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

Andrew C. Winters
School of Earth and Atmospheric Sciences
Georgia Institute of Technology
Atlanta, GA

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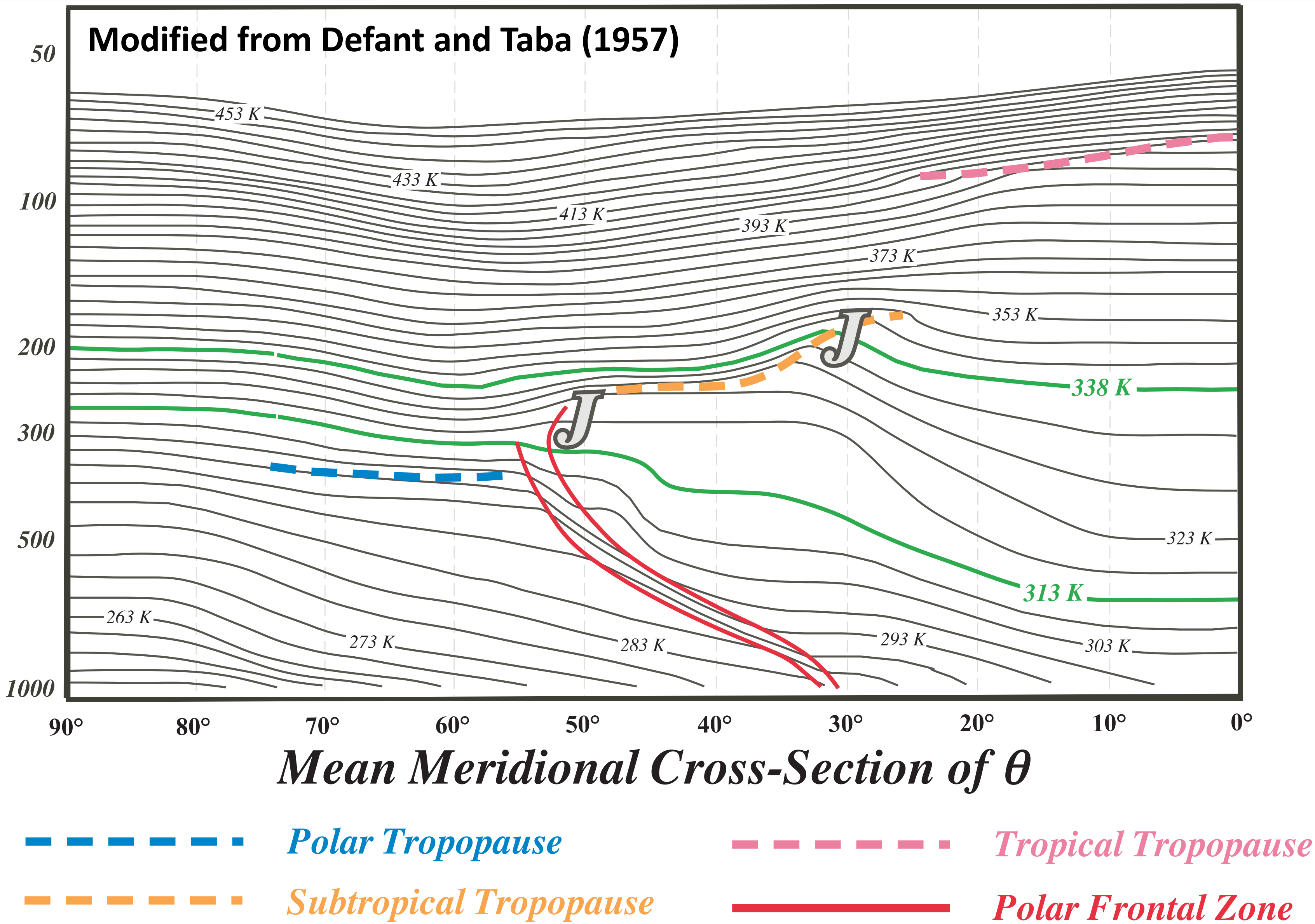
Background


Modified from Defant and Taba (1957)
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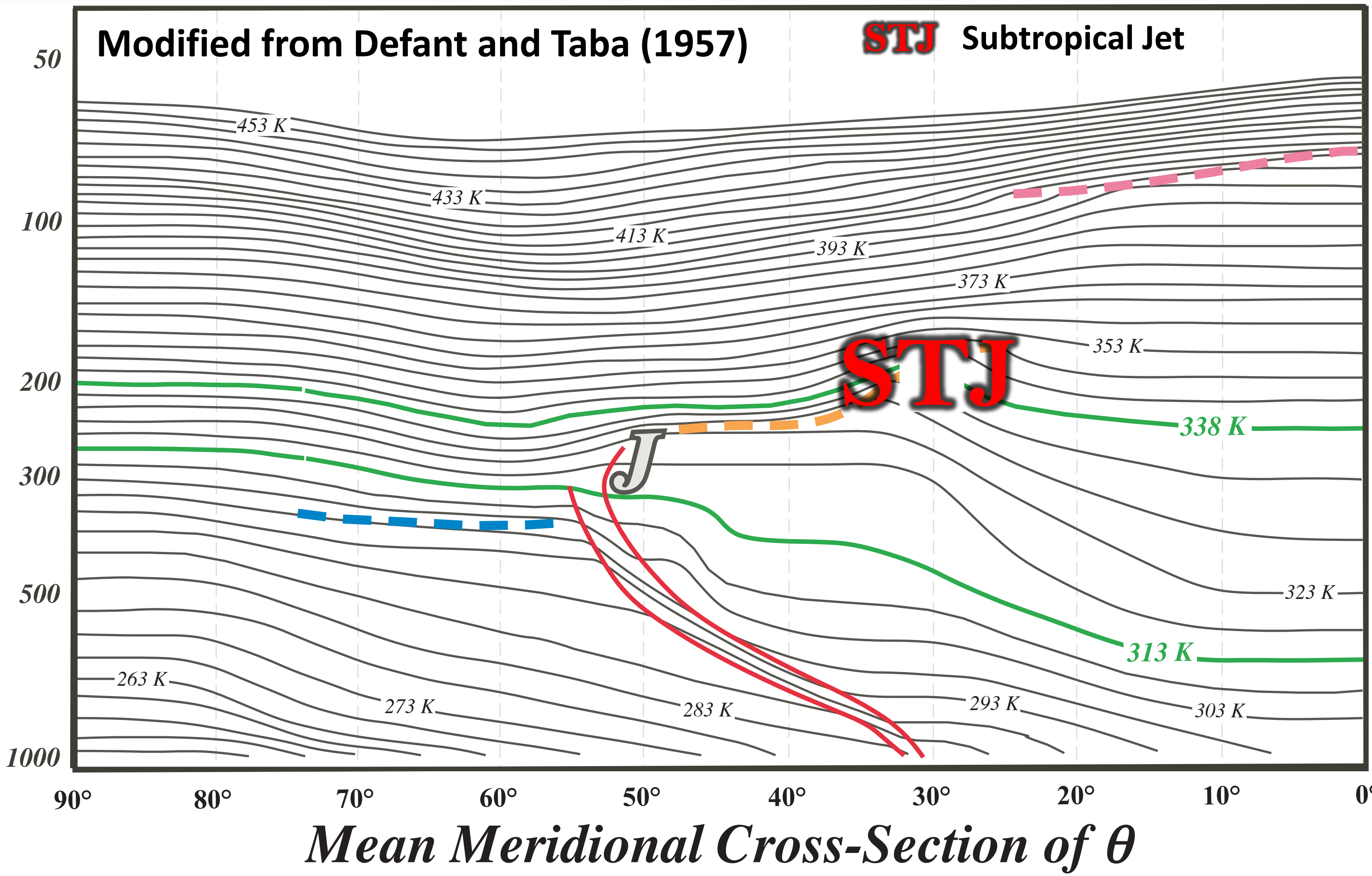
Mean Meridional Cross-Section of θ
Polar Tropopause
Tropical Tropopause
Subtropical Tropopause
Polar Frontal Zone

Background



Polar Tropopause

Tropical Tropopause

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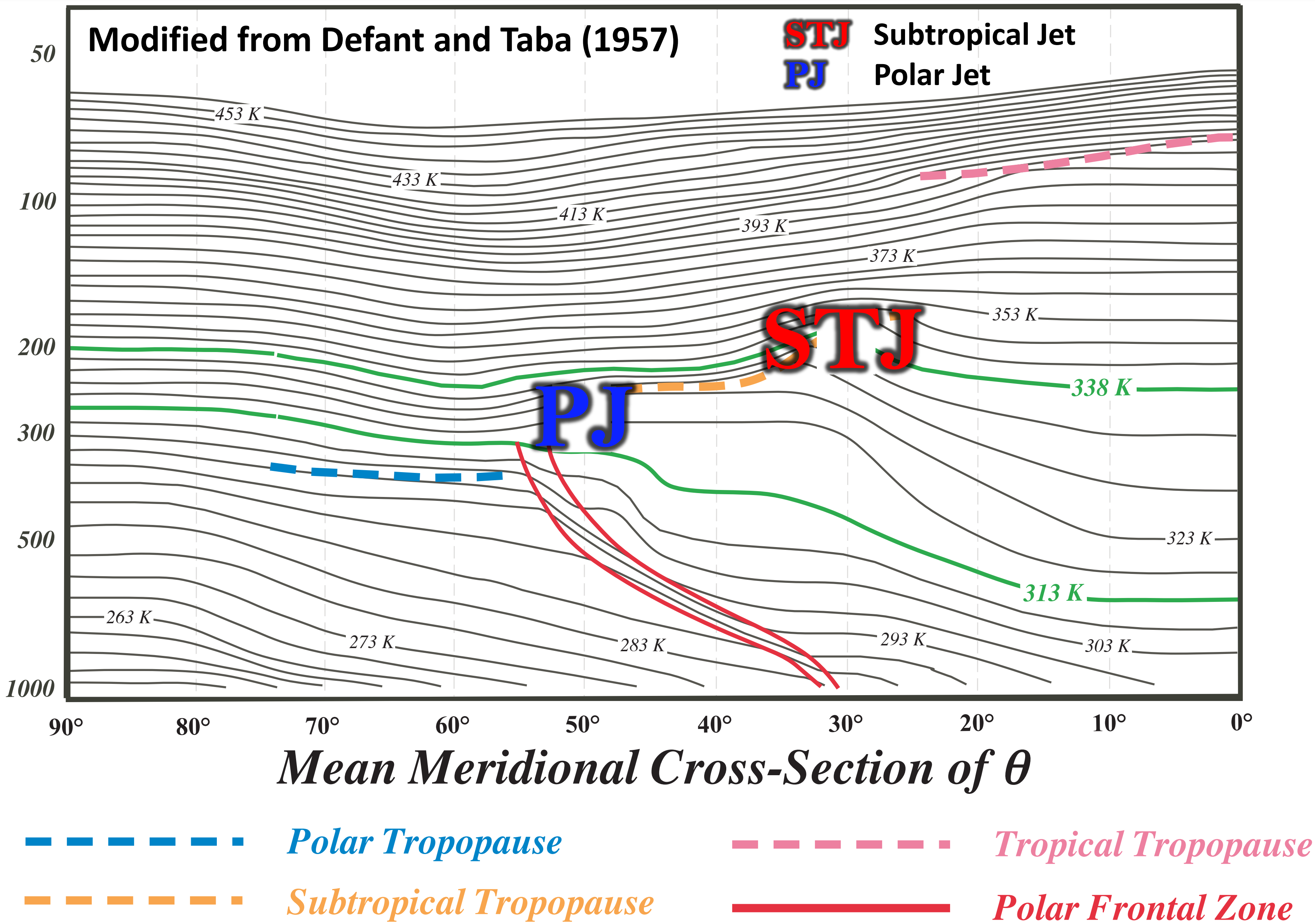

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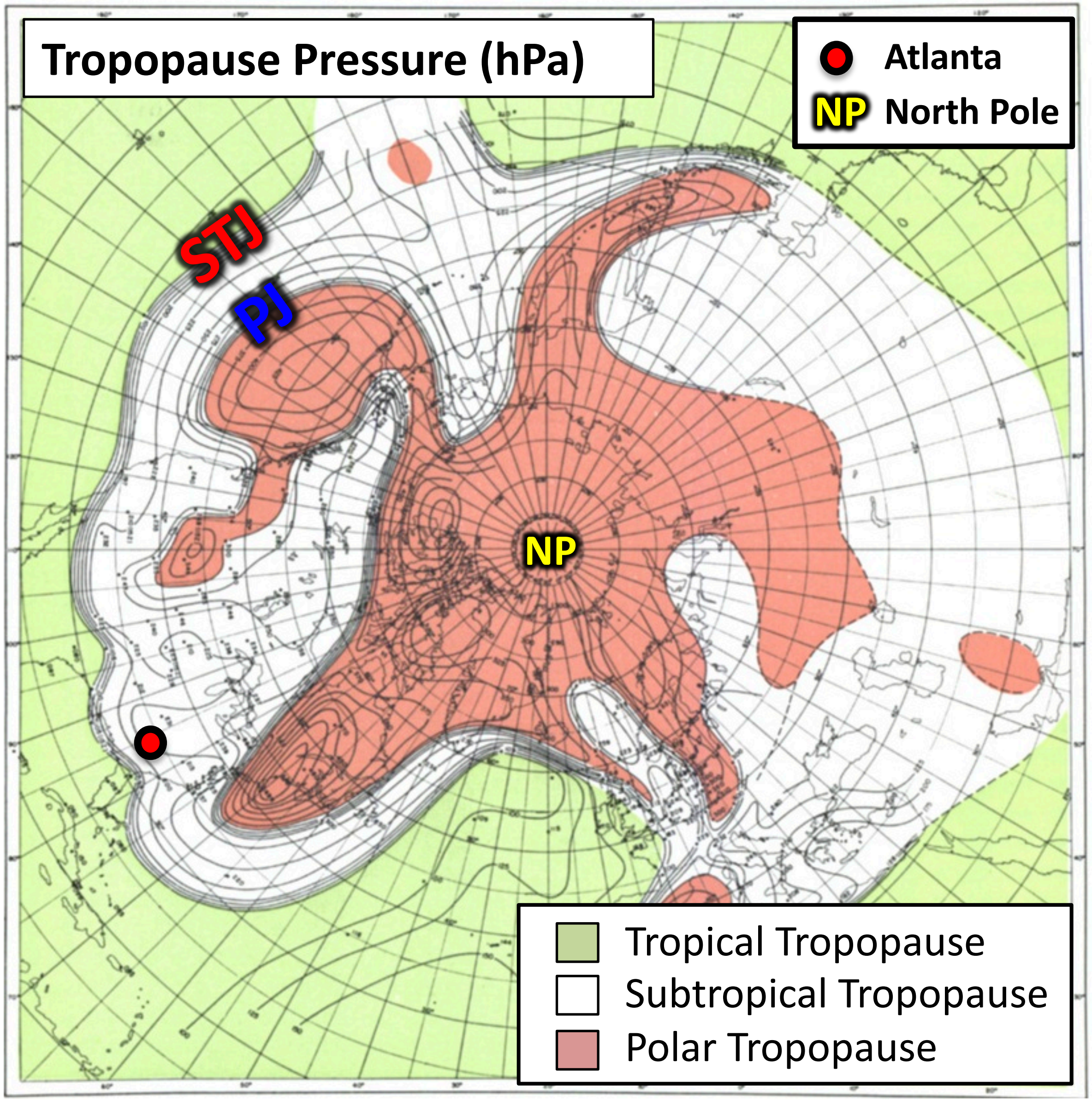

Maps of tropopause pressure help to identify the location of the jets.

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

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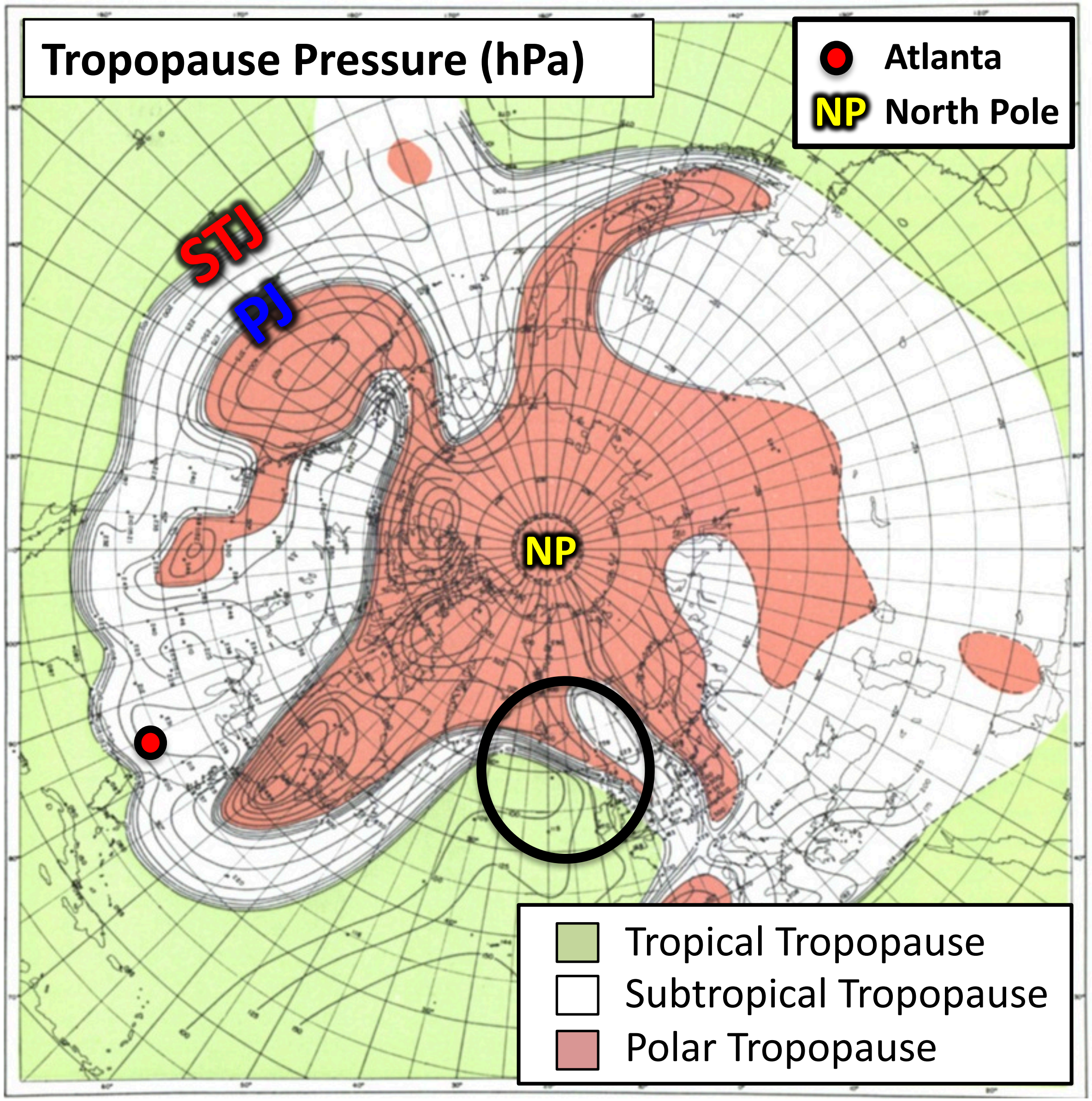

Maps of tropopause pressure help to identify the location of the jets.

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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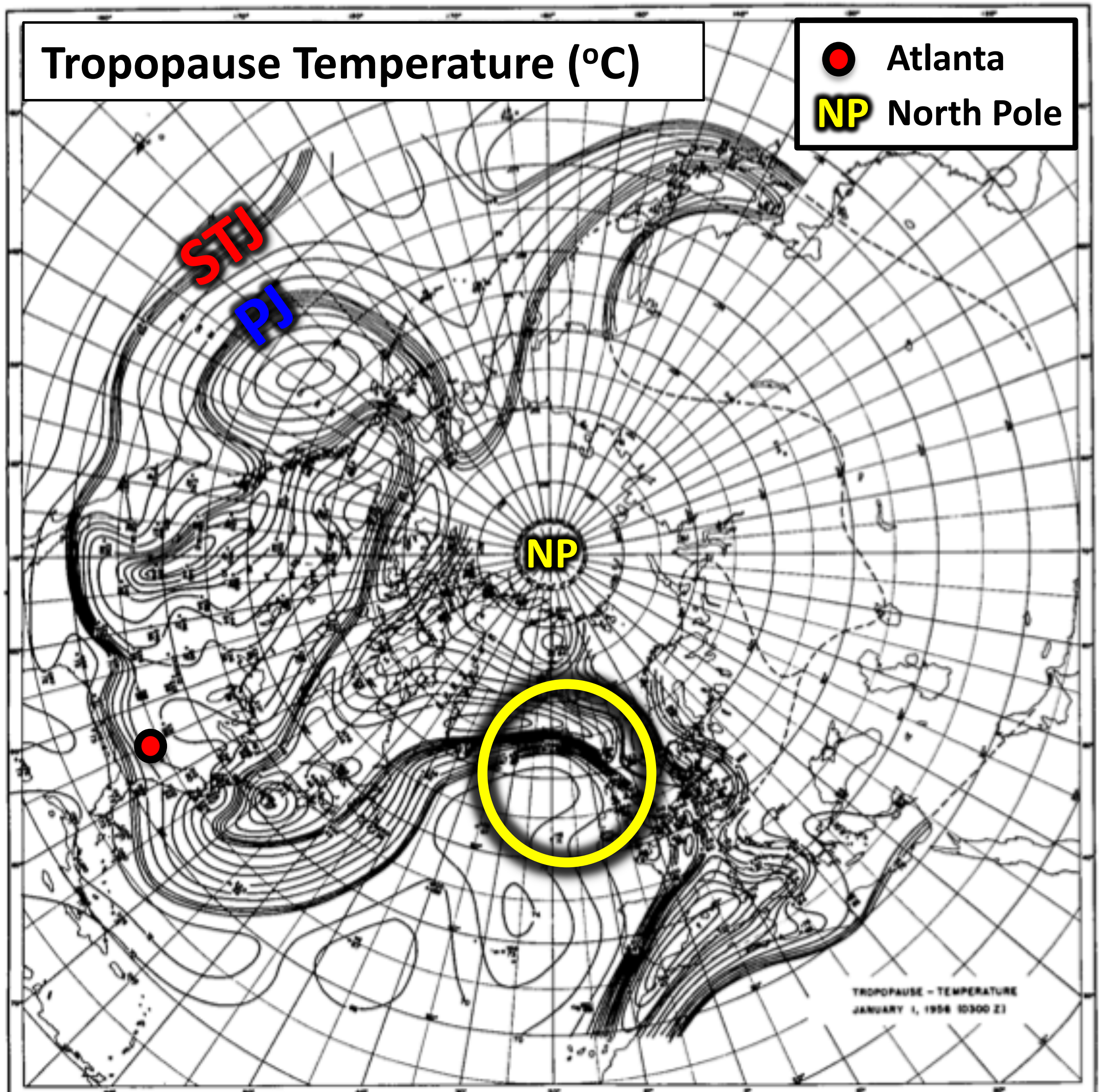
Background



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

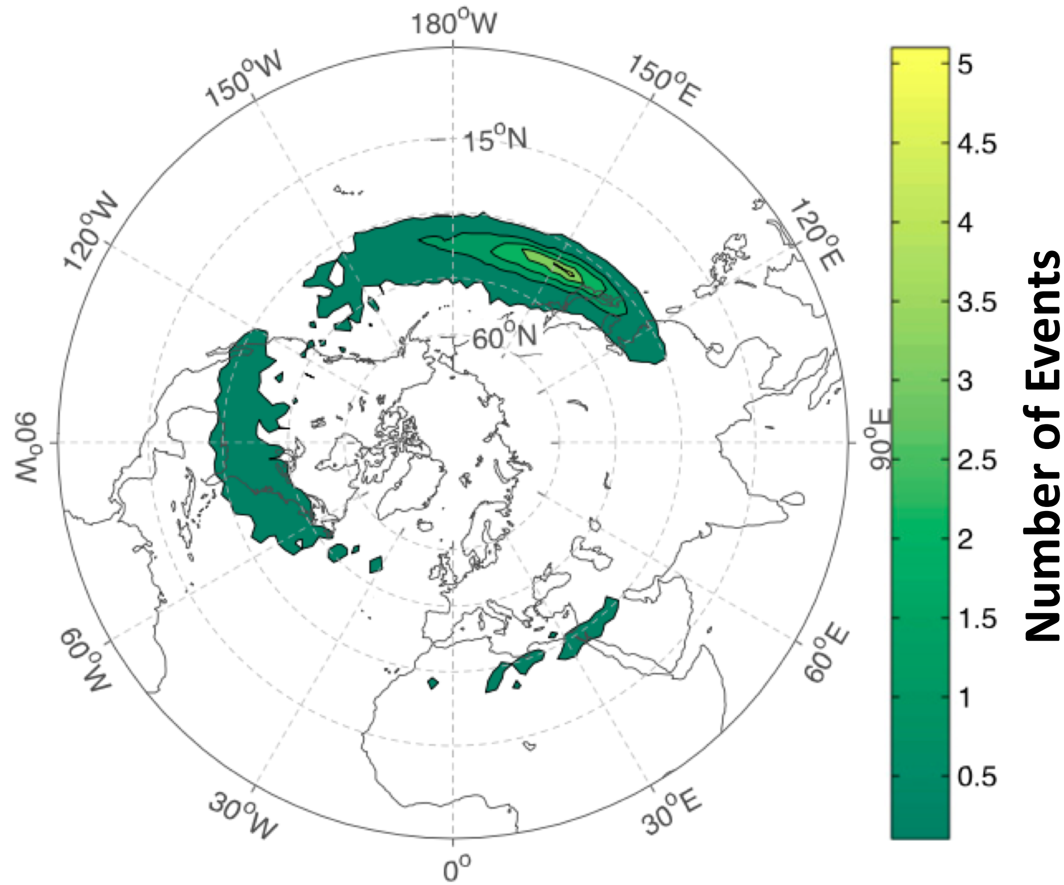
Christenson et al. (2017) highlight three locations that experience the greatest frequency of jet superpositions:

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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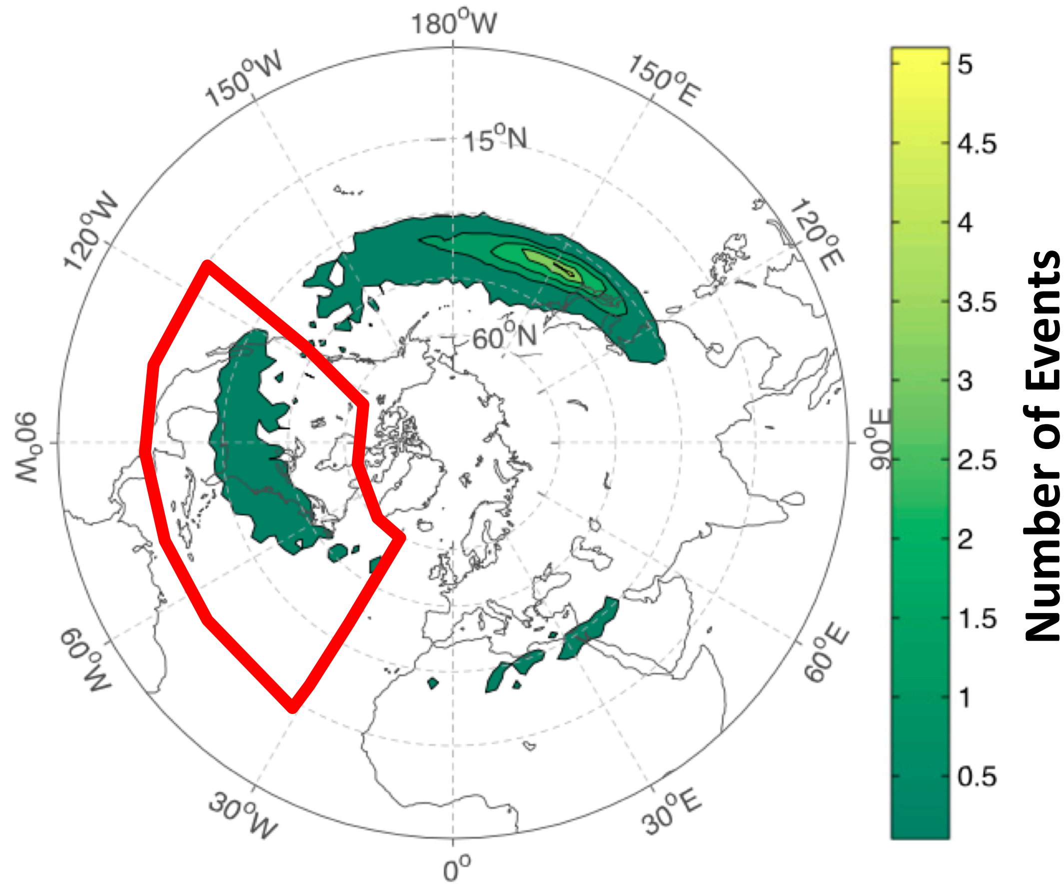
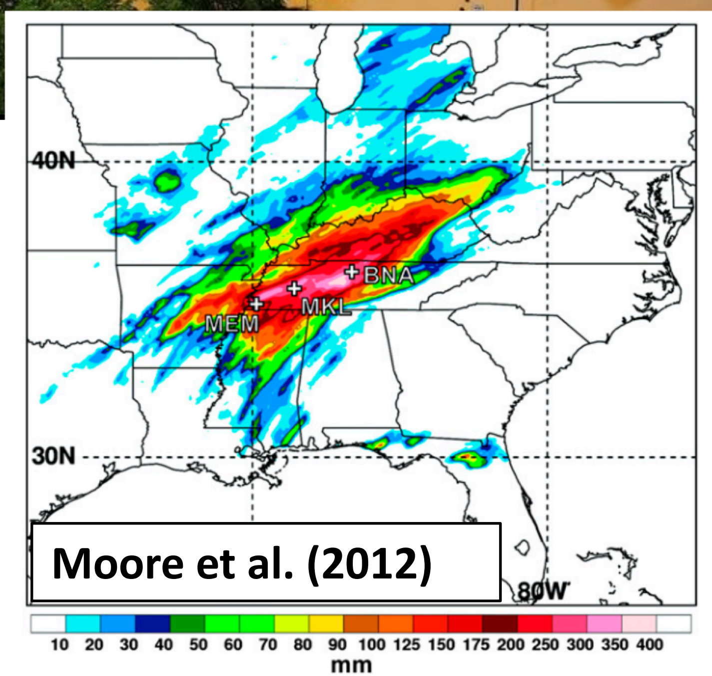


Christenson et al. (2017)

Jet Superpositions and High-Impact Weather

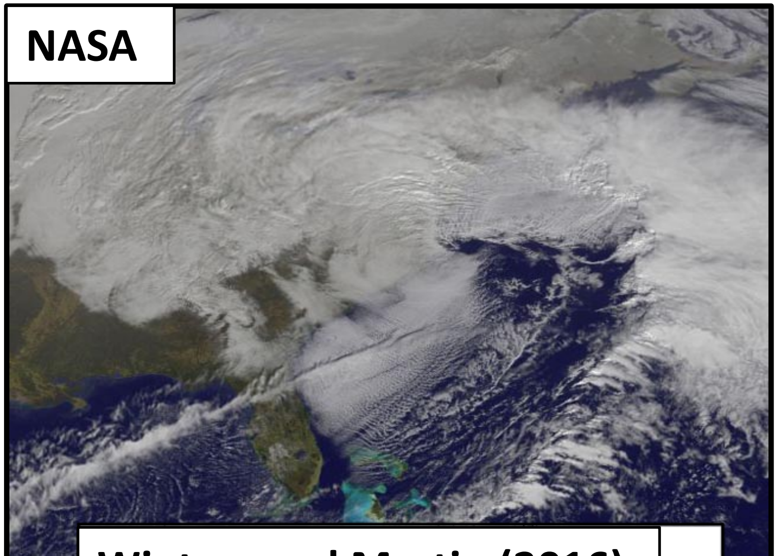


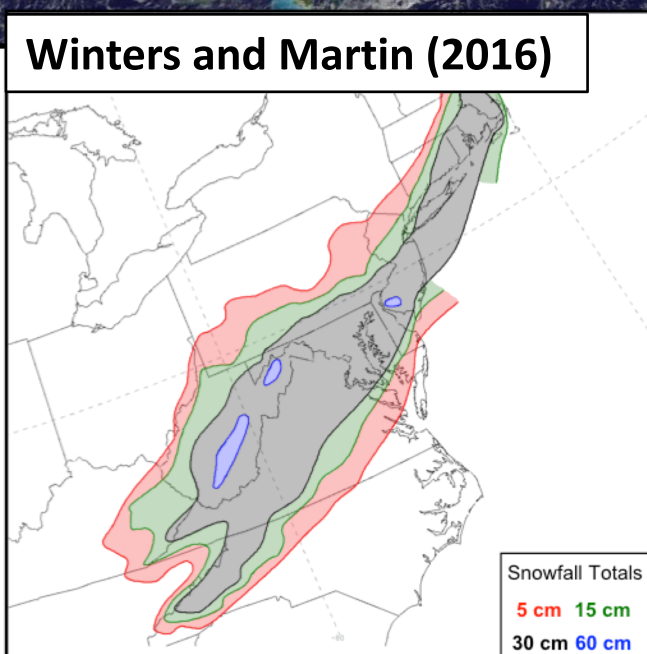
Jet superpositions can be an element of high-impact weather events

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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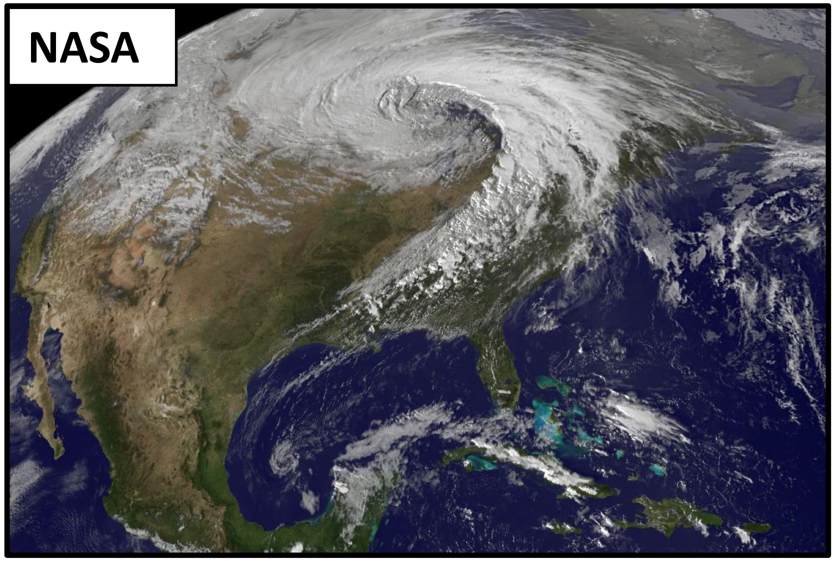
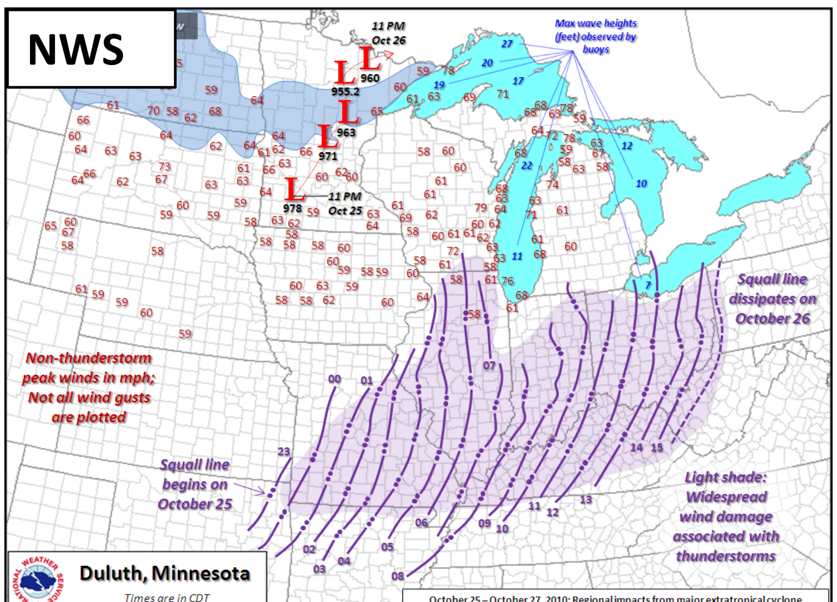
Jet Superpositions and High-Impact Weather





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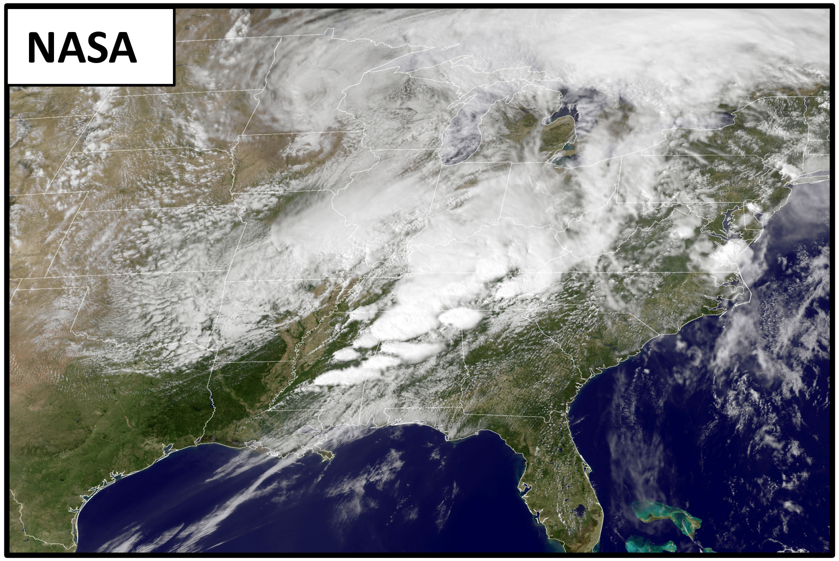
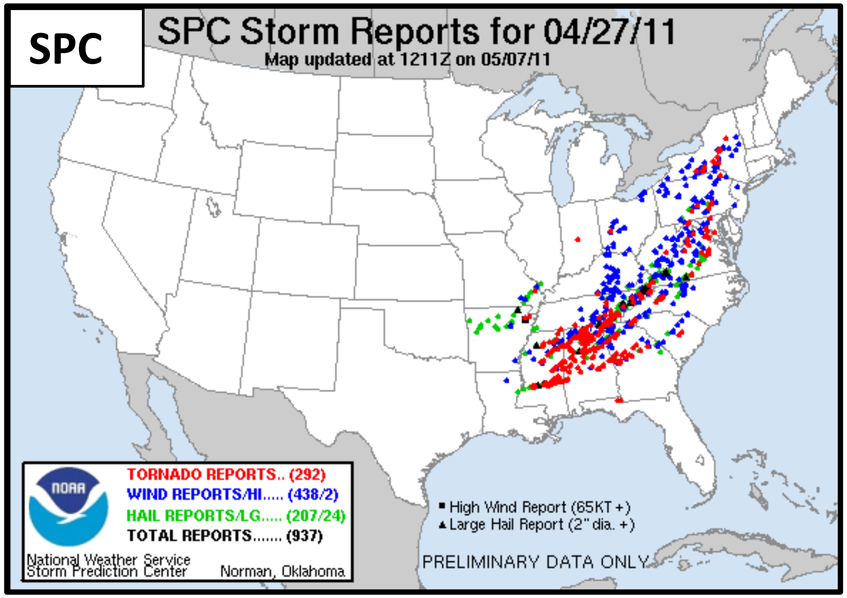
26 October 2010: Explosive Cyclogenesis Event

- 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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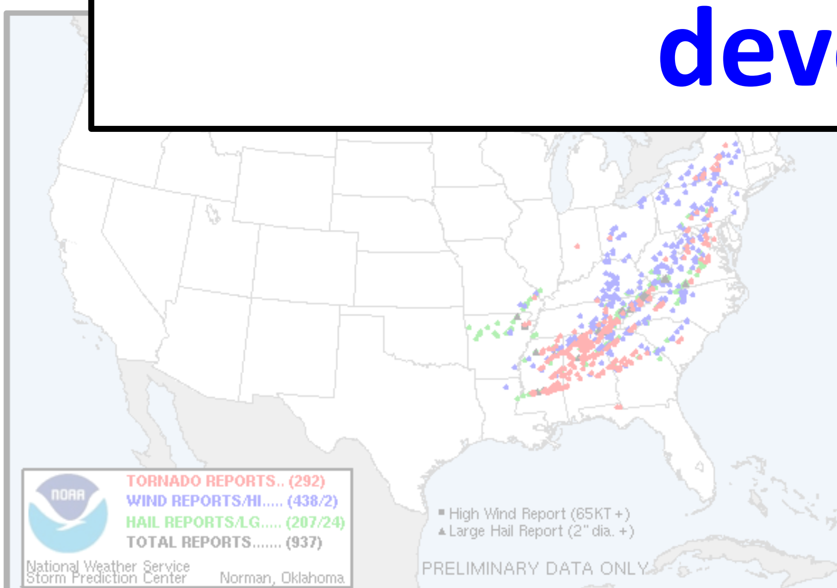
Jet Superpositions and High-Impact Weather



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

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How do these structures develop?

