Diagnosing the Characteristic Interaction between the Polar and Subtropical Jet Streams during North American Jet Superposition Events

Andrew C. Winters

Daniel Keyser and Lance F. Bosart

University at Albany, SUNY

99th AMS Annual Meeting

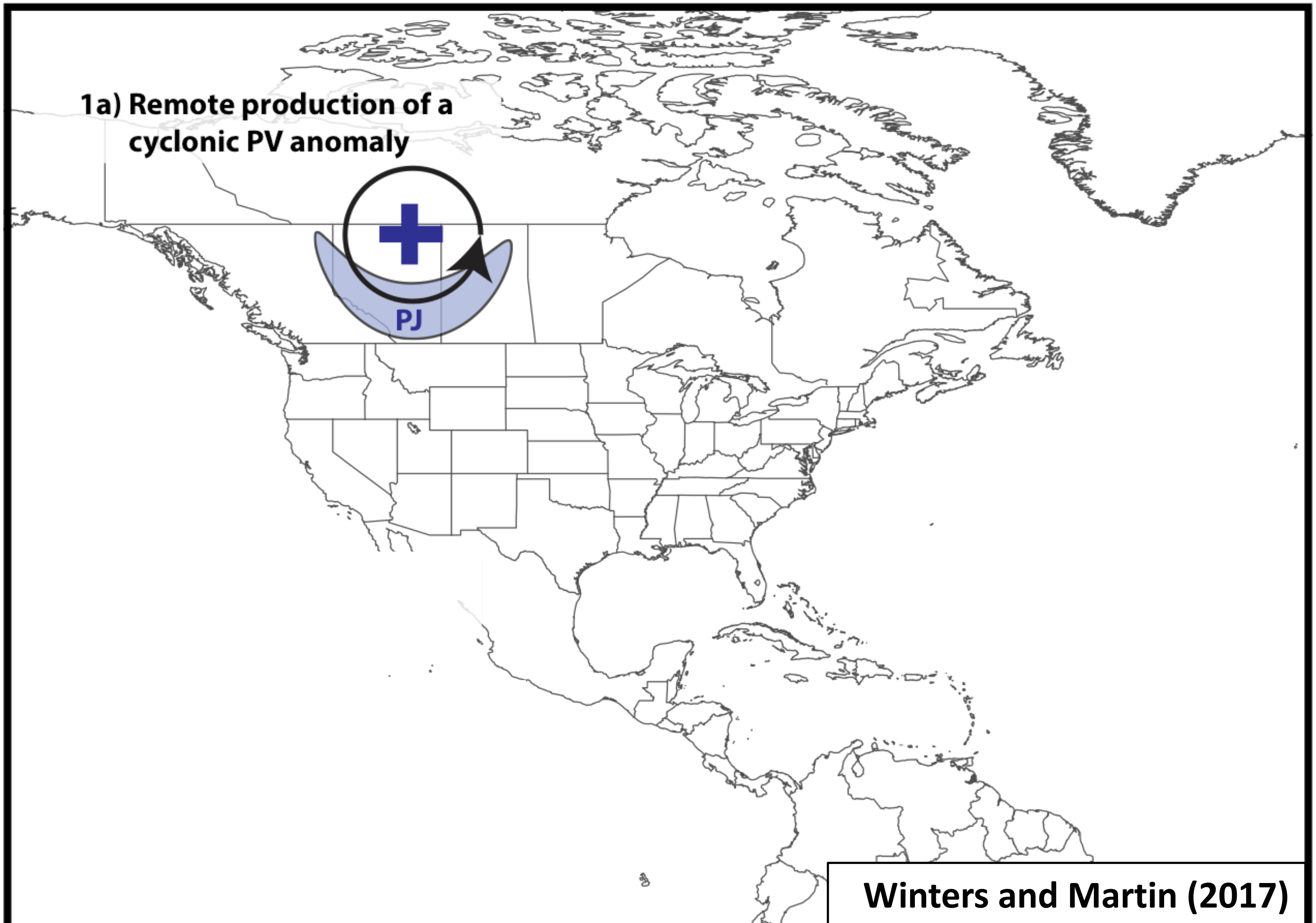
32nd Conference on Climate Variability and Change

Phoenix, AZ

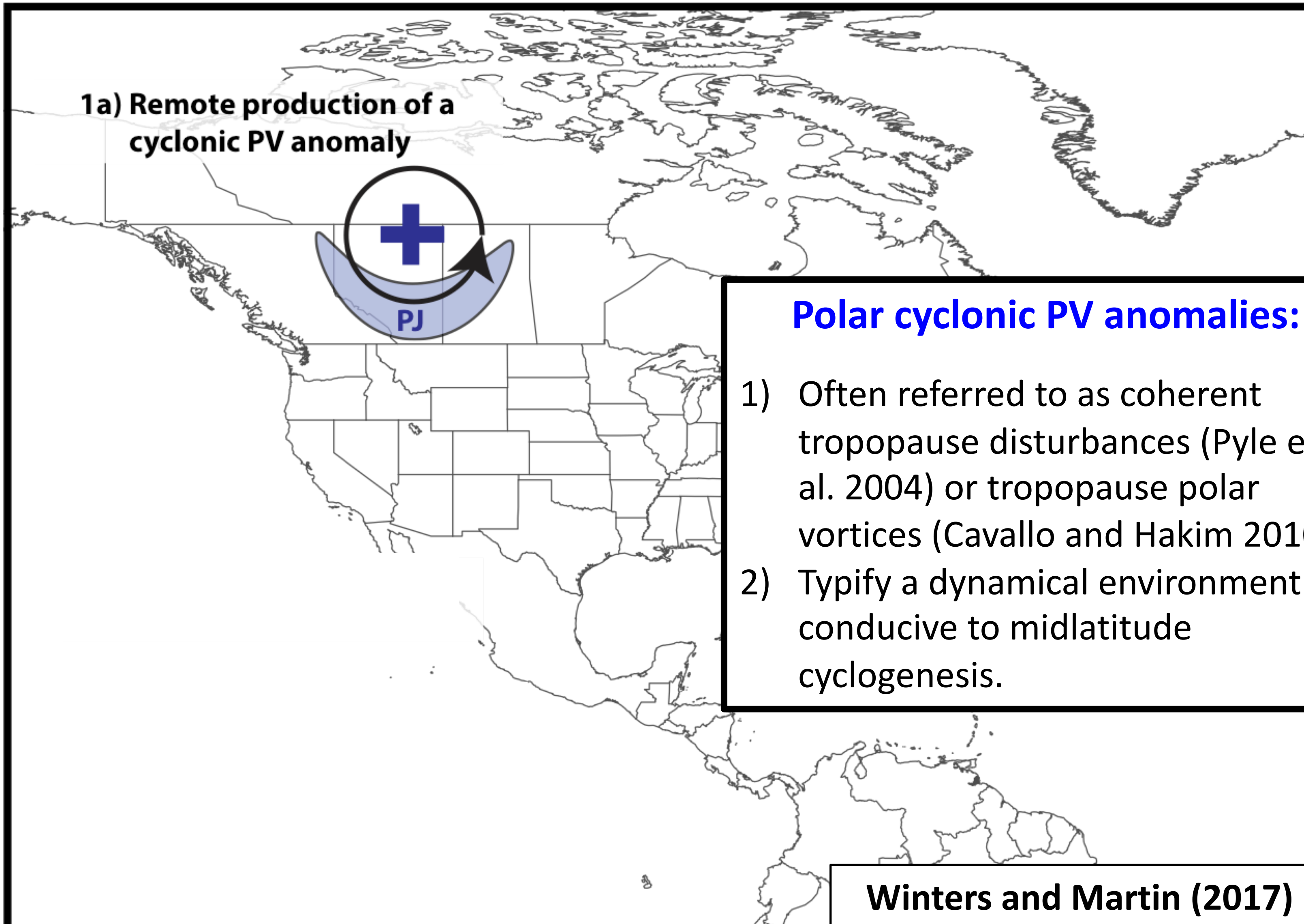
8 January 2019

This work is funded by an NSF-PRF (AGS-1624316)

