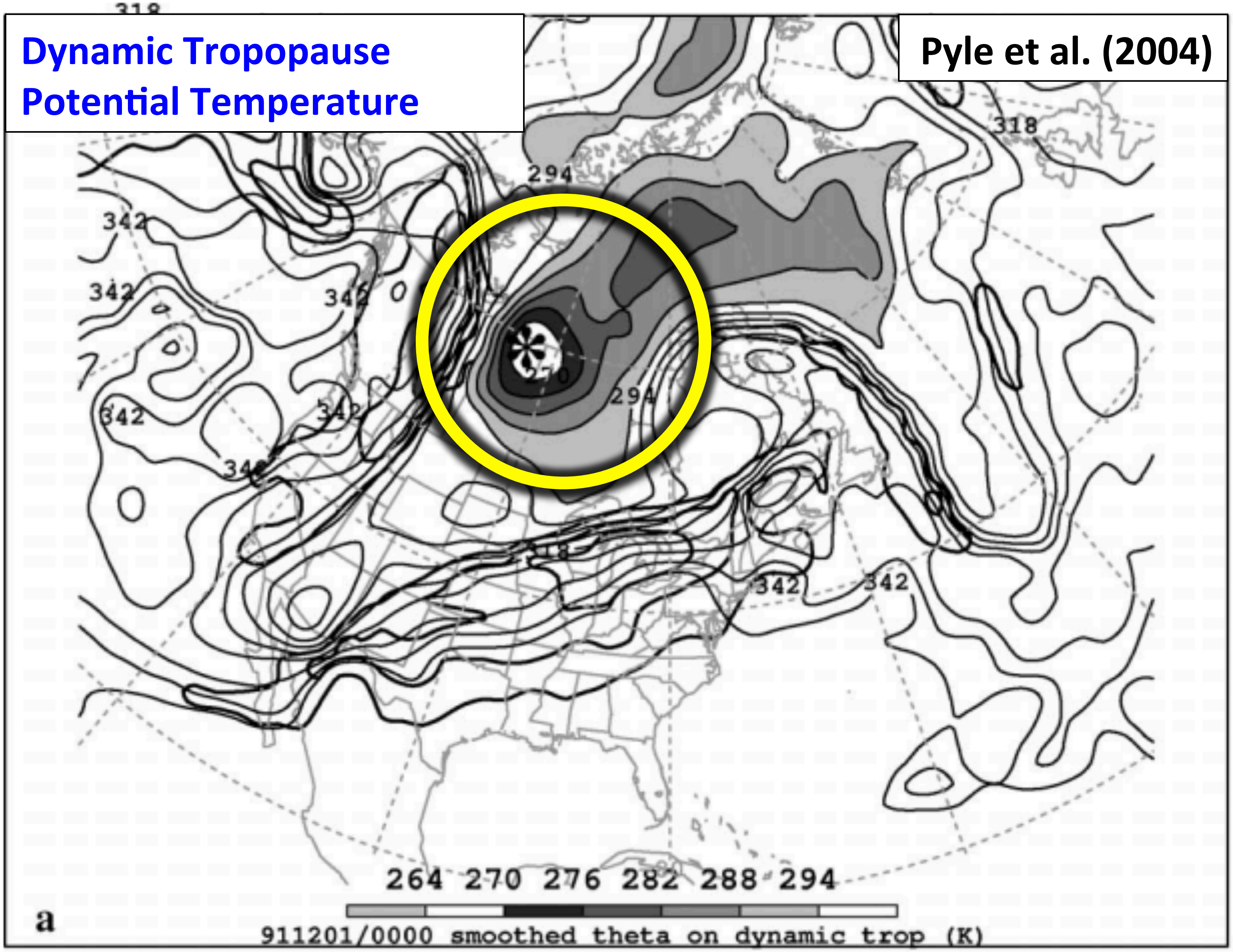
E. Subtropical Dominant Jet Superposition Events