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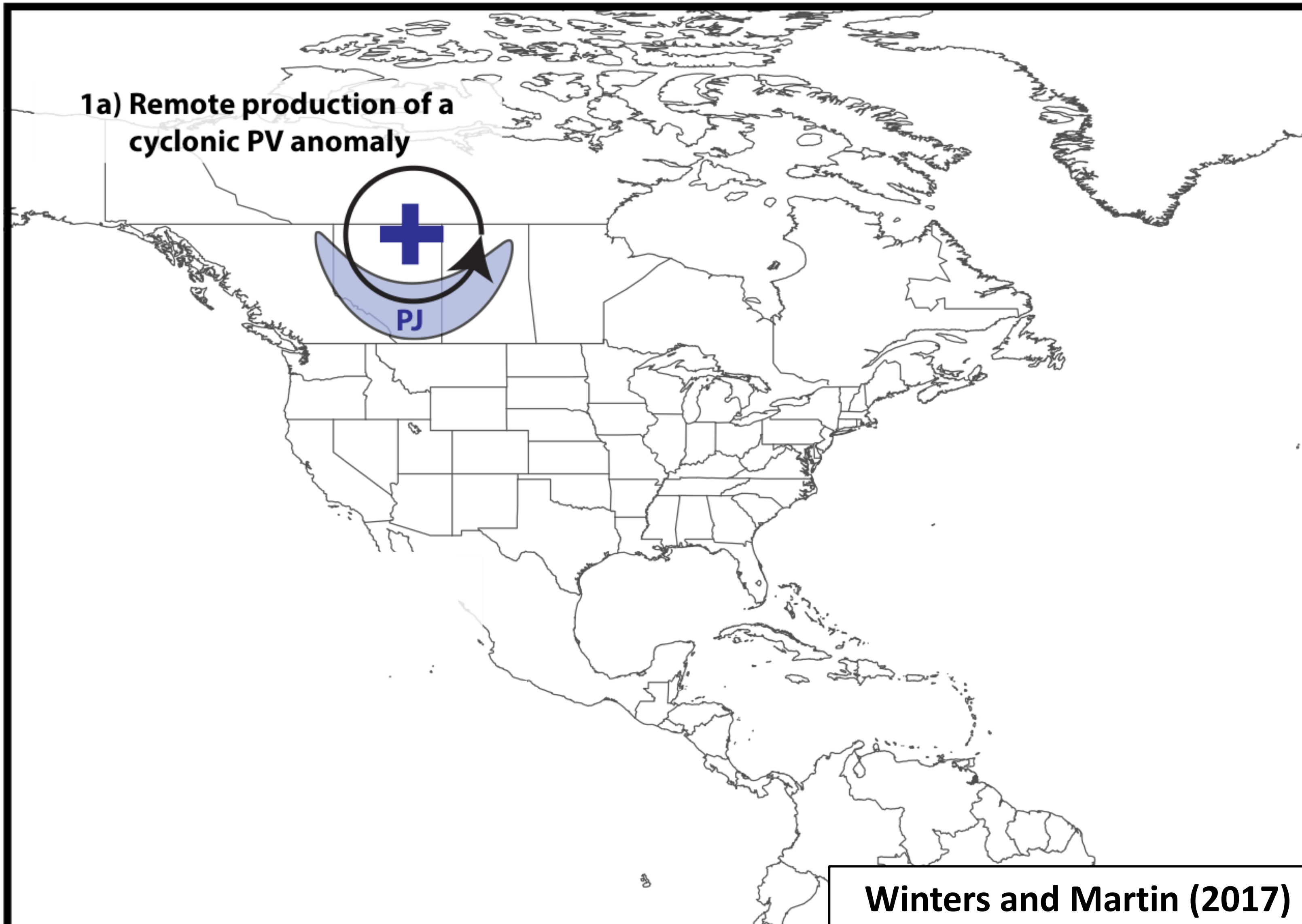
Jet Superposition Conceptual Model



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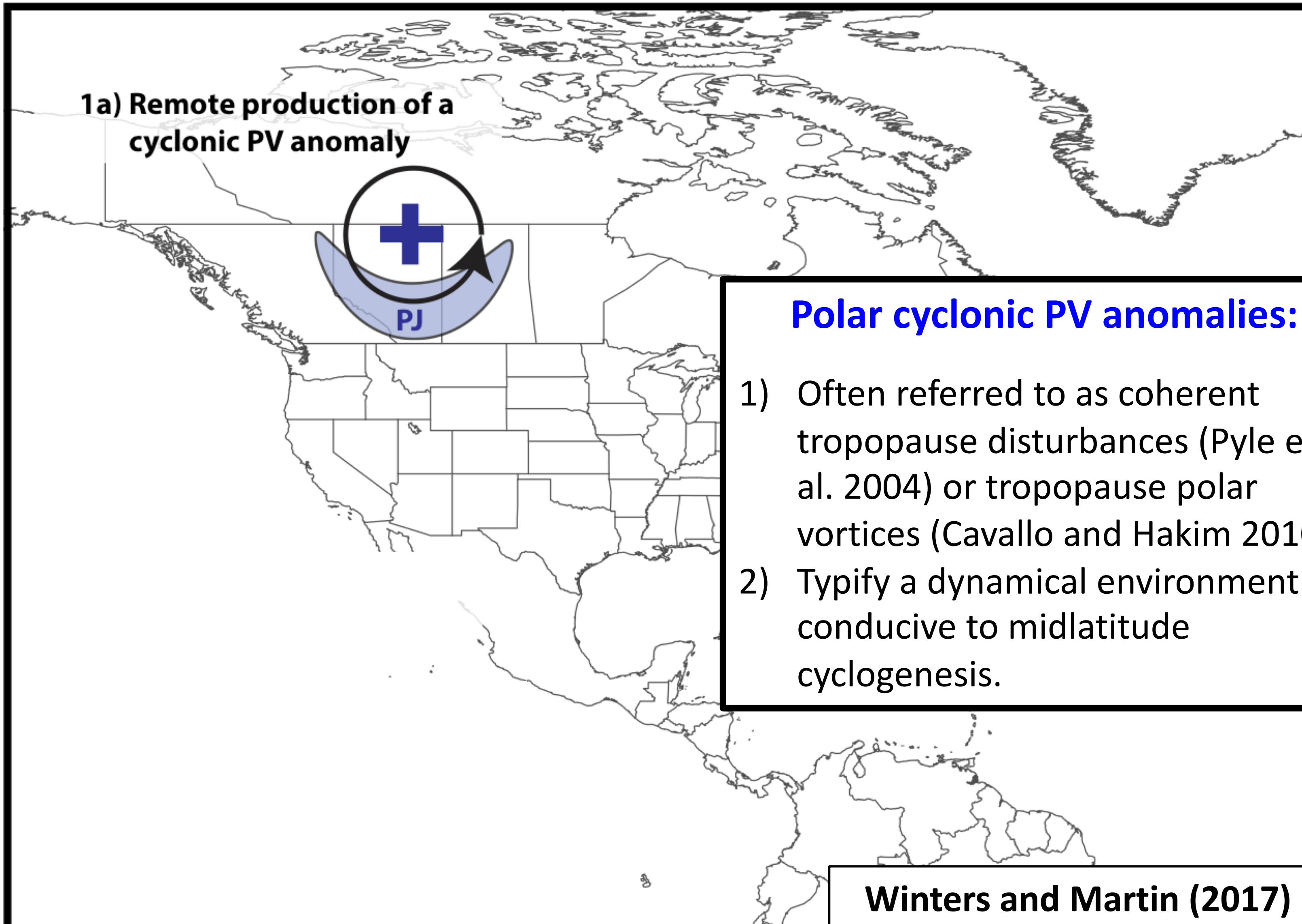
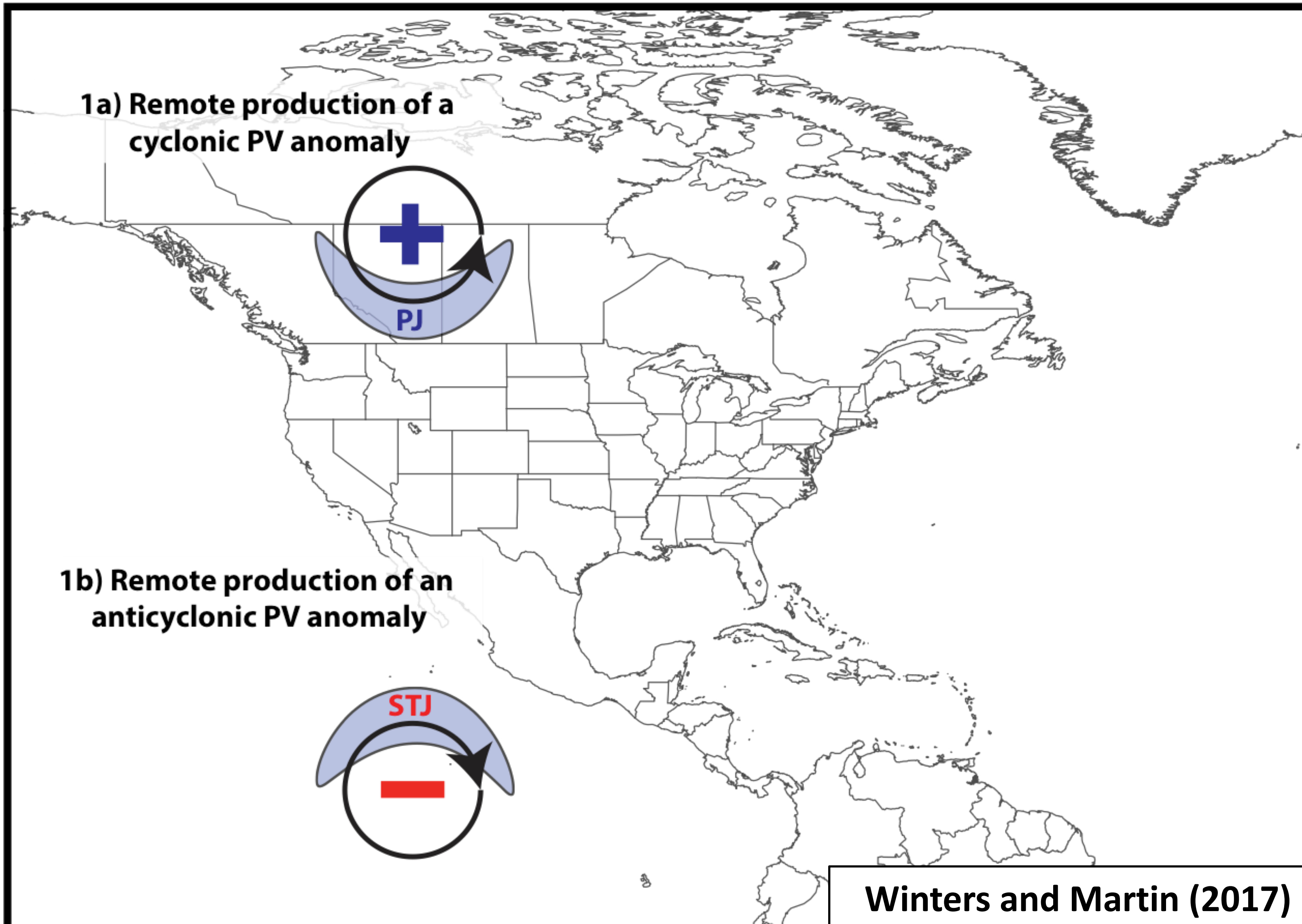


Winters and Martin (2017)

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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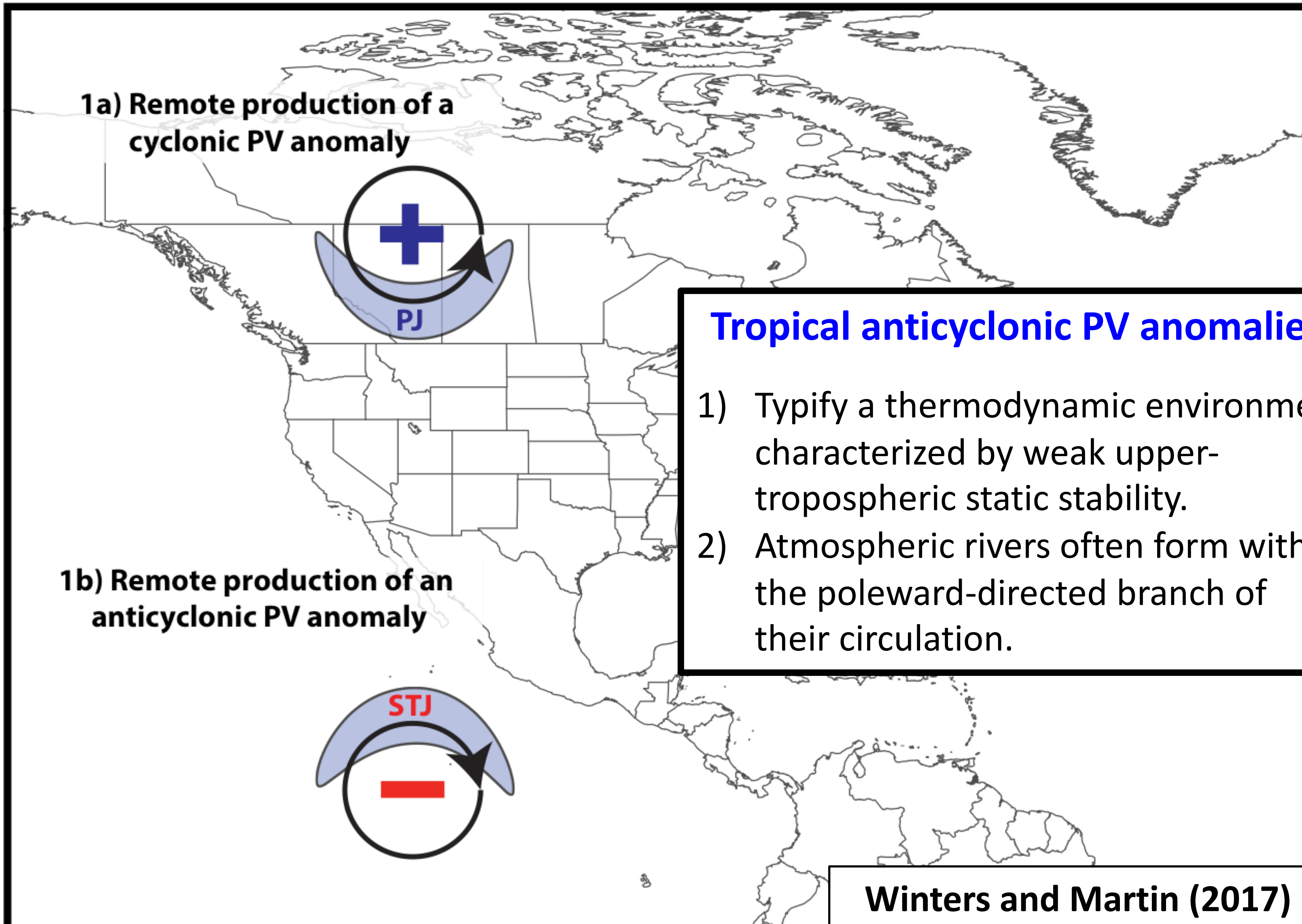
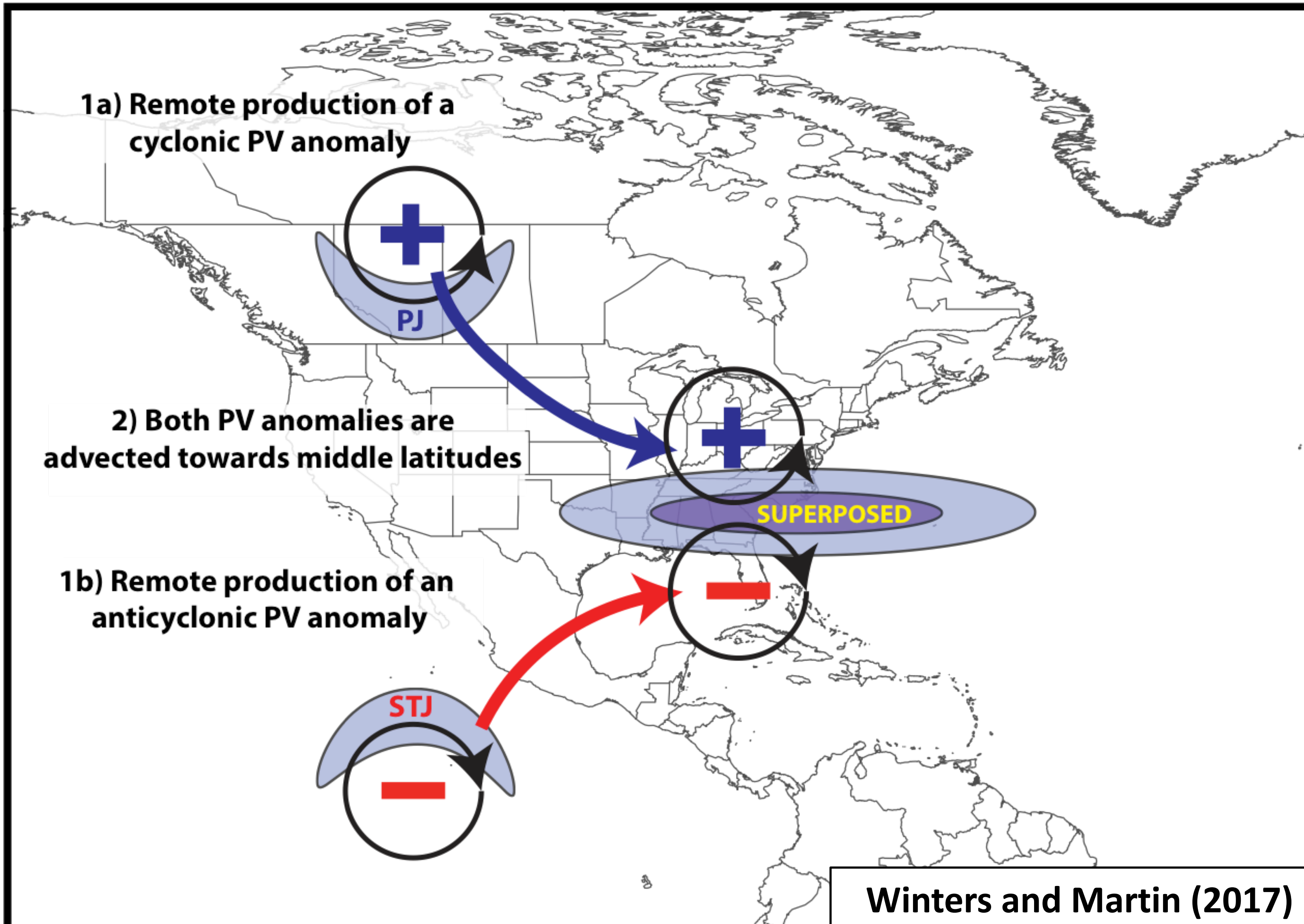


Tropical anticyclonic PV anomalies:

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)

Jet Superposition Conceptual Model



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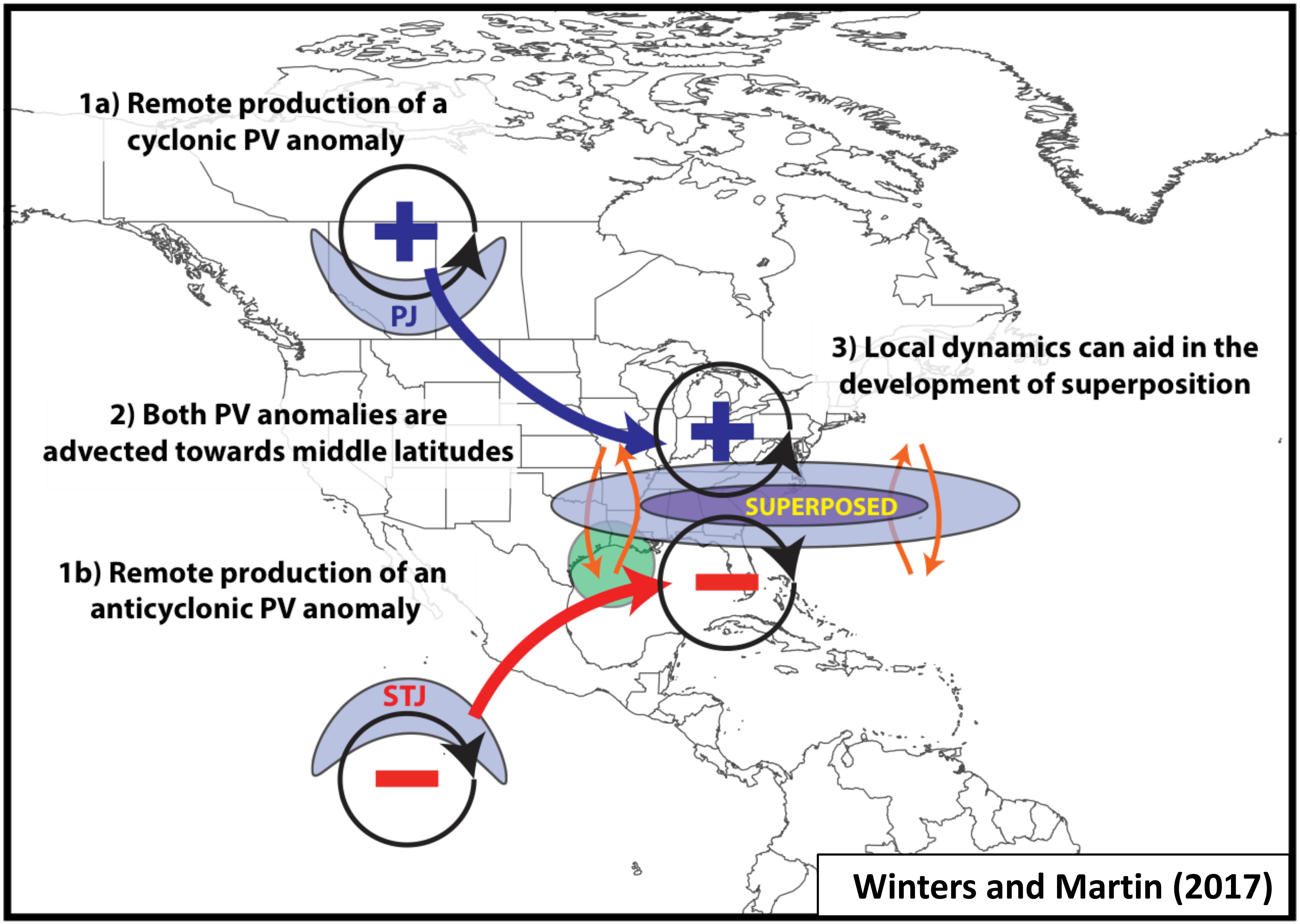

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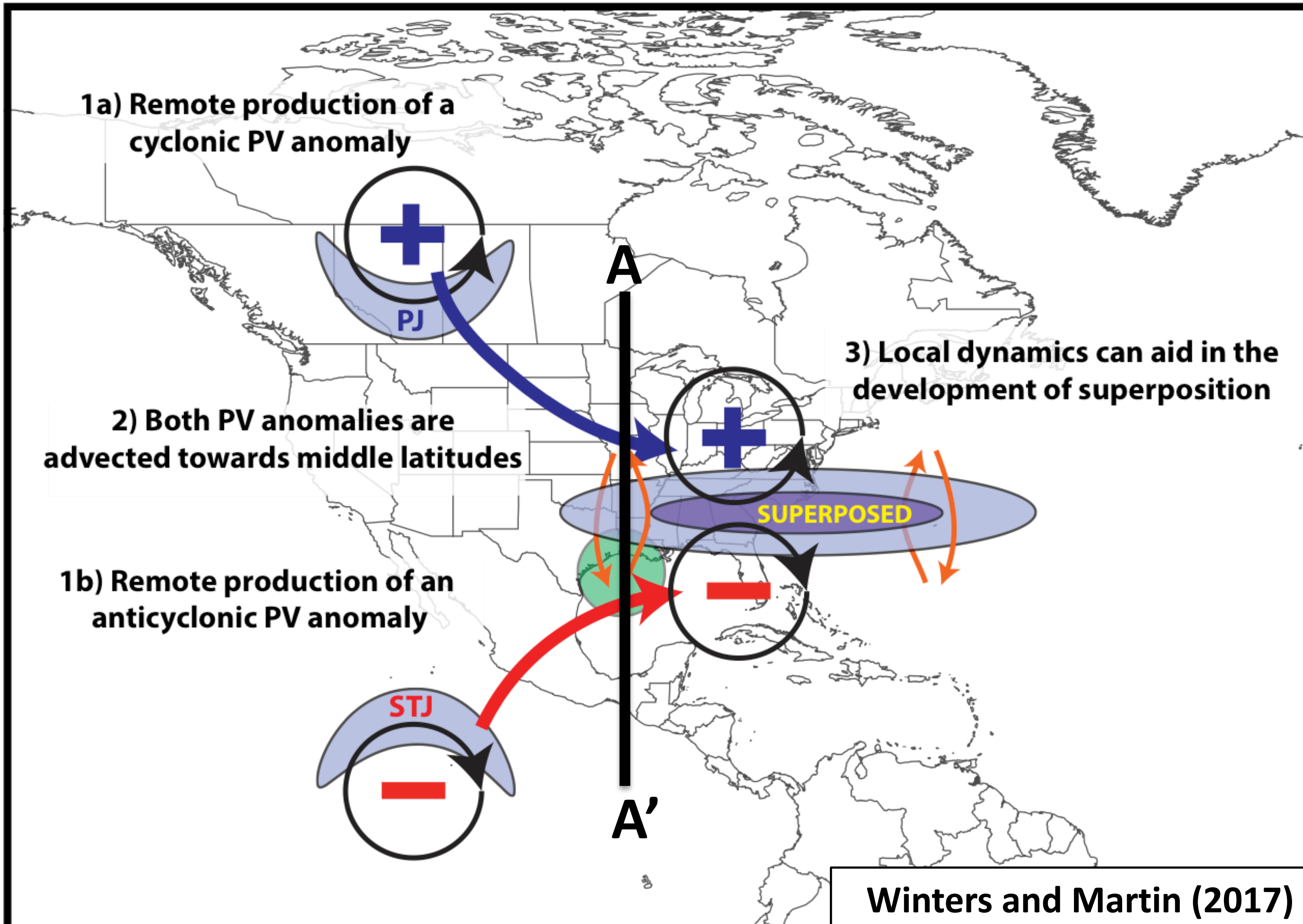

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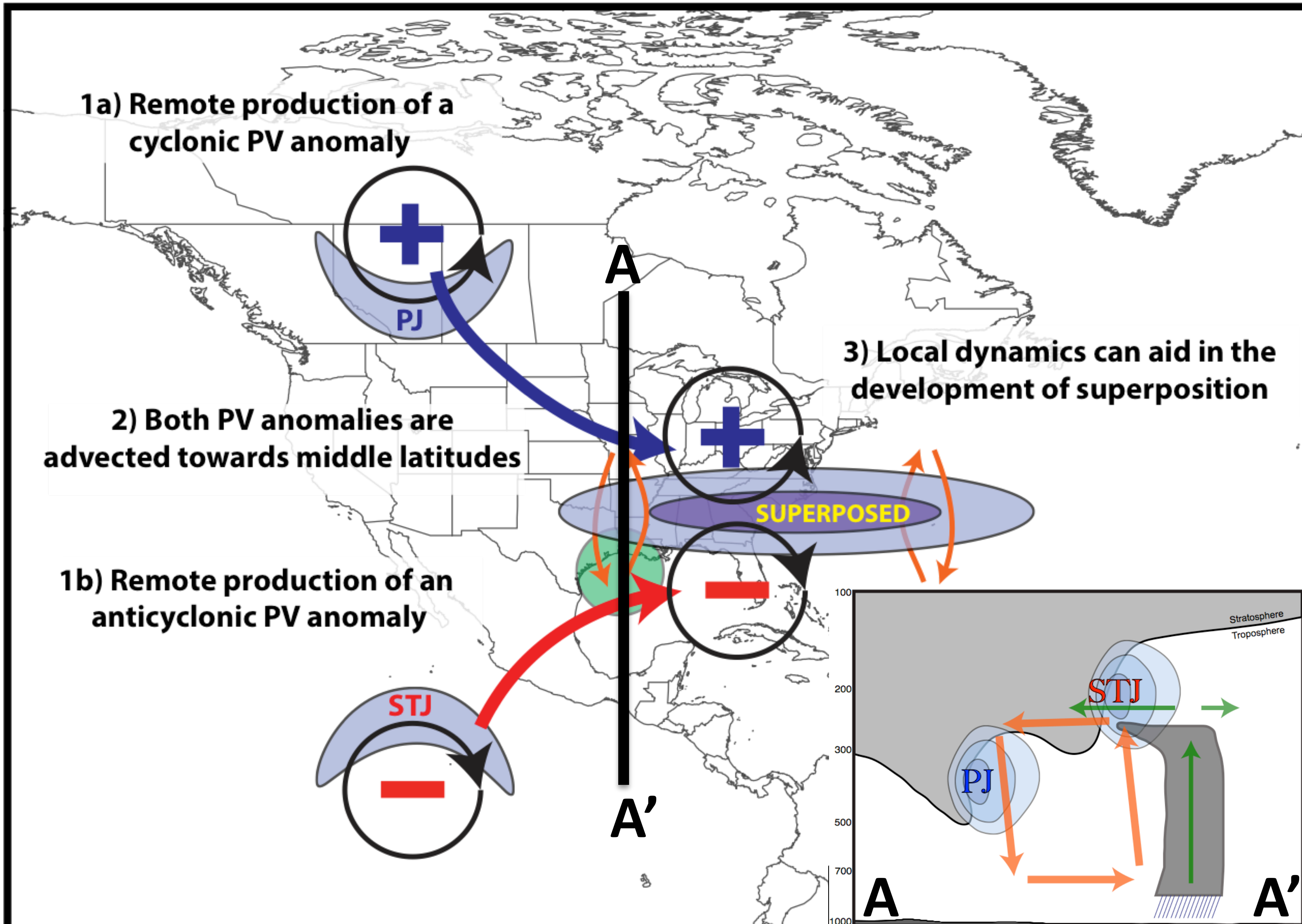

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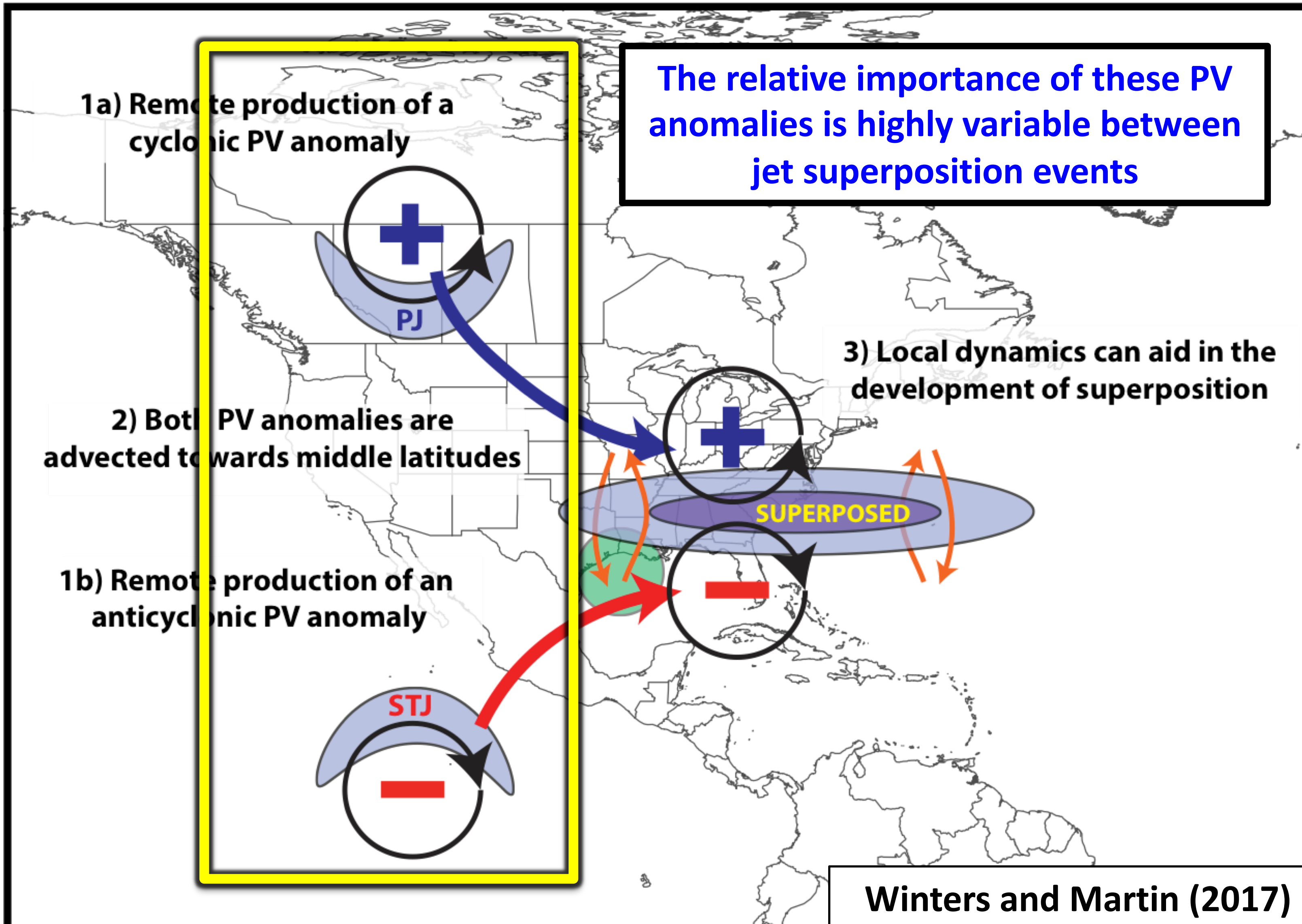

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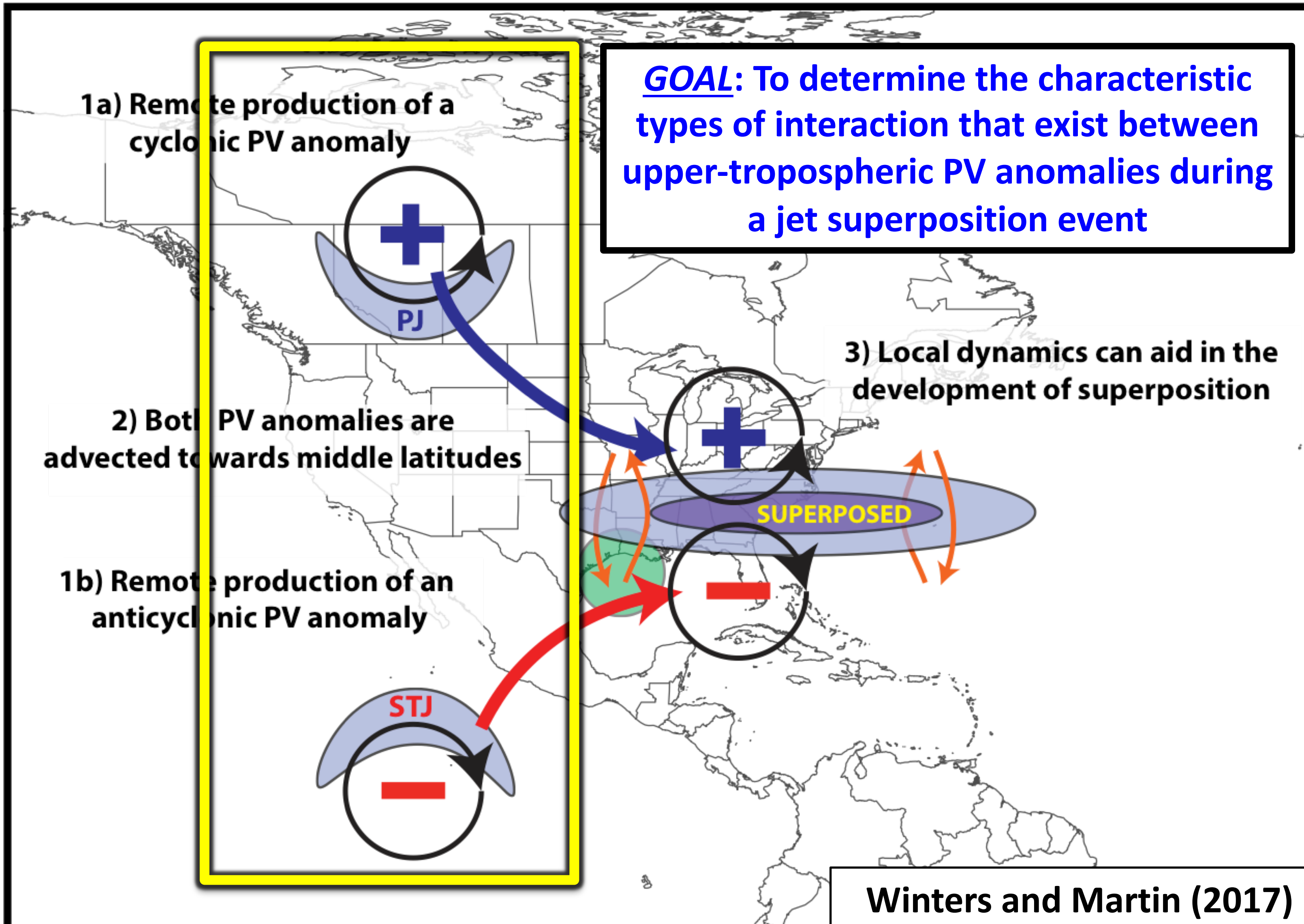
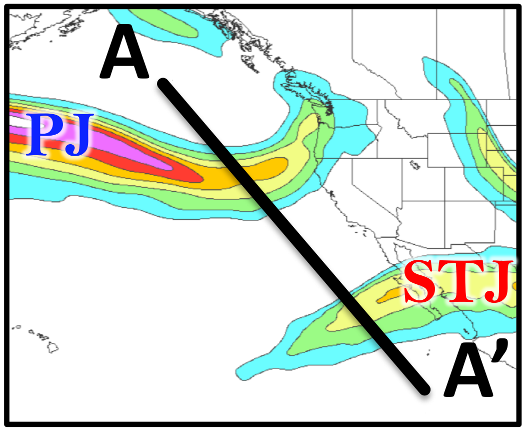


Jet Superposition Event Identification and Classification

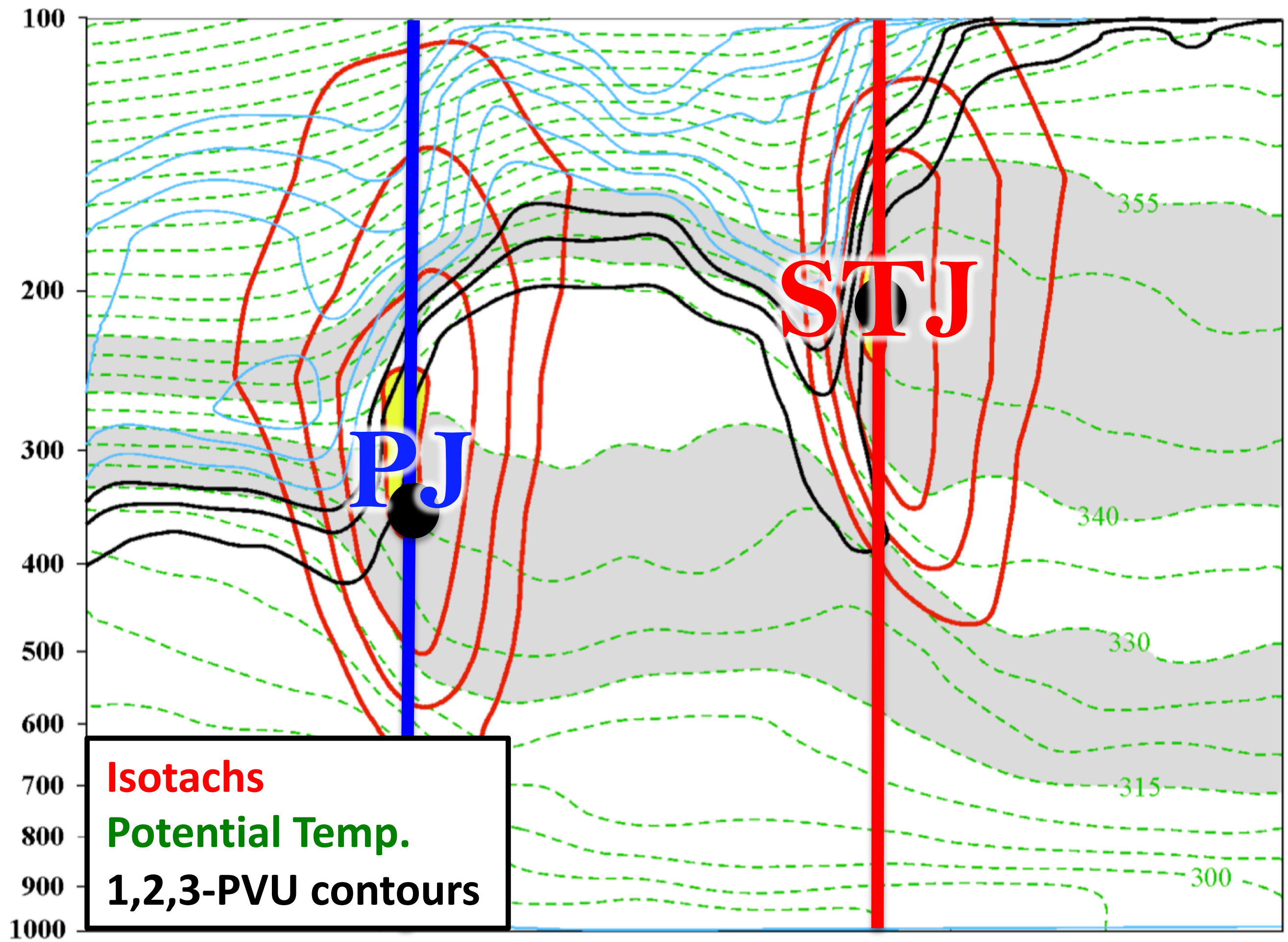
Jet Superposition Event Identification

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 et al. (2016)

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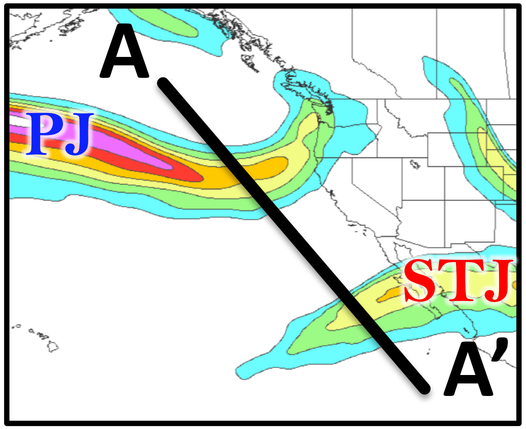

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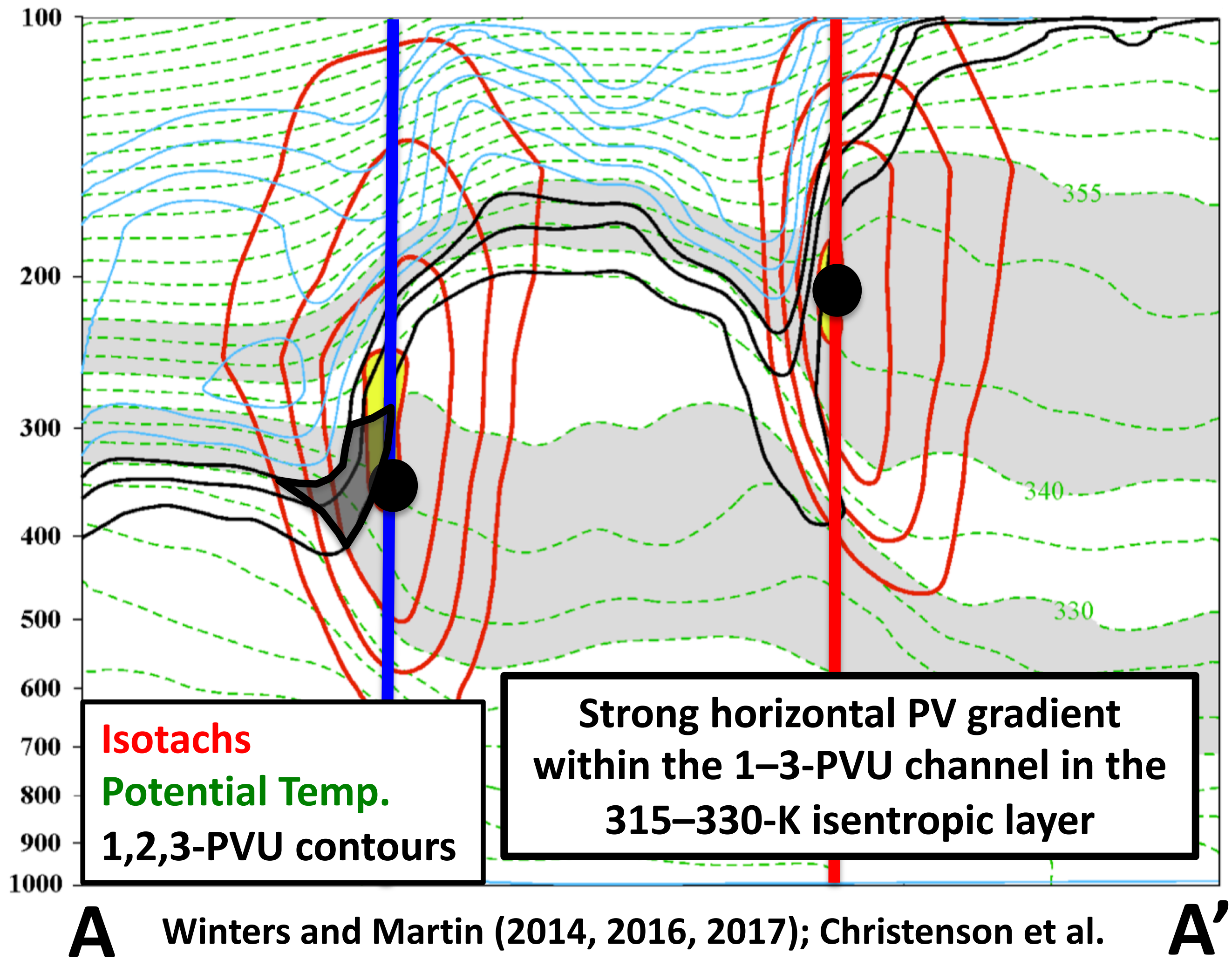

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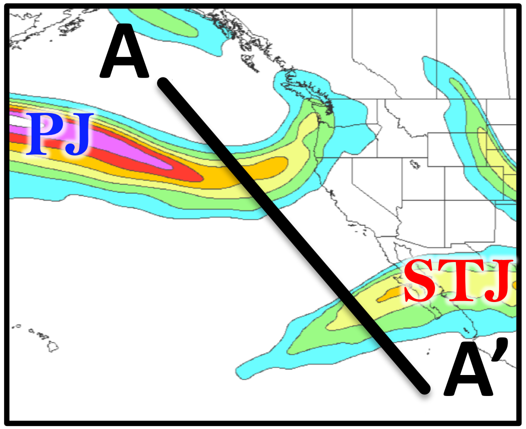

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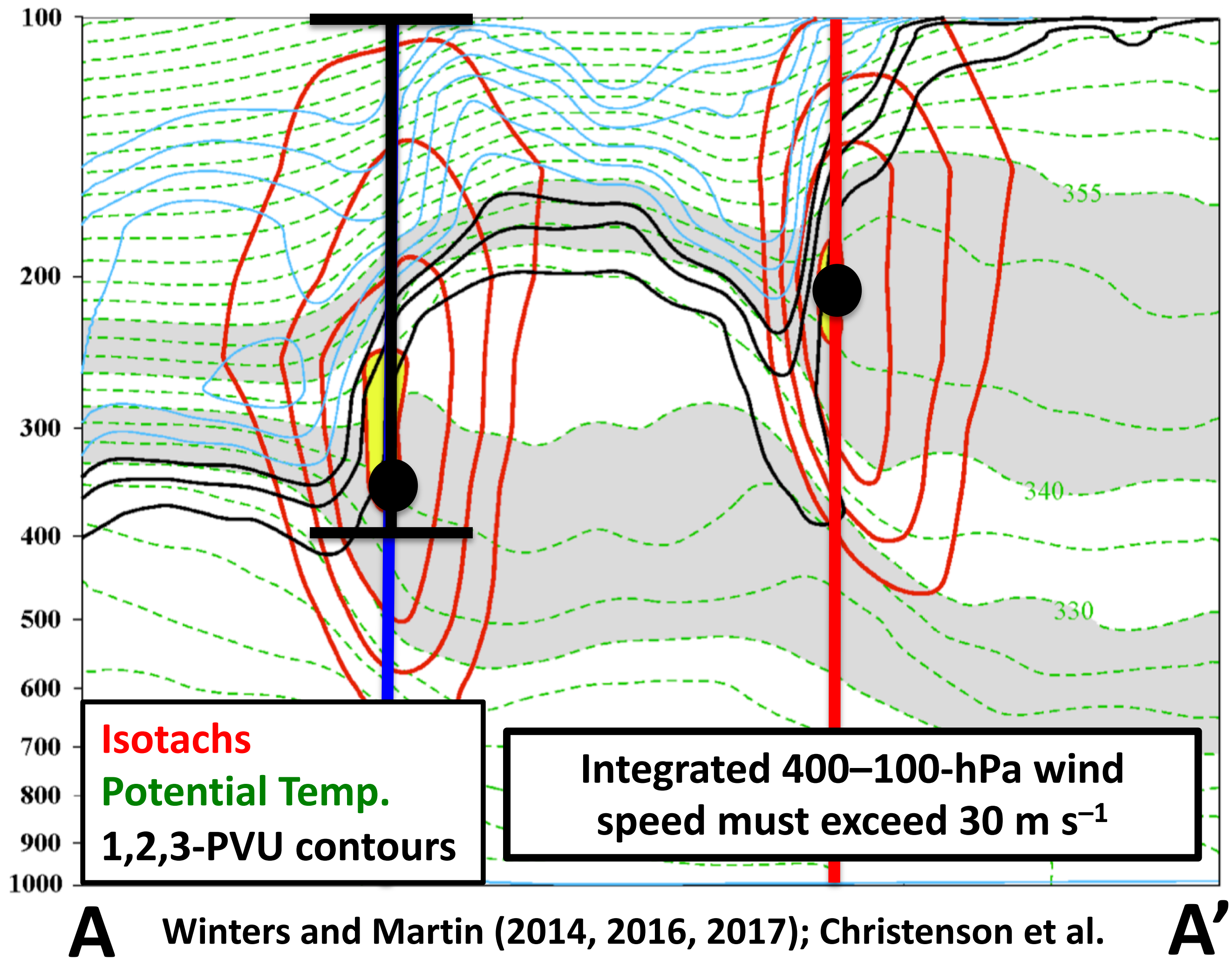