Jet Superposition Conceptual Model



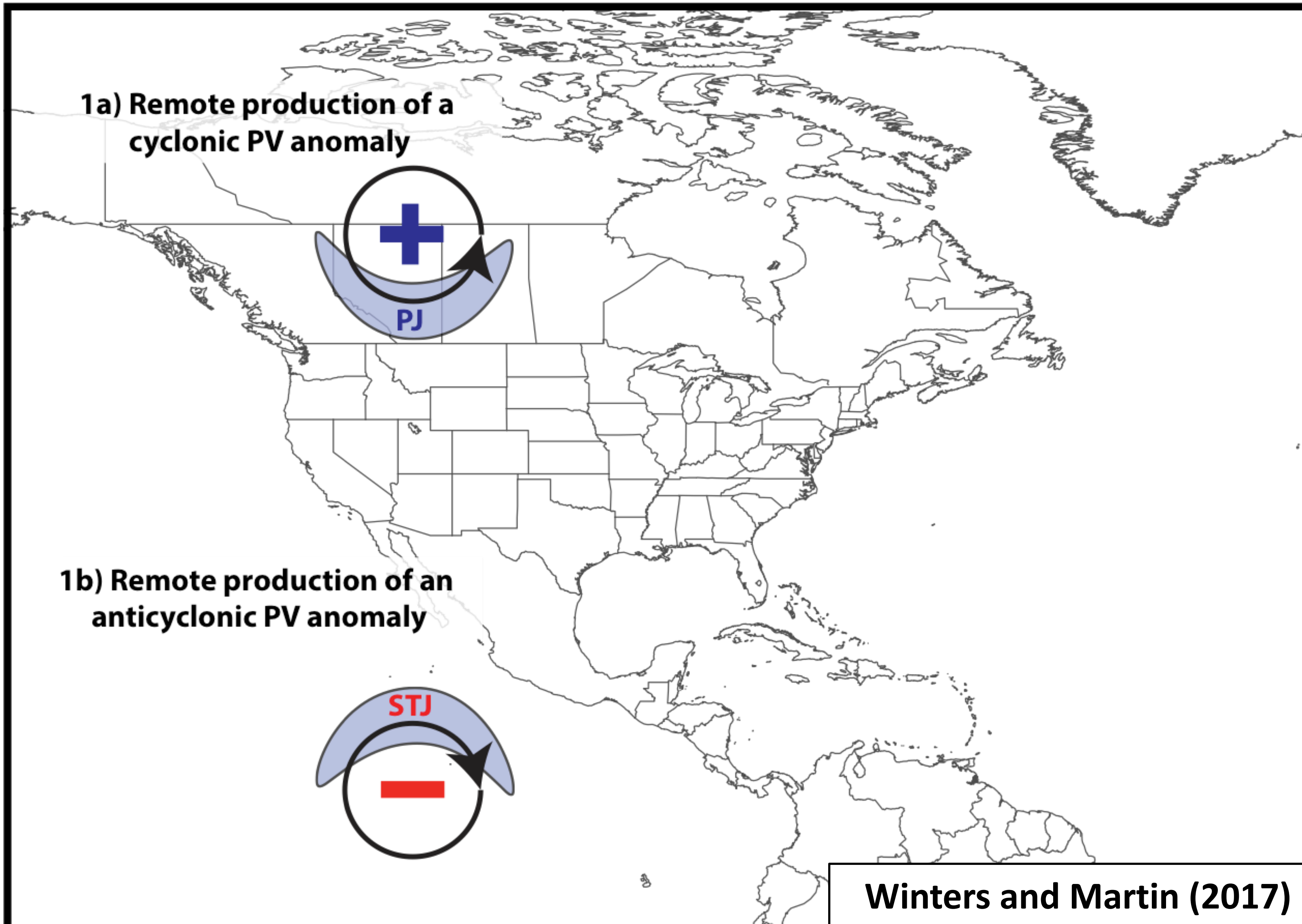
Jet Superposition Conceptual Model



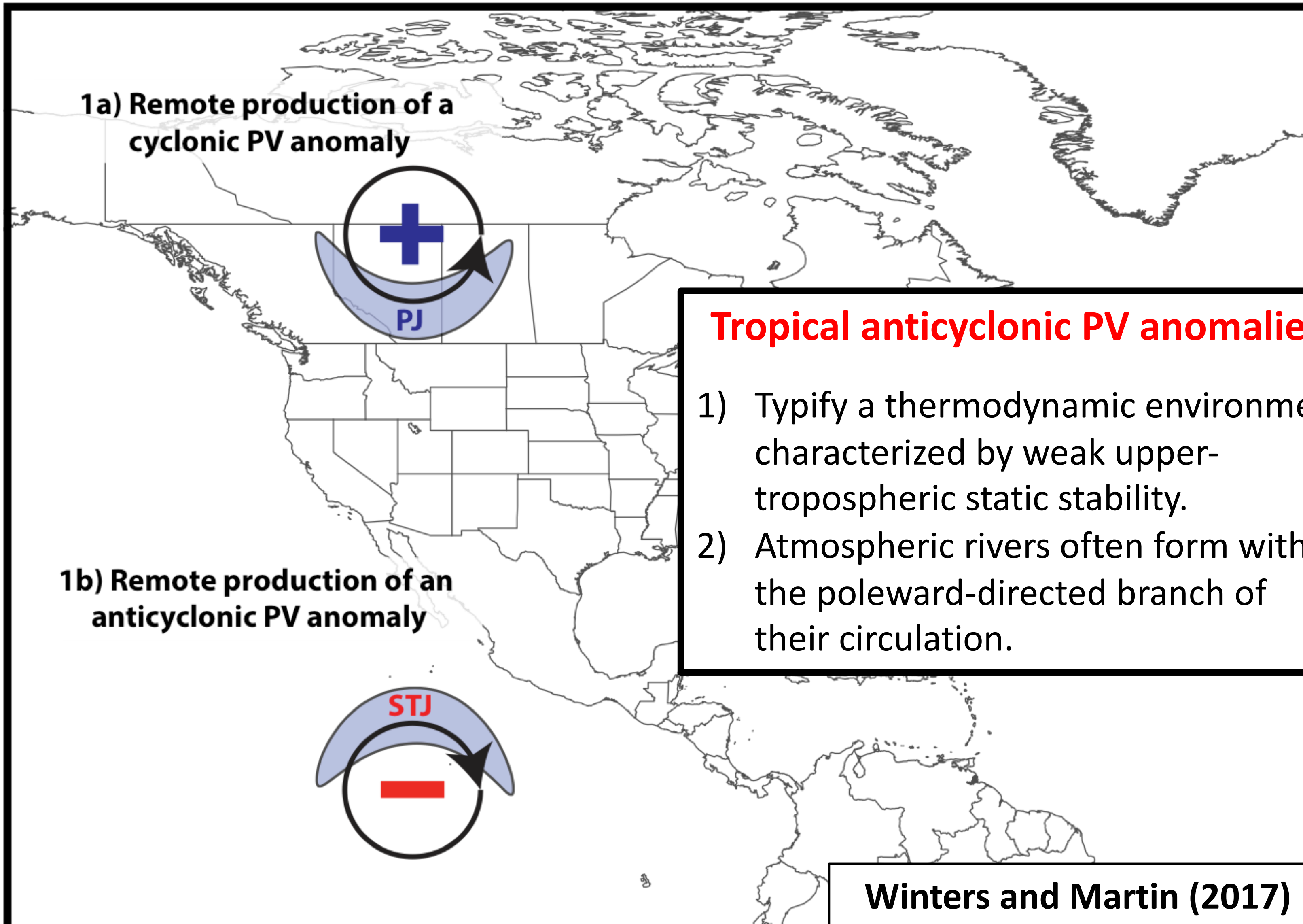
Polar cyclonic PV anomalies:

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



Jet Superposition Conceptual Model

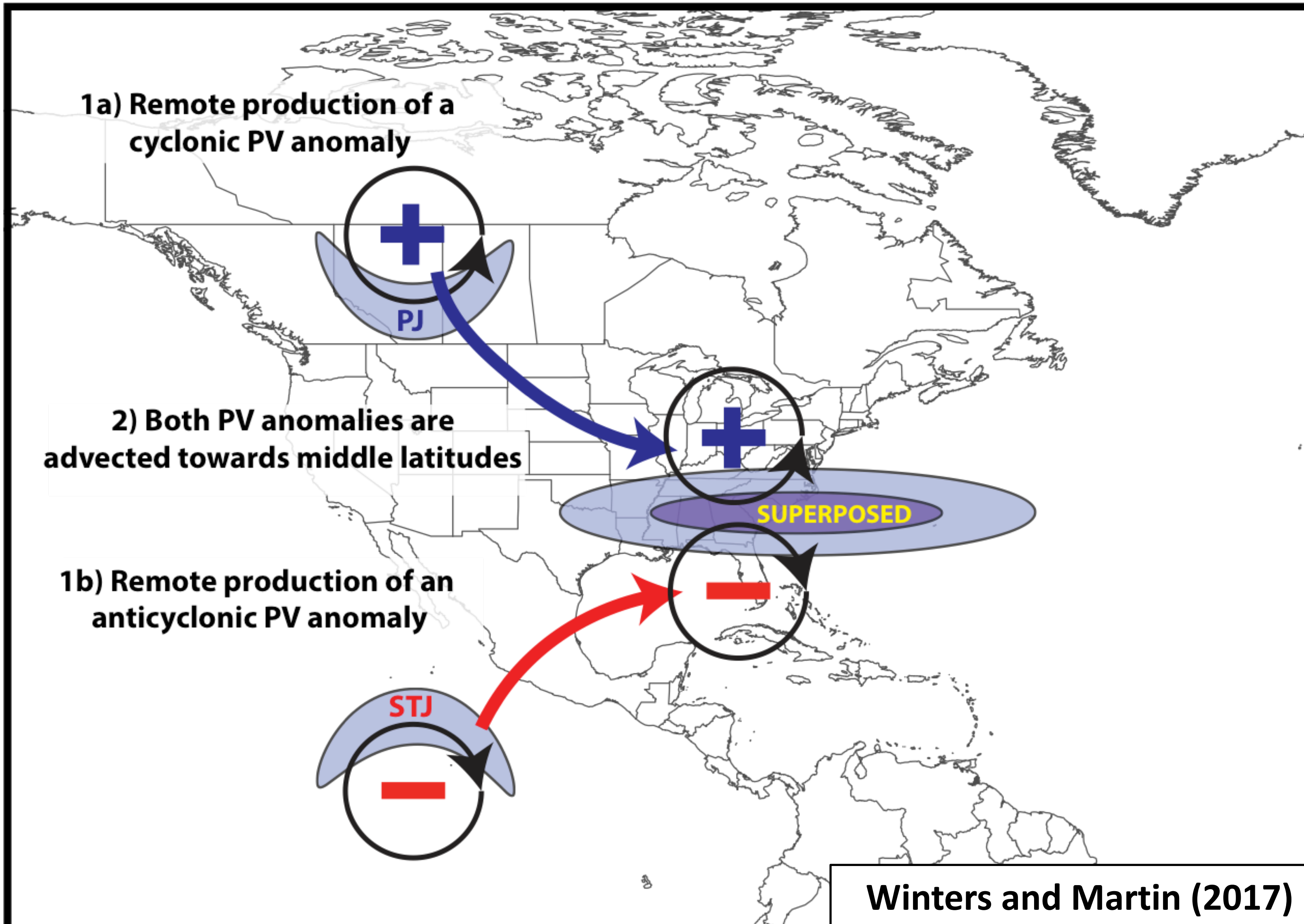


Tropical anticyclonic PV anomalies:

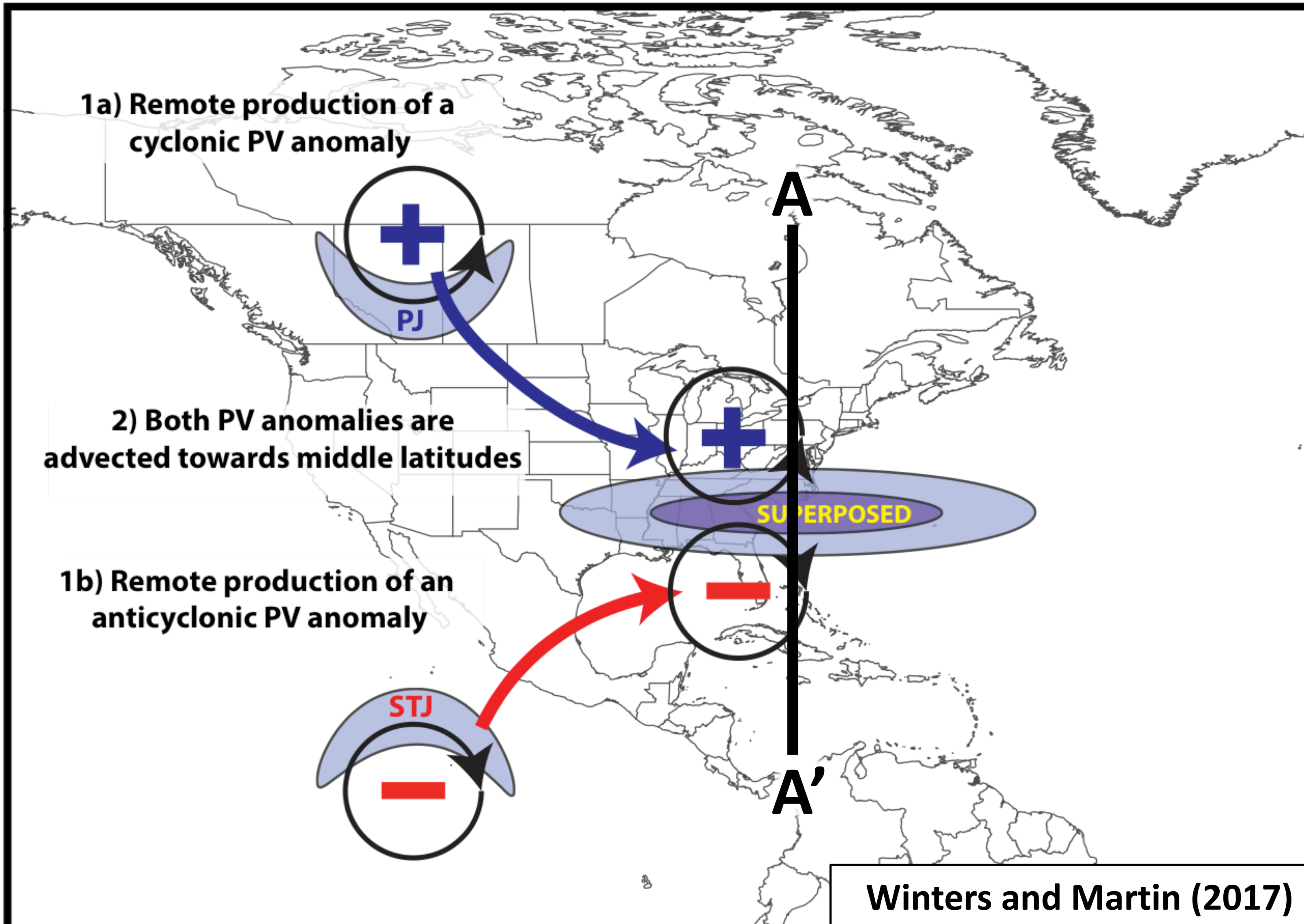
1) Typify a thermodynamic environment characterized by weak upper-tropospheric static stability.
2) Atmospheric rivers often form within the poleward-directed branch of their circulation.

Winters and Martin (2017)