3 Days Prior to Jet Superposition

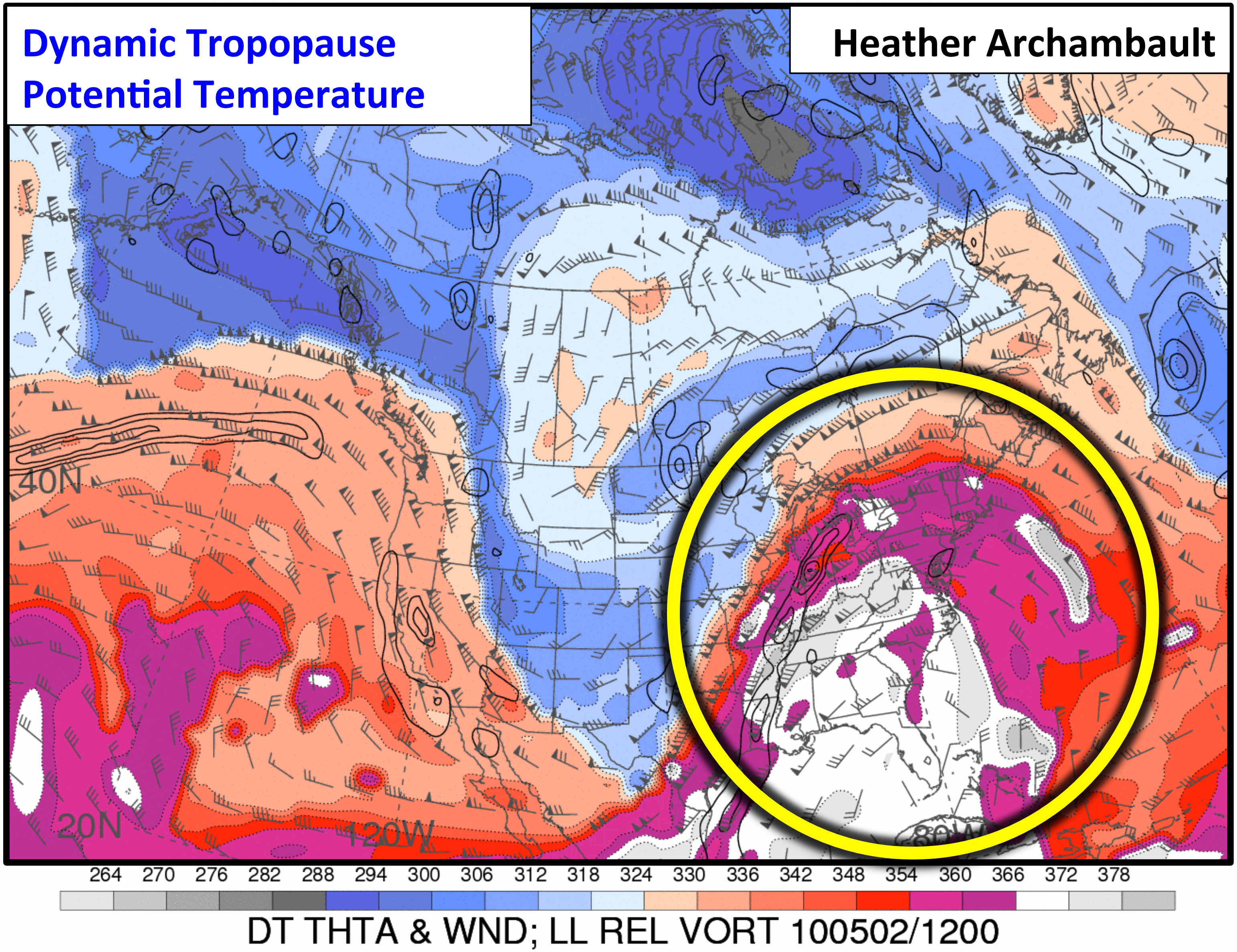


N=76

Jet Superposition Conceptual Model



Jet Superposition Conceptual Model

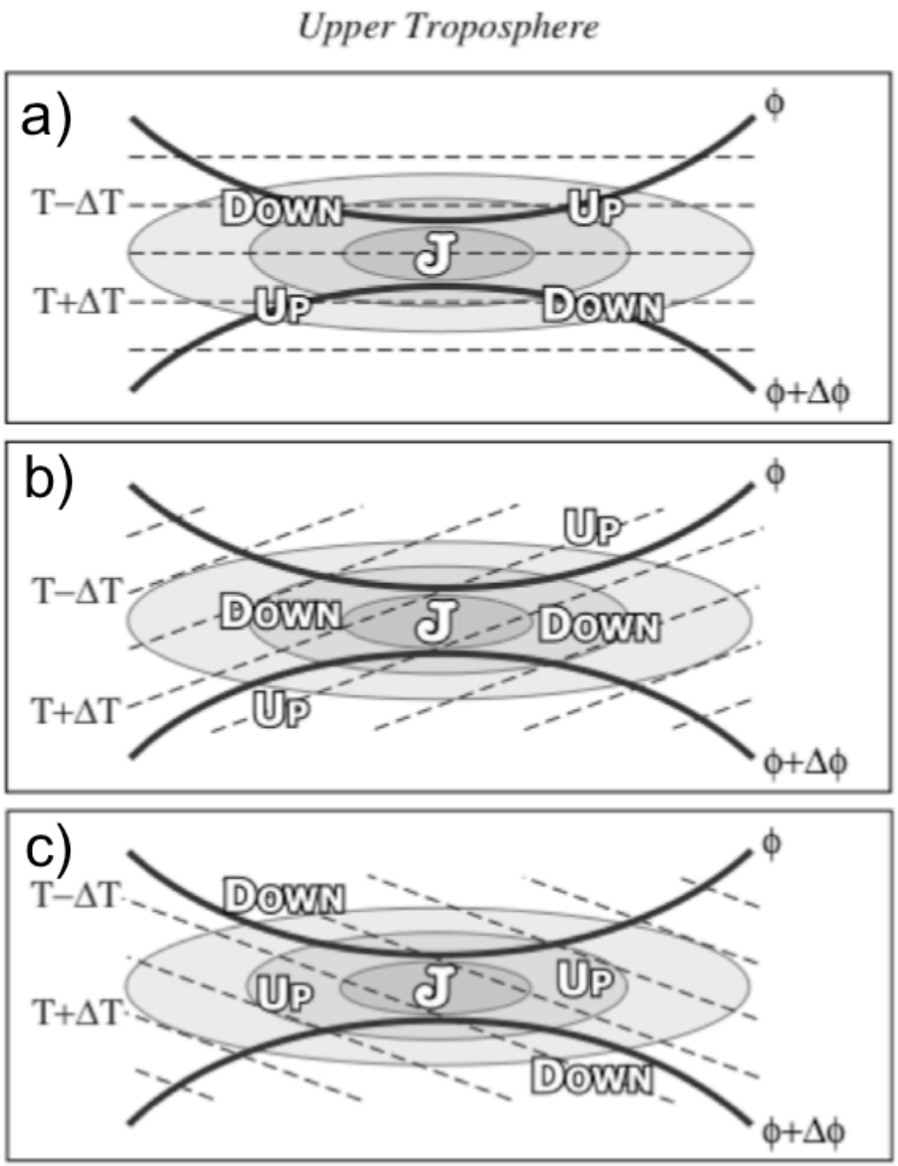


Ageostrophic Transverse Jet Circulations