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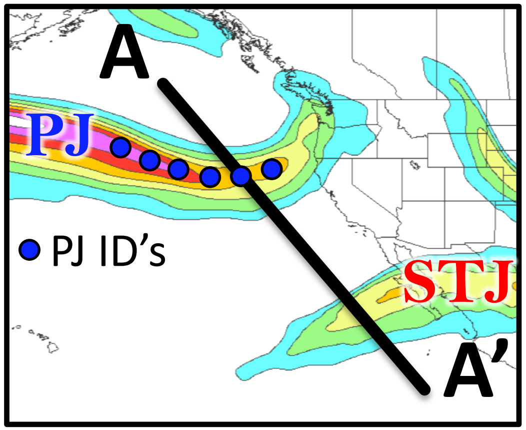

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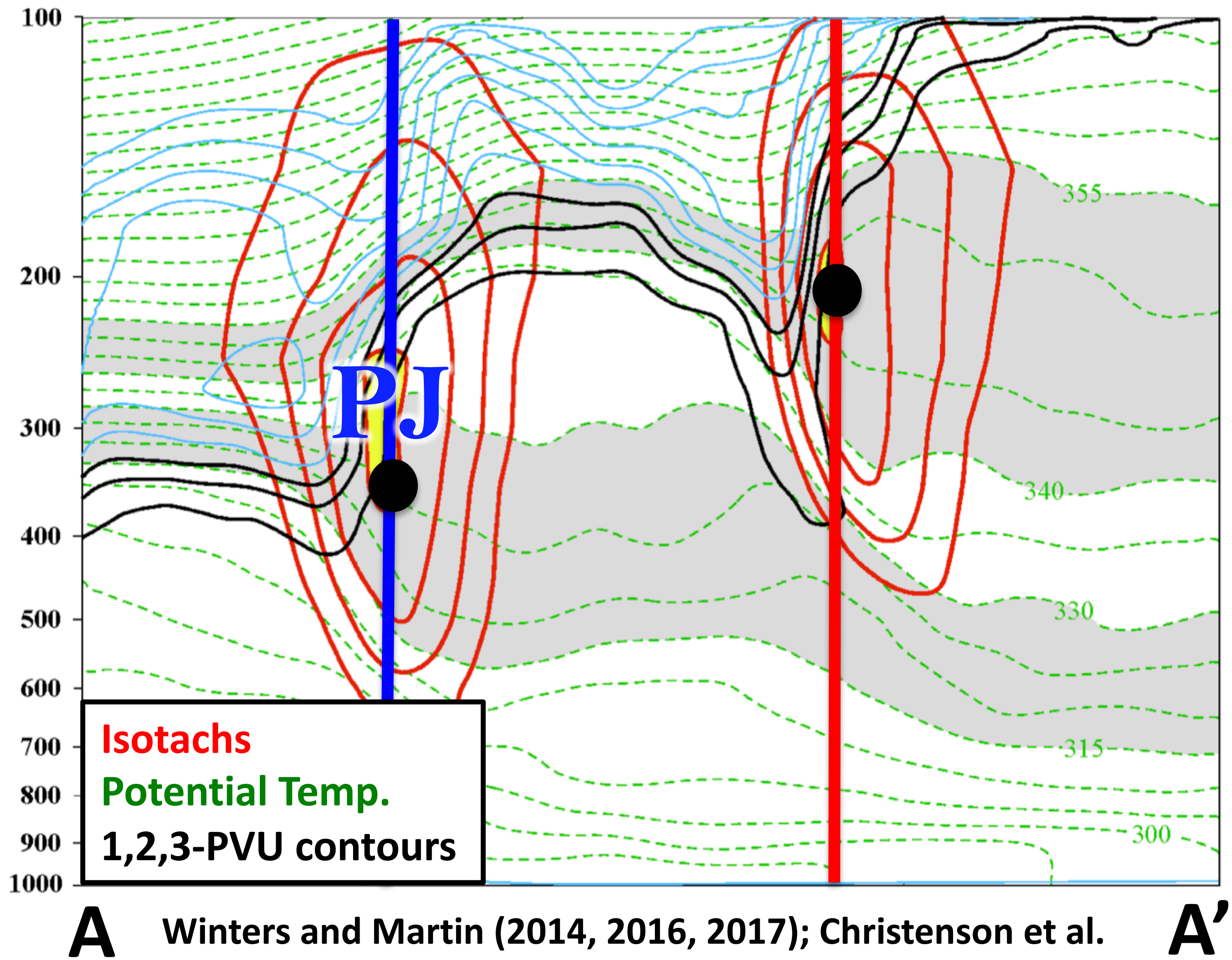

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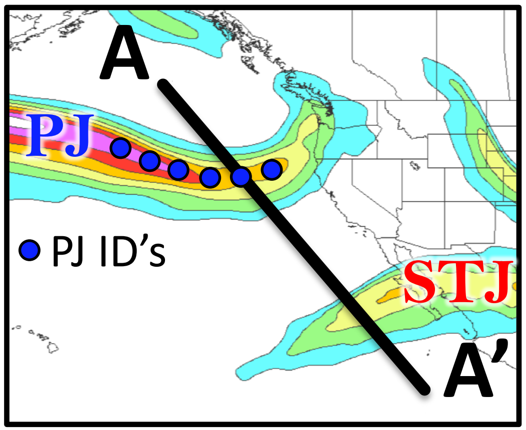

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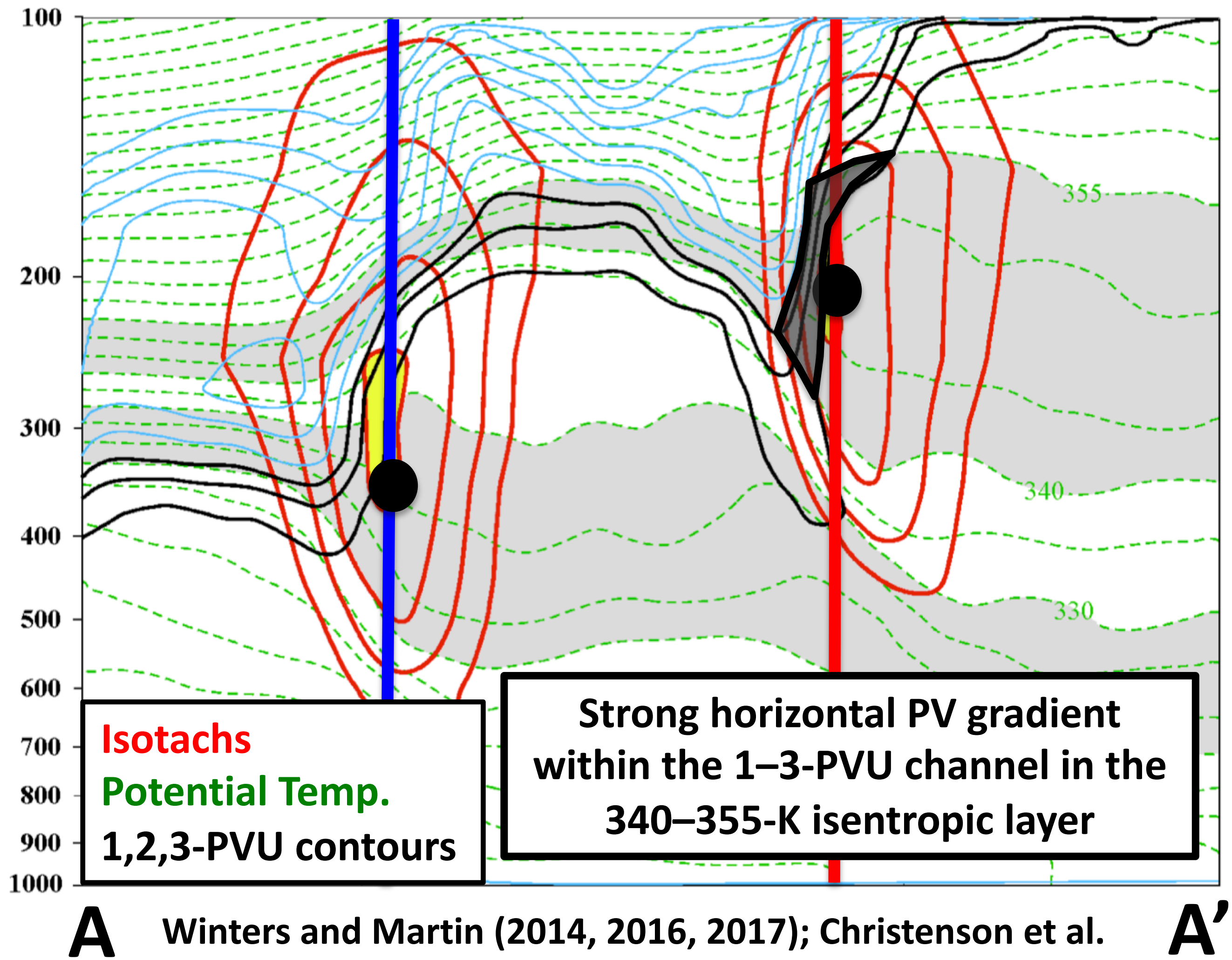

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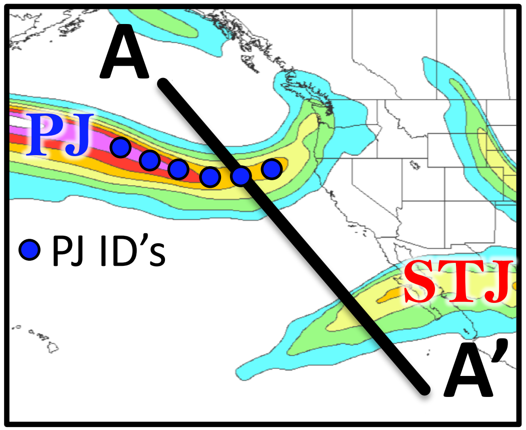

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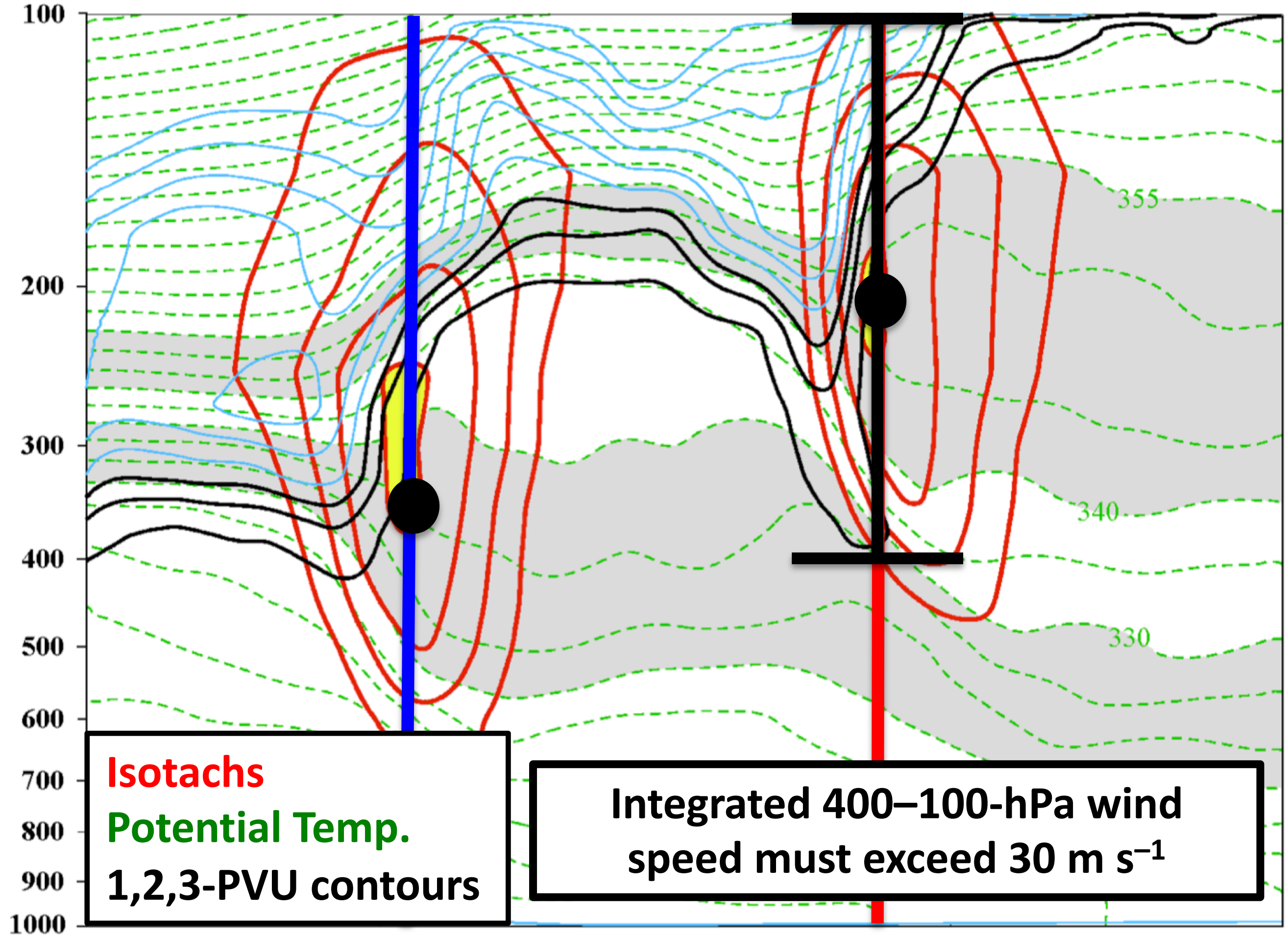

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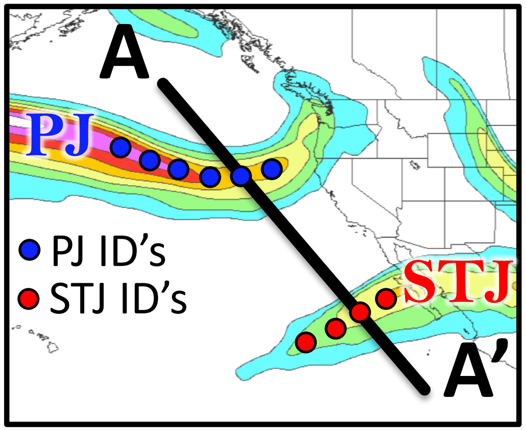

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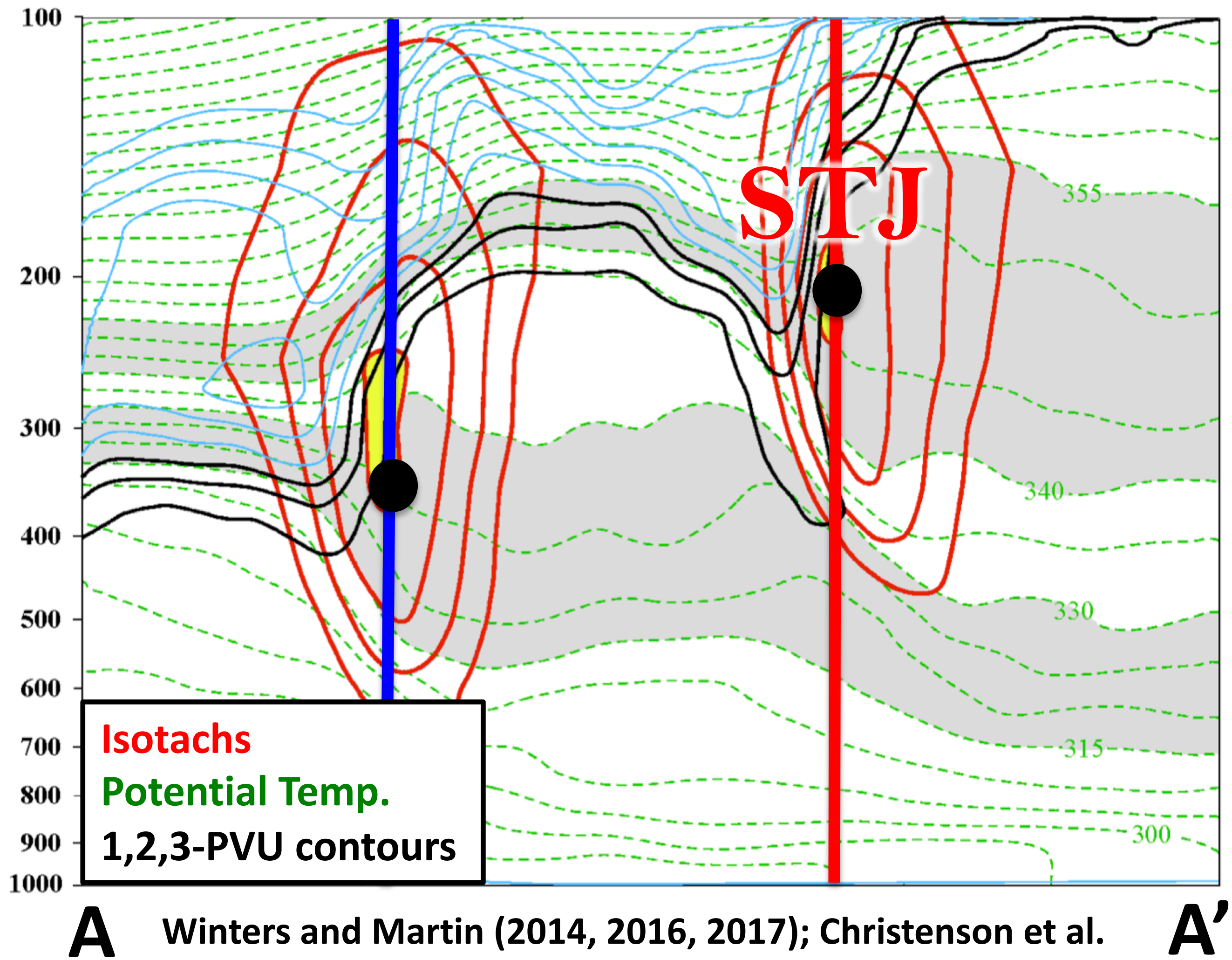

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Jet Superposition Event Identification

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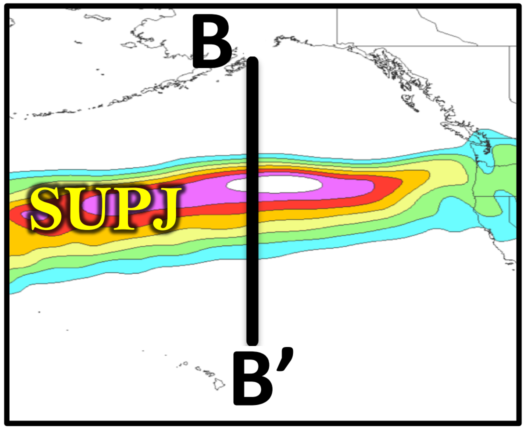

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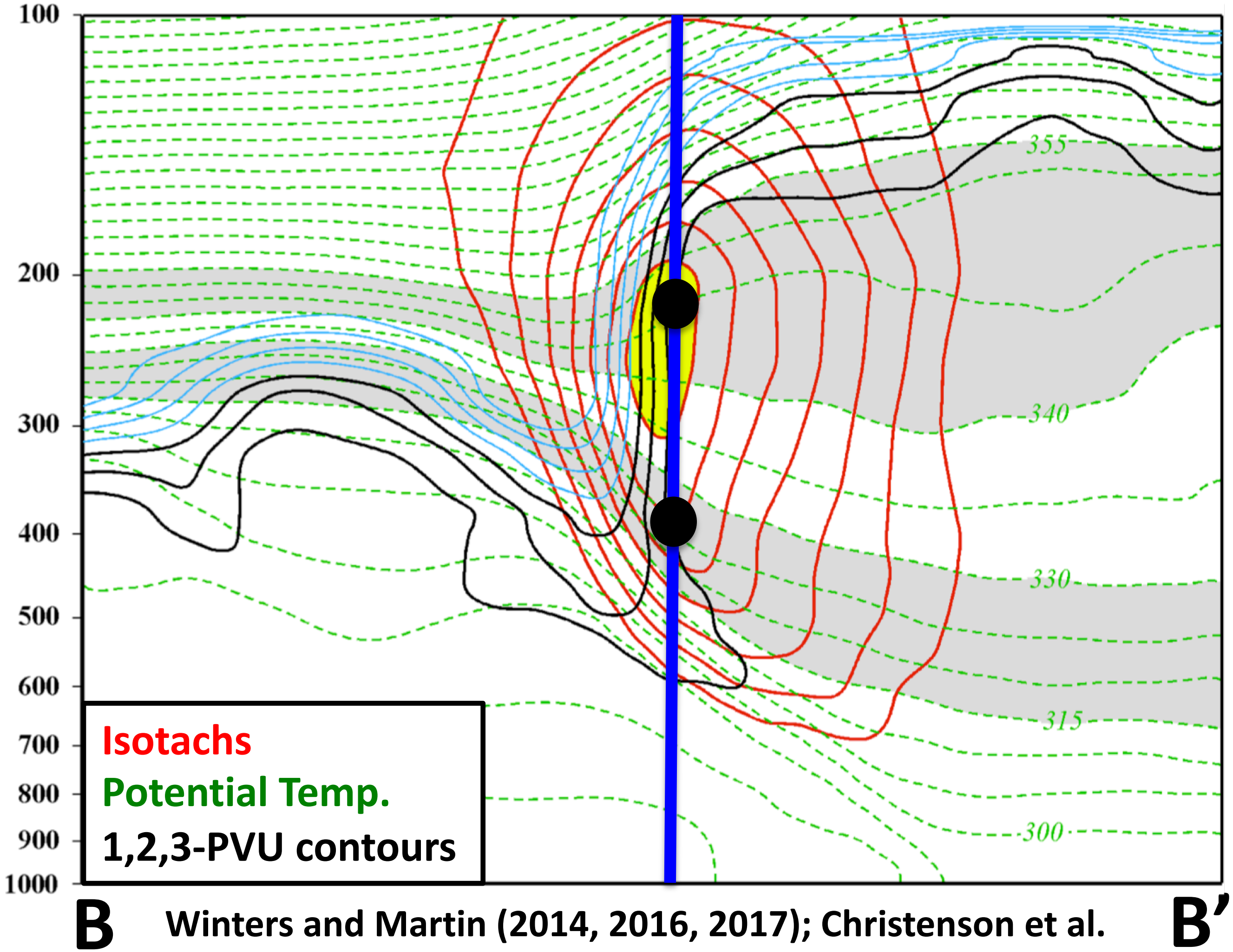

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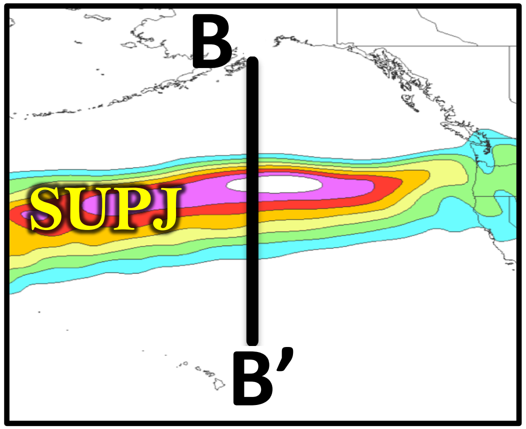

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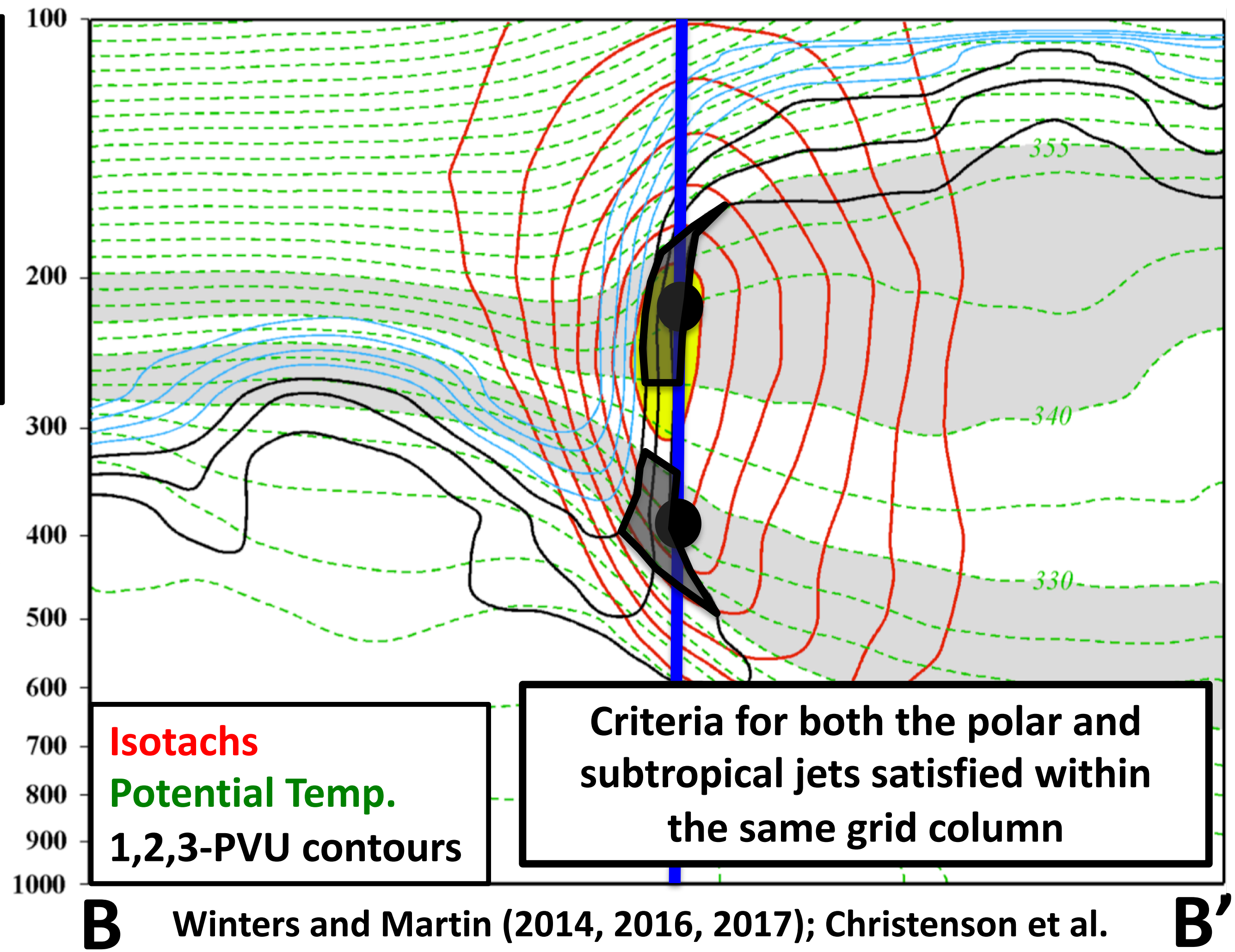

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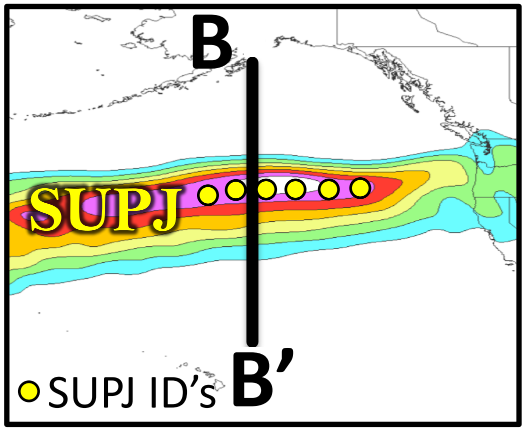

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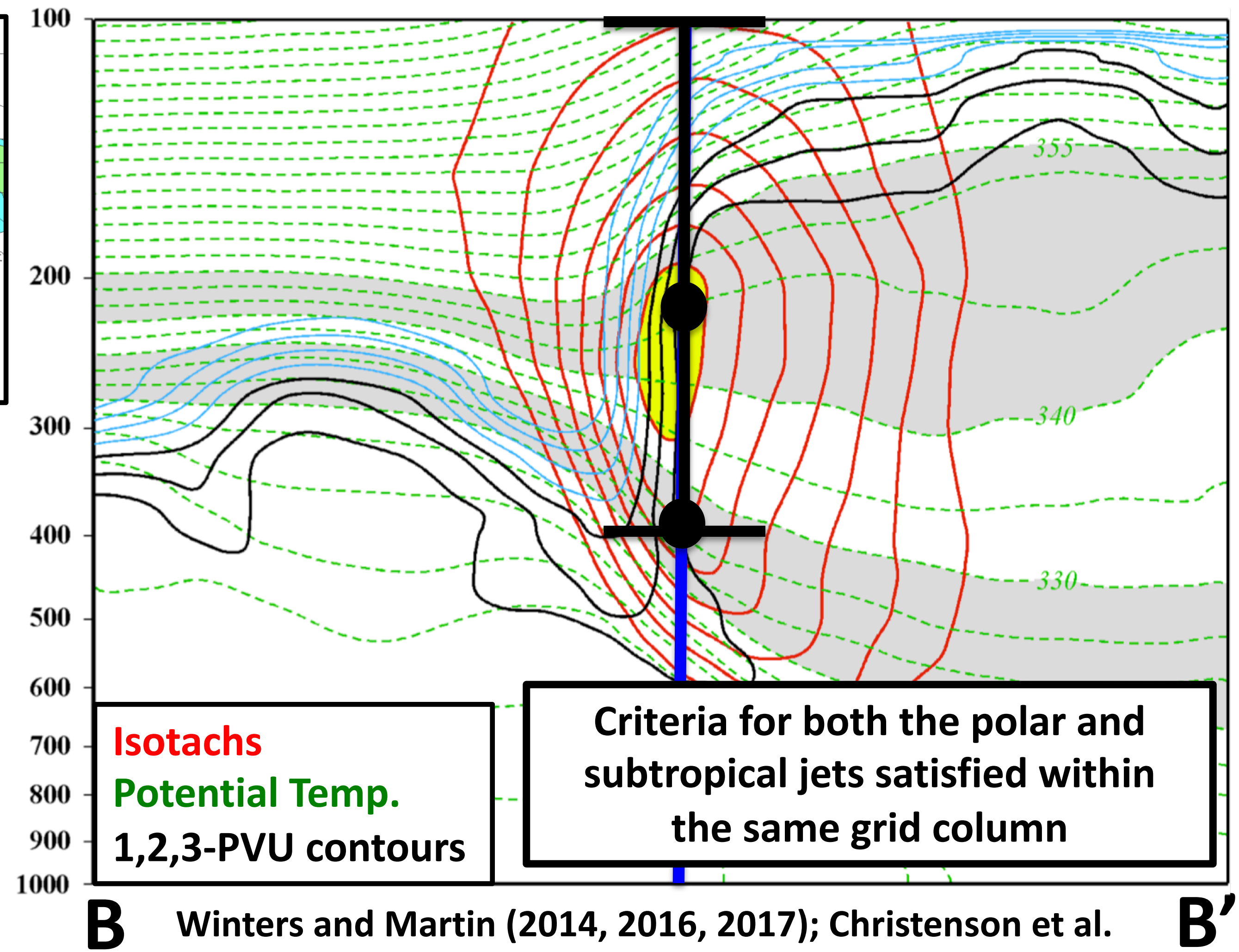

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Jet Superposition Event Identification

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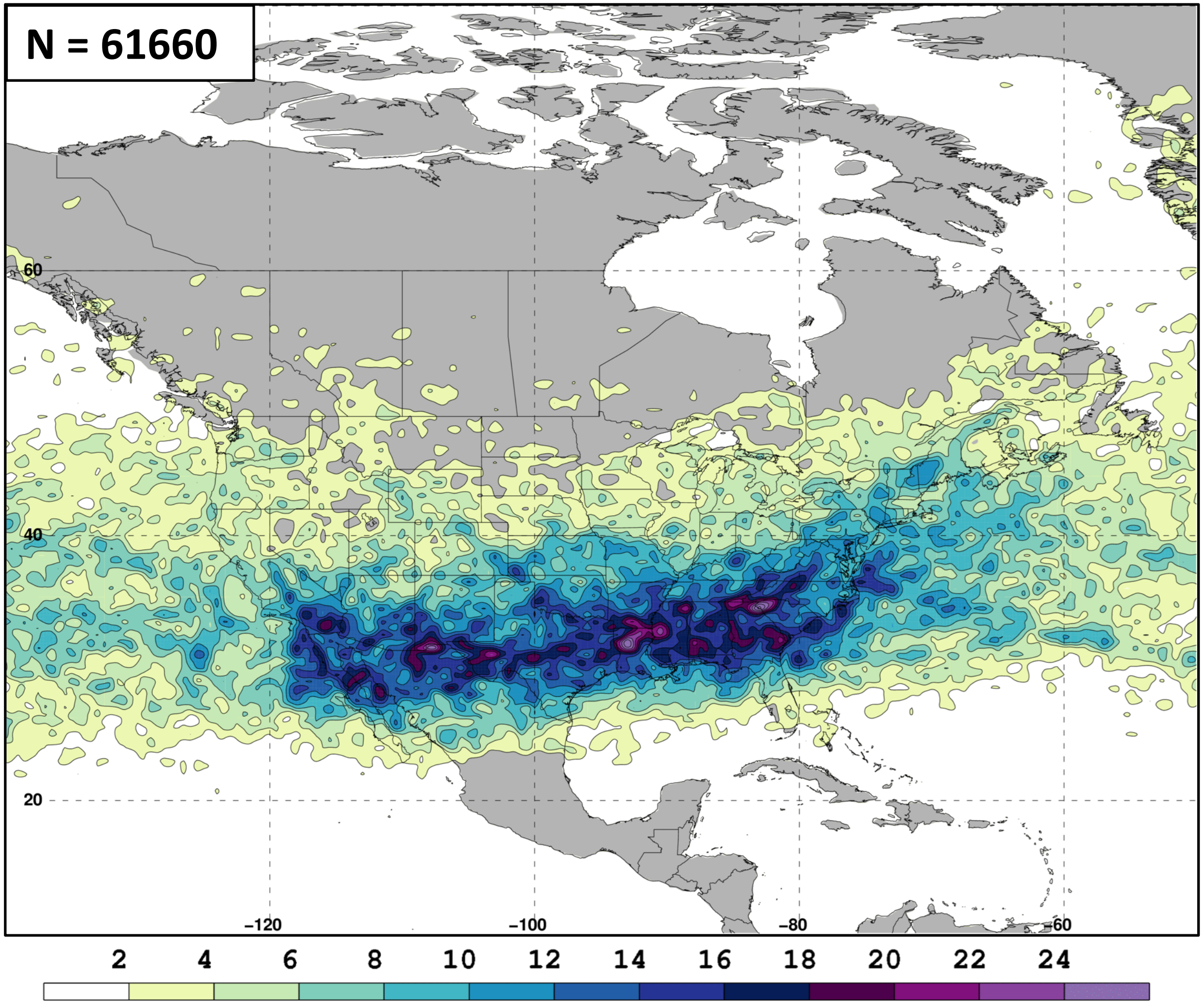
Jet Superposition Frequency – All Times

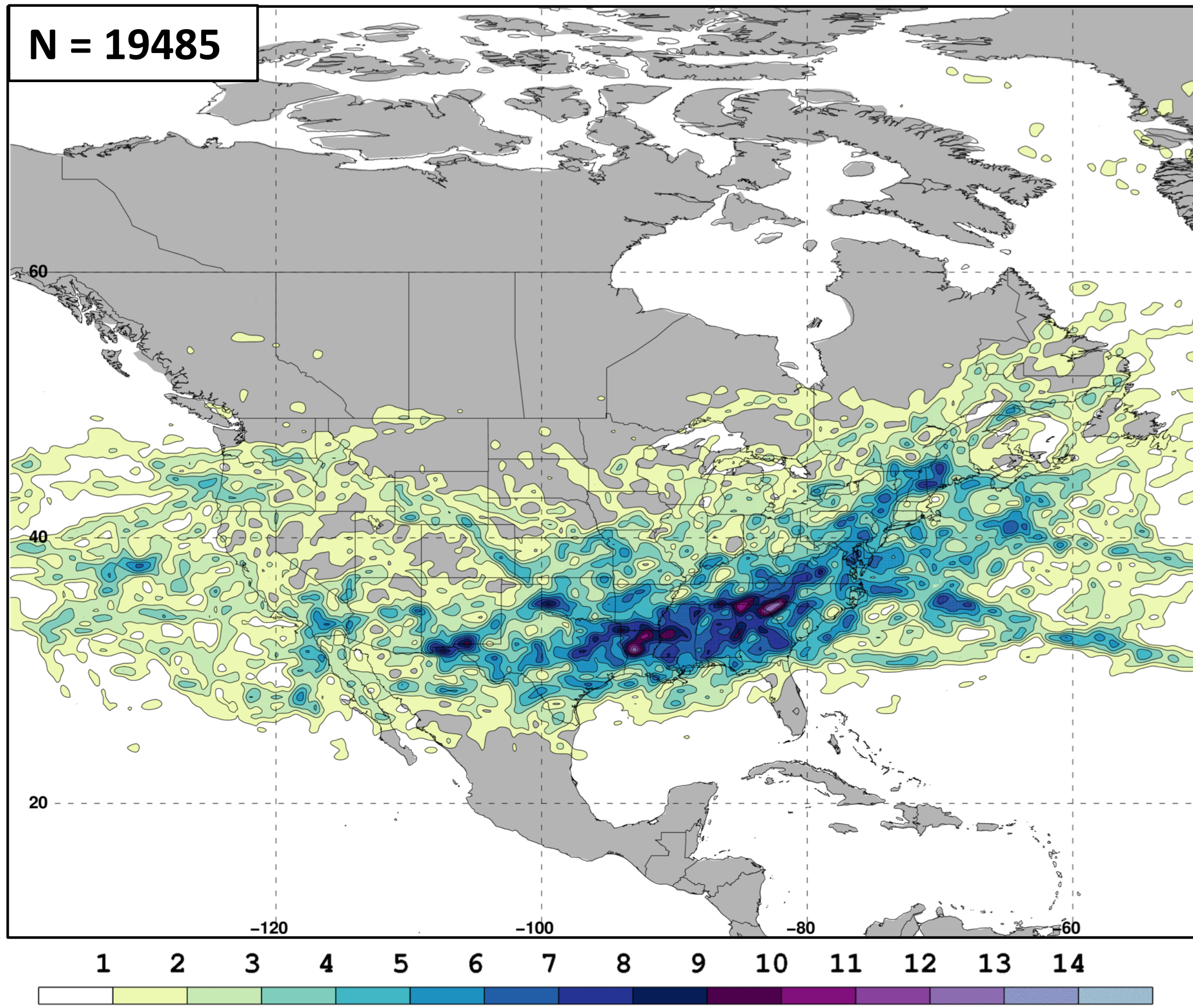


Jet Superposition Event Identification

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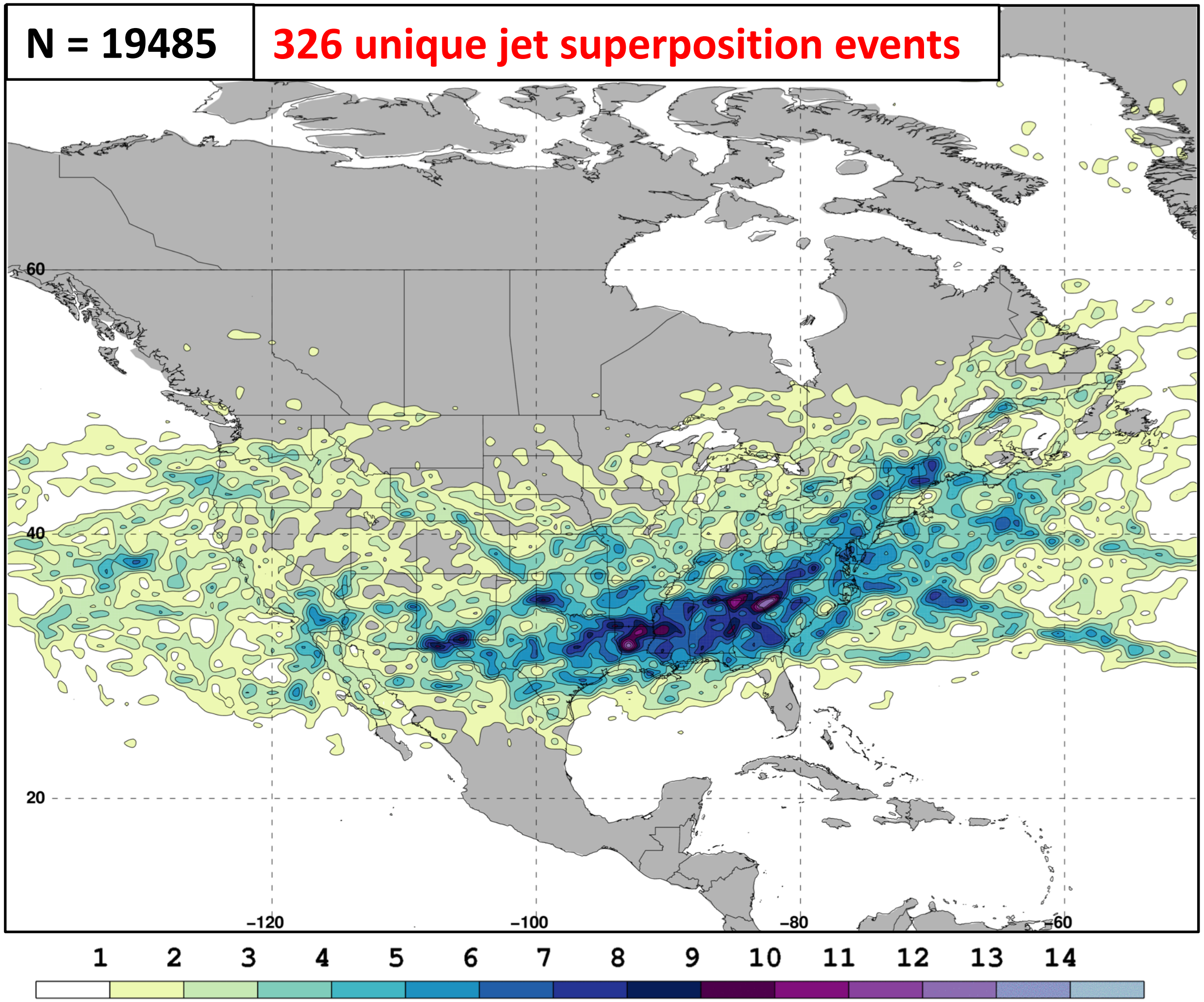
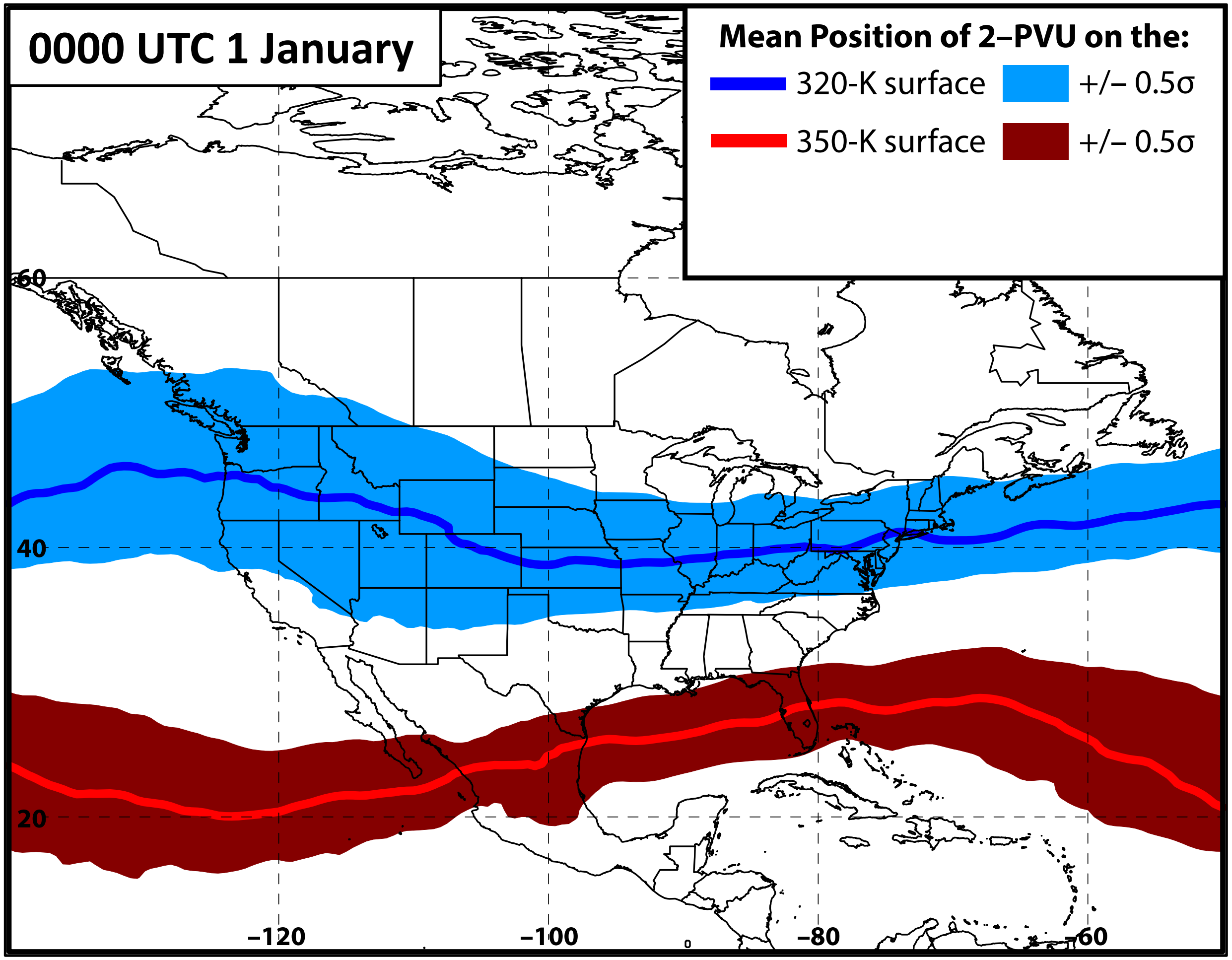
3. Filtered retained analysis times to group together jet superpositions that are < 30 h and < 1500 km of one another.