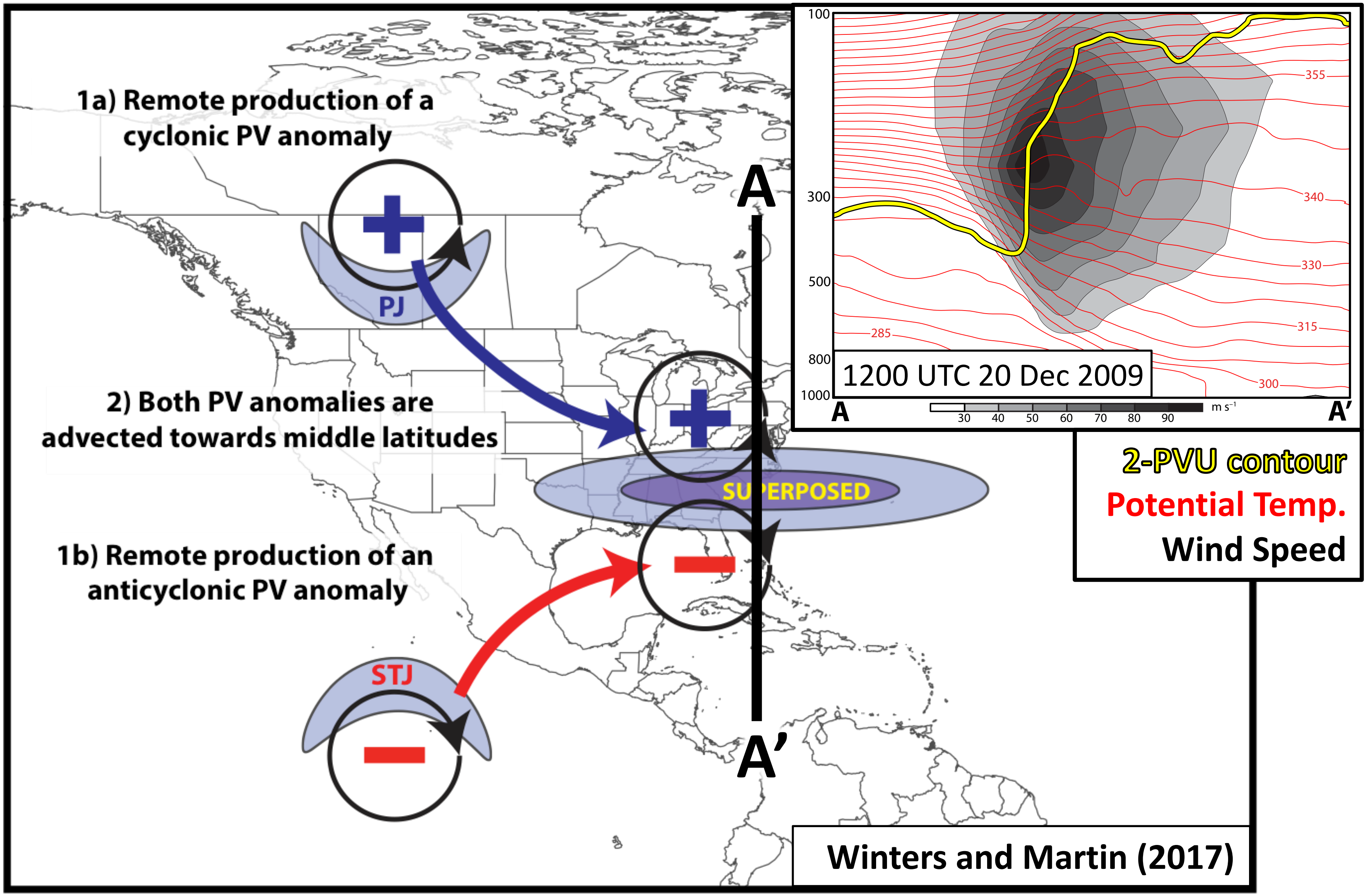
Jet Superposition Conceptual Model



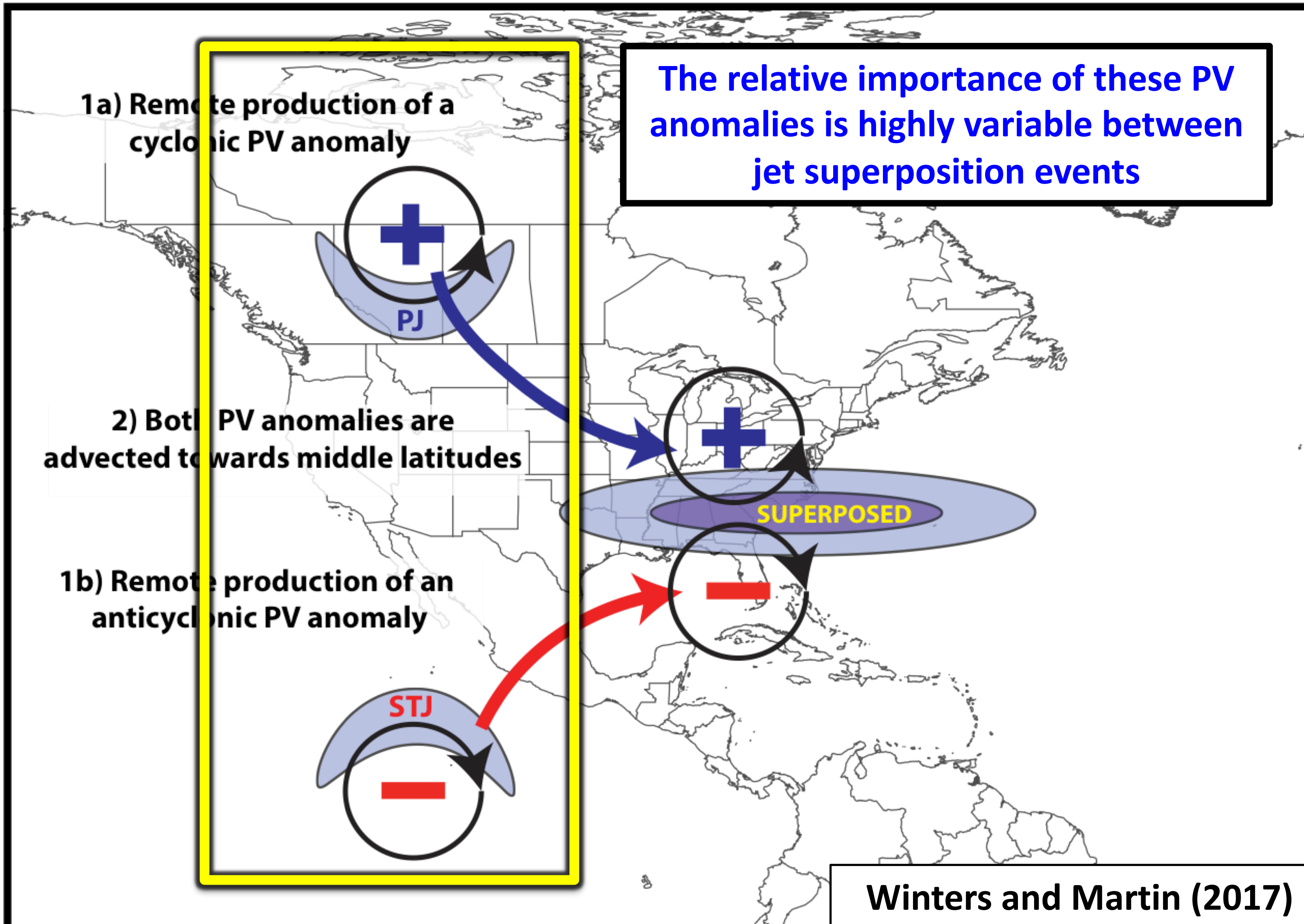
Jet Superposition Conceptual Model



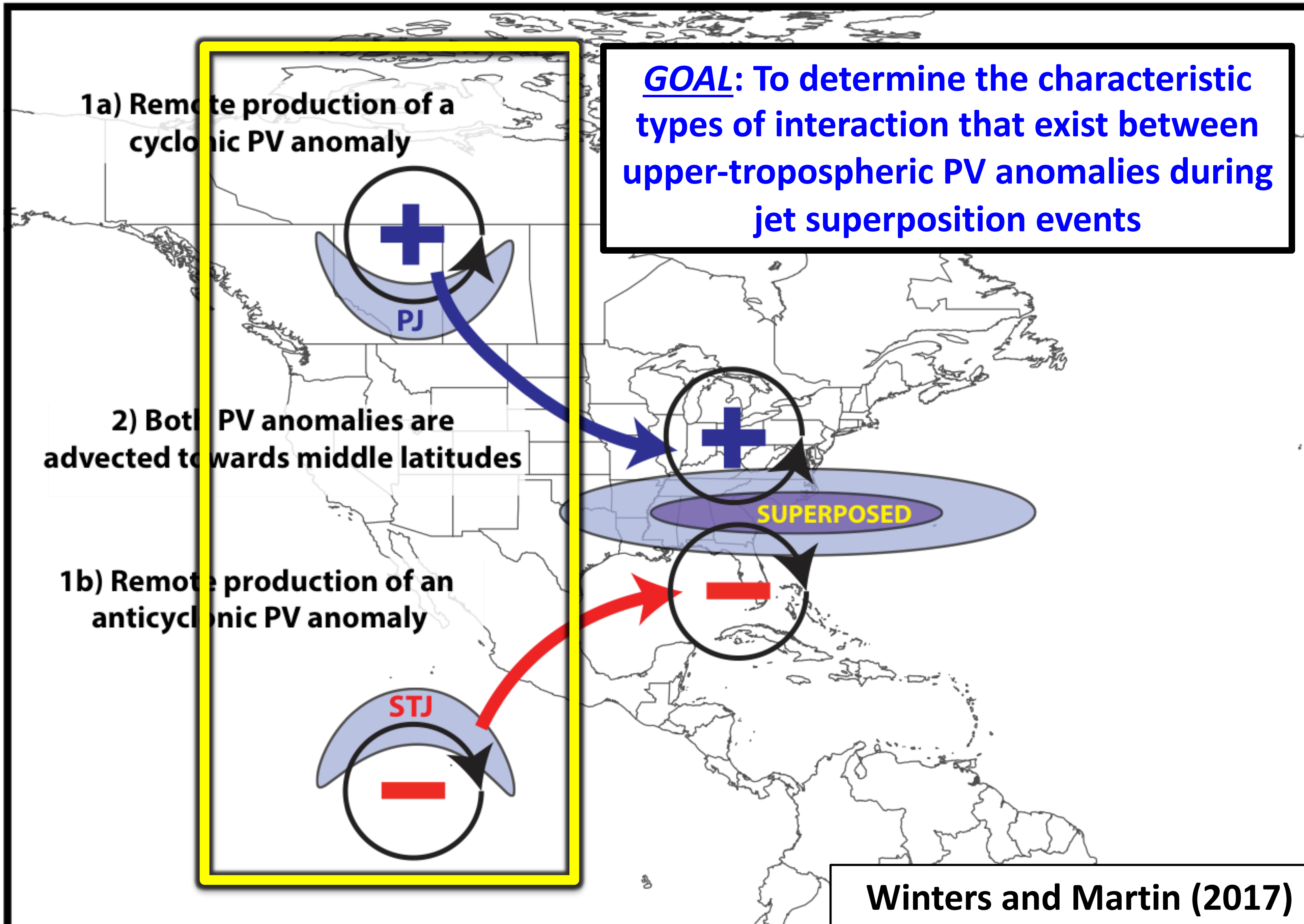
Jet Superposition Conceptual Model



Jet Superposition Conceptual Model



Jet Superposition Conceptual Model



Jet Superposition Event Identification and Classification

Jet Superposition Event Identification

- Isolated NCEP CFSR (Saha et al. 2014) grid points over North America characterized by a jet superposition during Nov.–Mar. 1979–2010 using the Christenson et al. (2017) scheme.
- Retained analysis times that rank in the top 10% in terms the number of grid points characterized by a jet superposition.
- Filtered retained analysis times to group together jet superpositions that are < 30 h and < 1500 km apart.