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)

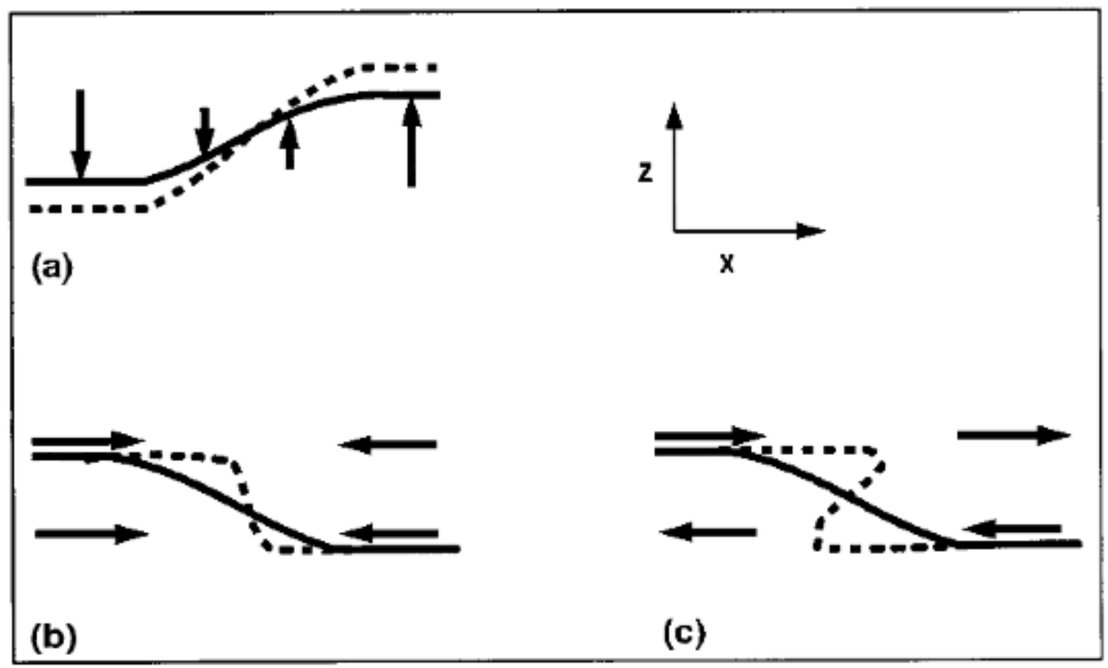
Background

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 <u>vertically steepen</u> the tropopause.