Jet Superposition Frequency – Top 10% Times



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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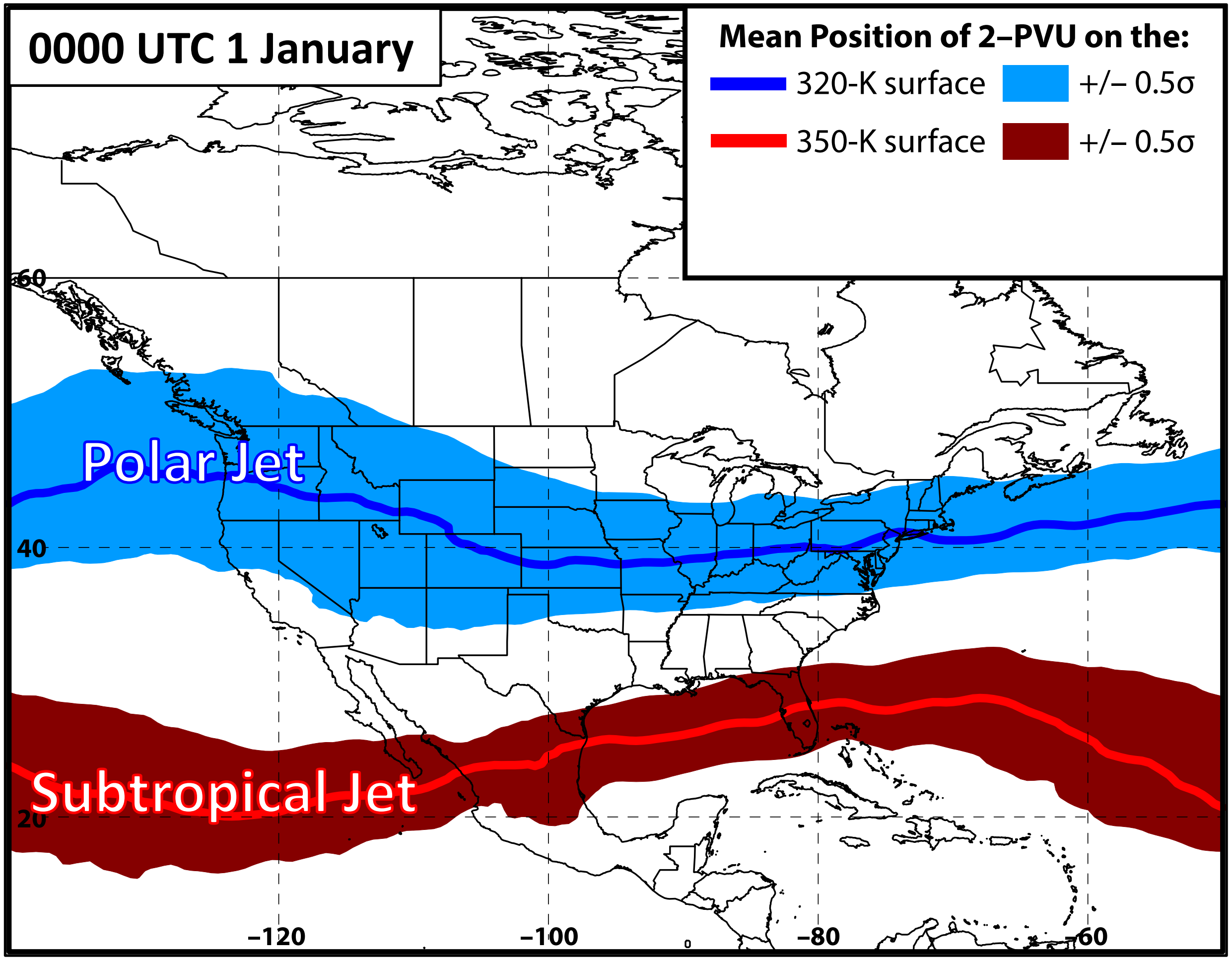
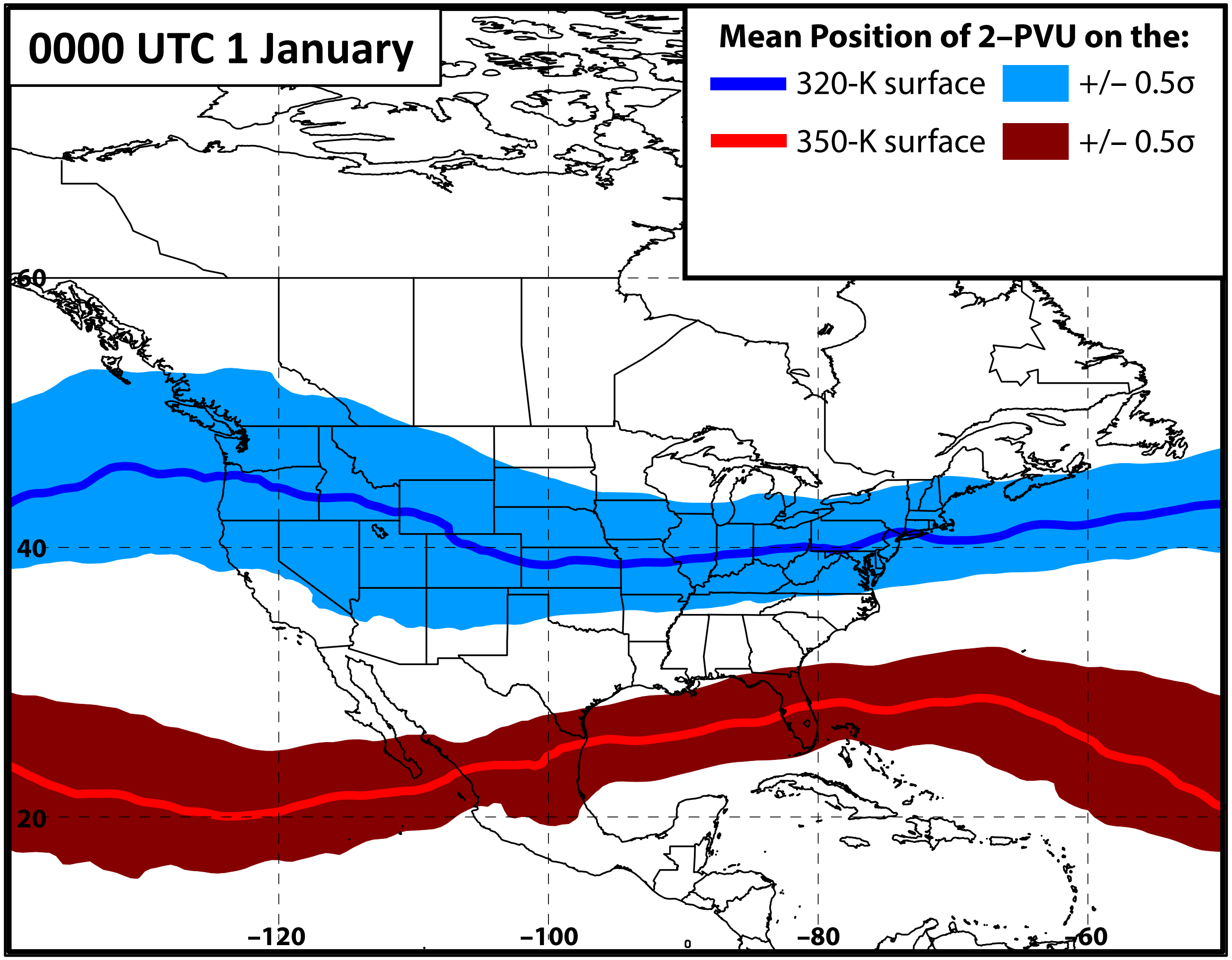


Jet Superposition Event Classification

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.

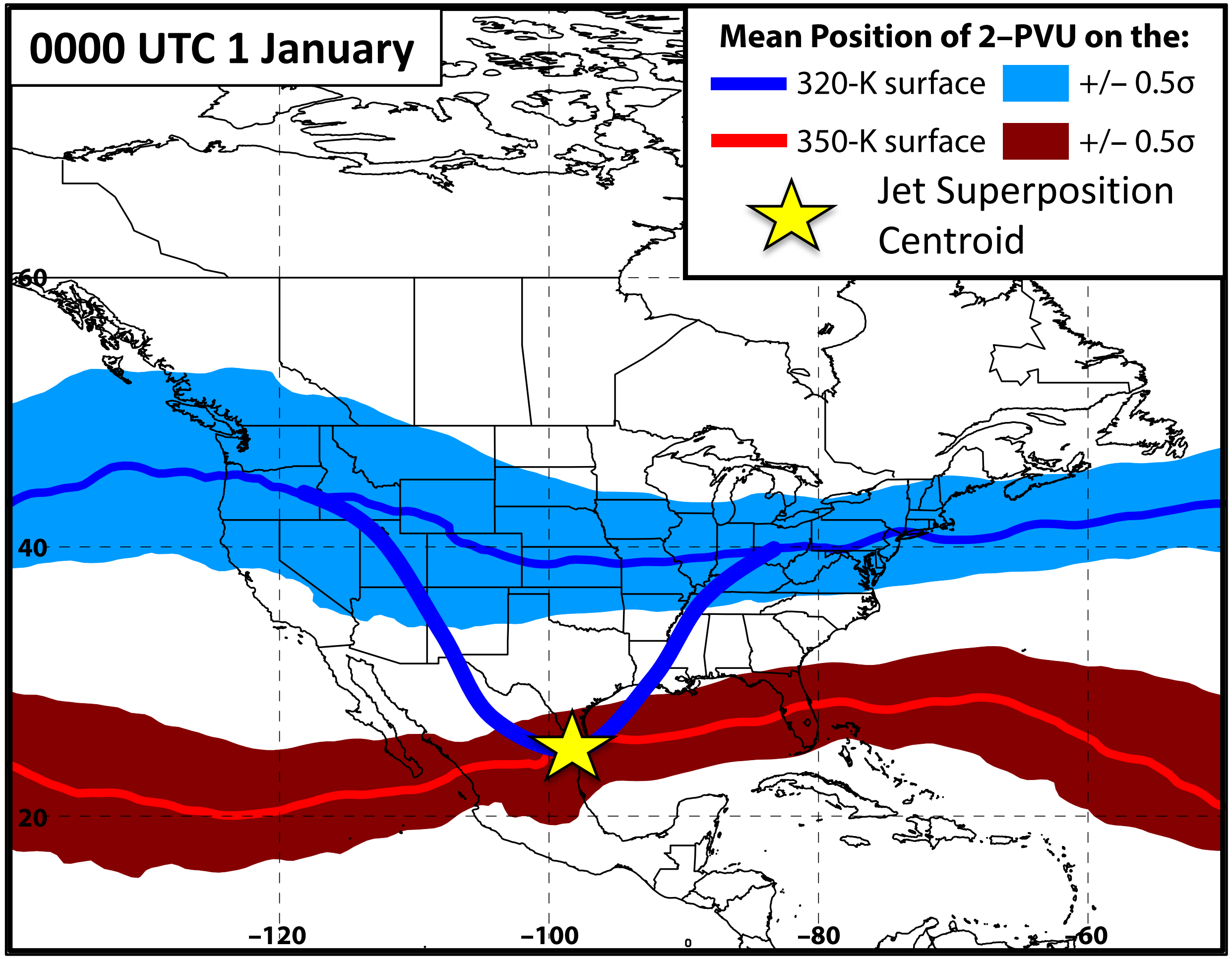


Jet Superposition Event Classification

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.

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**

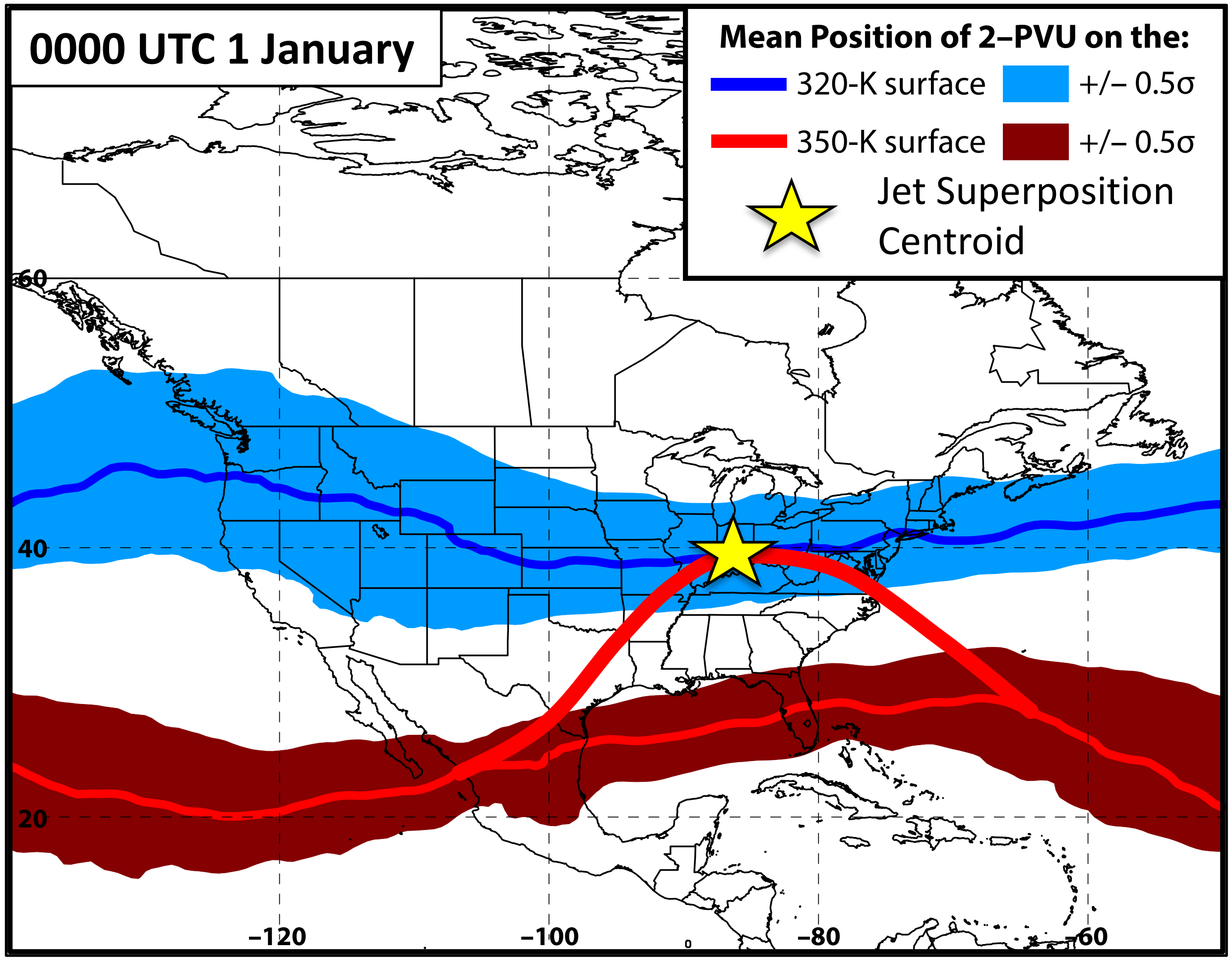


Jet Superposition Event Classification

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**

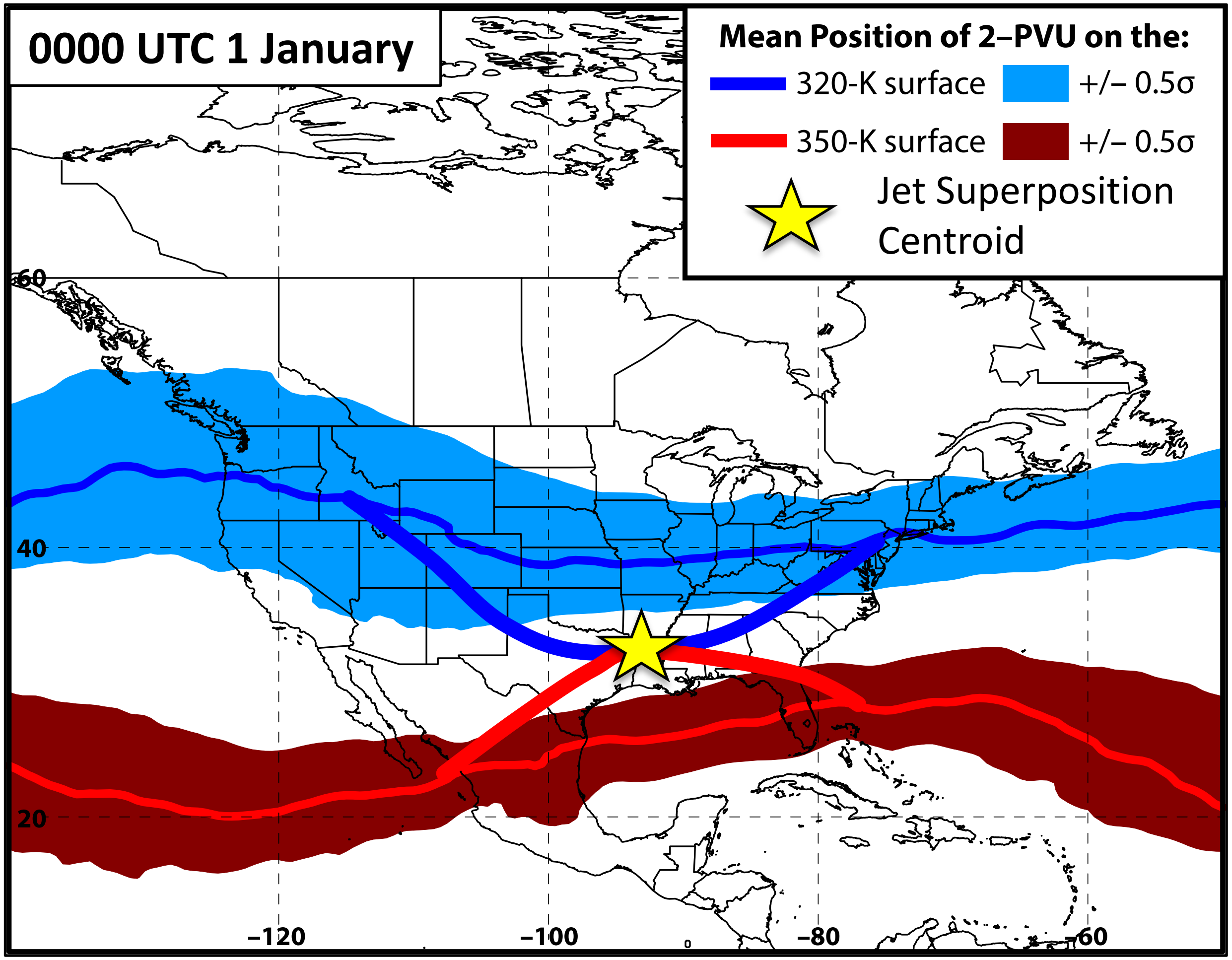


Jet Superposition Event Classification

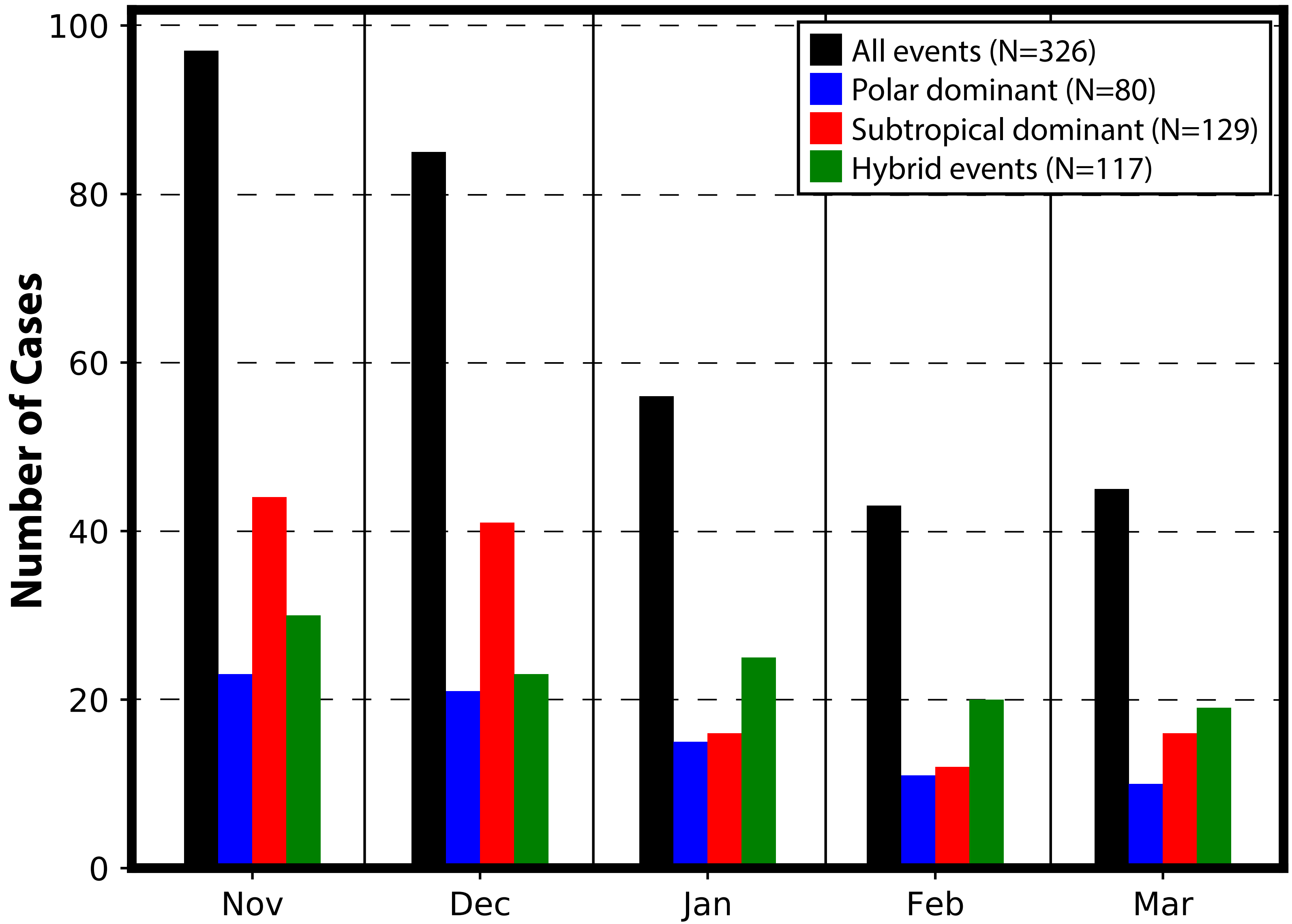
1. Determined the mean position of the 2-PVU contour on the 320-K and 350-K surfaces at each analysis time in the CFSR.

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

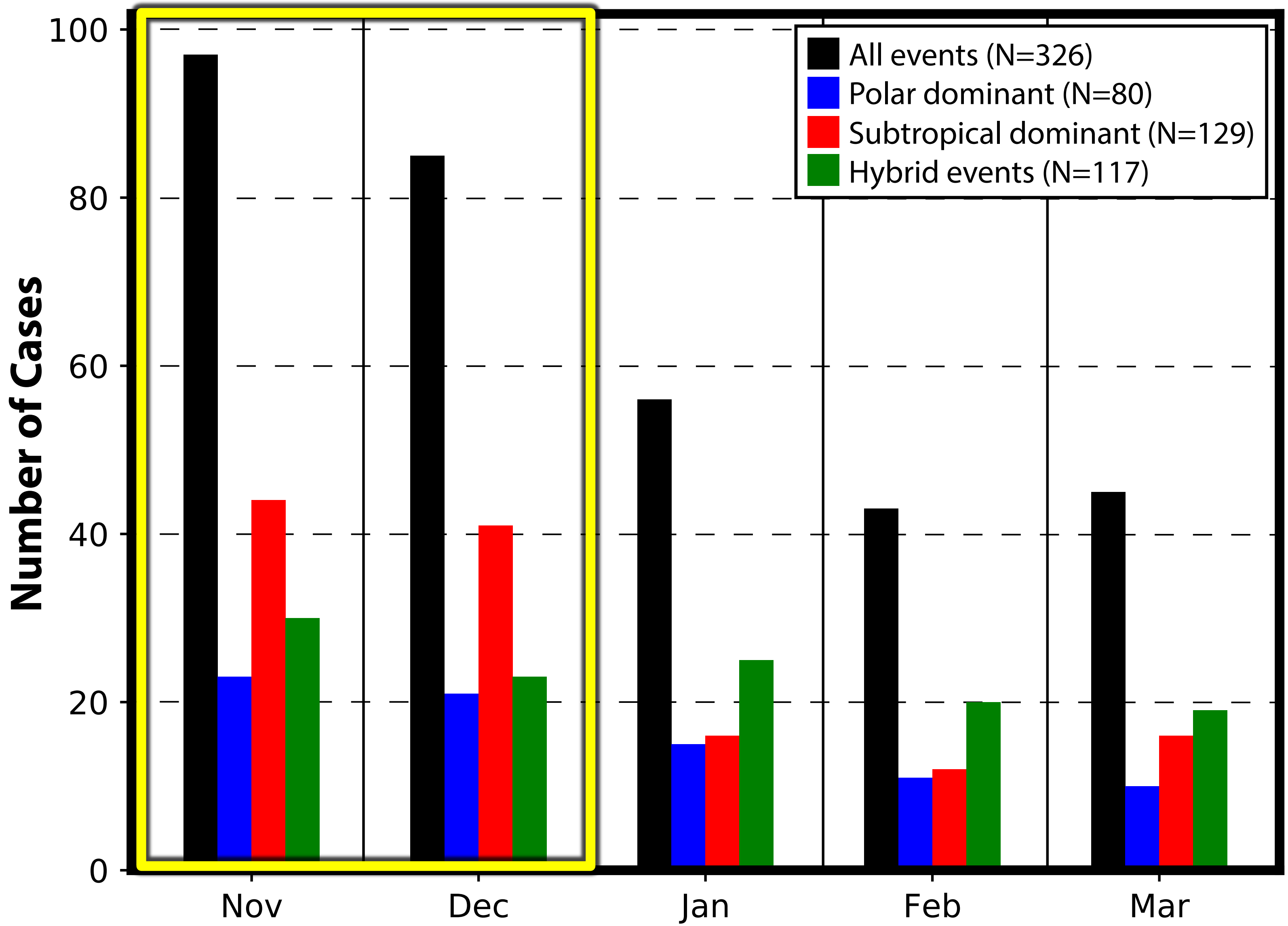
- Polar Dominant
- Subtropical Dominant
- **Hybrid**



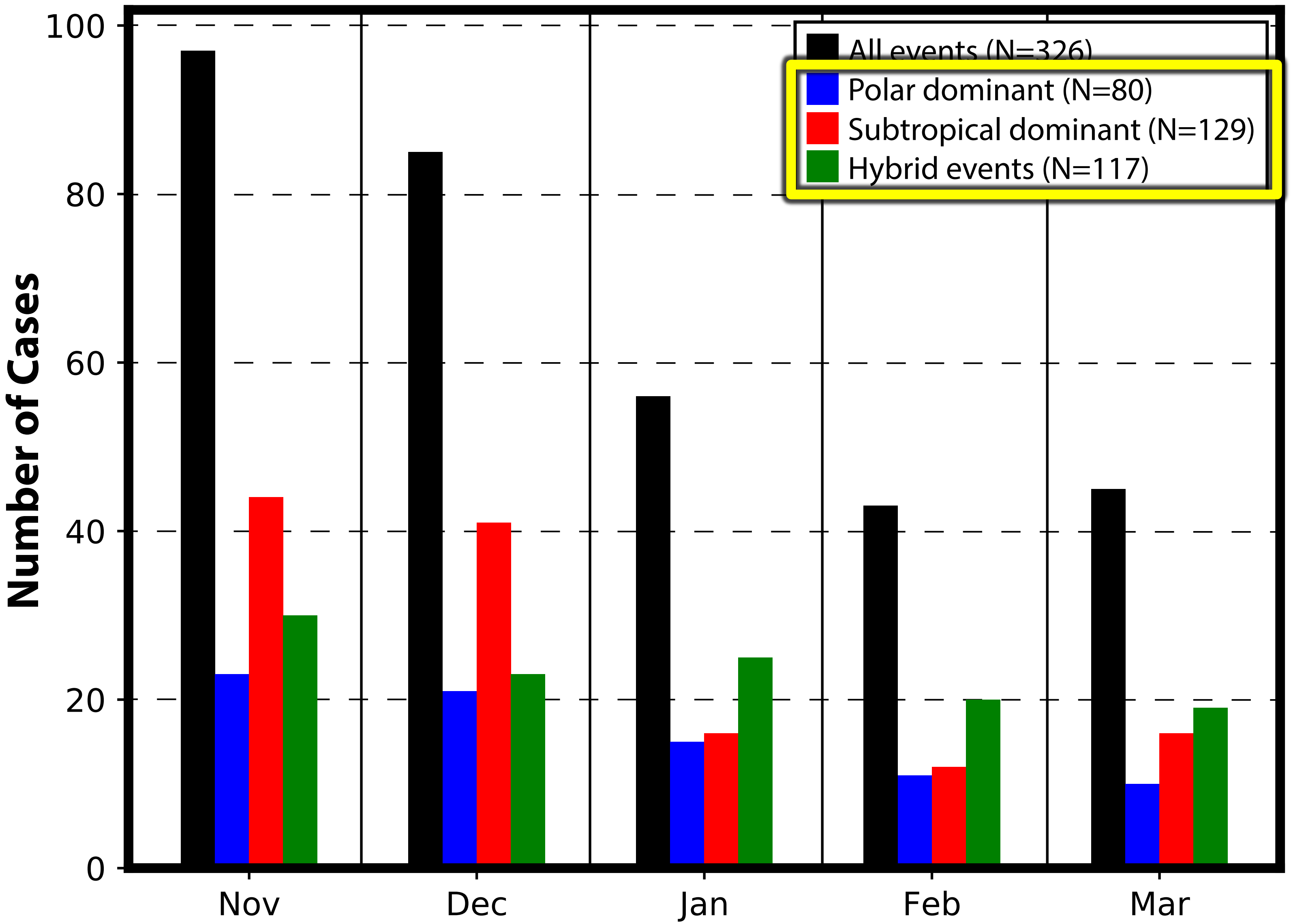
Jet Superposition Event Classification



Jet Superposition Event Classification

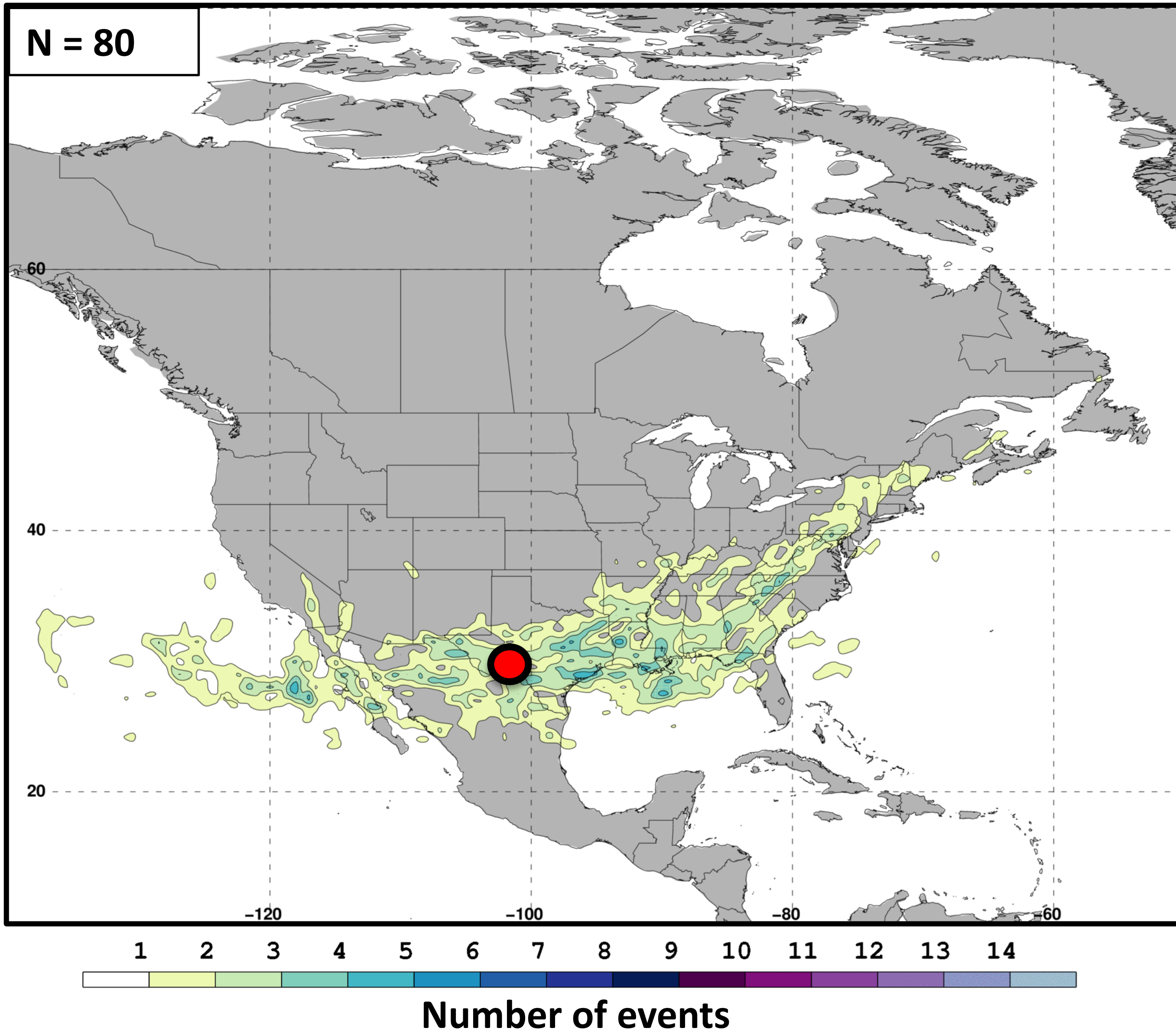


Jet Superposition Event Classification



Jet Superposition Event Classification

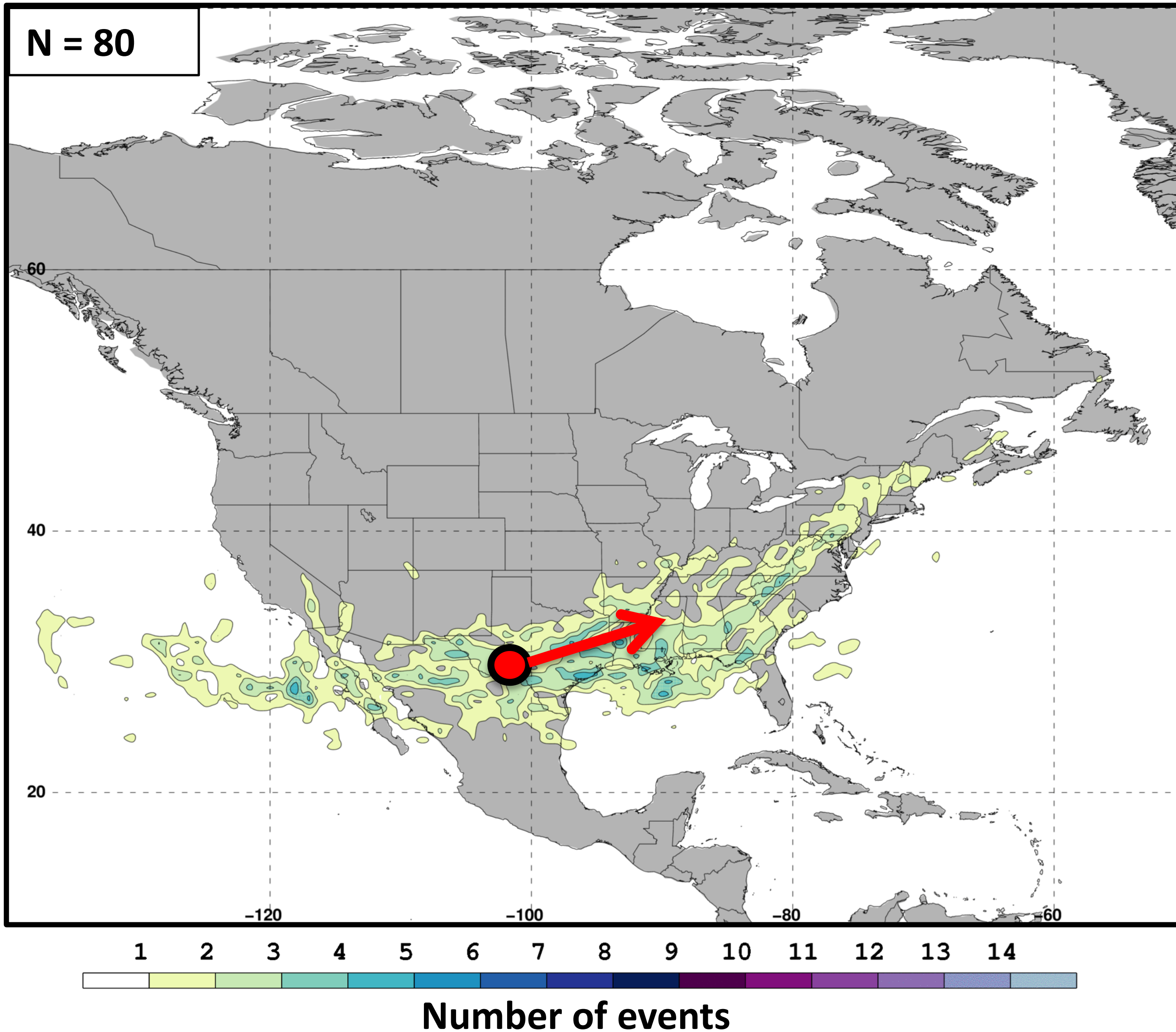
Frequency of
Polar Dominant
Jet
Superposition
Events