326 unique jet superposition events

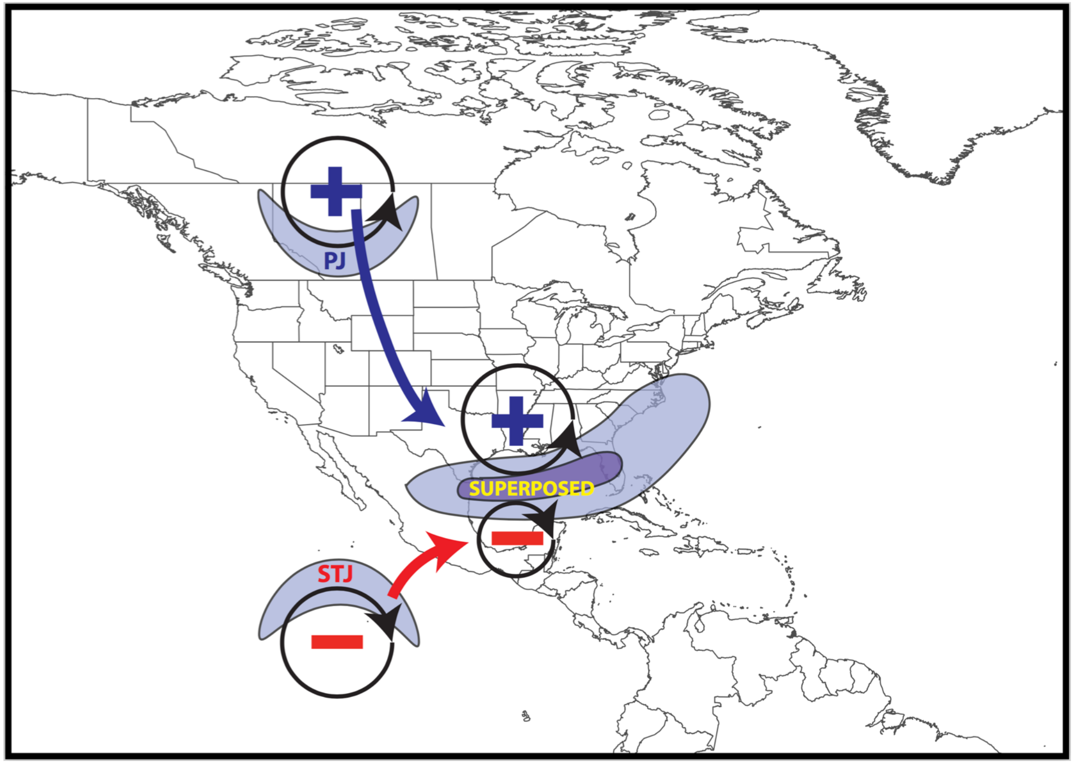
Jet Superposition Event Classification

- Classified jet superposition events into event types based on the deviation of the polar and subtropical jets from their respective climatological latitude bands at the time of jet superposition.

Jet Superposition Event Classification

- Classified jet superposition events into event types based on the deviation of the polar and subtropical jets from their respective climatological latitude bands at the time of jet superposition.

1) **Polar Dominant (N=80)**

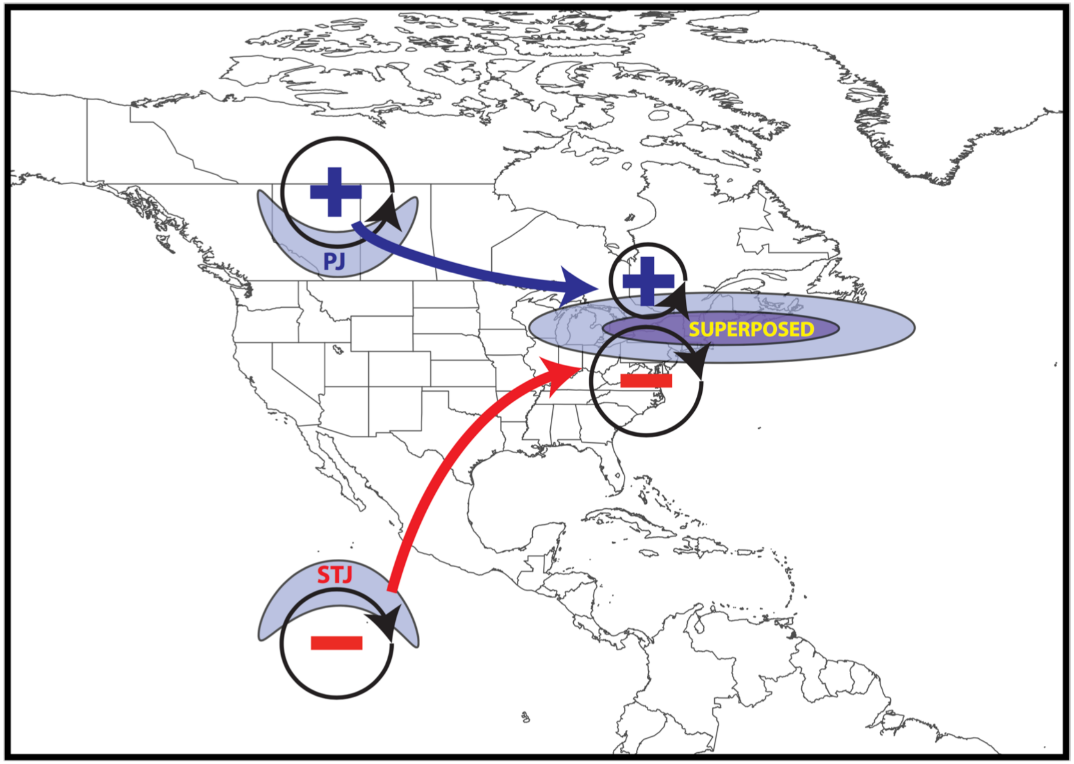


Jet Superposition Event Classification

- Classified jet superposition events into event types based on the deviation of the polar and subtropical jets from their respective climatological latitude bands at the time of jet superposition.

1) **Polar Dominant (N=80)**

2) **Subtropical Dominant (N=129)**



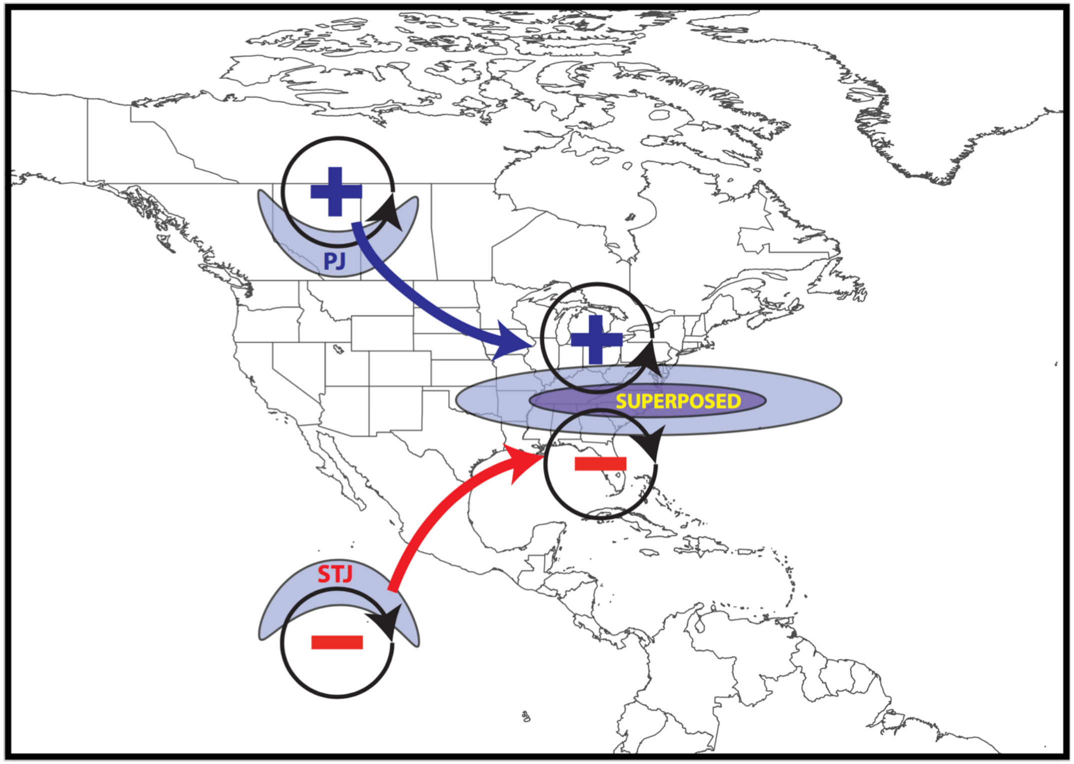
Jet Superposition Event Classification

- Classified jet superposition events into event types based on the deviation of the polar and subtropical jets from their respective climatological latitude bands at the time of jet superposition.