2) **Convergence** or a **vertical shear** can produce a <u>differential horizontal advection</u> 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)

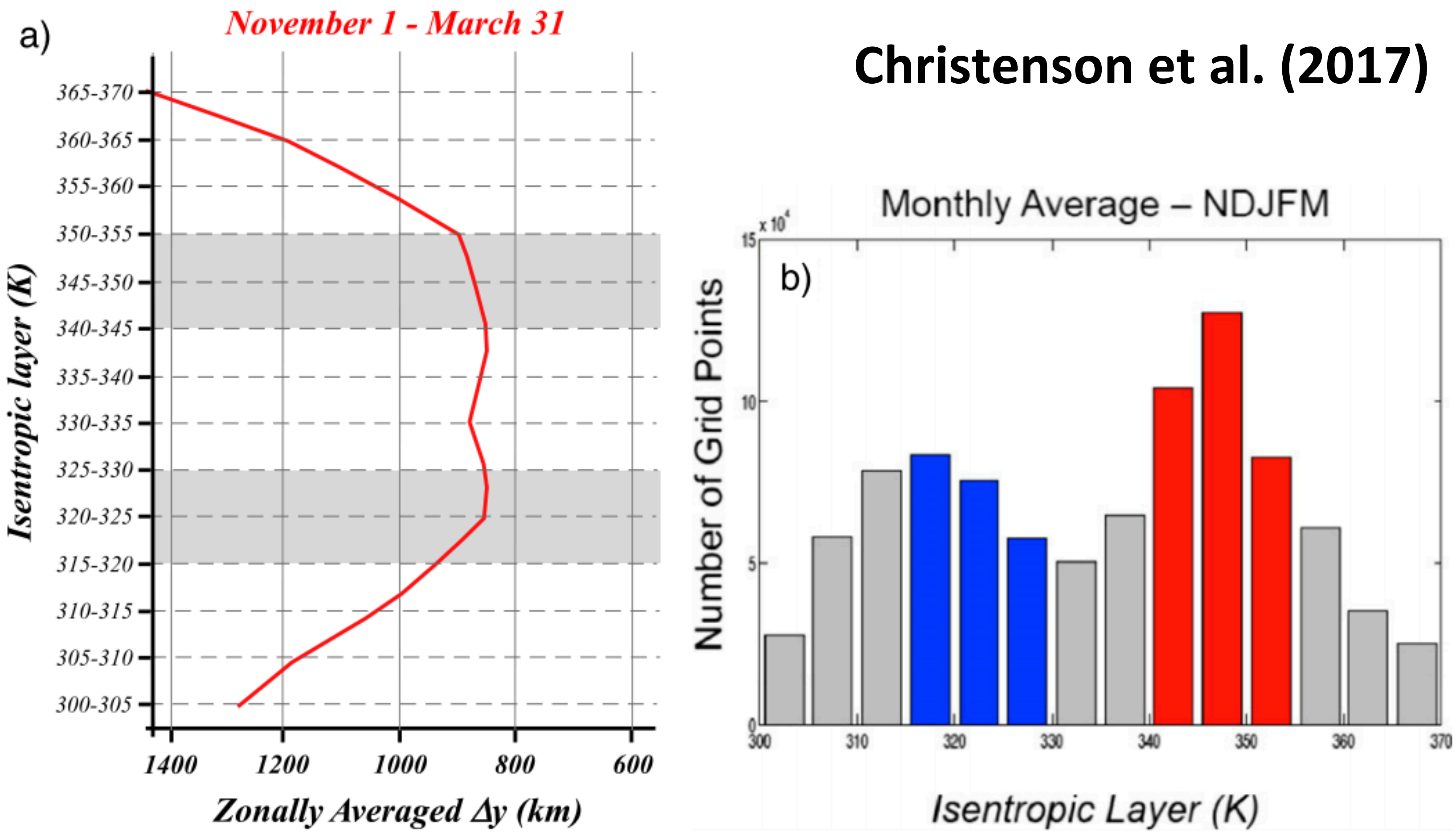


FIG. 2. (a) Cold season average of zonally averaged Δ*y* (km) for 5-K isentropic layers ranging from 300–305 to 365–370 K. The 315–330- and 340–355-K layers are highlighted in light gray shading. (b) The average frequency of occurrence of grid points with a maximum wind speed value within the 5-K isentropic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