Legend
Centroid of all events
Composite movement of superposition

Jet Superposition Event Classification

Frequency of Polar Dominant Jet Superposition Events

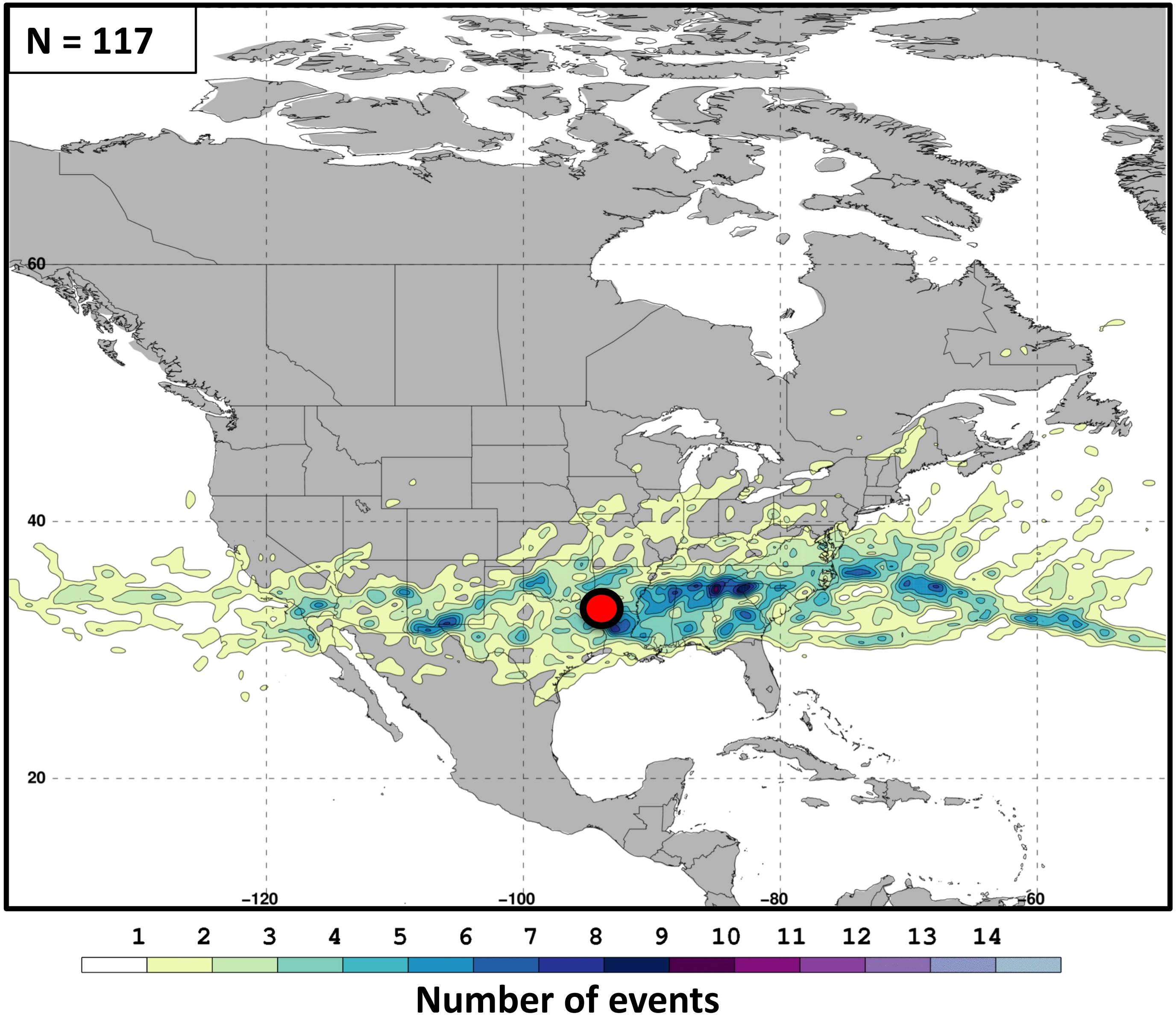


Legend

- Centroid of all events
- Composite movement of superposition

Jet Superposition Event Classification

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

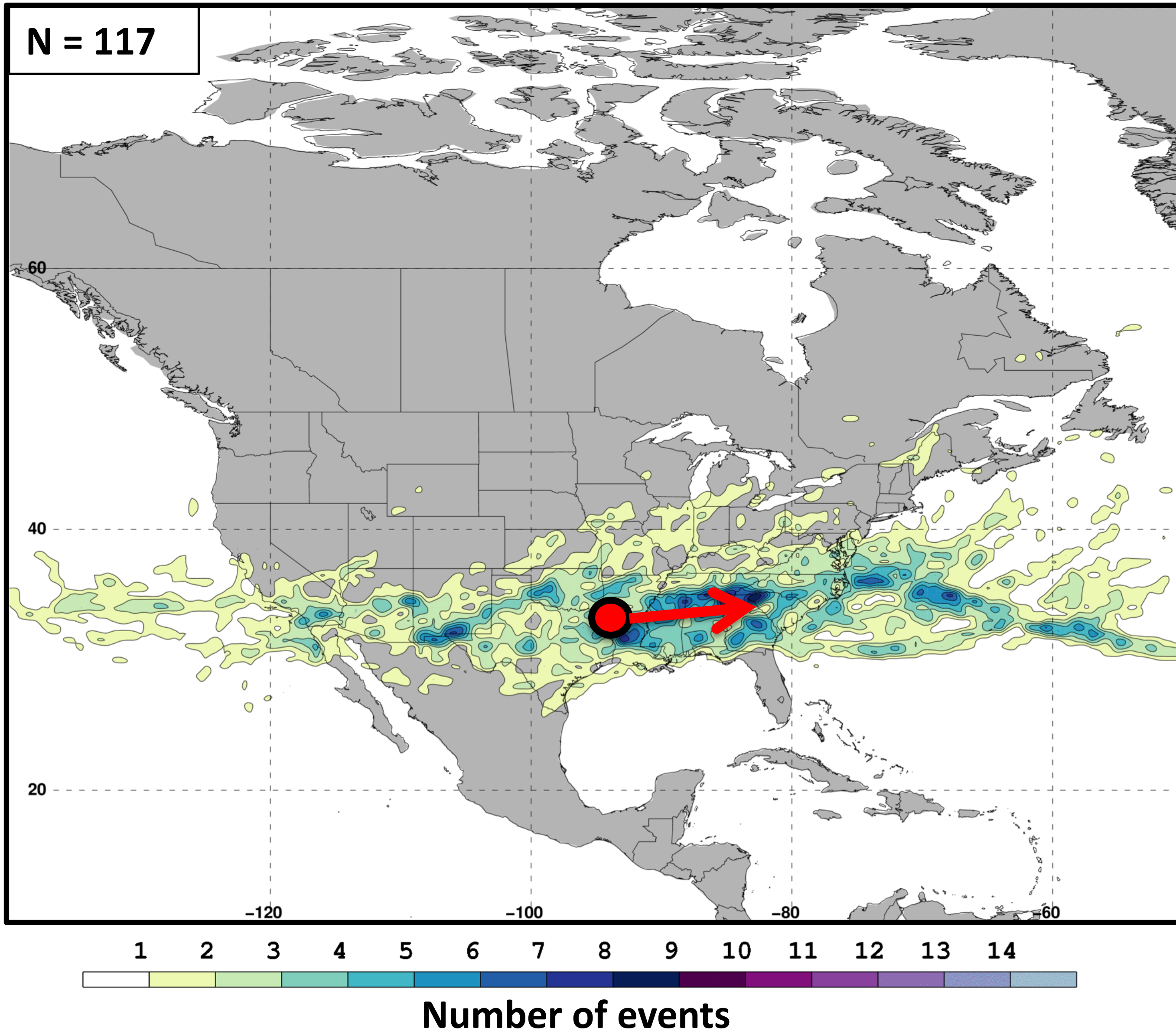


Legend

- Centroid of all events
- Composite movement of superposition

Jet Superposition Event Classification

Frequency of
Hybrid
Jet Superposition Events



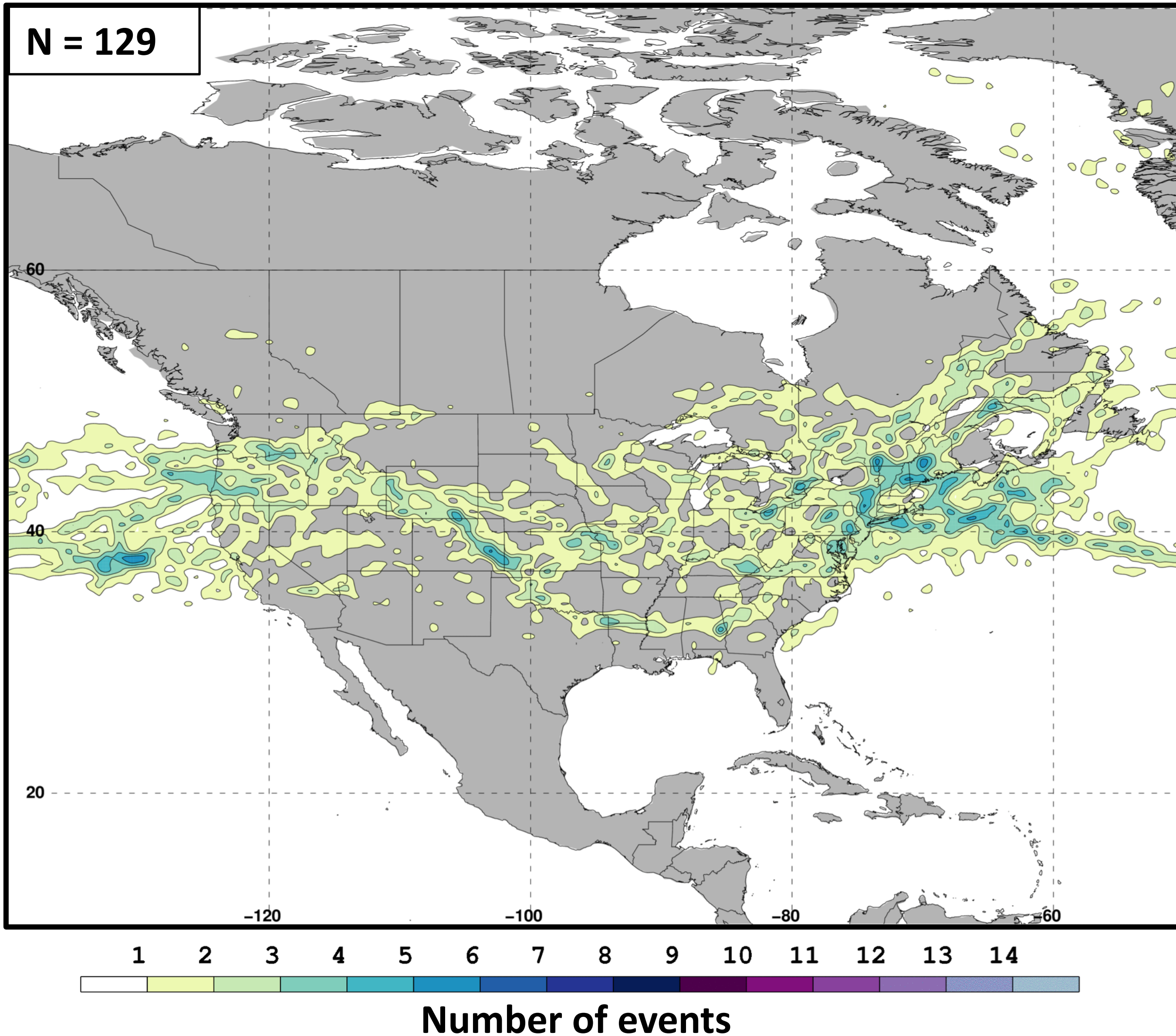
Legend

Centroid of all events

Composite movement of superposition

Jet Superposition Event Classification

Frequency of Subtropical Dominant Jet Superposition Events

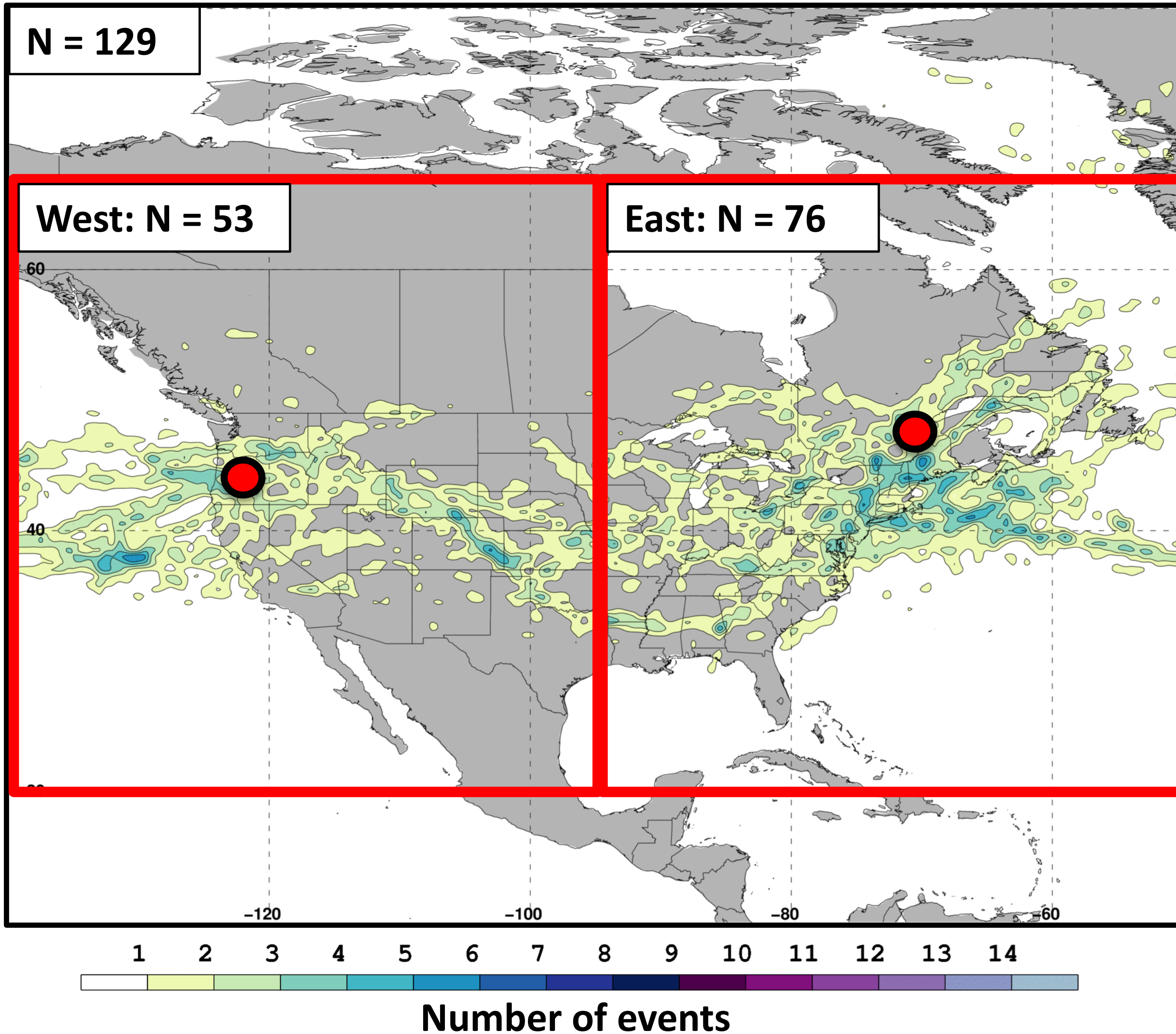


Legend

- Centroid of all events
- Composite movement of superposition

Jet Superposition Event Classification

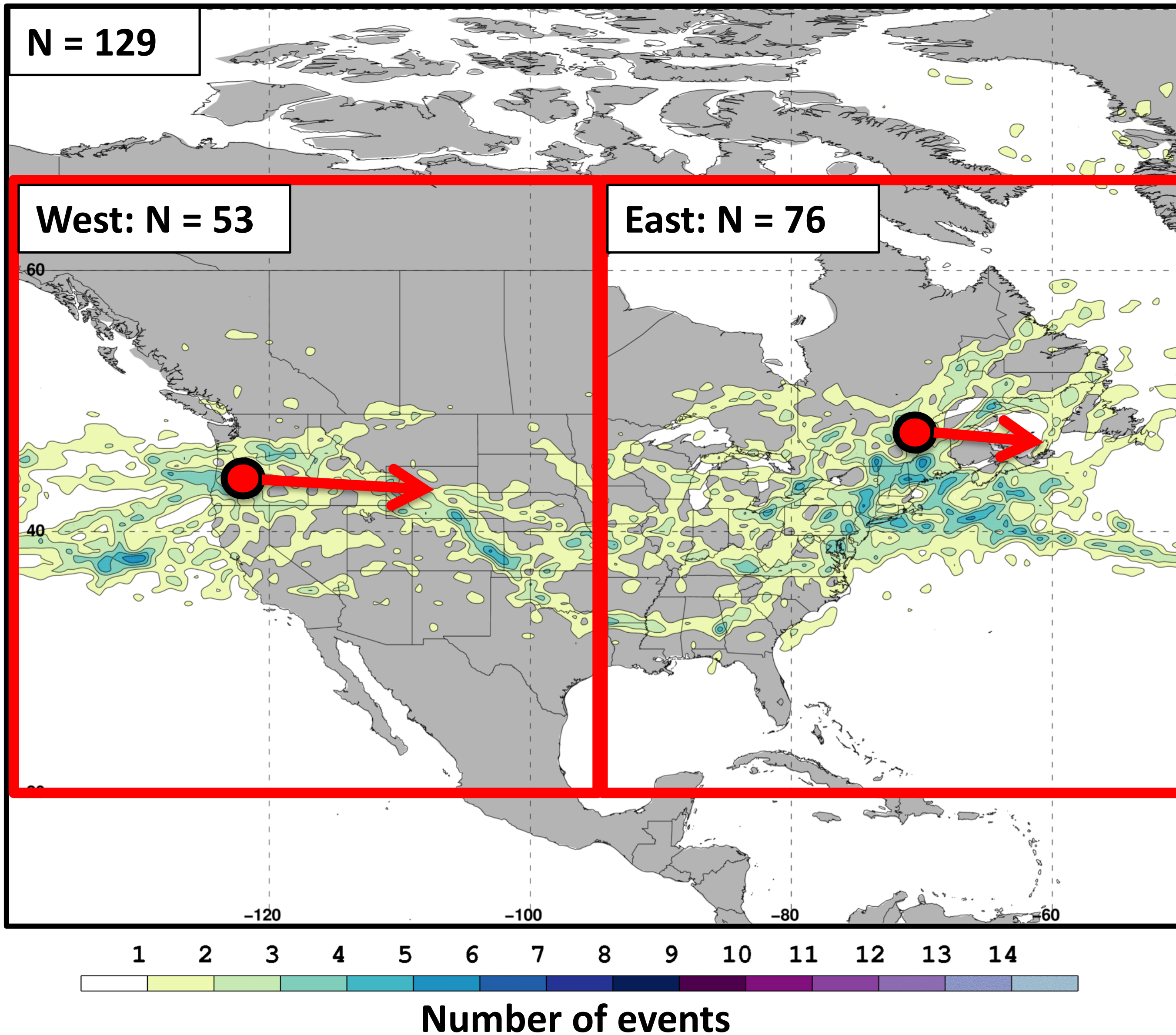
Frequency of Subtropical Dominant Jet Superposition Events



Legend	
●	Centroid of all events
→	Composite movement of superposition

Jet Superposition Event Classification

Frequency of Subtropical Dominant Jet Superposition Events



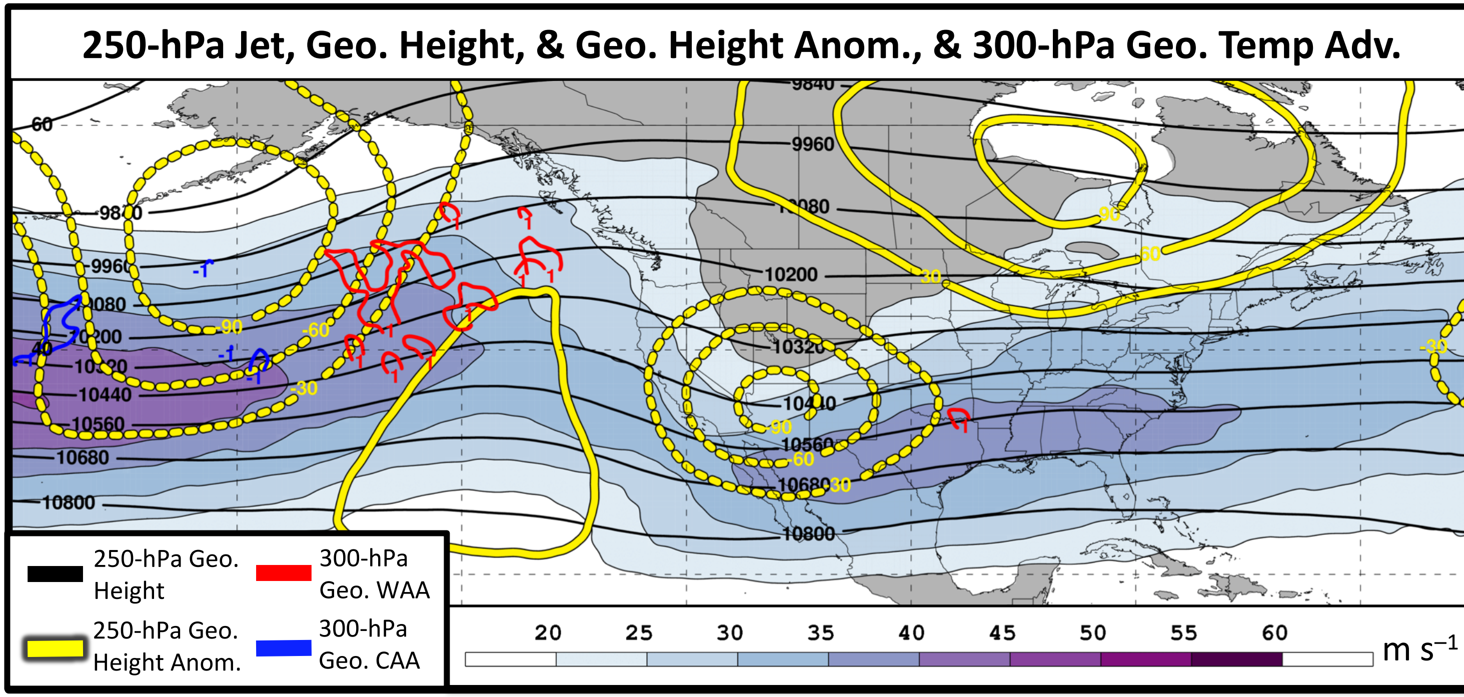
Legend	
●	Centroid of all events
→	Composite movement of superposition

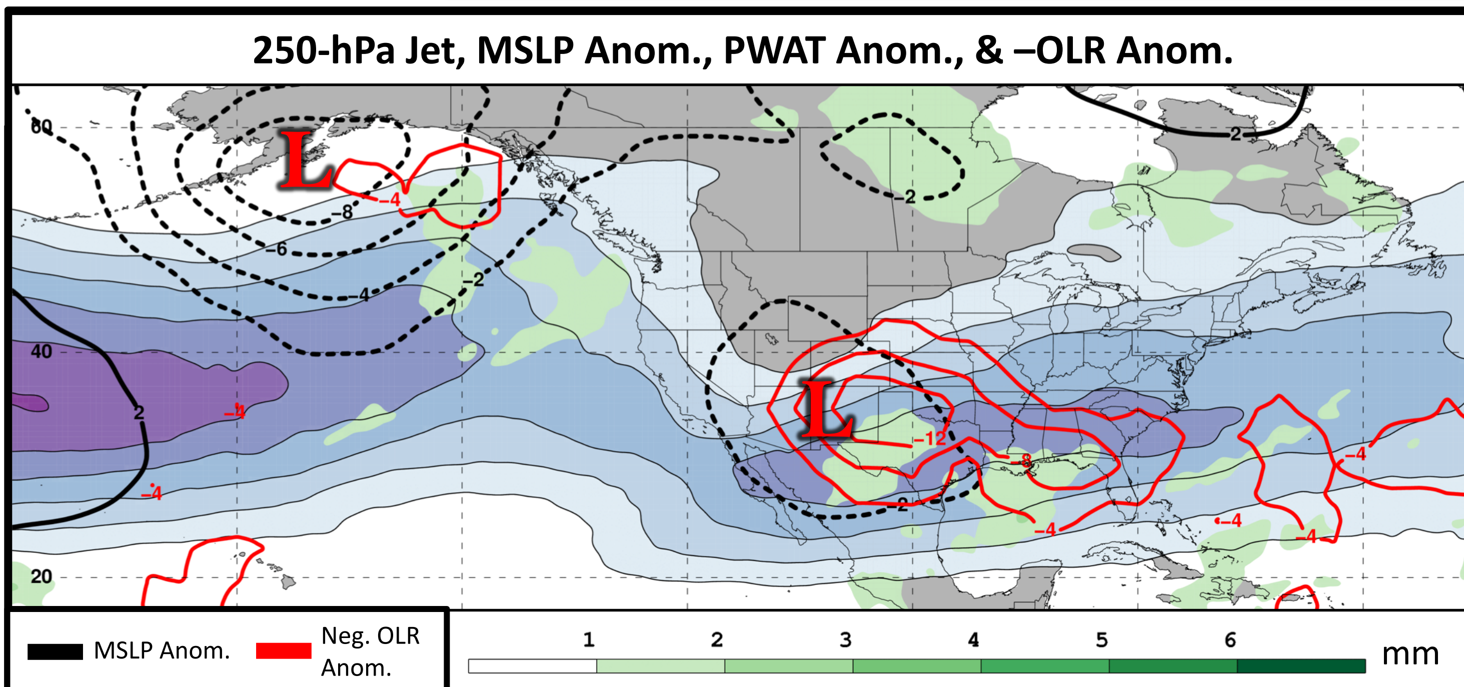
Jet Superposition Event Composites:

Polar Dominant
vs.
East Subtropical Dominant

Polar Dominant Jet Superposition Events

2 Days Prior to Jet Superposition

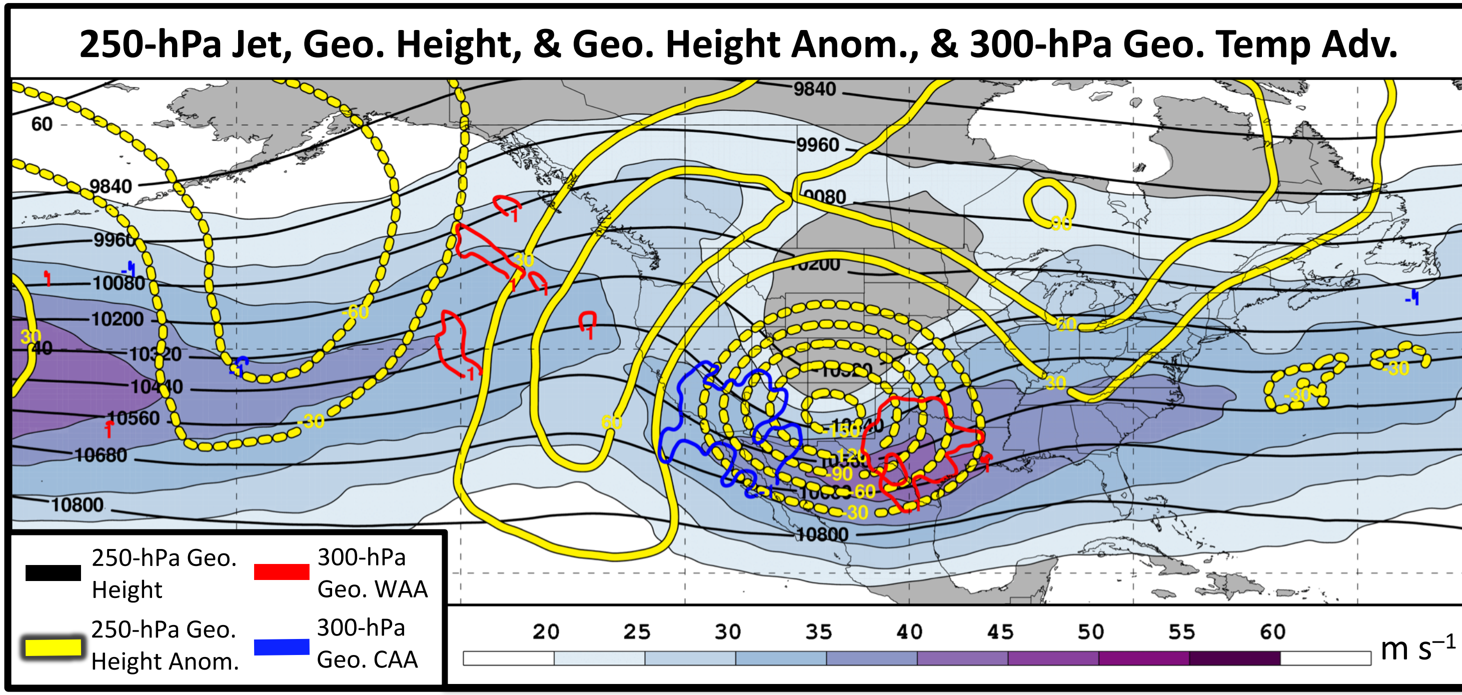


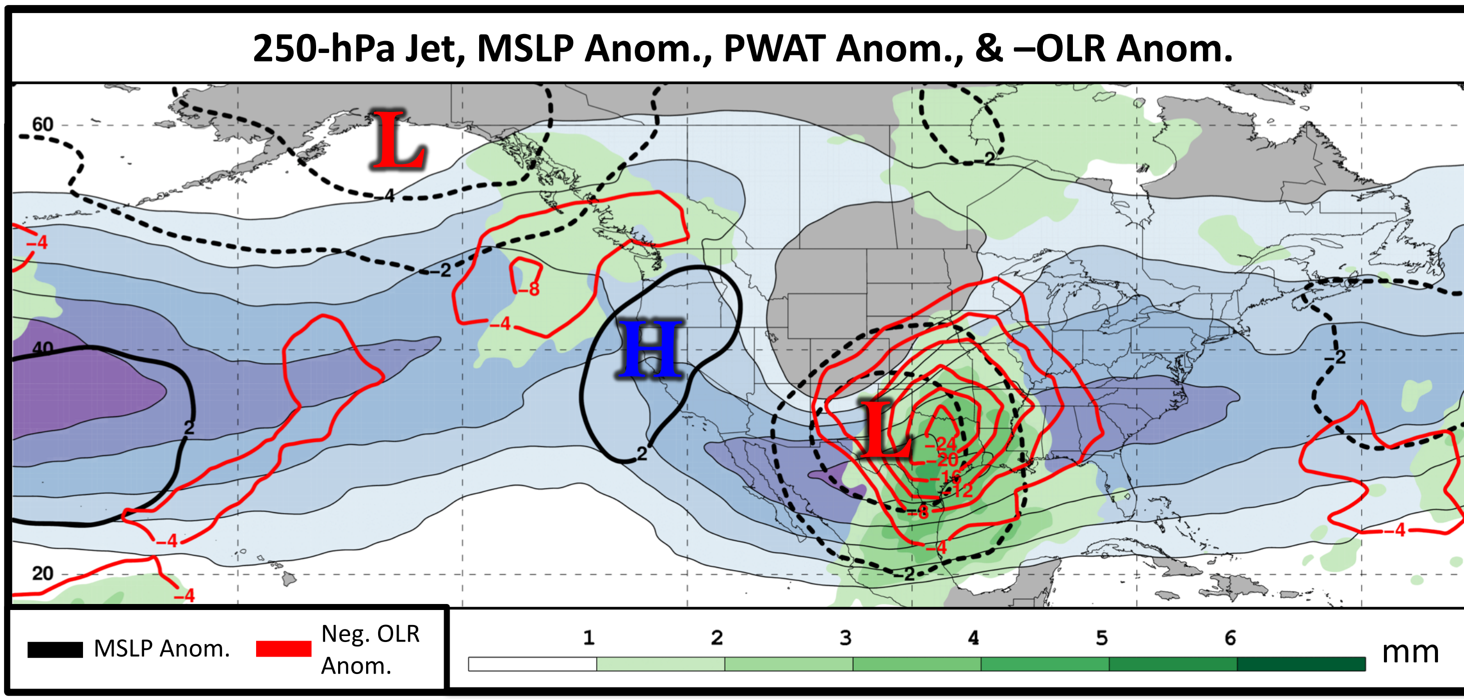


N=80

Polar Dominant Jet Superposition Events

1 Day Prior to Jet Superposition

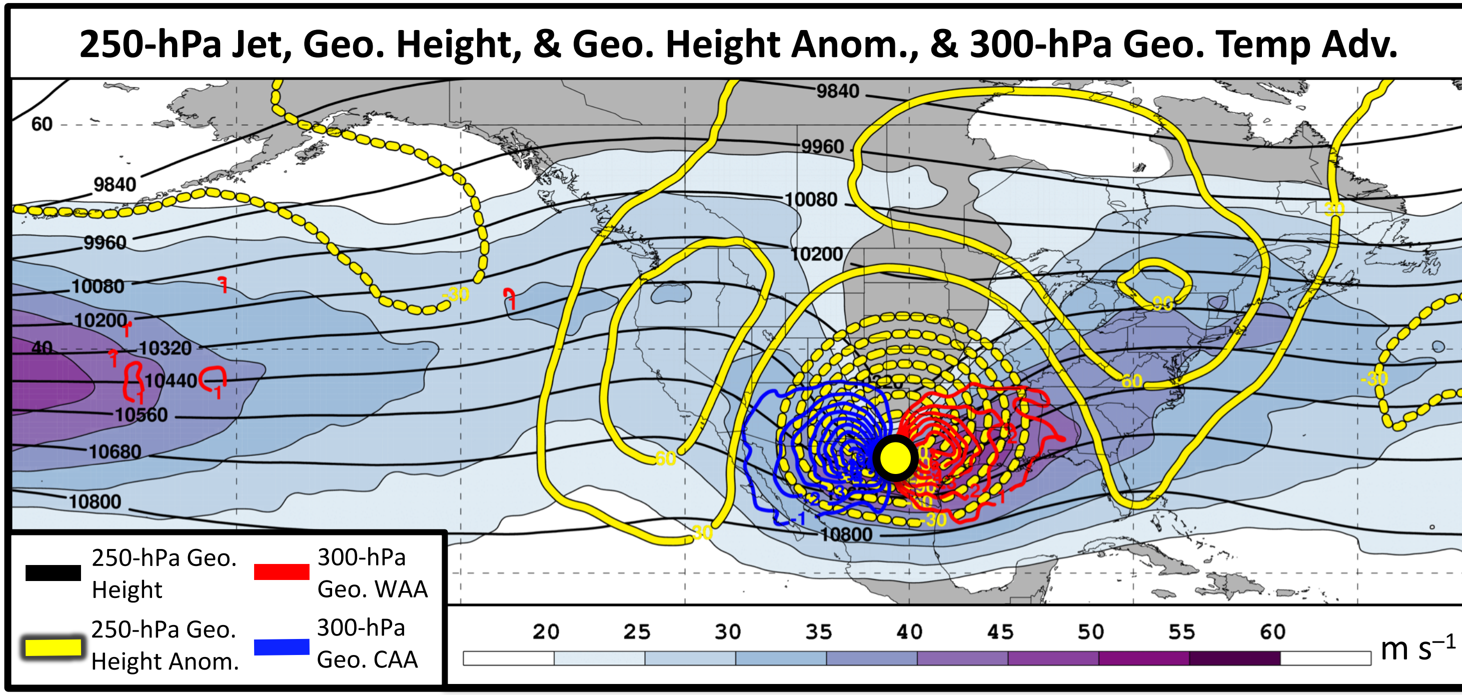


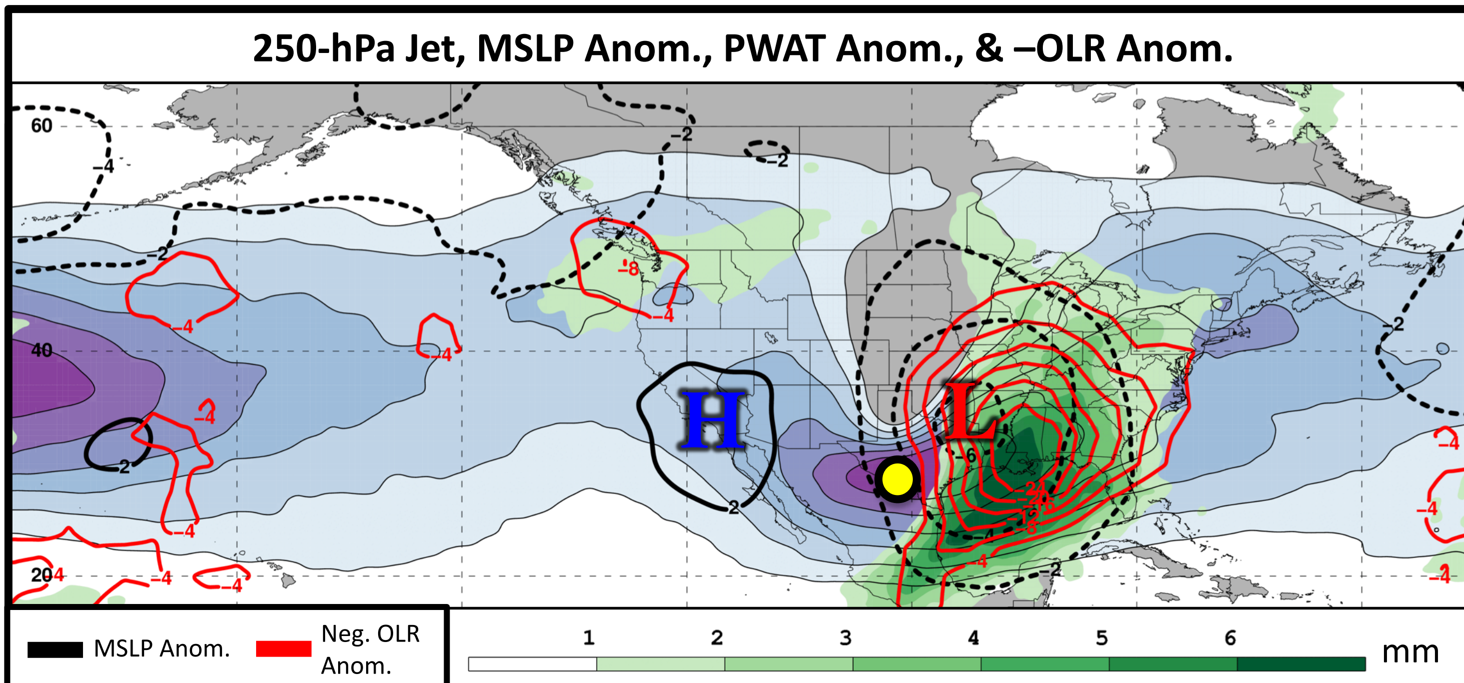


N=80

Polar Dominant Jet Superposition Events

0 Days Prior to Jet Superposition



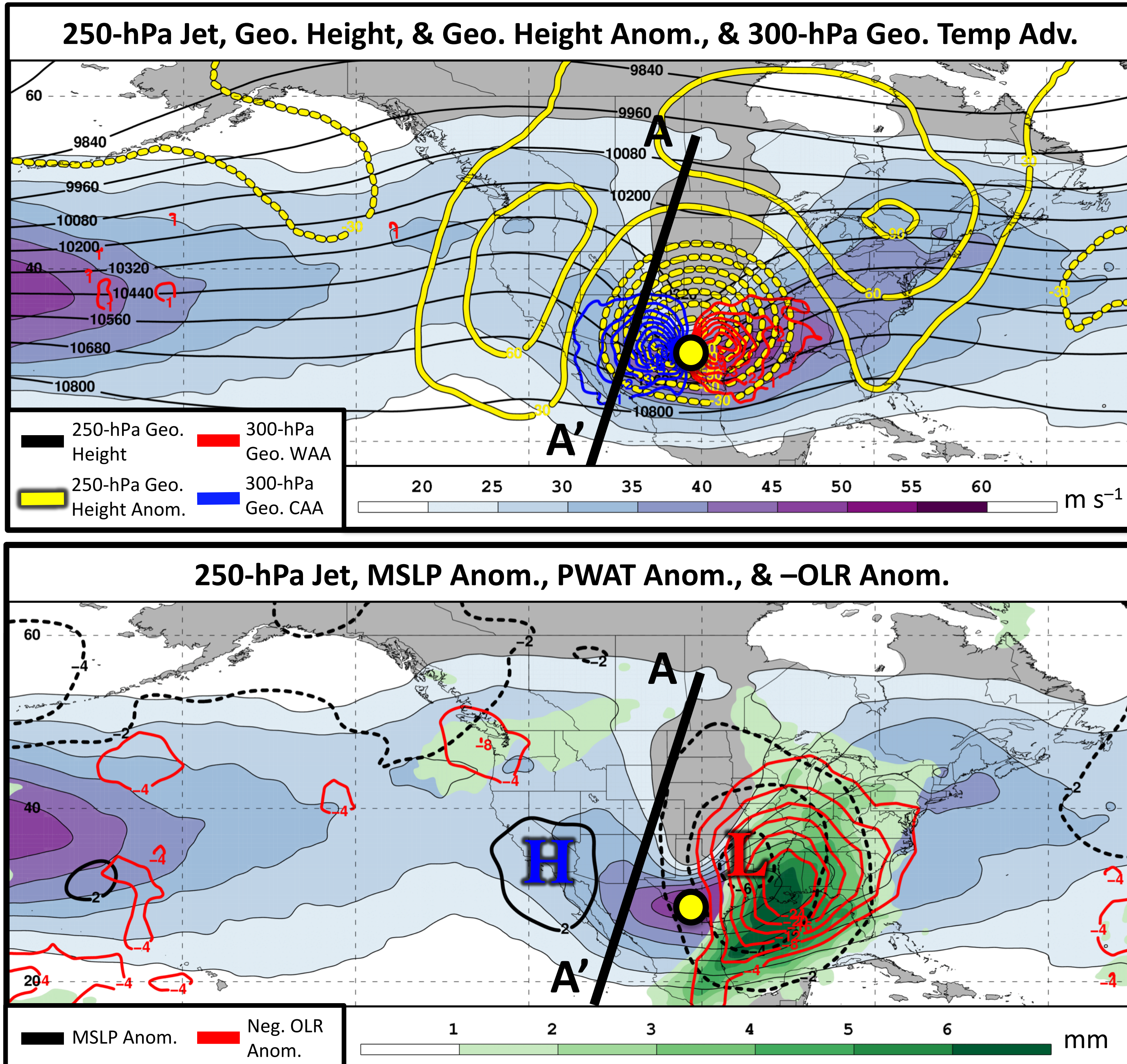


Jet Superposition Centroid

N=80

Polar Dominant Jet Superposition Events

0 Days Prior to Jet Superposition

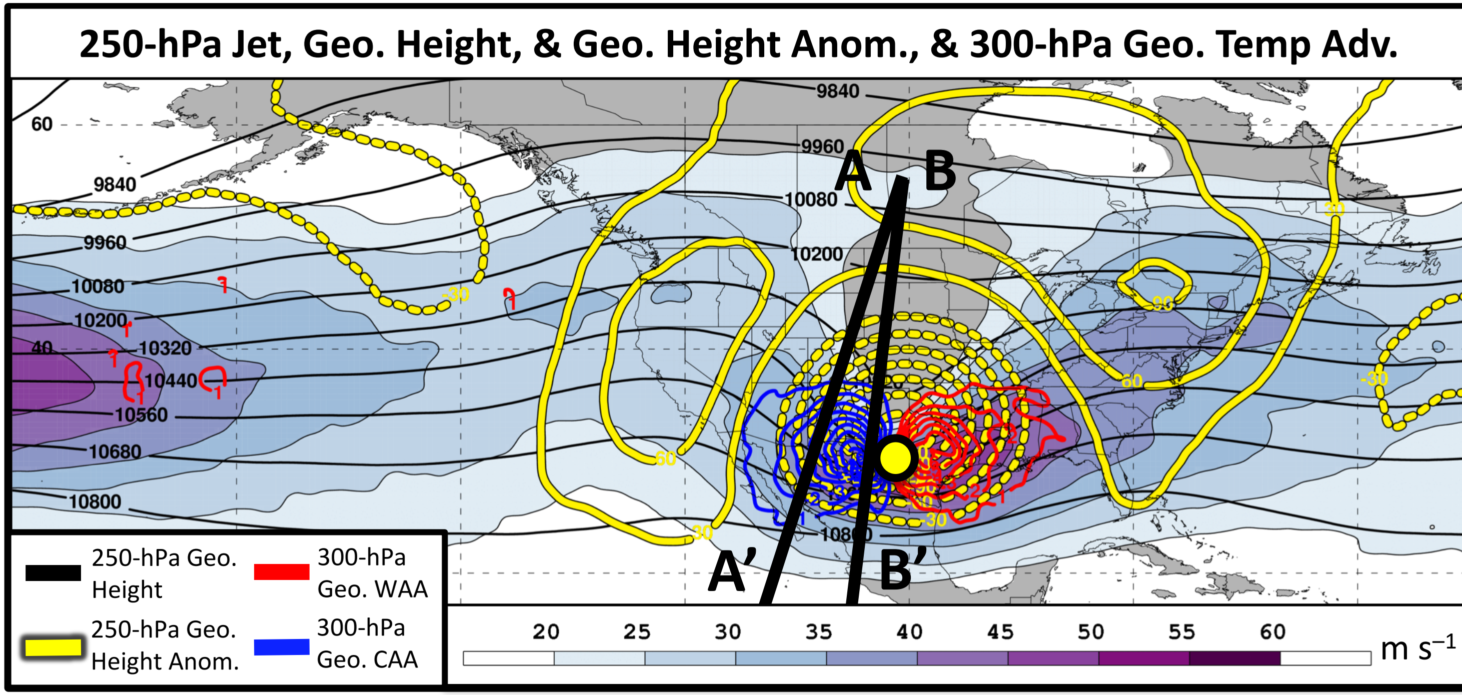


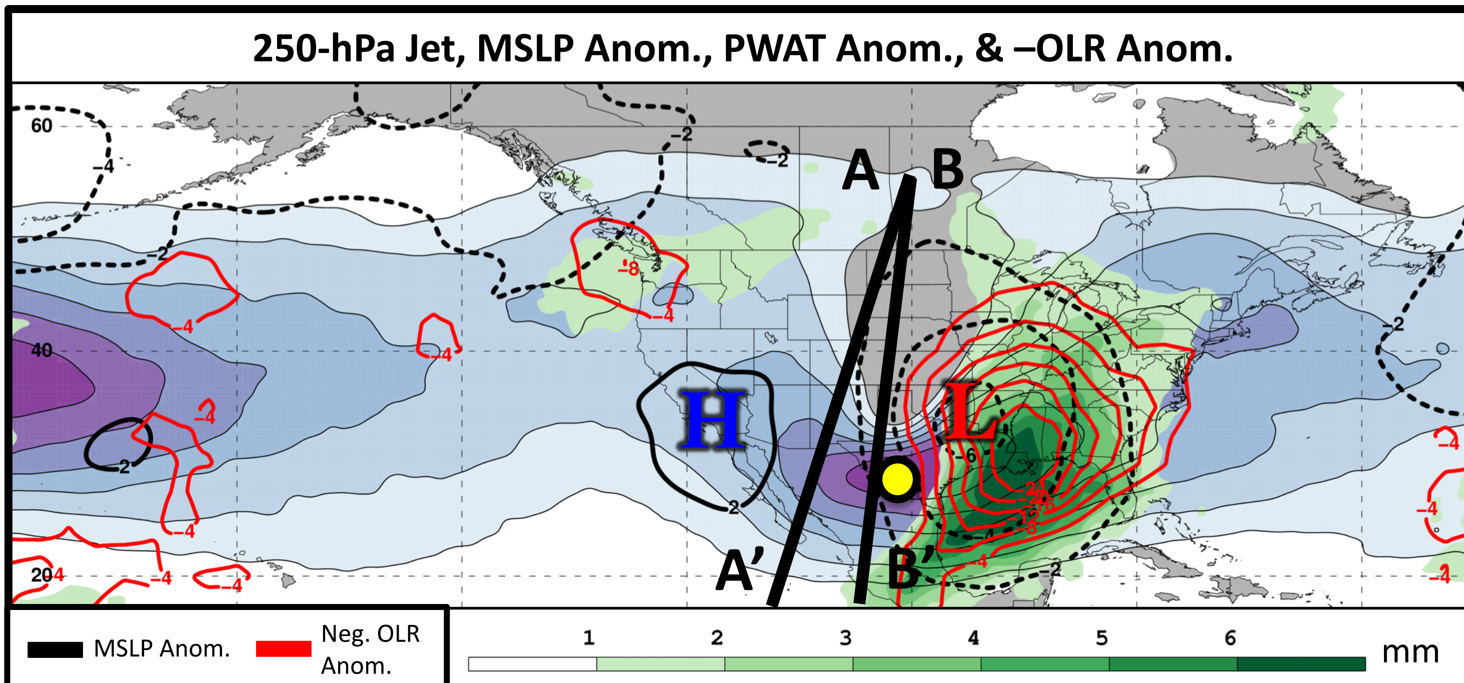
Jet Superposition Centroid

N=80

Polar Dominant Jet Superposition Events

0 Days Prior to Jet Superposition

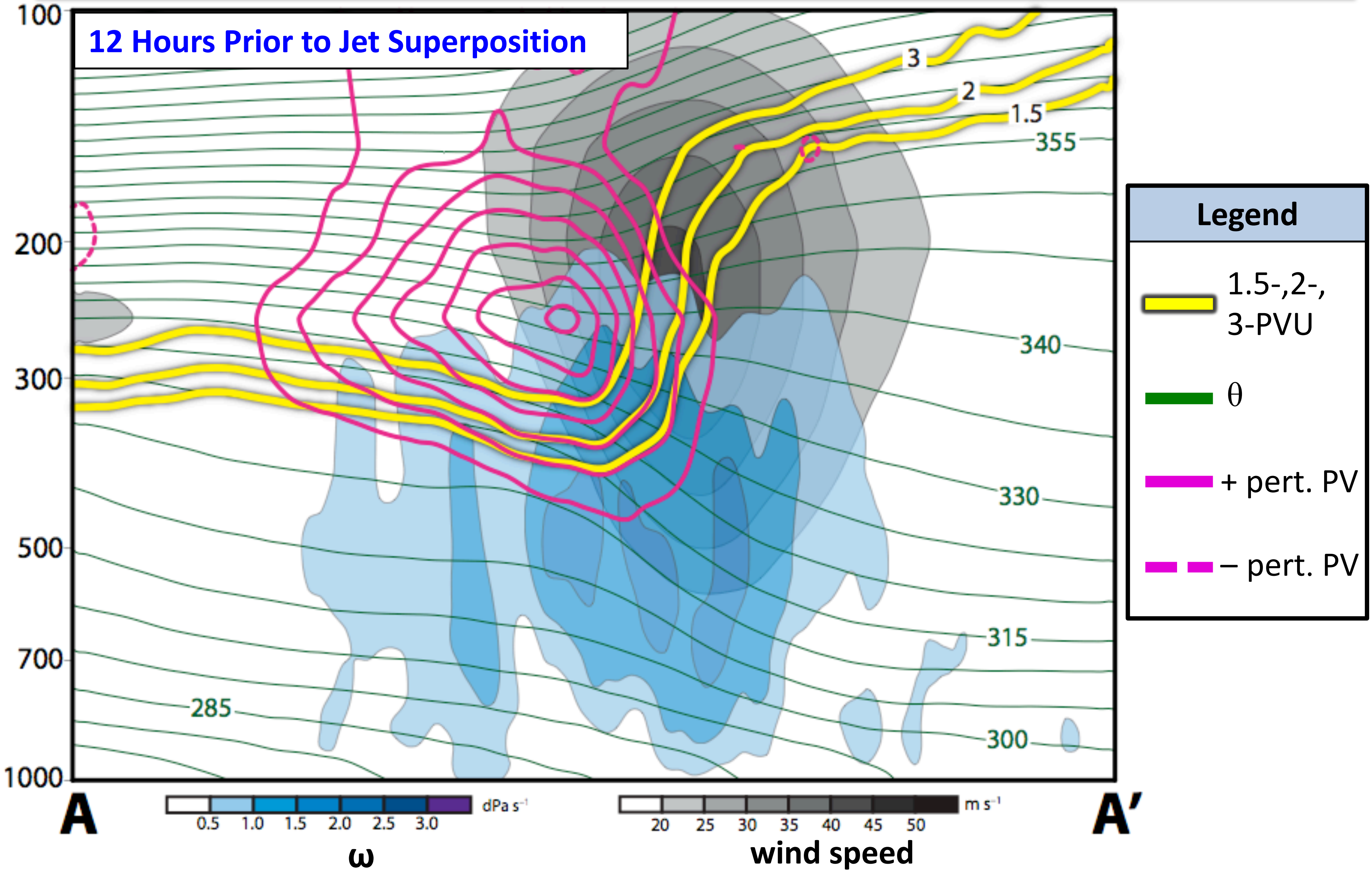




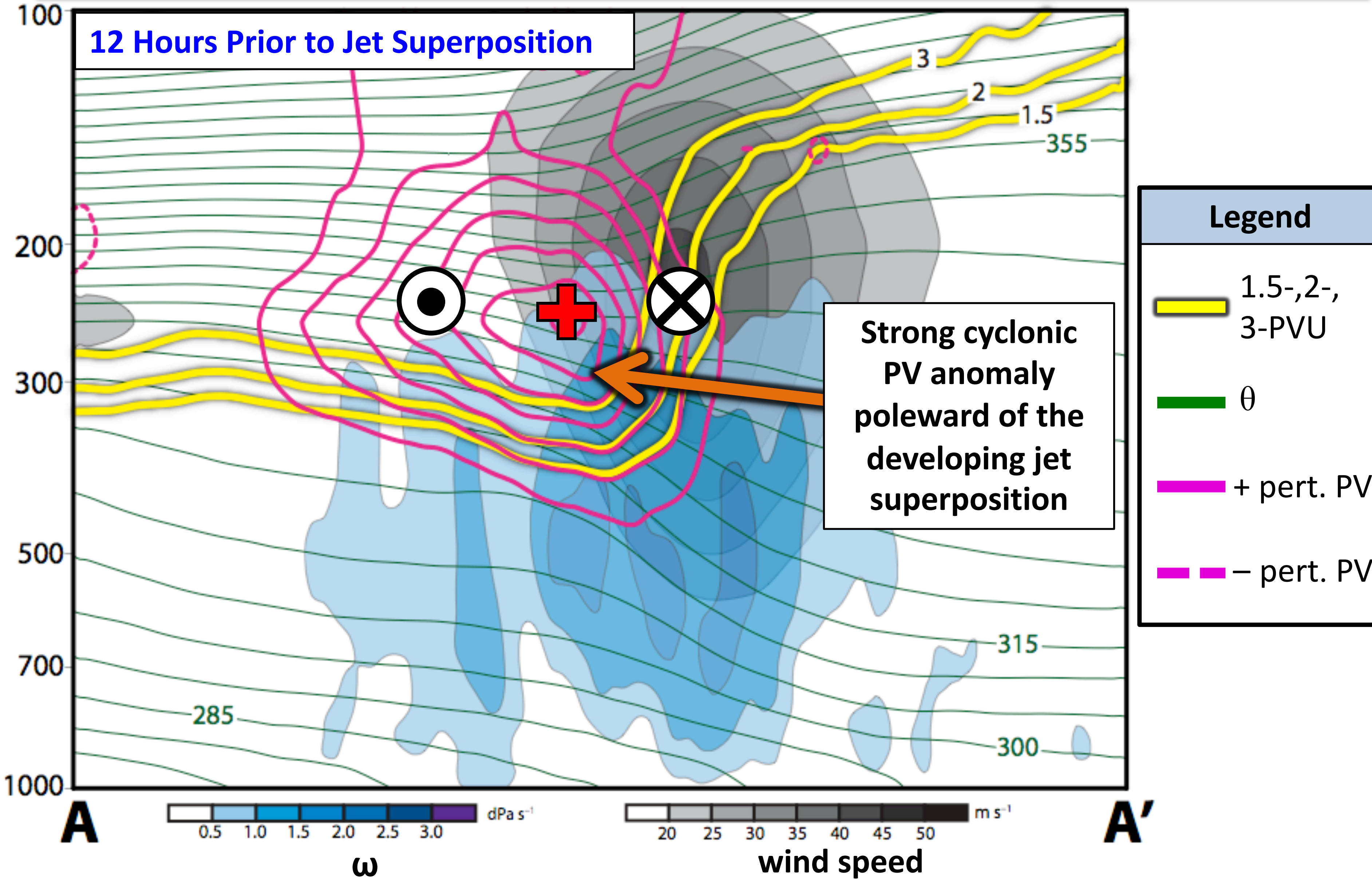
Jet Superposition Centroid

N=80

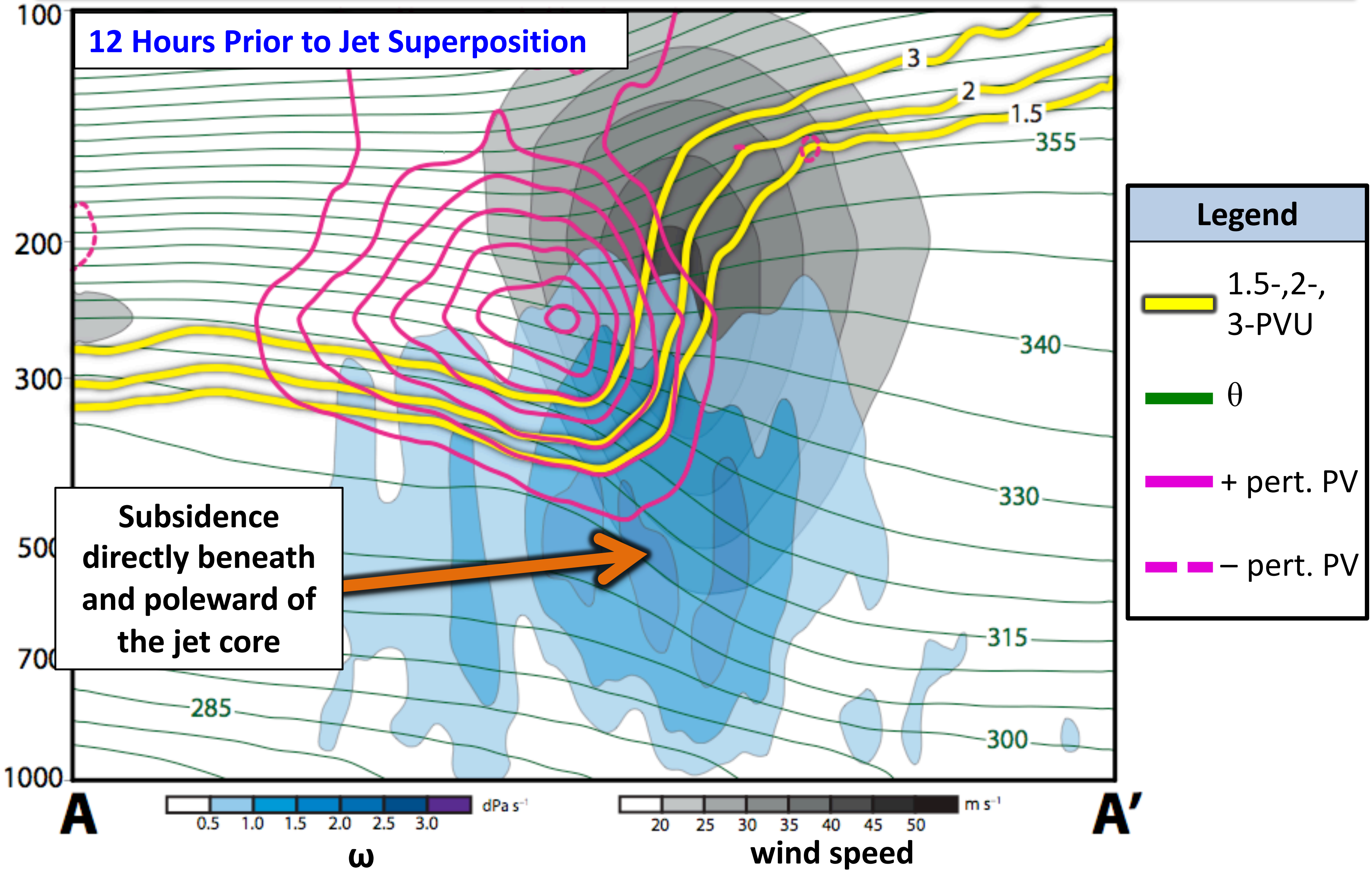
Polar Dominant Jet Superposition Events



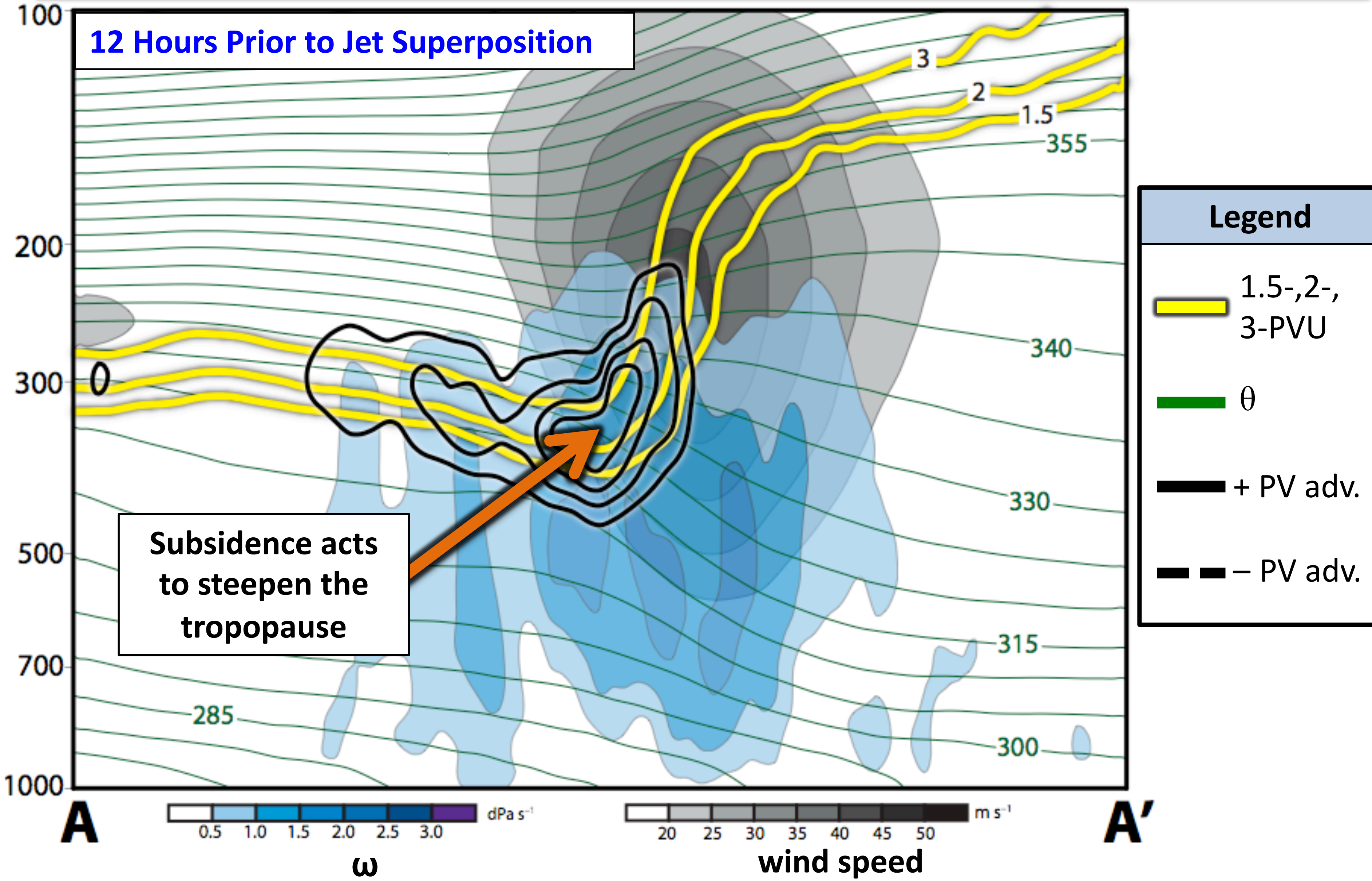
Polar Dominant Jet Superposition Events



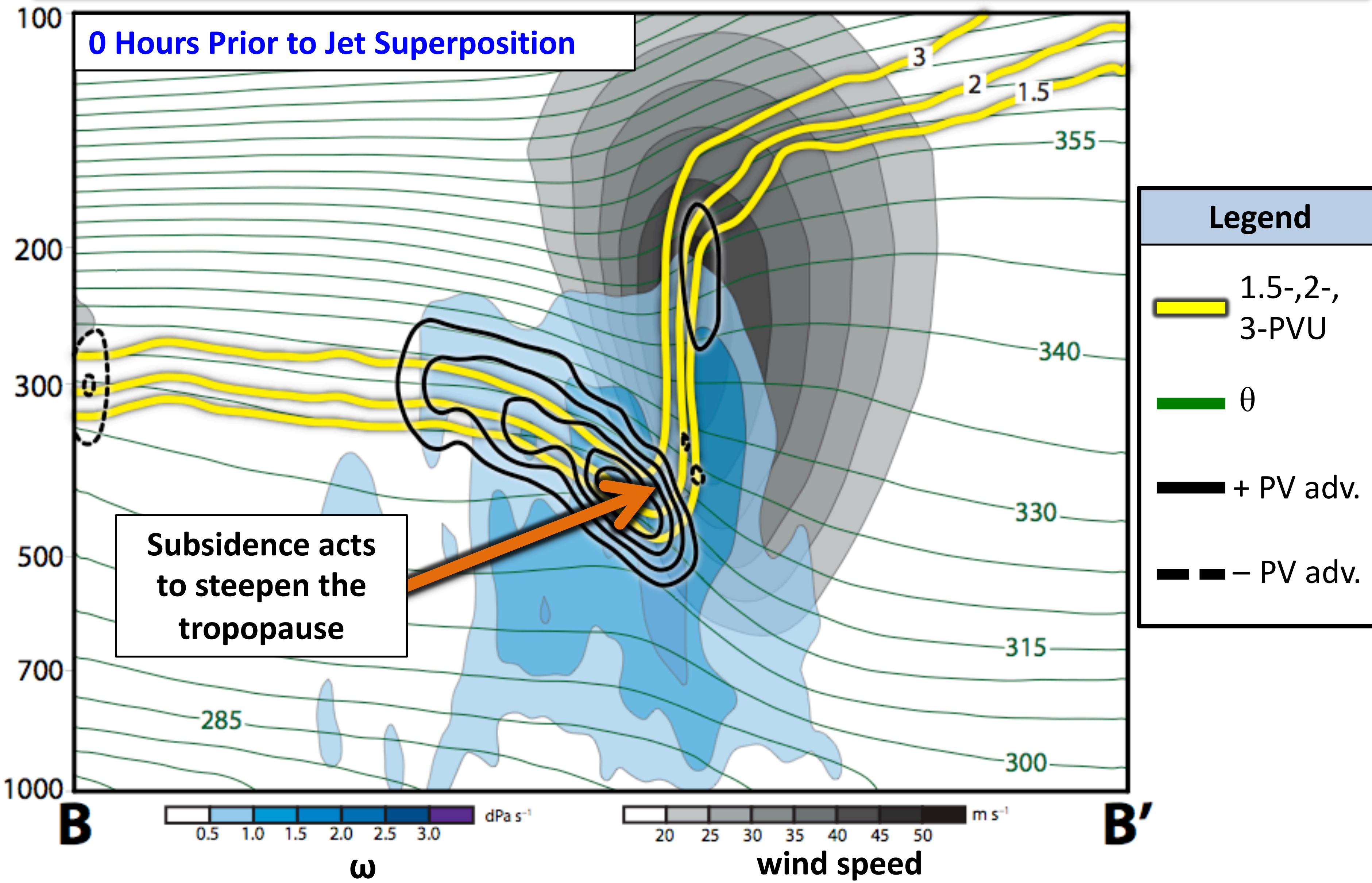
Polar Dominant Jet Superposition Events



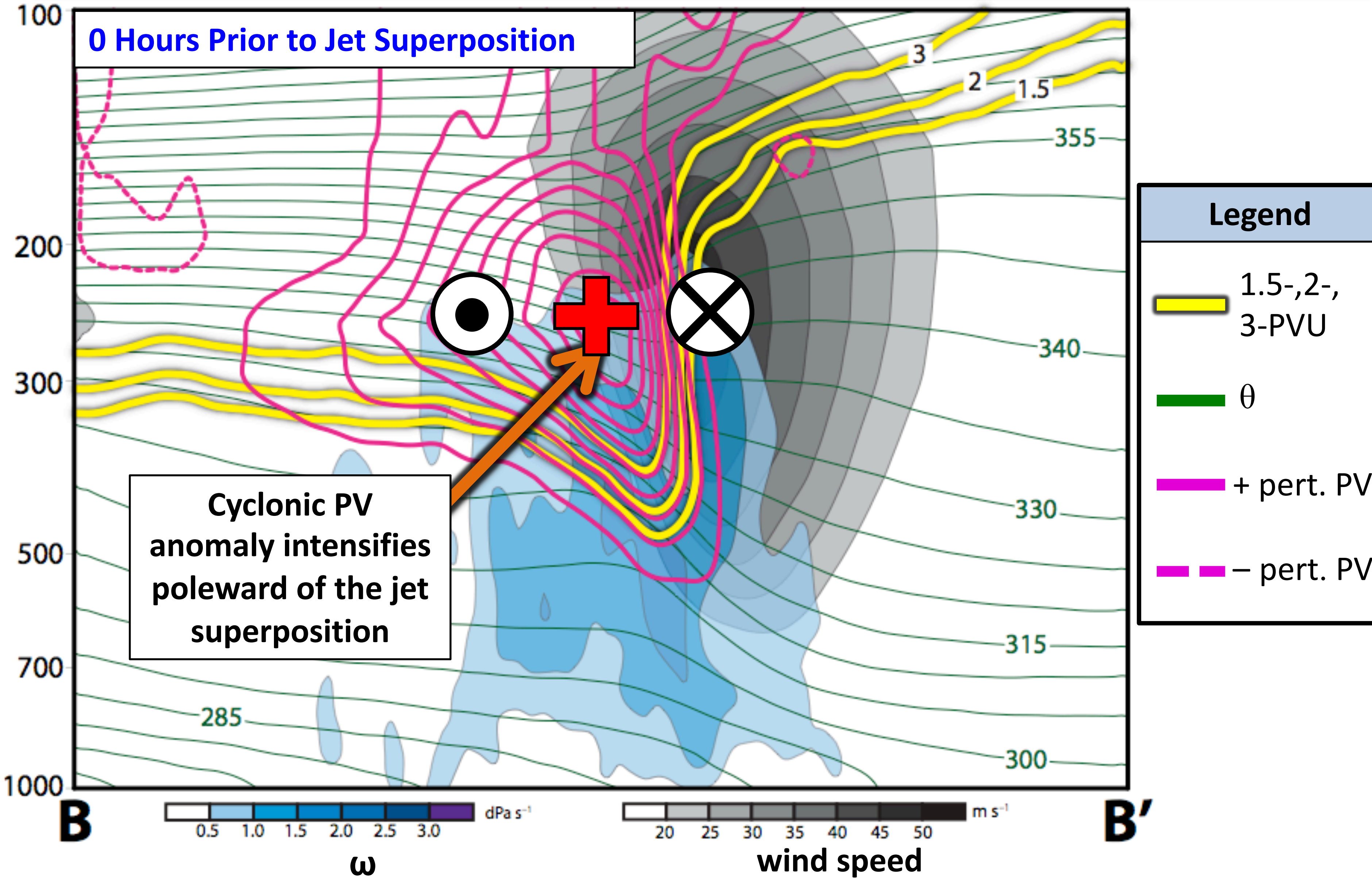
Polar Dominant Jet Superposition Events



Polar Dominant Jet Superposition Events

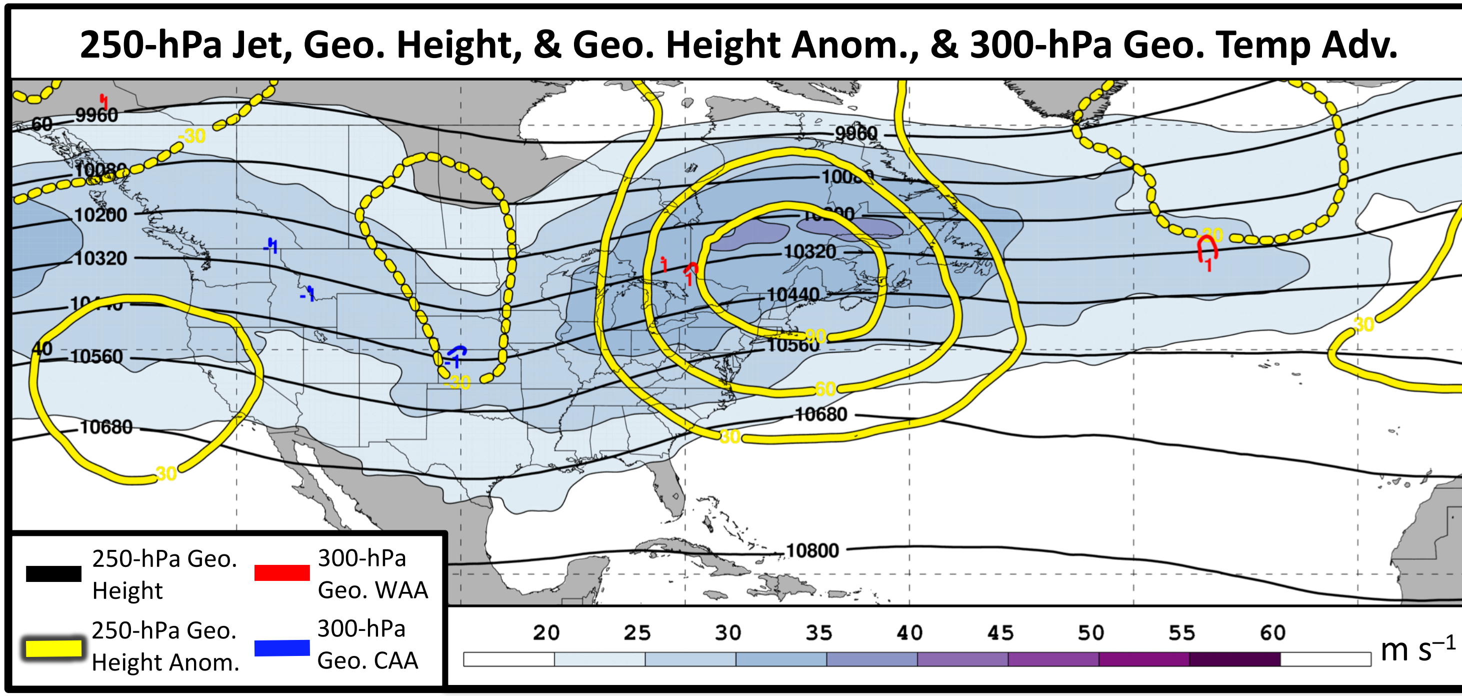


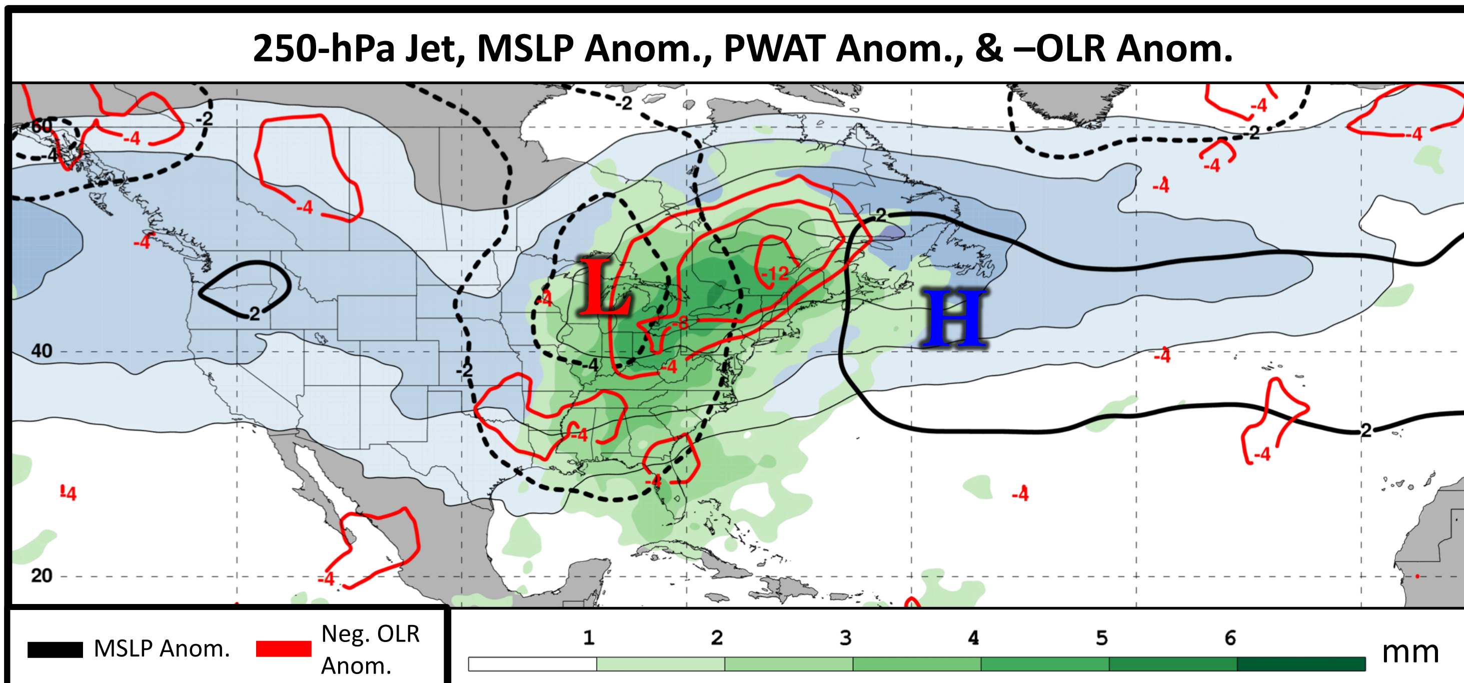
Polar Dominant Jet Superposition Events



E. Subtropical Dominant Jet Superposition Events

2 Days Prior to Jet Superposition



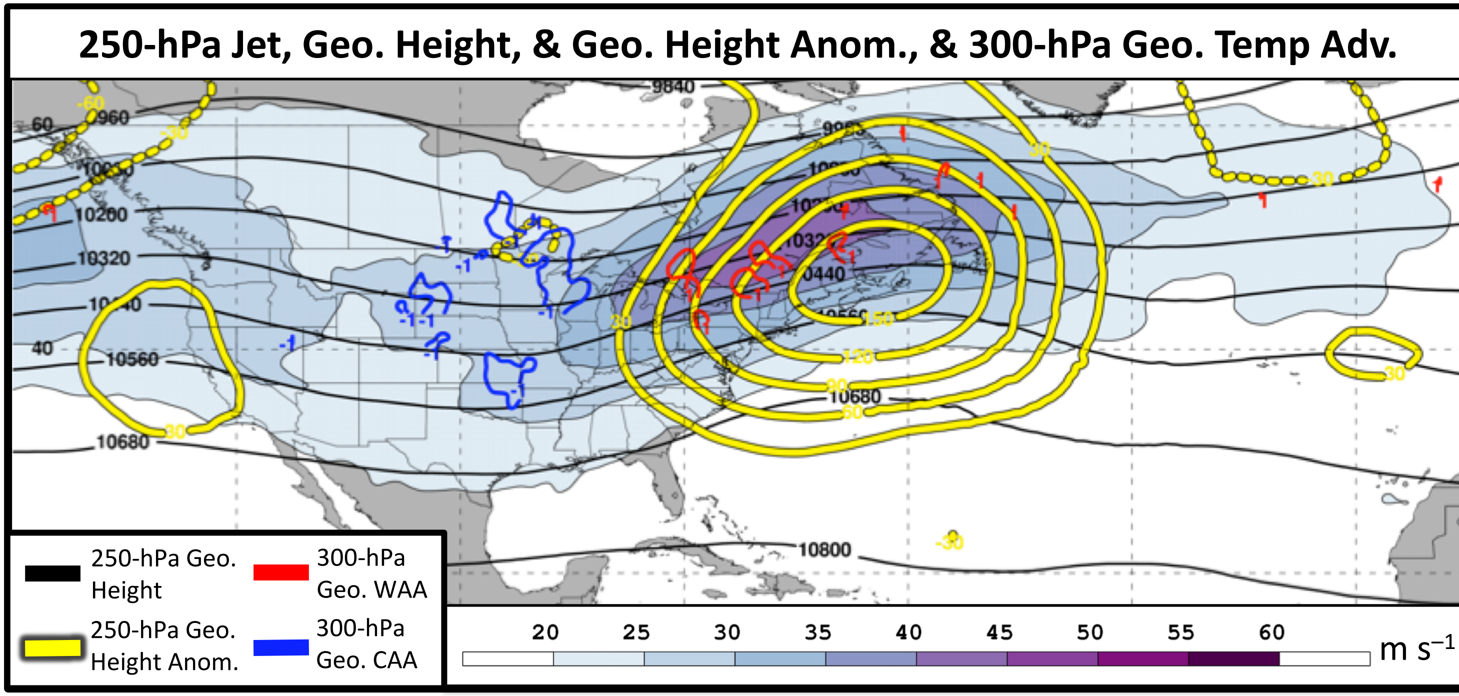


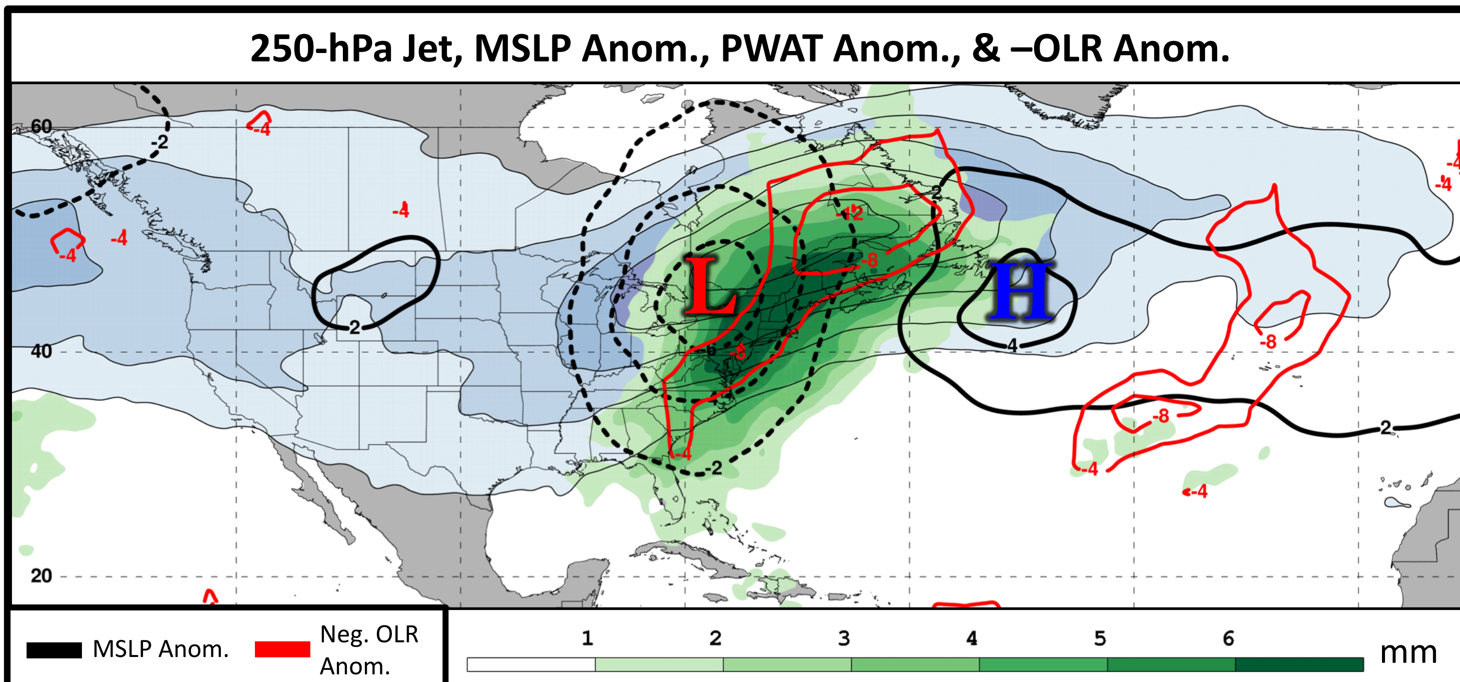
N=76

E. Subtropical Dominant Jet Superposition Events

1 Day Prior to Jet Superposition

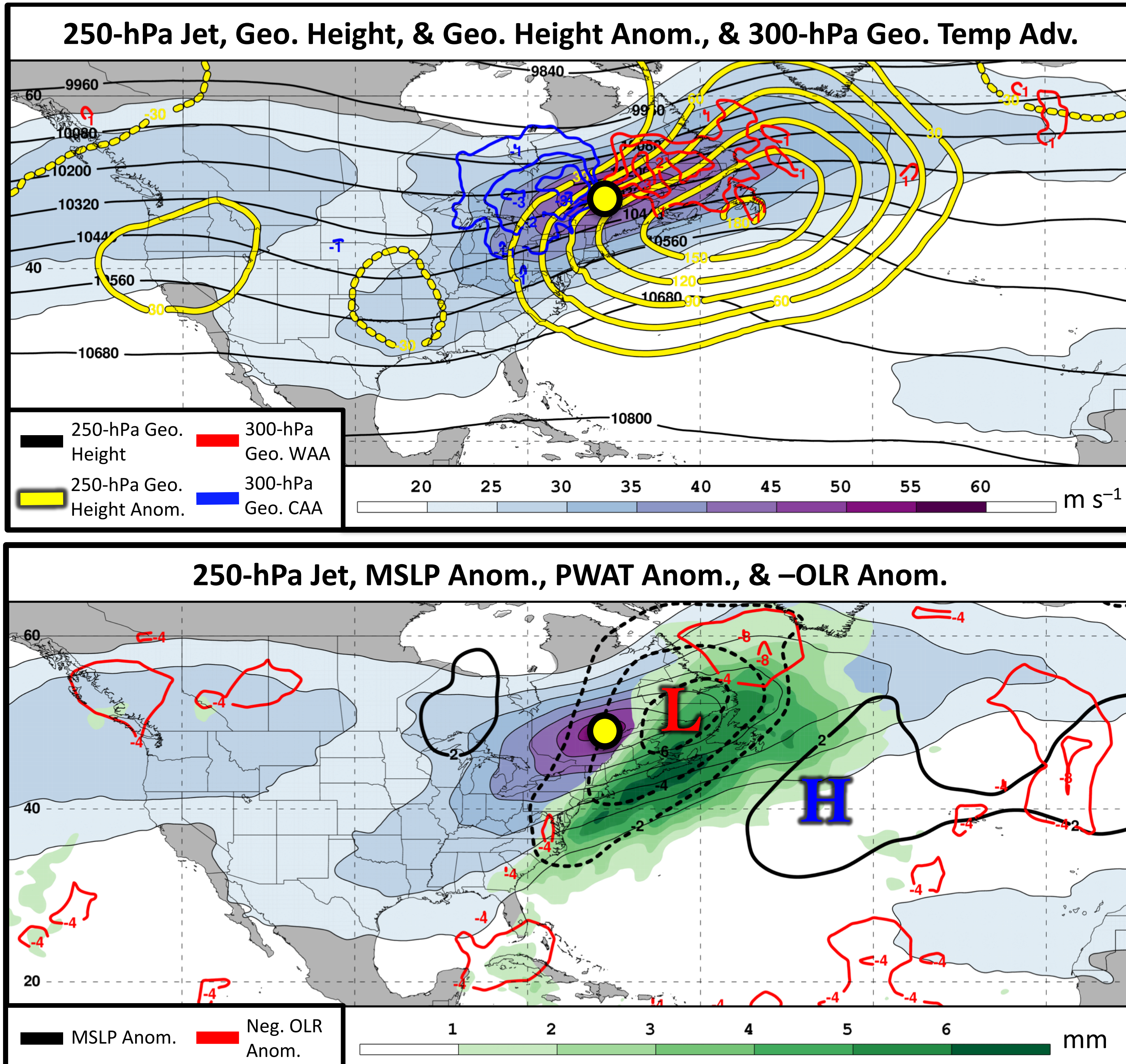
N=76





E. Subtropical Dominant Jet Superposition Events

0 Days Prior to Jet Superposition

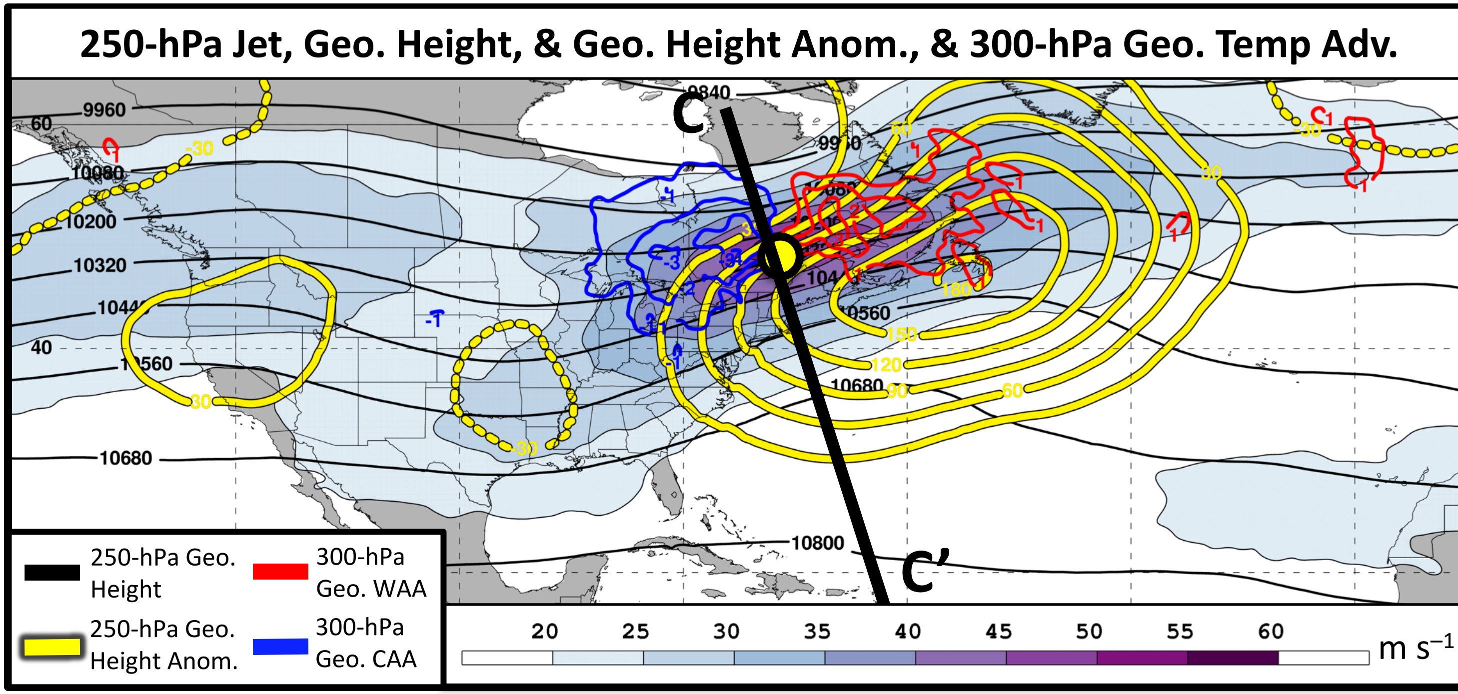