1) Polar Dominant (N=80)

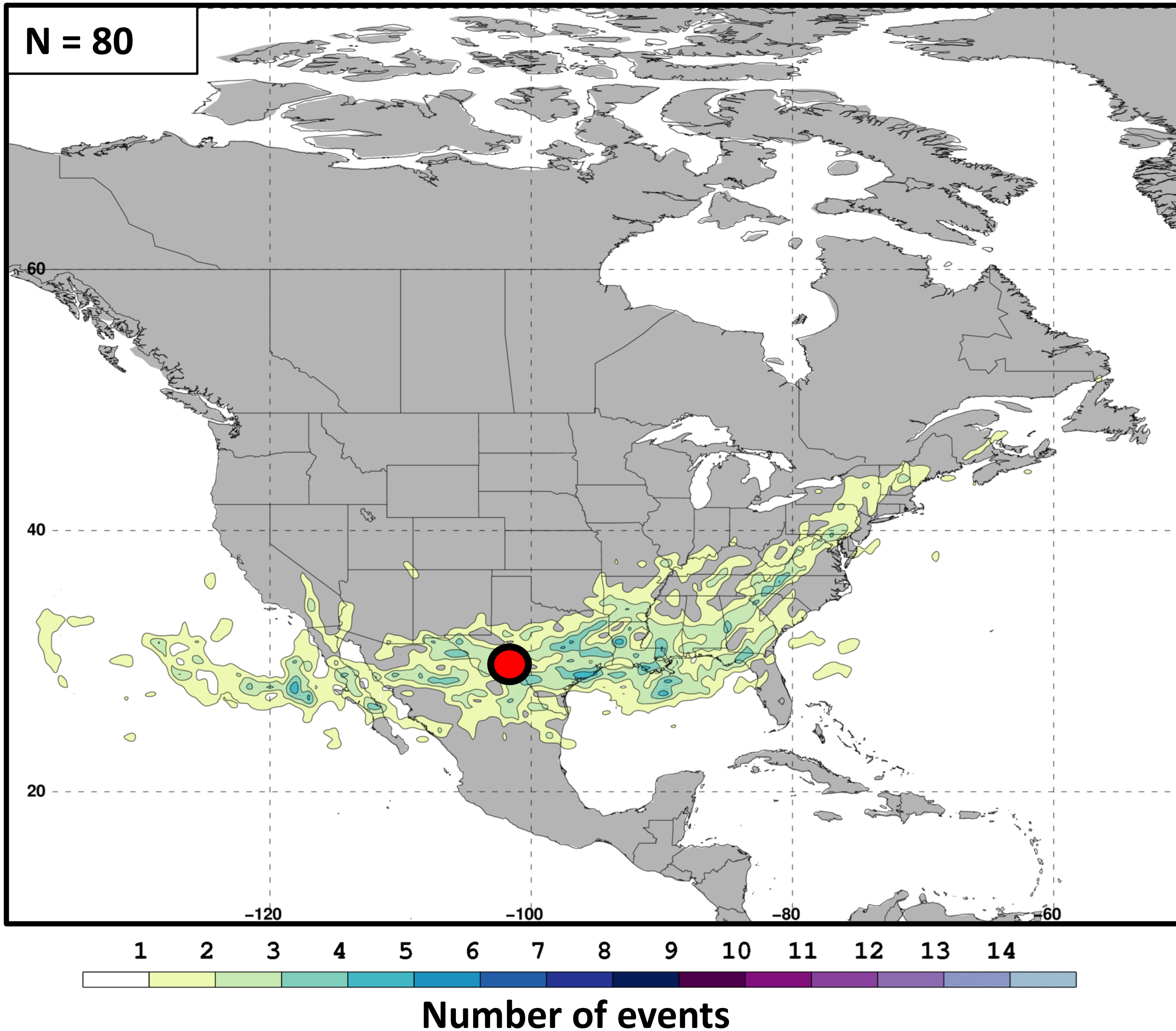
2) Subtropical Dominant (N=129)

3) Hybrid (N=117)