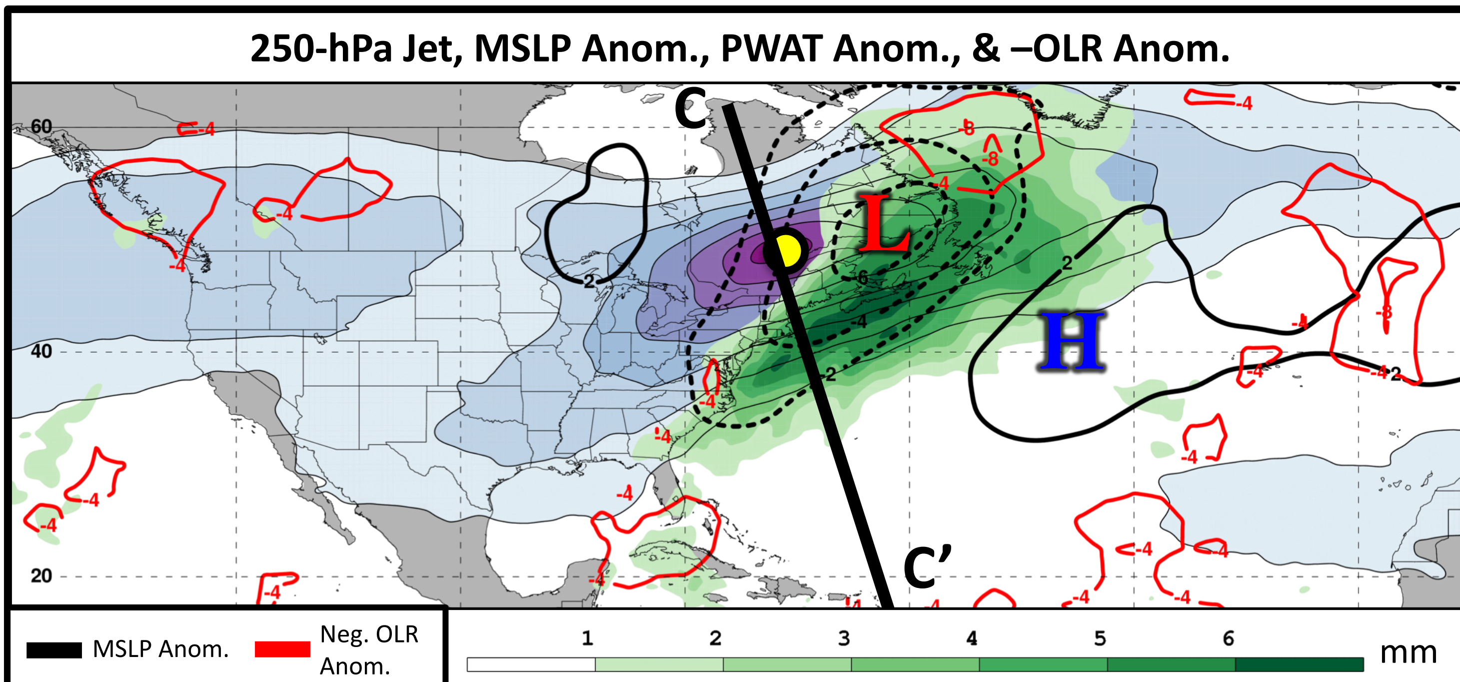
Jet Superposition Centroid

N=76

E. Subtropical Dominant Jet Superposition Events

0 Days Prior to Jet Superposition

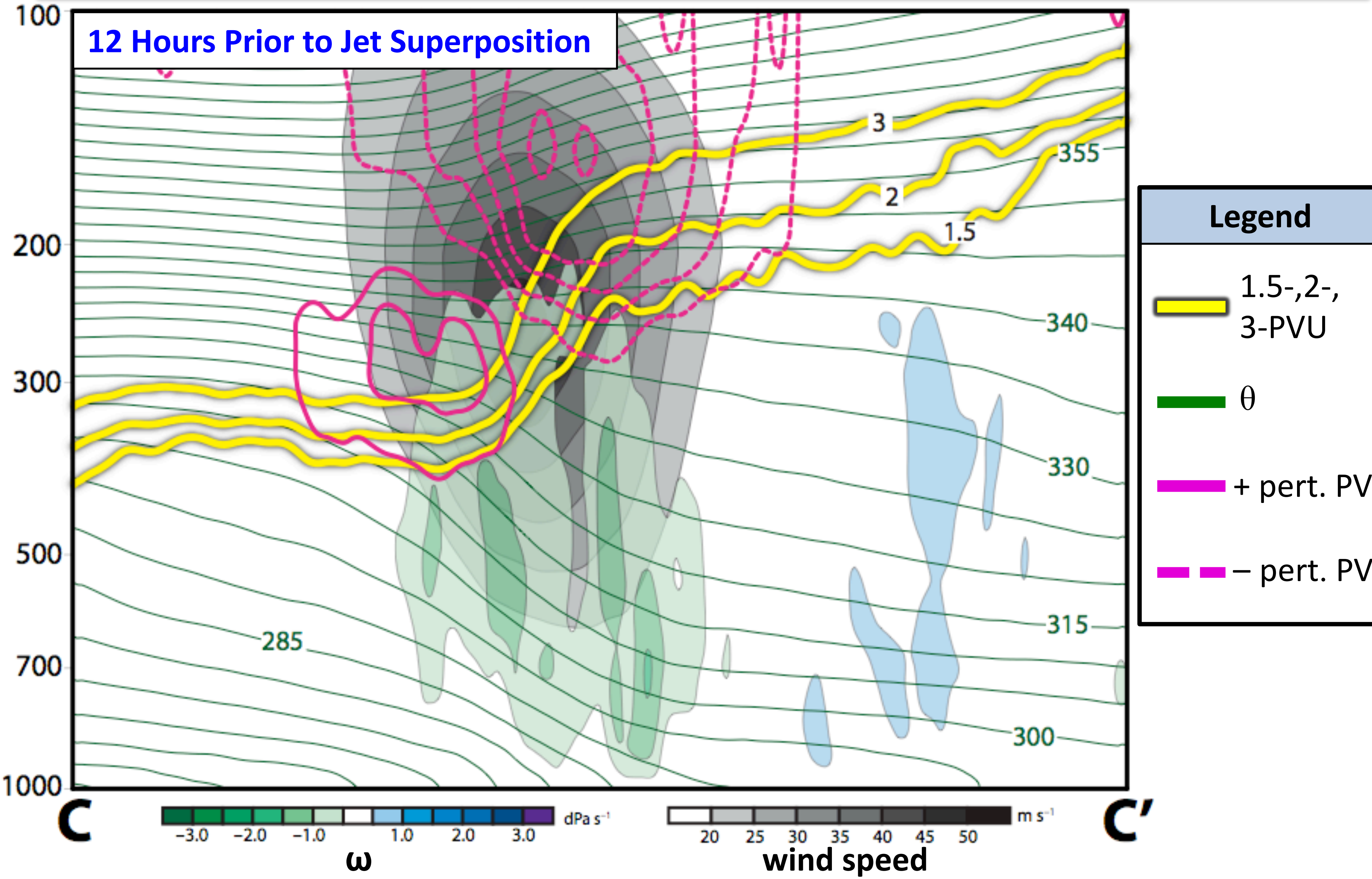




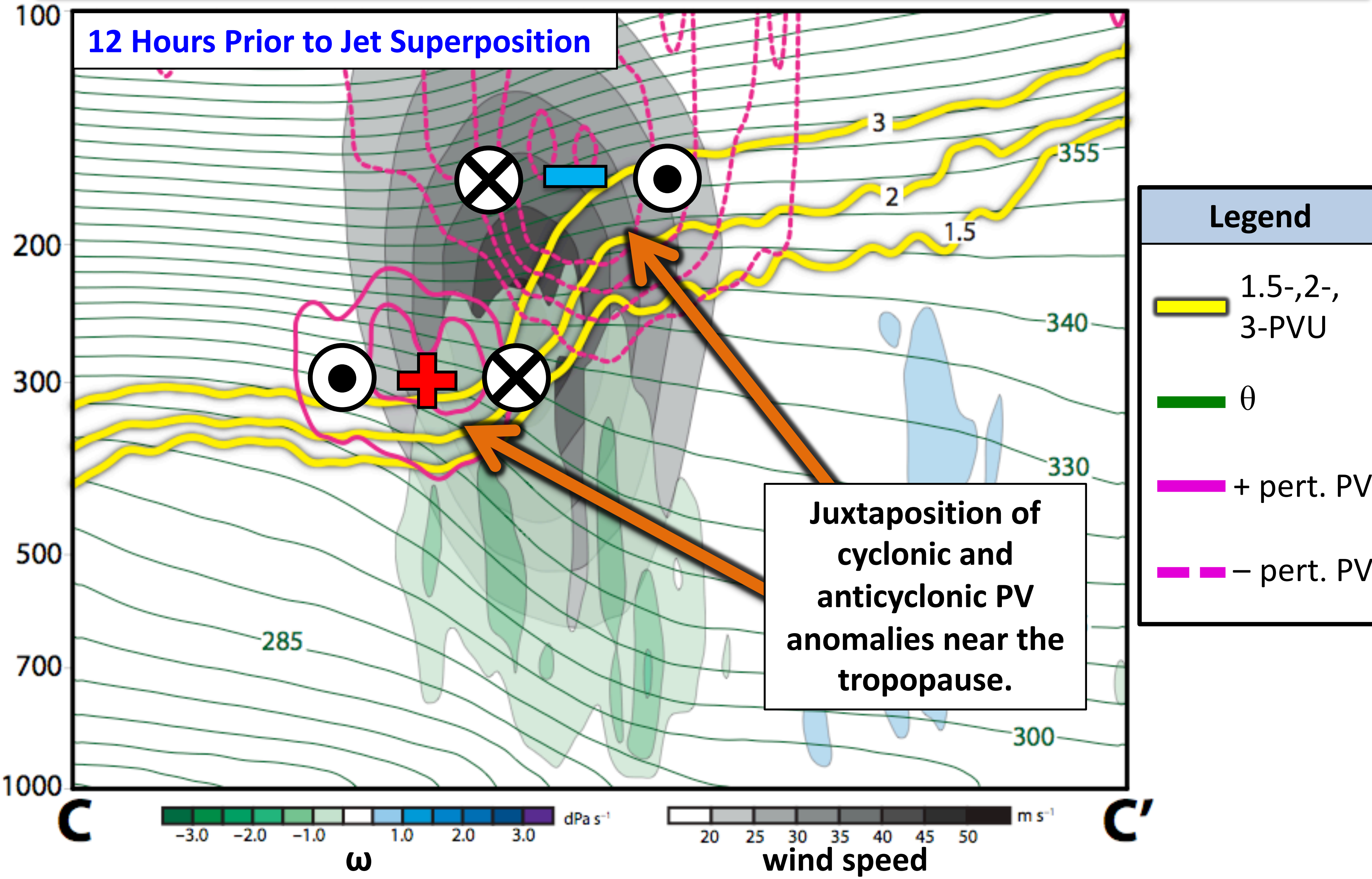
Jet Superposition Centroid

N=76

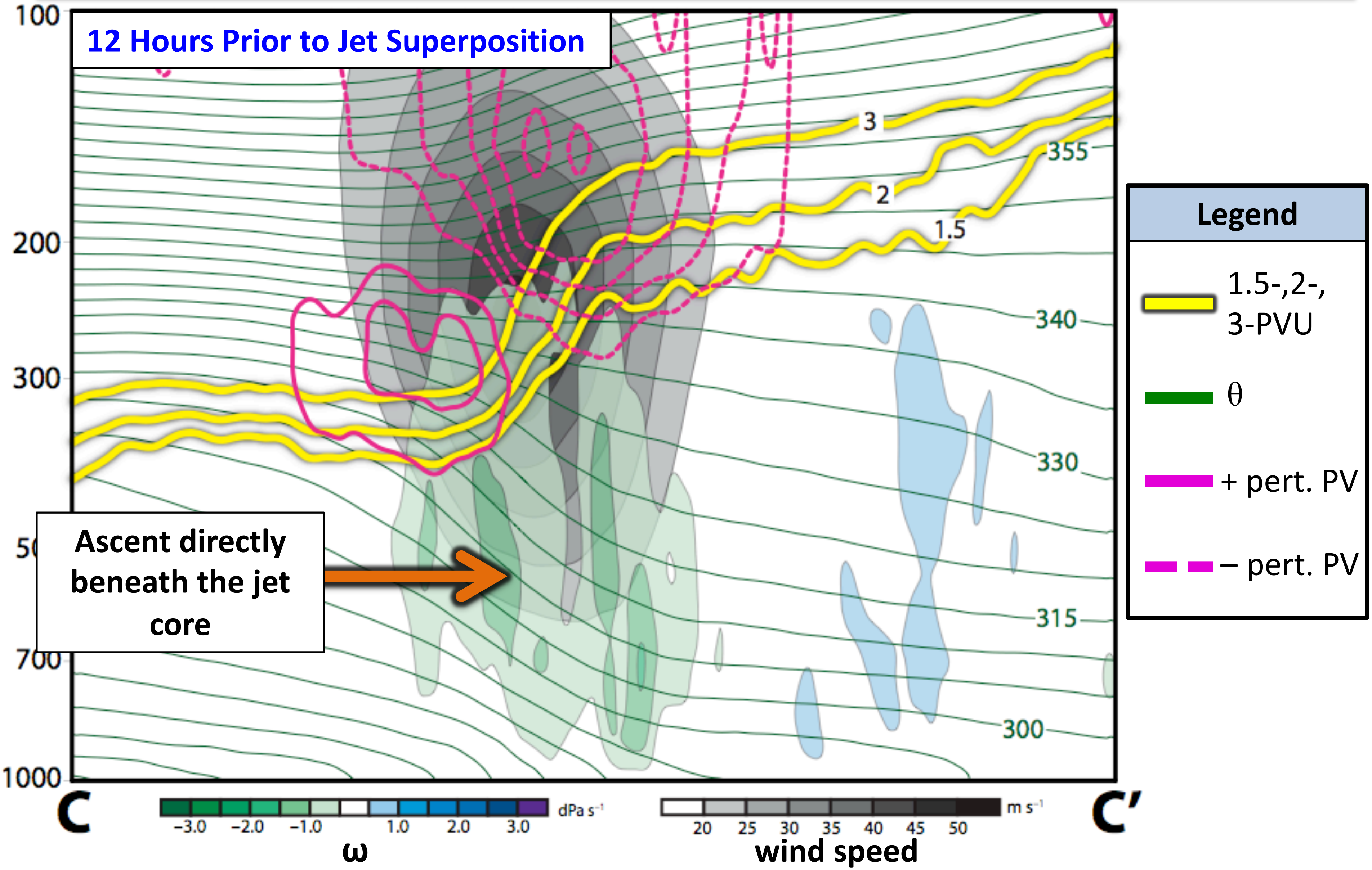
E. Subtropical Dominant Jet Superposition Events



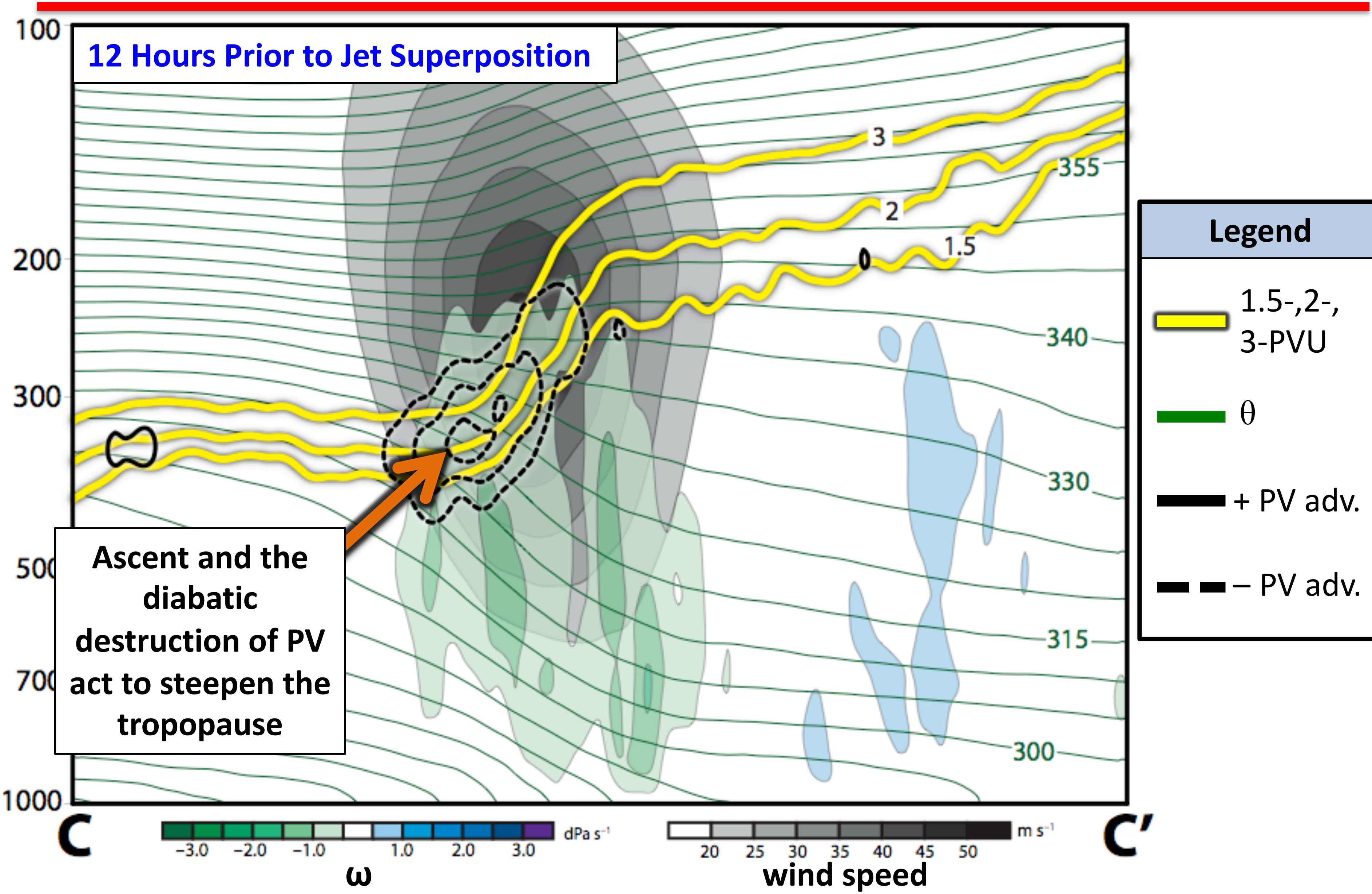
E. Subtropical Dominant Jet Superposition Events



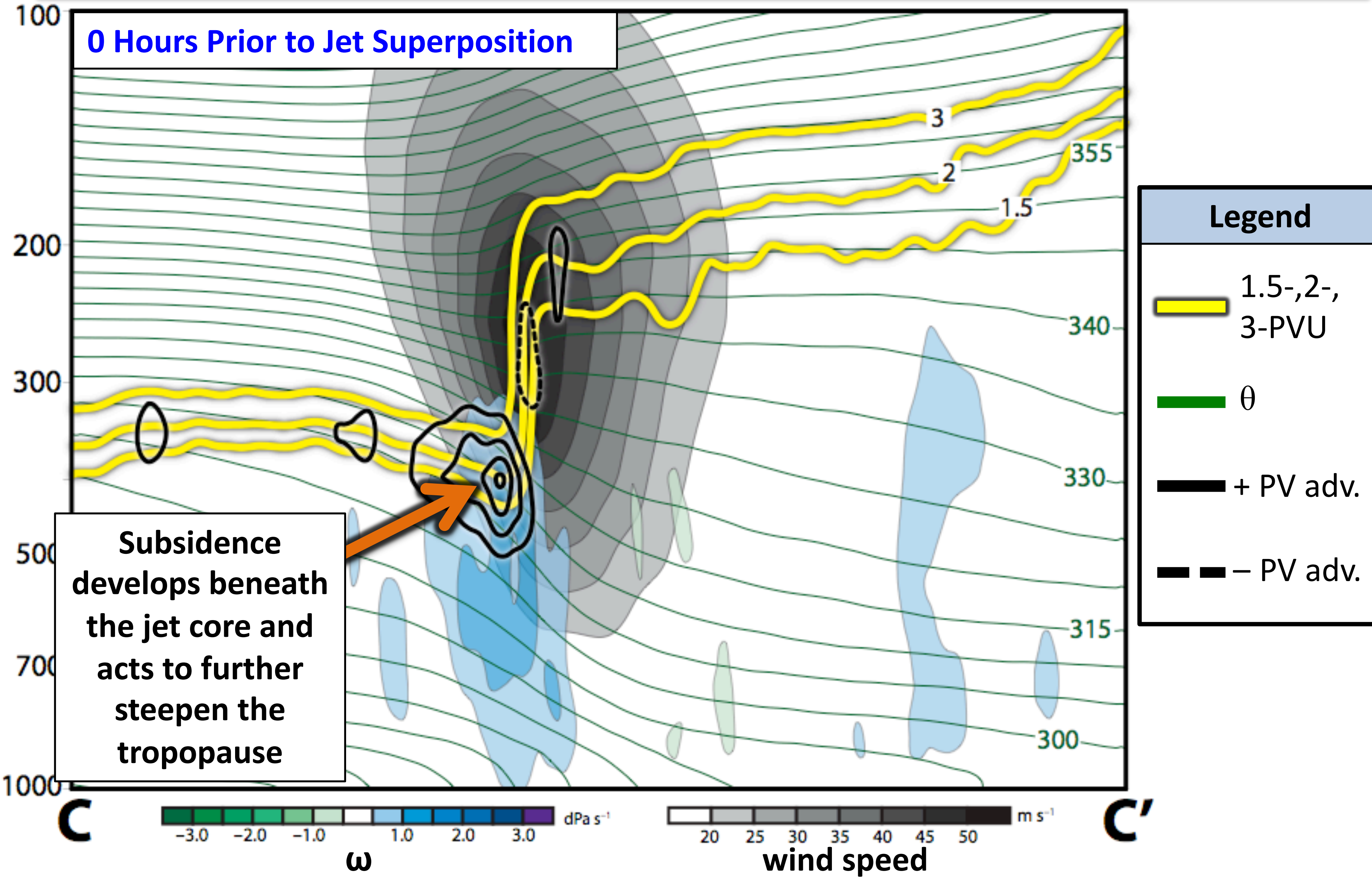
E. Subtropical Dominant Jet Superposition Events



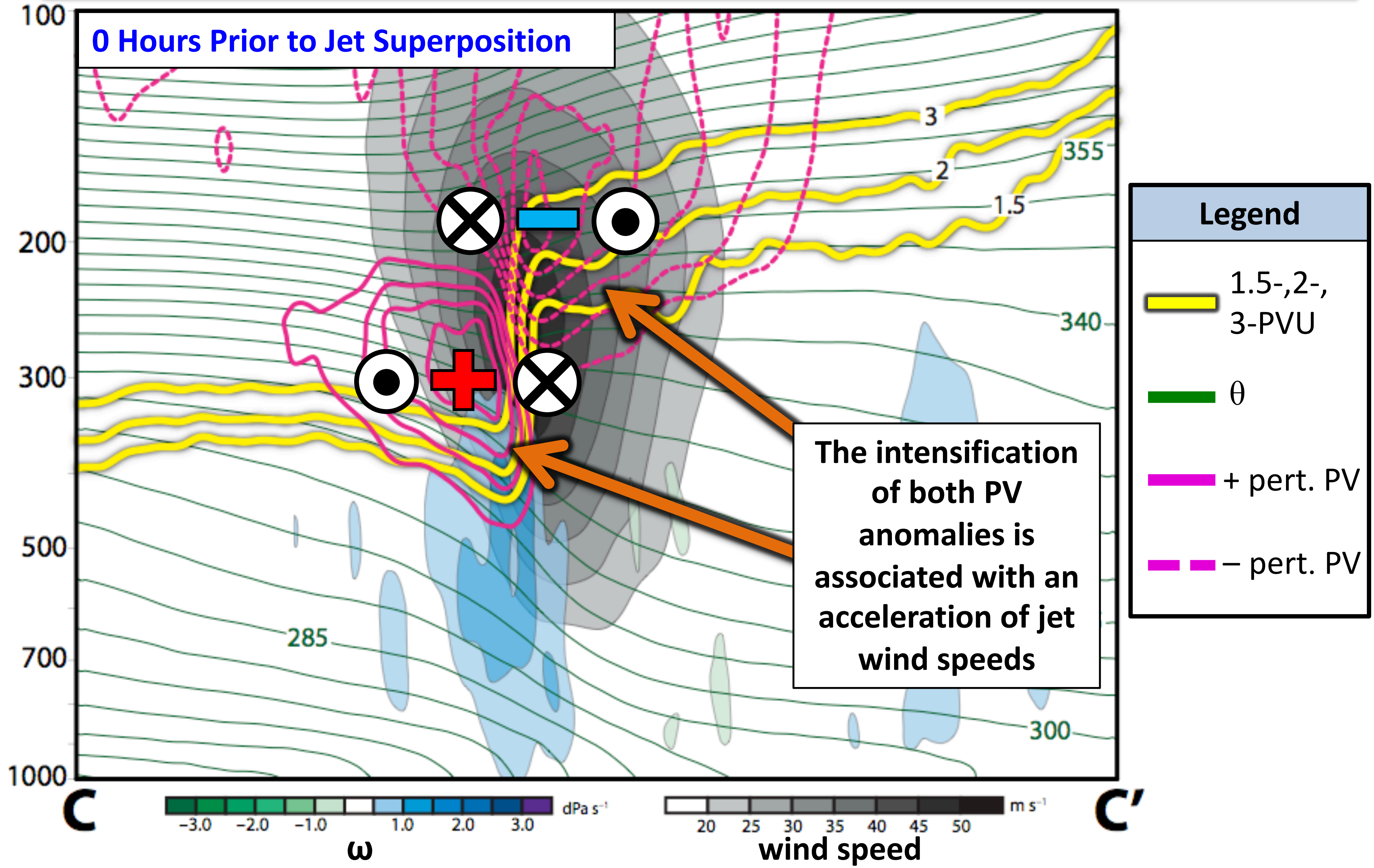
E. Subtropical Dominant Jet Superposition Events



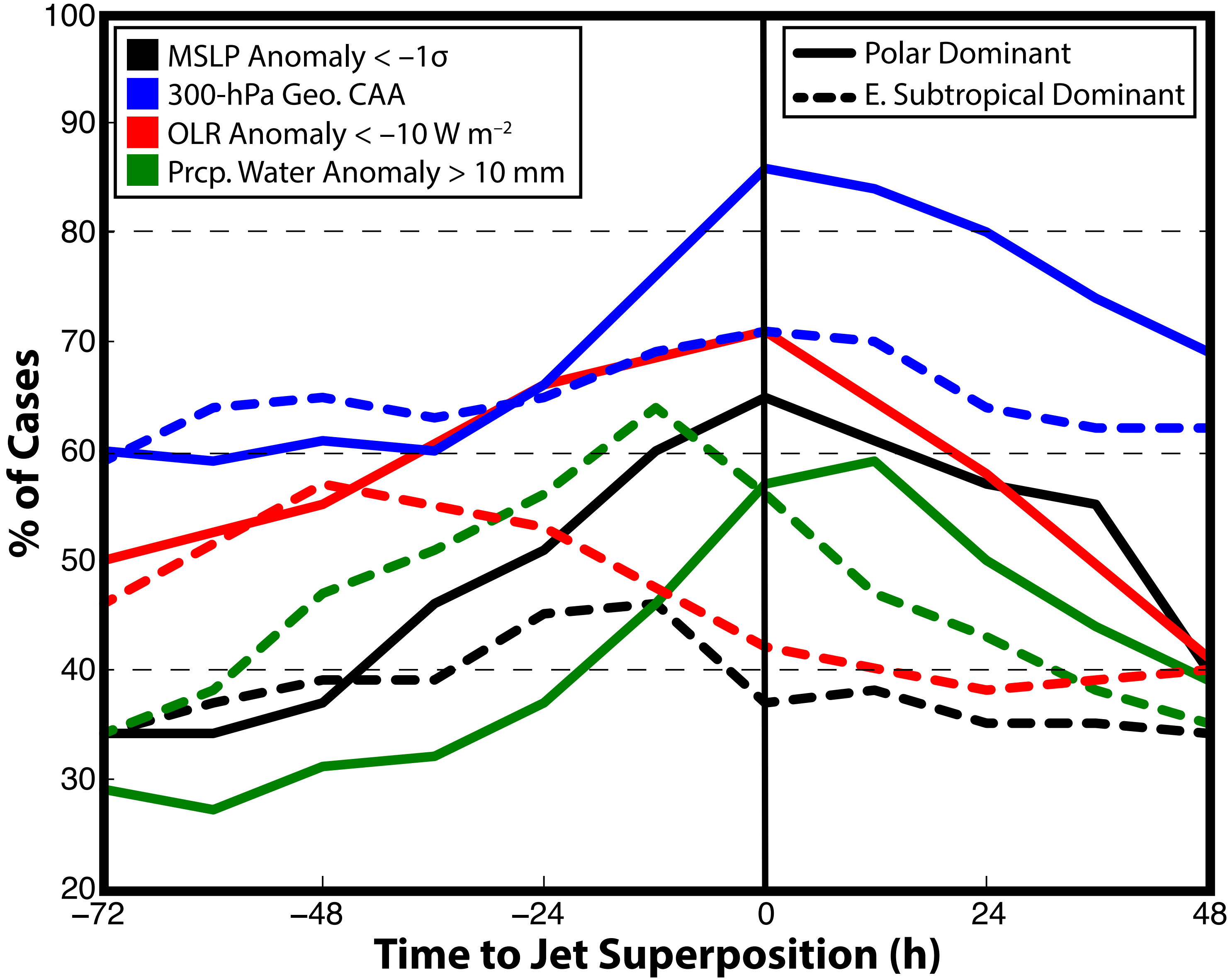
E. Subtropical Dominant Jet Superposition Events



E. Subtropical Dominant Jet Superposition Events

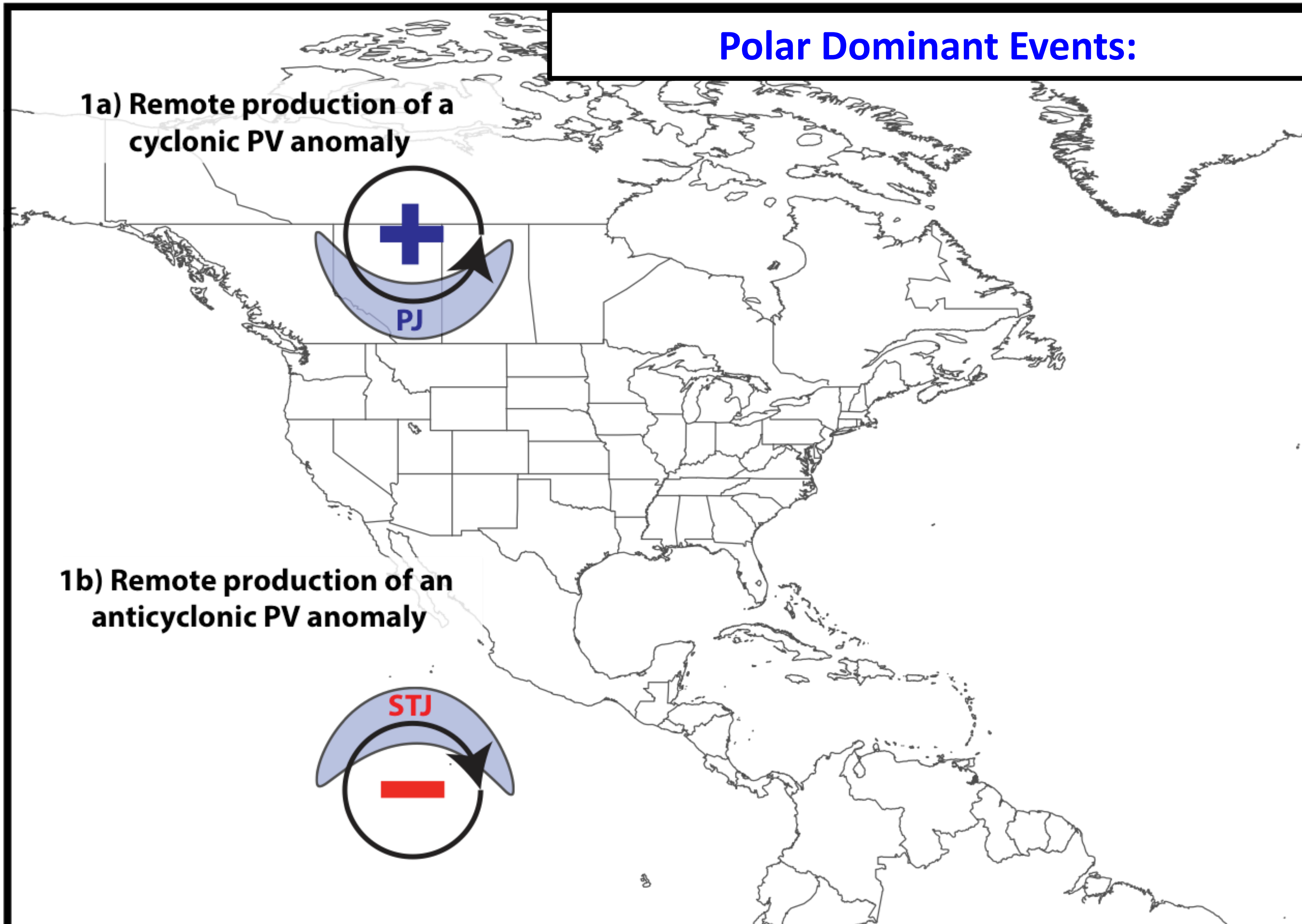


Summary



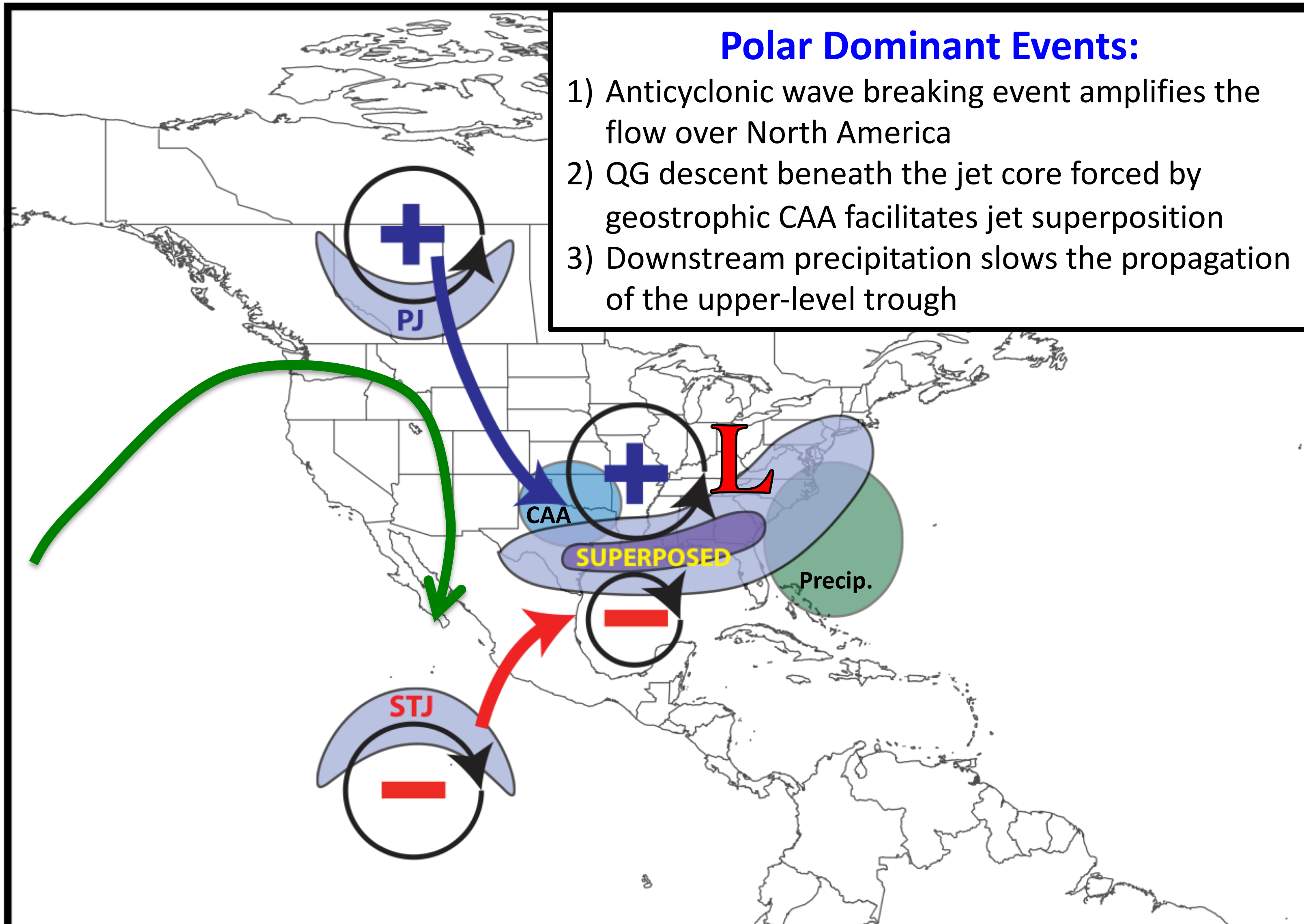
MSLP Anomaly < −1σ
300-hPa Geo. CAA
OLR Anomaly < −10 W m−2
Prcp. Water Anomaly > 10 mm
Polar Dominant
E. Subtropical Dominant
% of Cases
100
90
80
70
60
50
40
30
20
−72
−48
−24
0
24
48
Time to Jet Superposition (h)

Summary



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

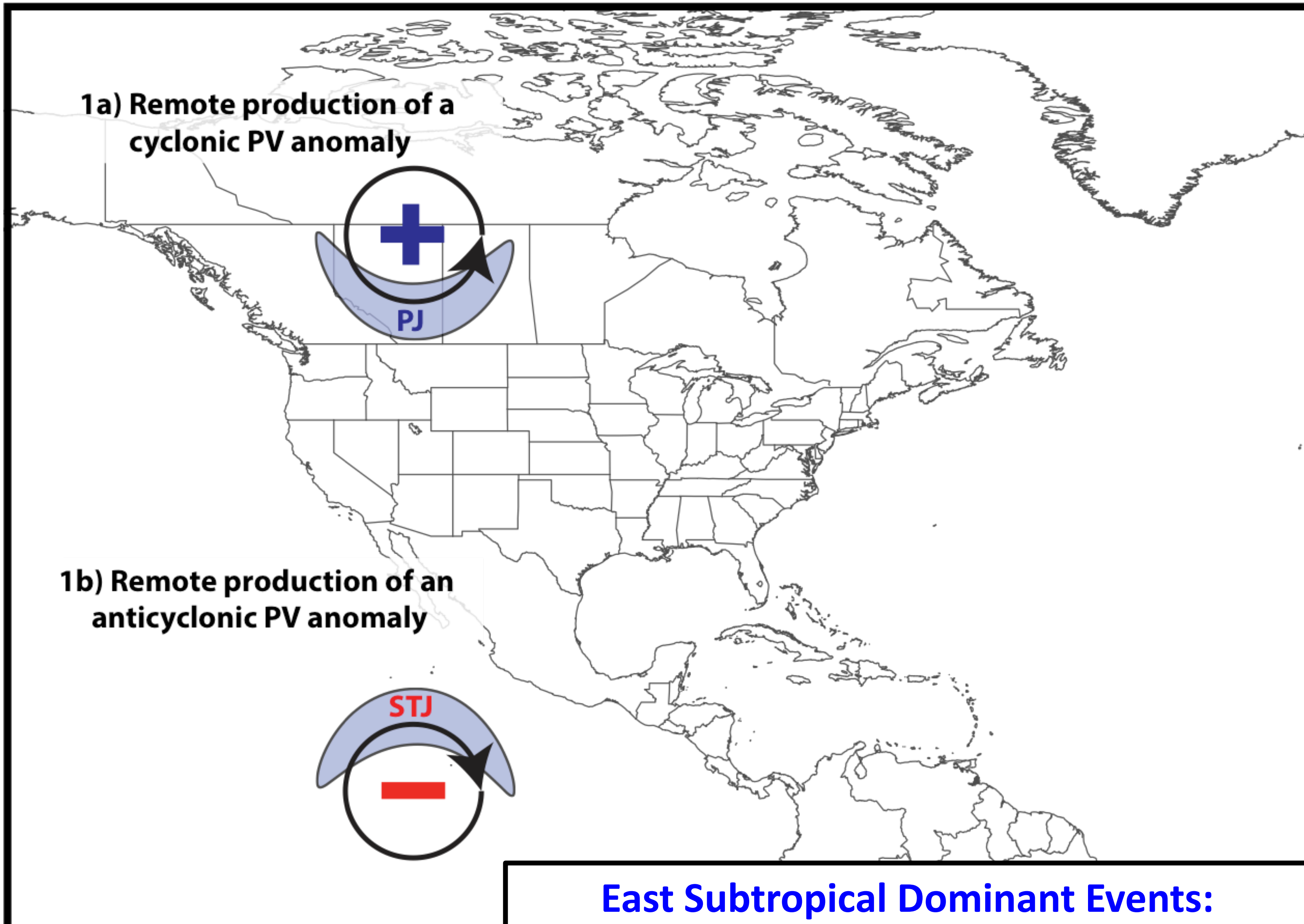
Summary



Polar Dominant Events:

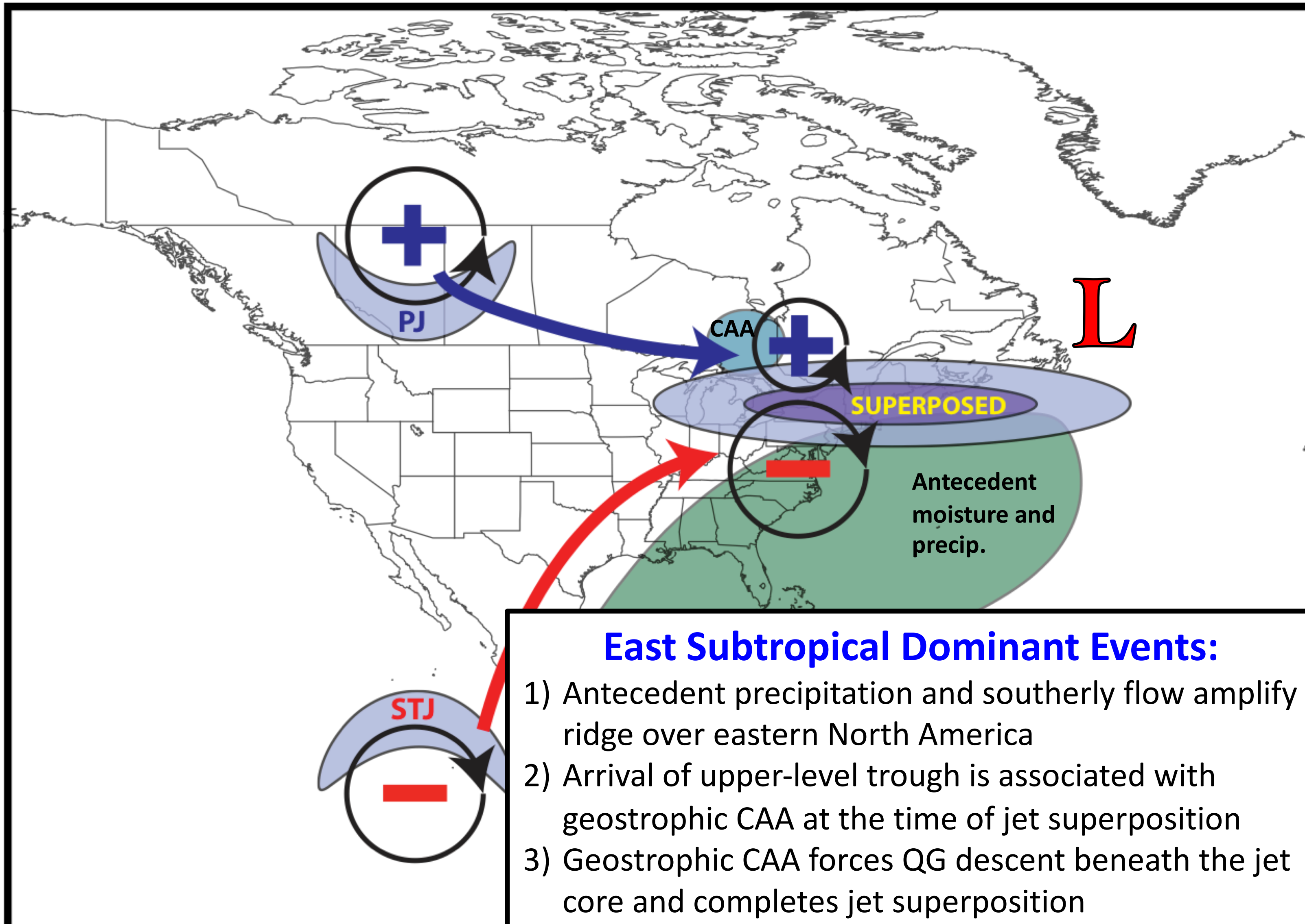
1) Anticyclonic wave breaking event amplifies the flow over North America
2) QG descent beneath the jet core forced by geostrophic CAA facilitates jet superposition
3) Downstream precipitation slows the propagation of the upper-level trough

Summary



1a) Remote production of a cyclonic PV anomaly
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) 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 restructuring 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

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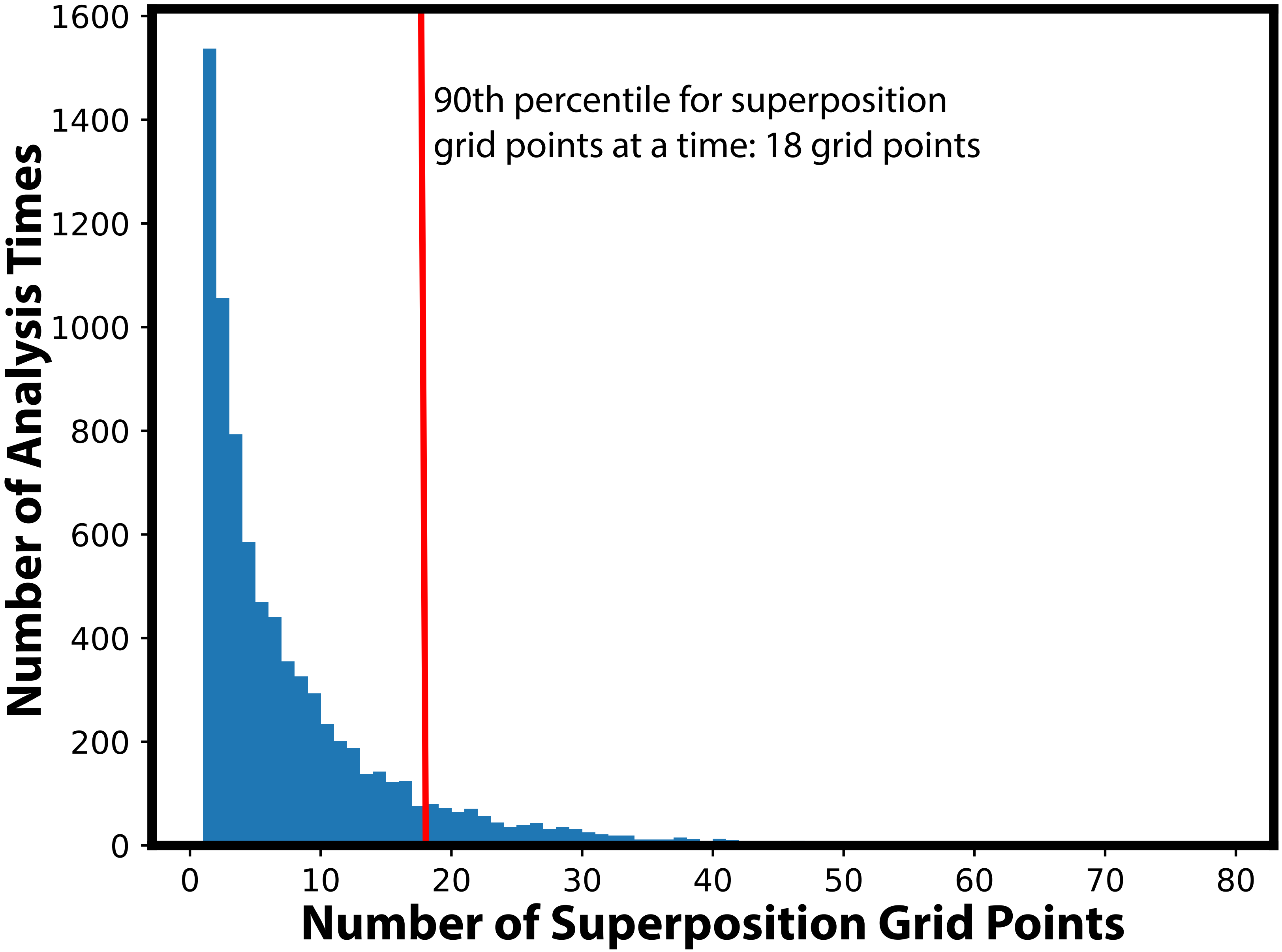
Jet Superposition Event Identification

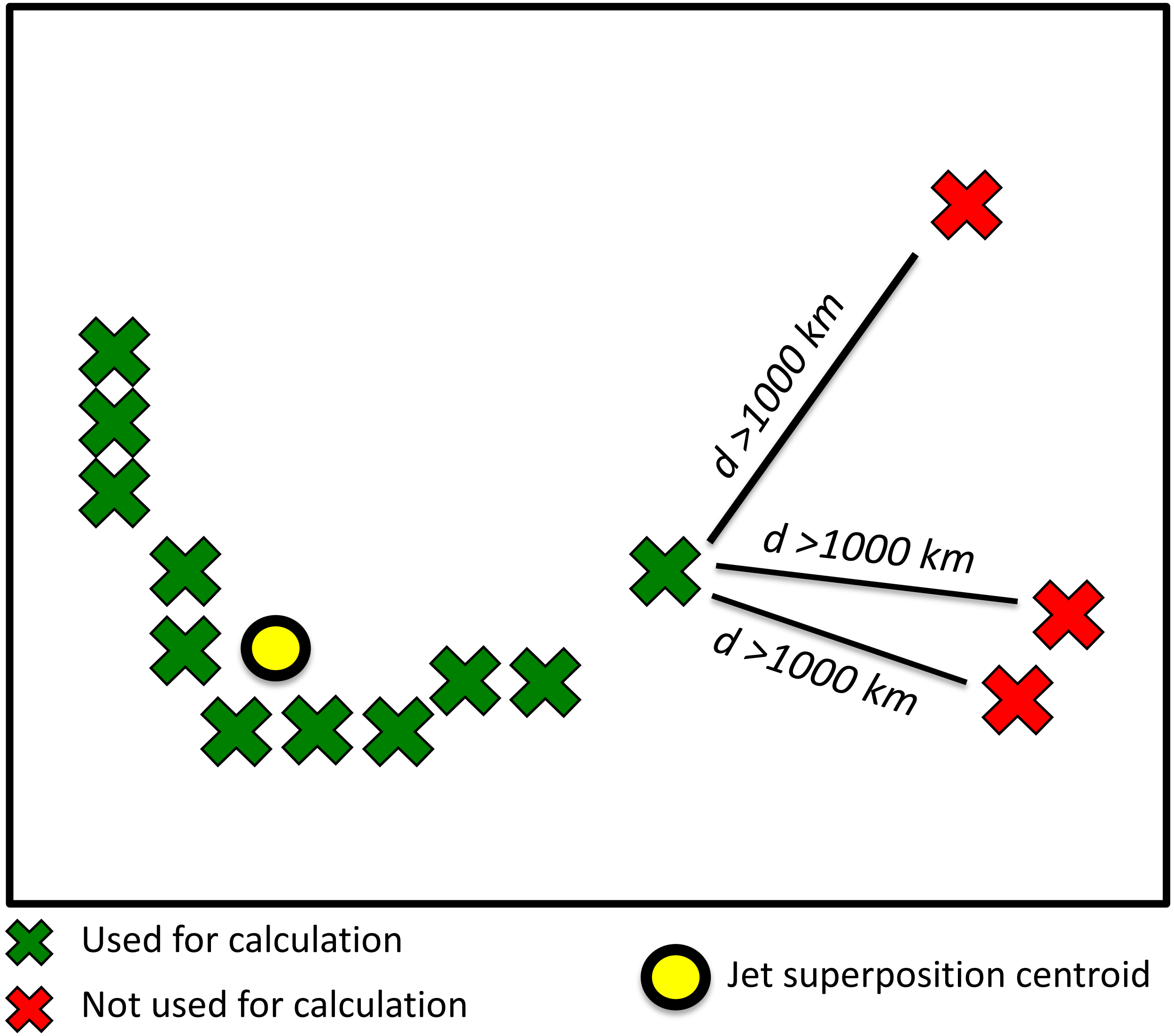


Jet Superposition Event Identification

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

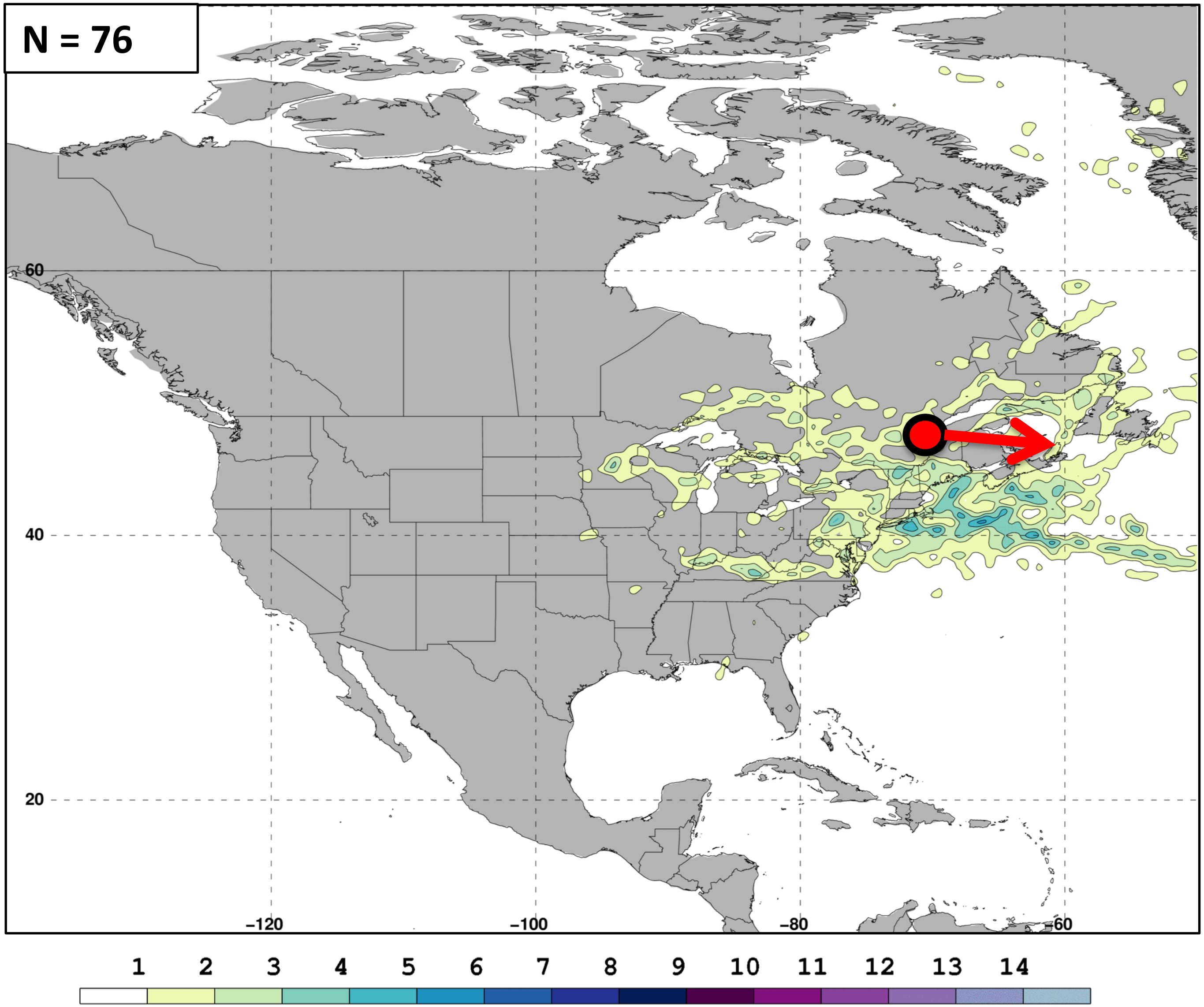
To calculate the centroid, there must exist a group of 18 superposition grid points, of which no superposition grid point is >1000 km away from another superposition grid point.

Sample Jet Superposition Centroid Calculation



Jet Superposition Event Identification

Frequency of East Subtropical Dominant Jet Superposition Events

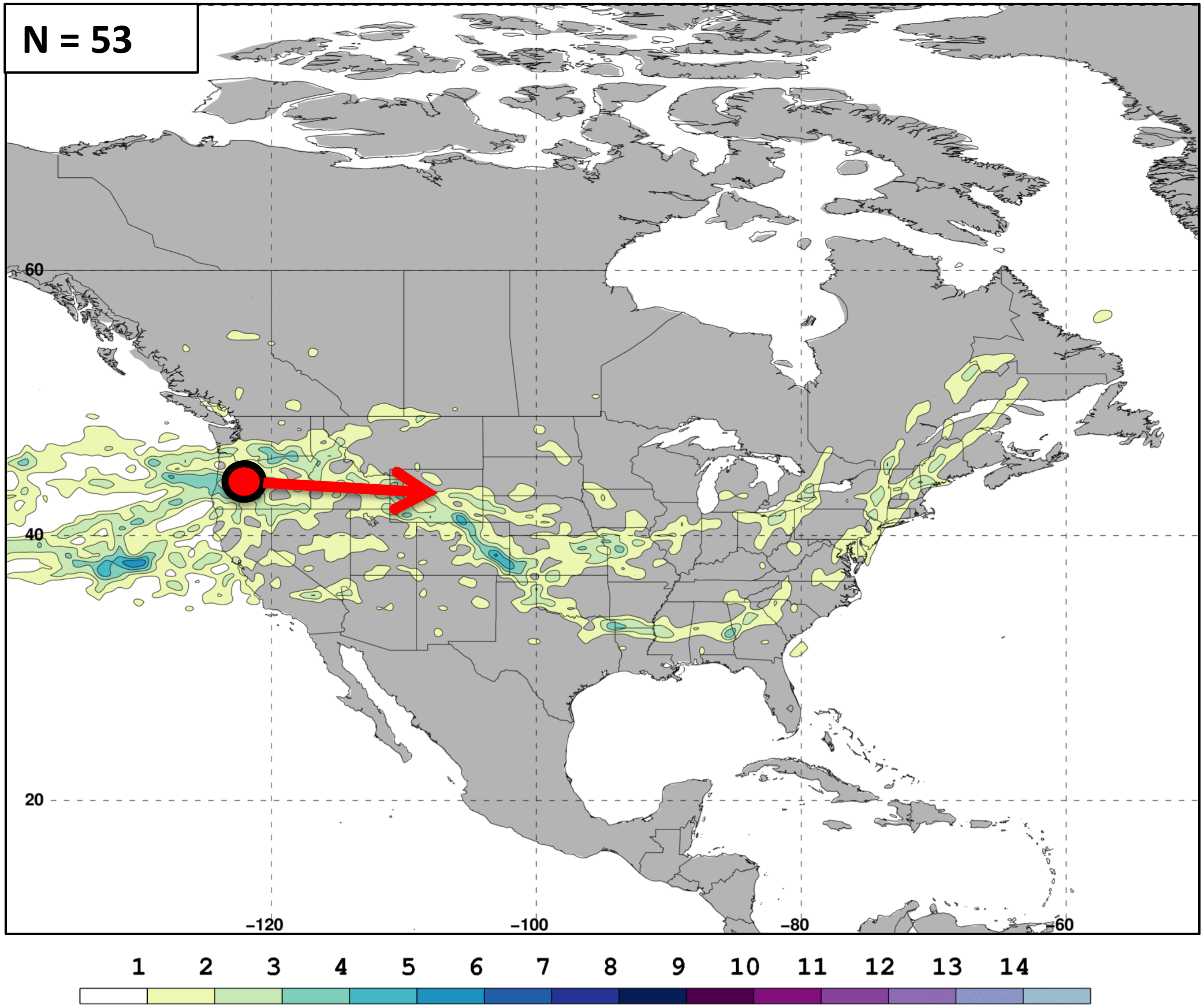


Legend

- Centroid of all events
- Composite movement of superposition

Jet Superposition Event Identification

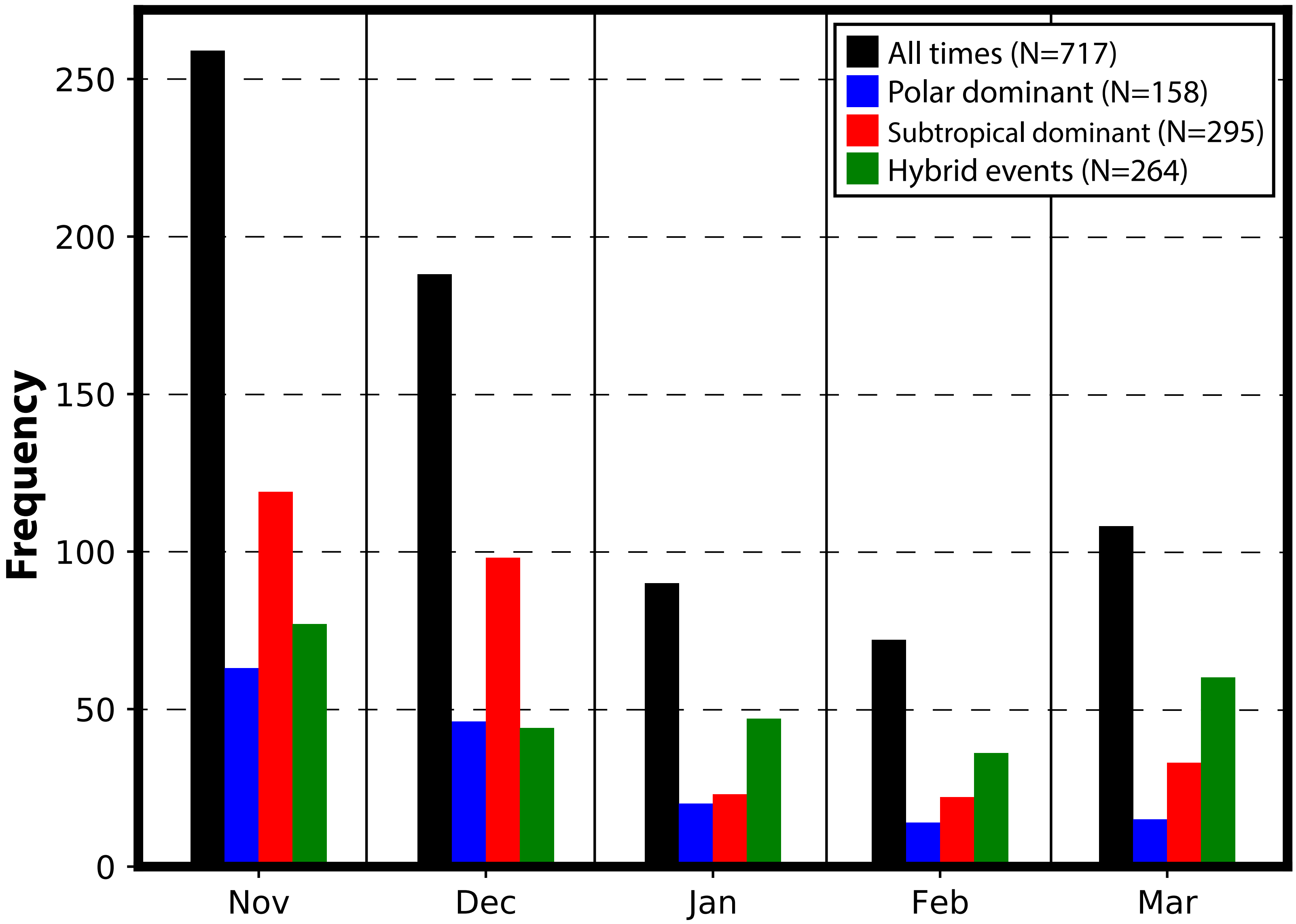
Frequency of West Subtropical Dominant Jet Superposition Events



Legend

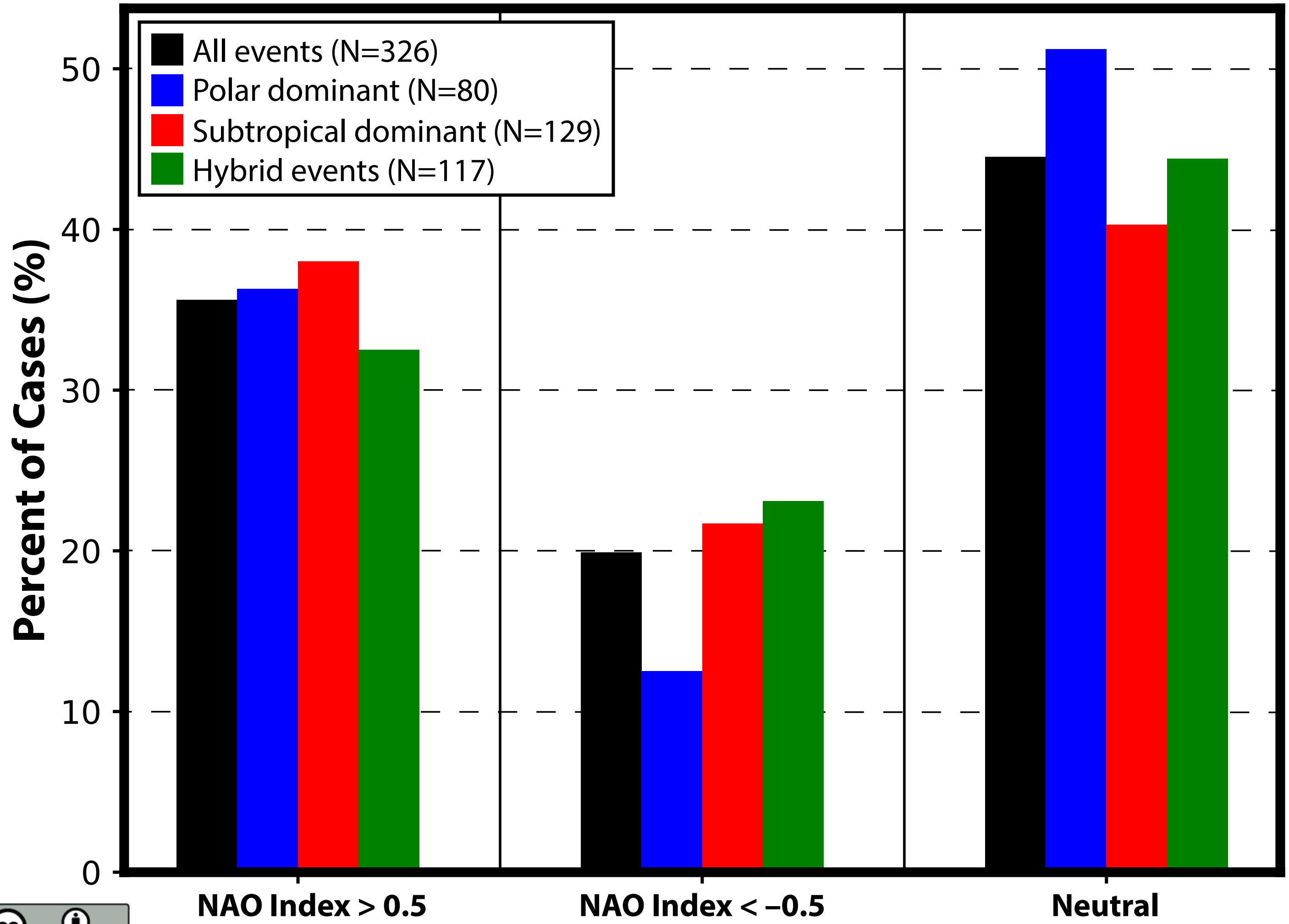
- Centroid of all events
- Composite movement of superposition

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

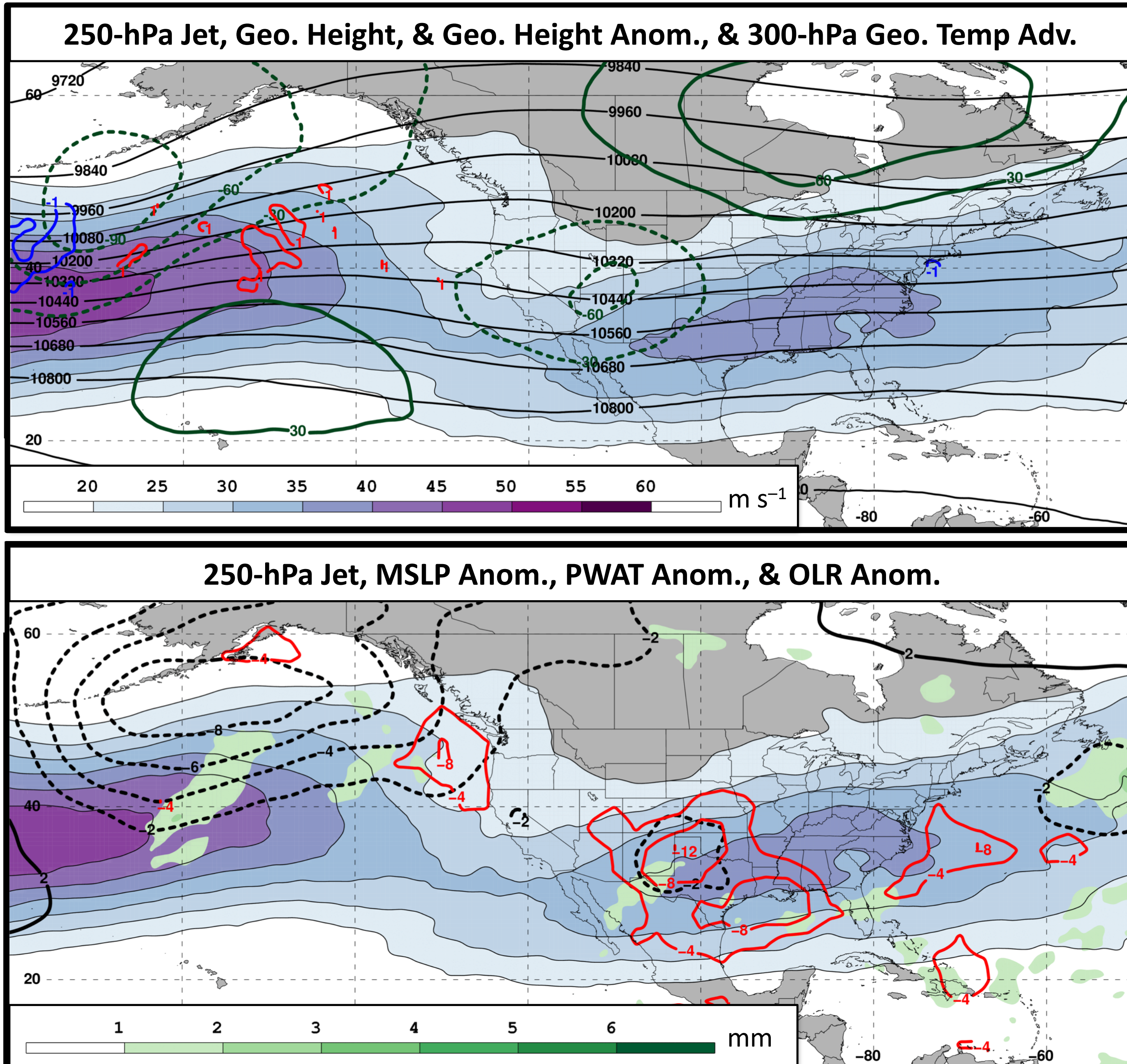
Ave. Hybrid ΔNAO
+0.07

CC BY

Polar Dominant Jet Superposition Events

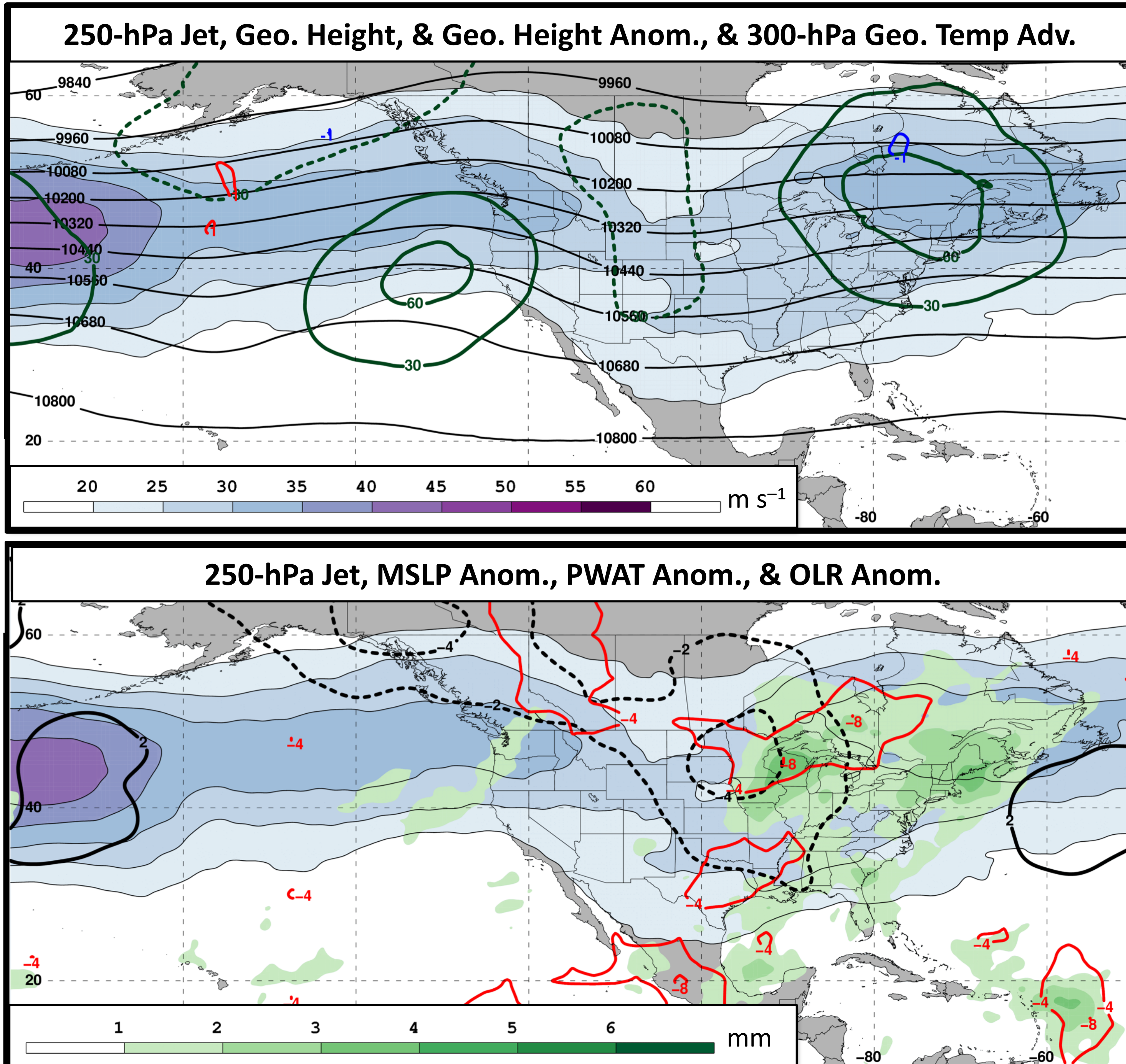
3 Days Prior to Jet Superposition

N=80



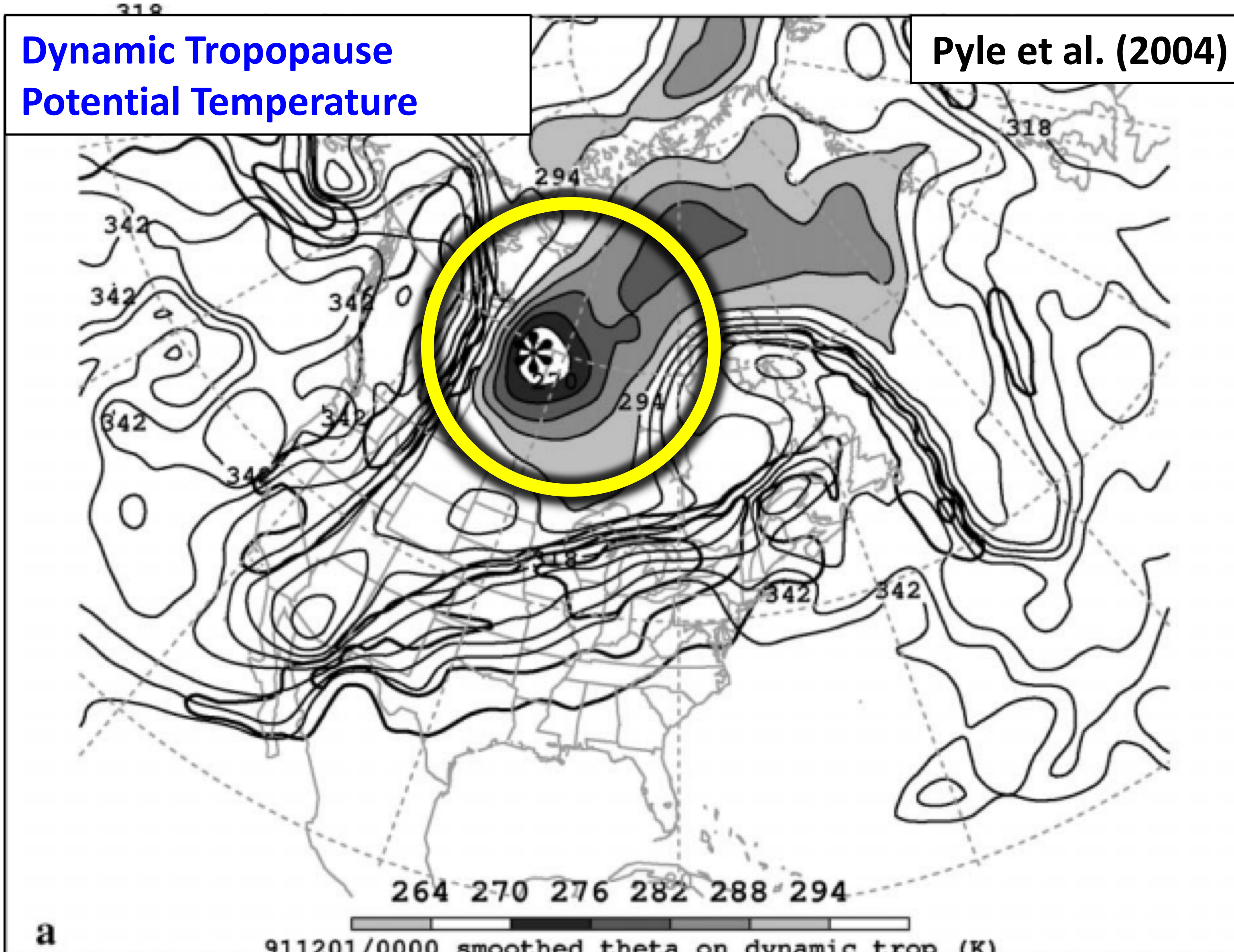
E. Subtropical Dominant Jet Superposition Events

3 Days Prior to Jet Superposition

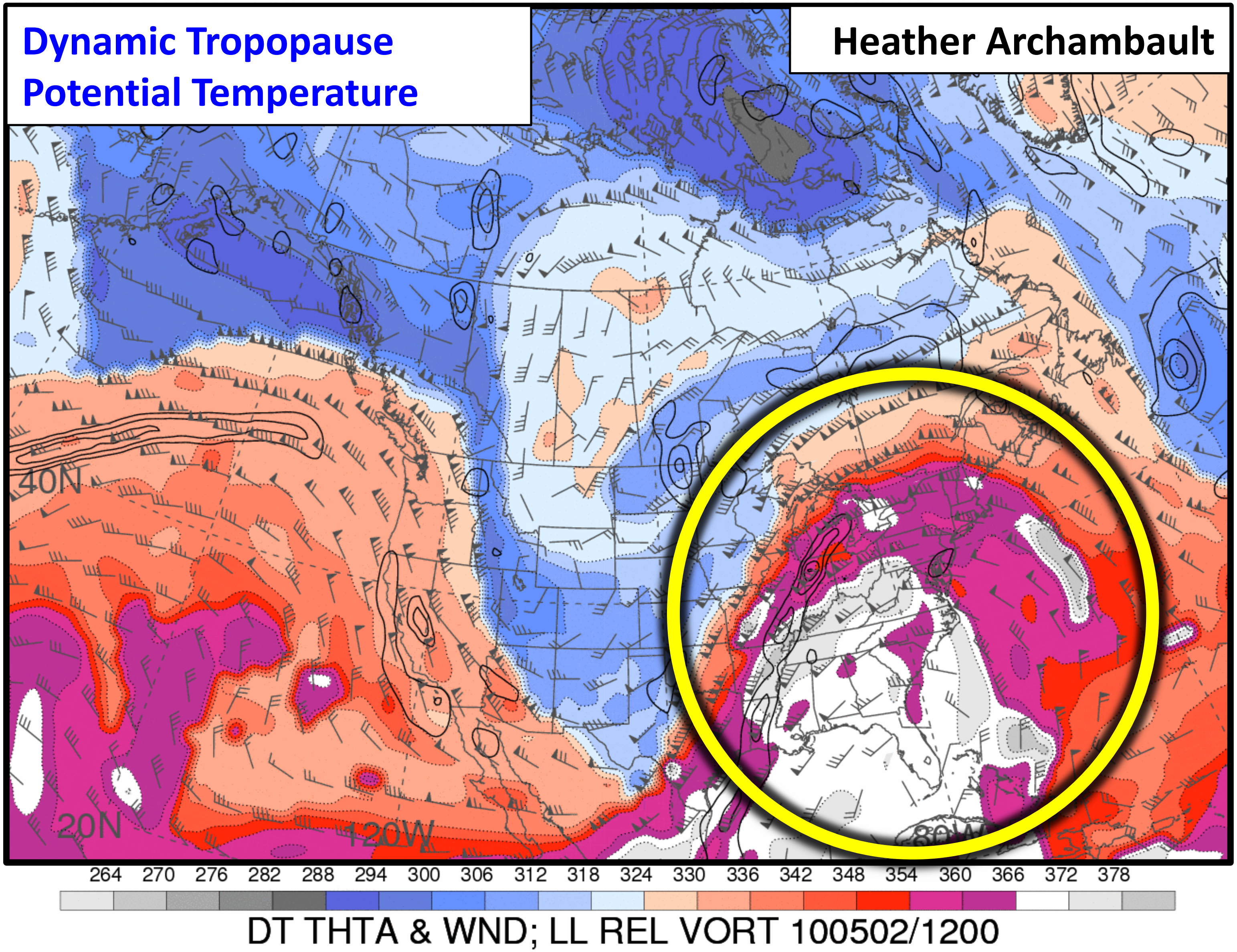


N=76

Jet Superposition Conceptual Model

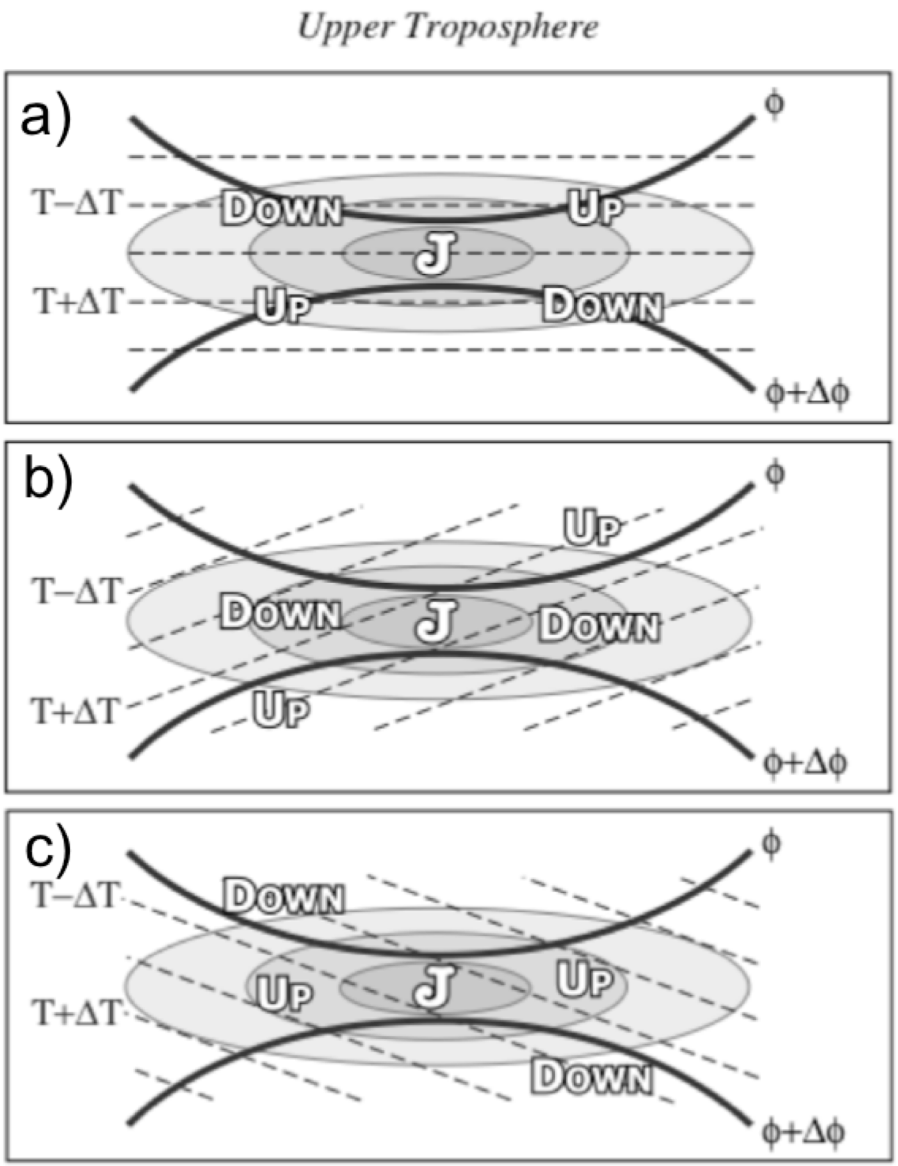


Jet Superposition Conceptual Model



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)

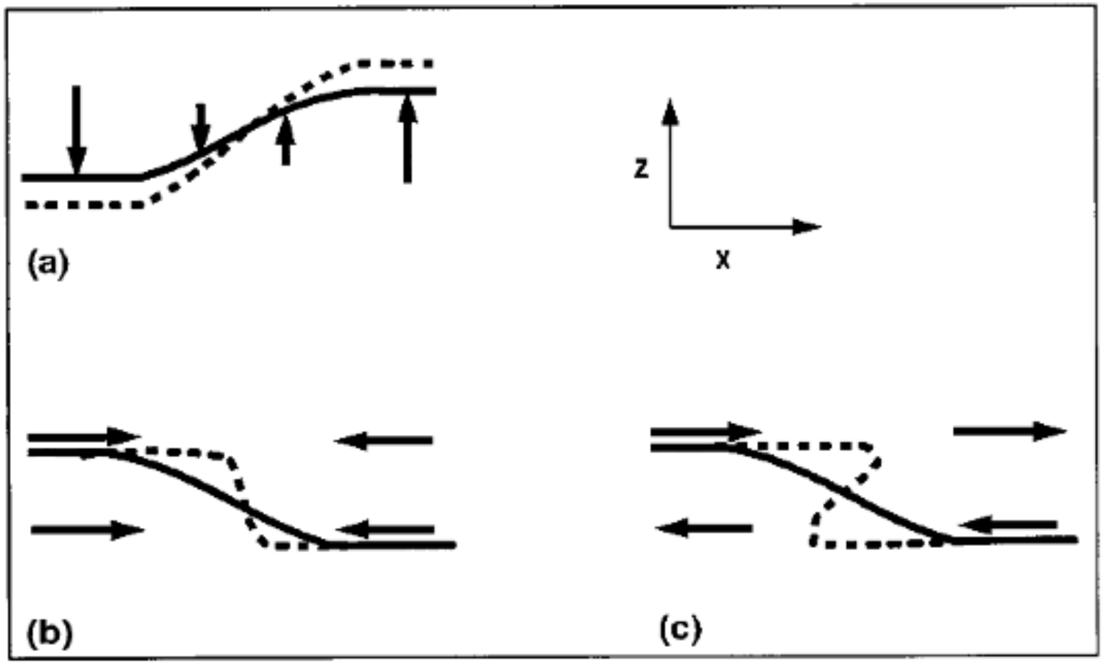
Background

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 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)

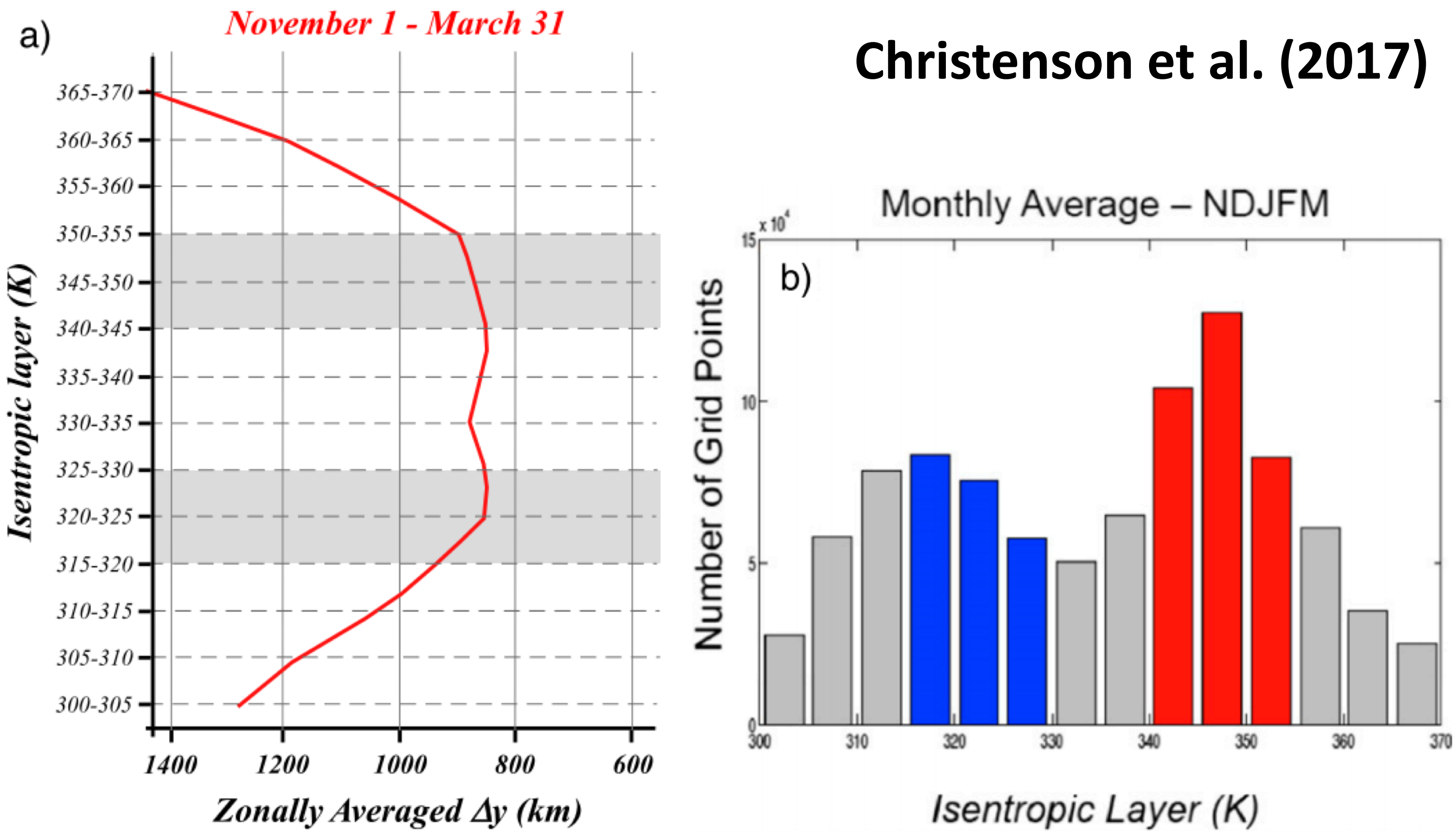


FIG. 2. (a) Cold season average of zonally averaged Δy (km) for 5-K isentropic layers ranging from 300–305 to 365–370 K. The 315–330- and 340–355-K layers are highlighted in light gray shading. (b) The average frequency of occurrence of grid points with a maximum wind speed value within the 5-K isentropic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