Jet Superposition Event Classification

Frequency of Polar Dominant Jet Superposition Events

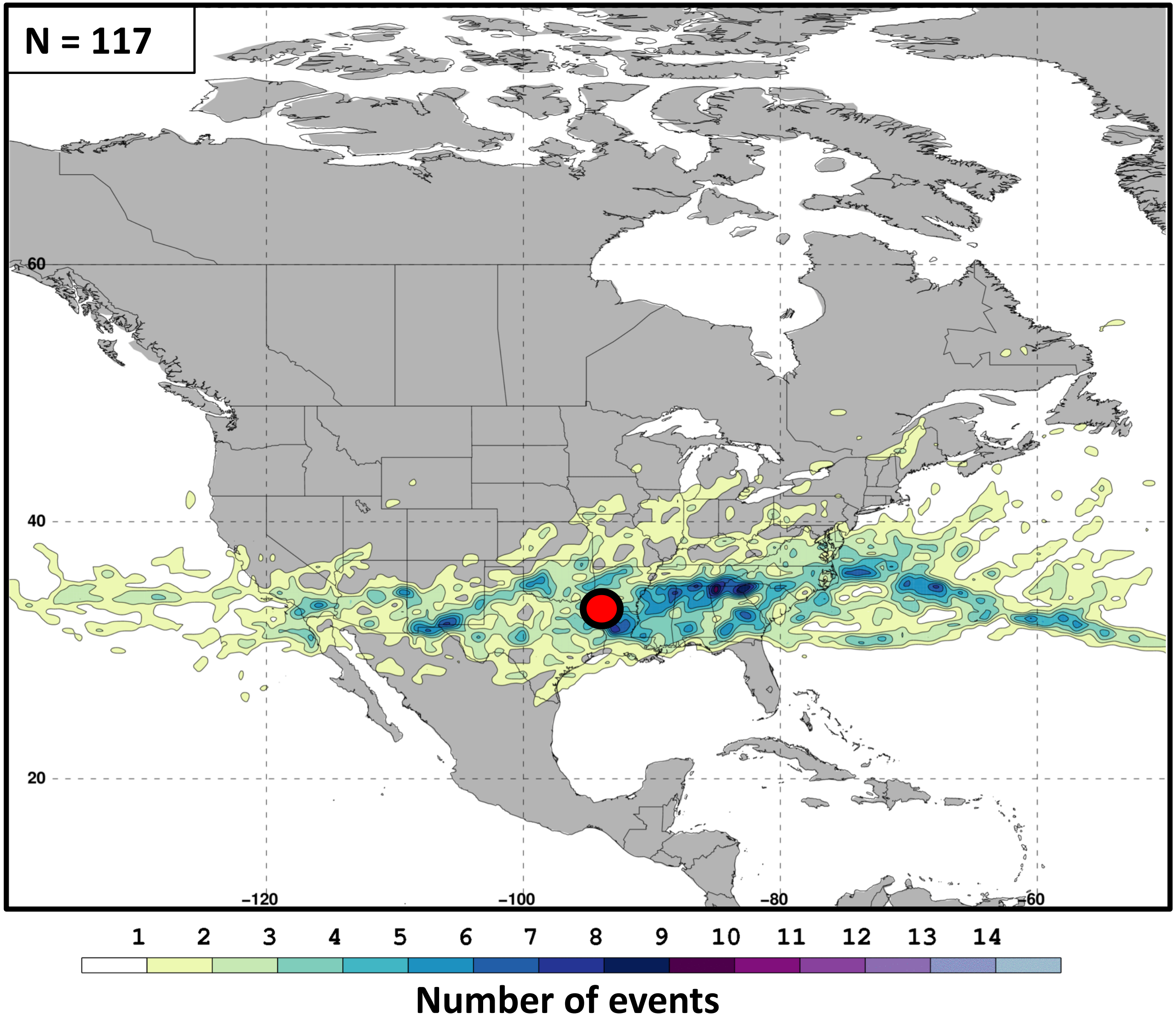


Legend

Avg. Location of Superposition

Jet Superposition Event Classification

Frequency of Hybrid Jet Superposition Events



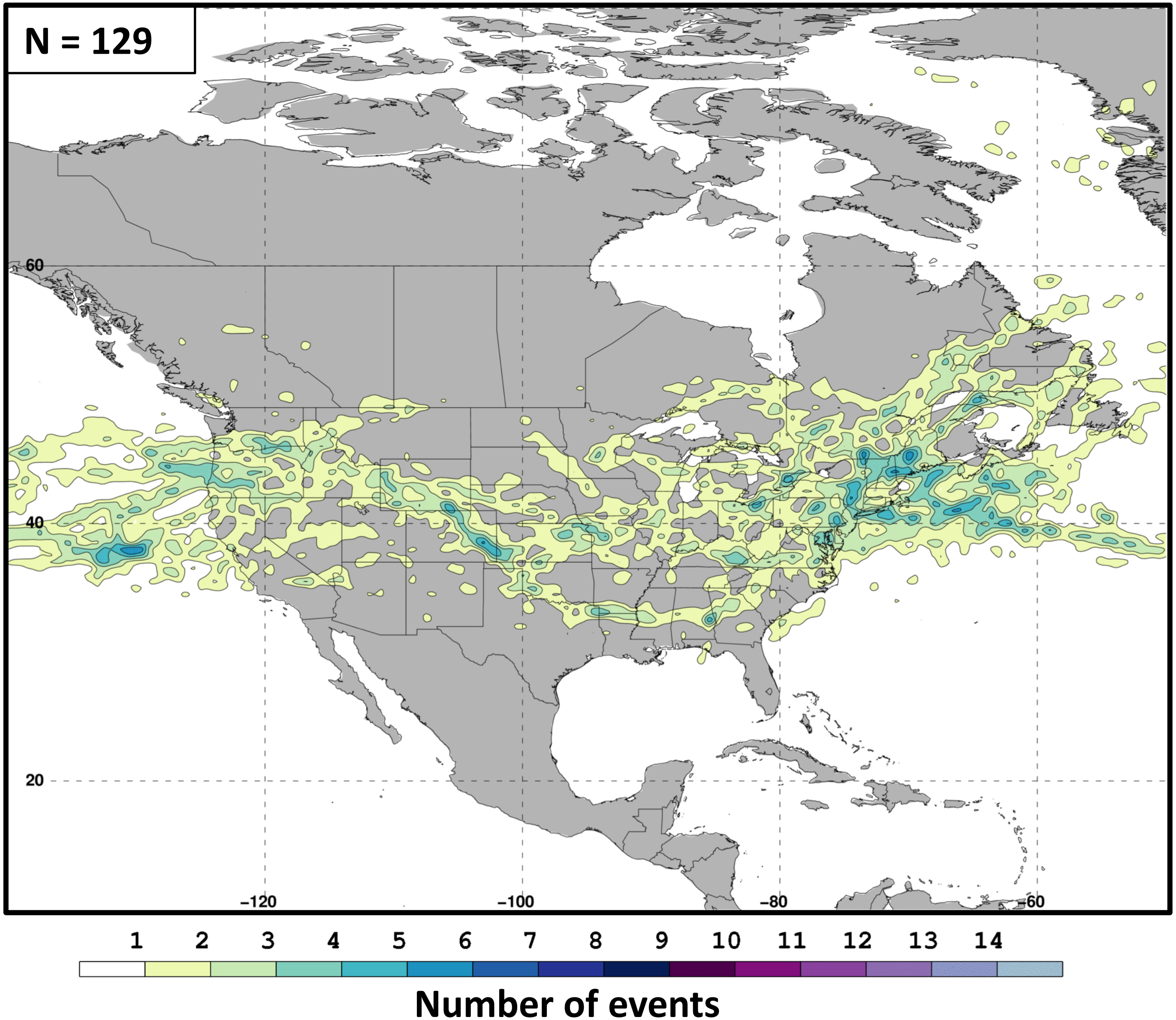
Legend

Avg. Location of Superposition

Jet Superposition Event Classification

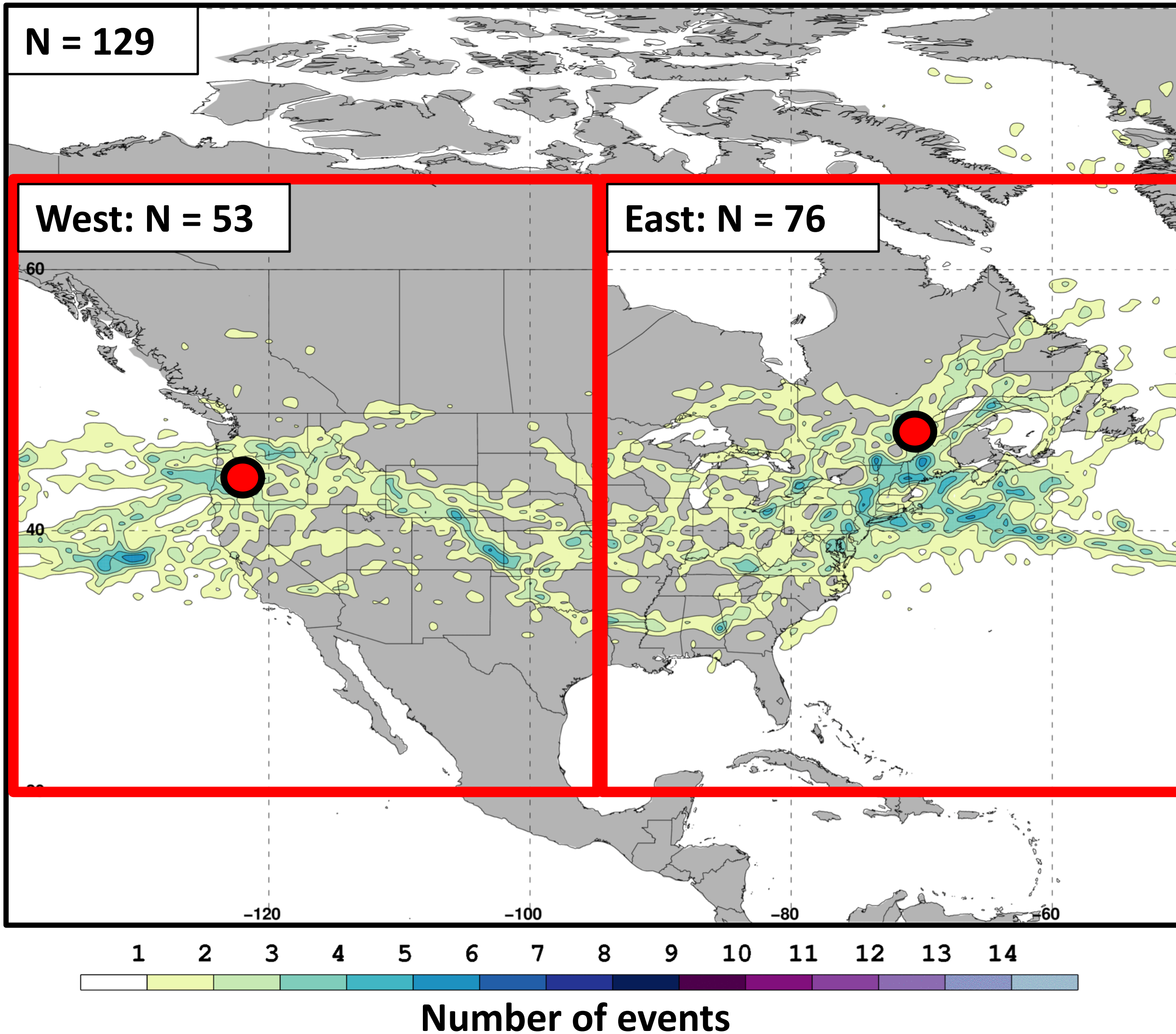
Frequency of Subtropical Dominant Jet Superposition Events

Legend
Avg. Location of Superposition



Jet Superposition Event Classification

Frequency of Subtropical Dominant Jet Superposition Events



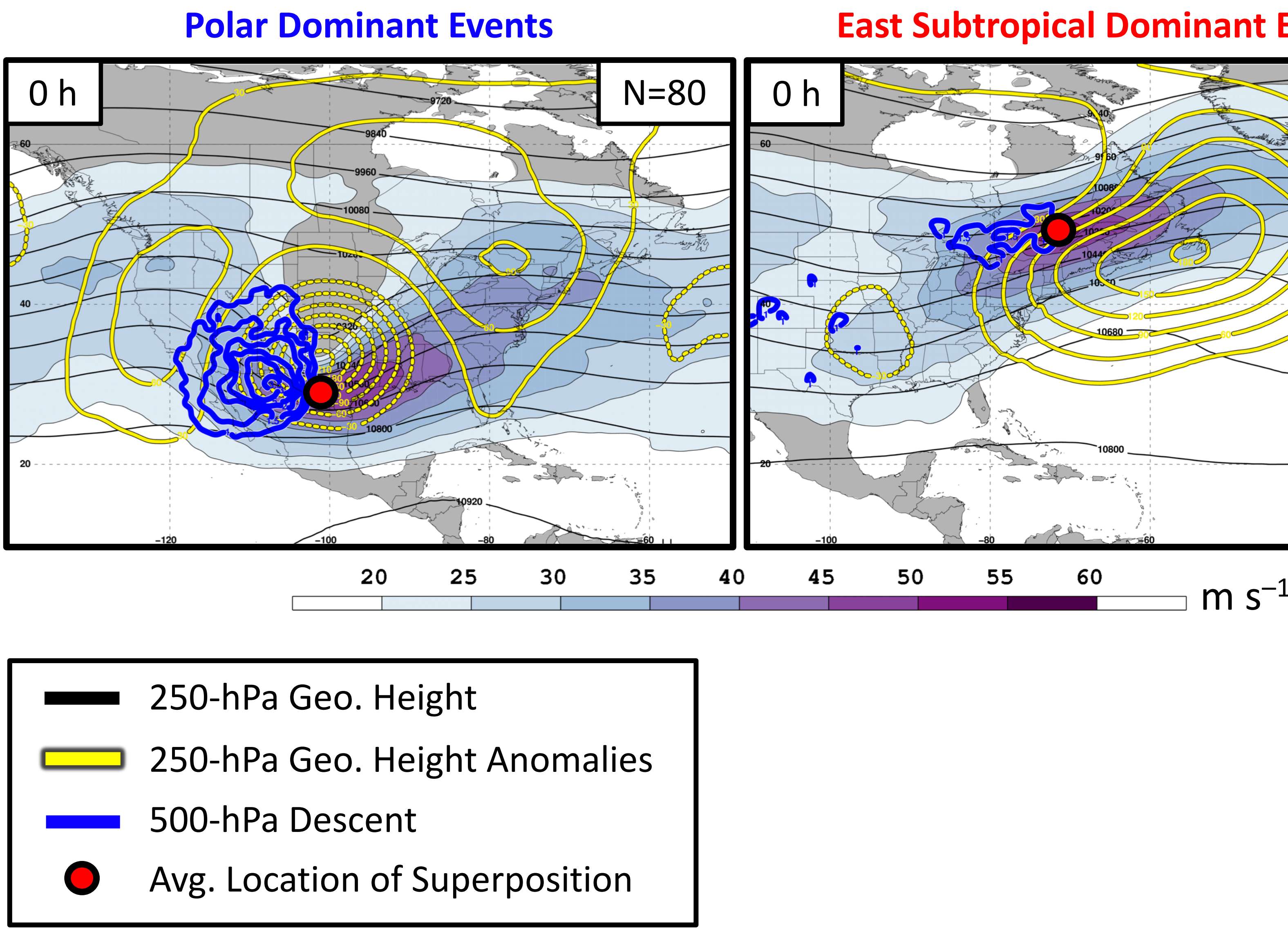
Legend

Avg. Location of Superposition

Jet Superposition Event Composites:

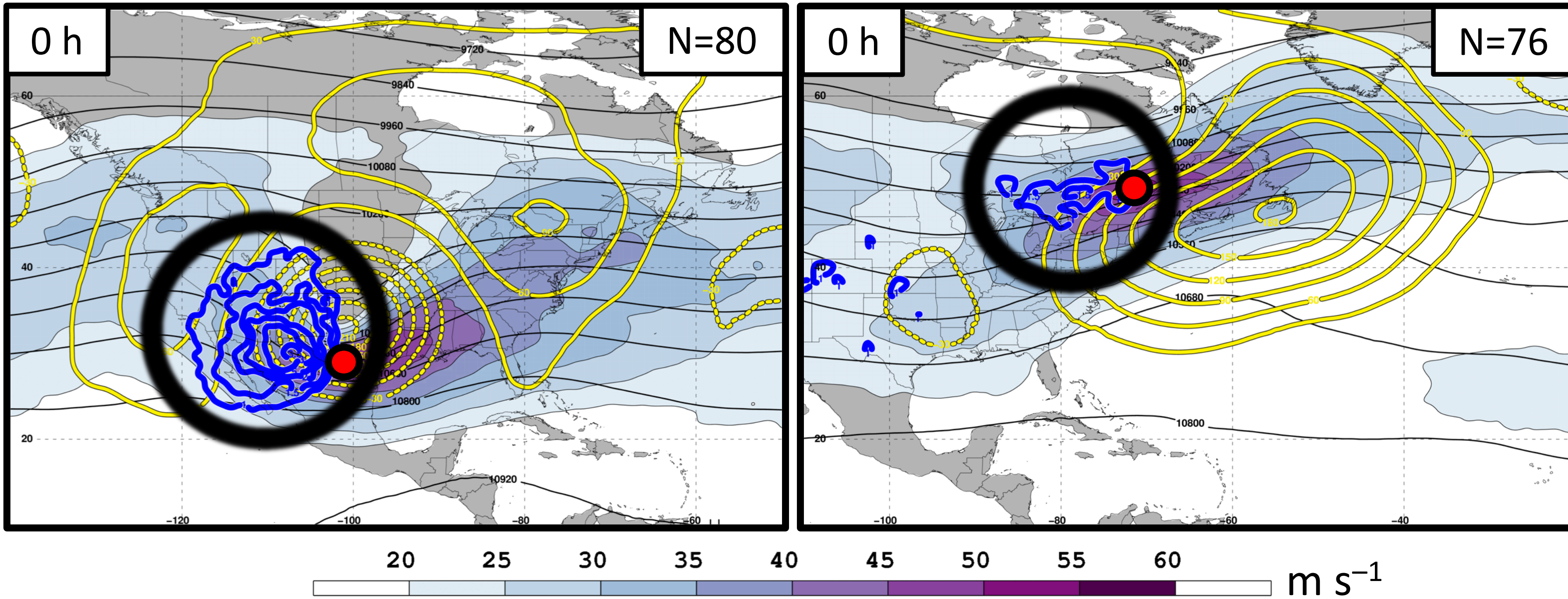
Polar Dominant
vs.
East Subtropical Dominant

Jet Superposition Event Composites



Jet Superposition Event Composites

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

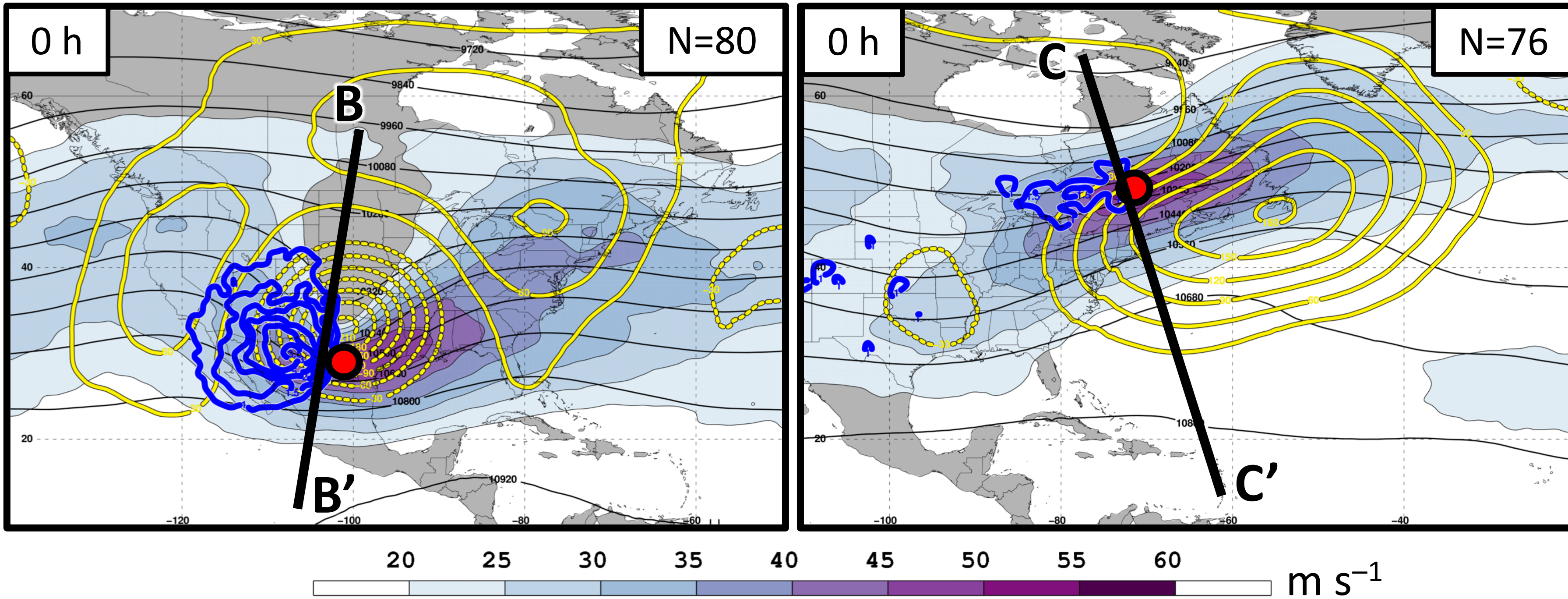


- 250-hPa Geo. Height
- 250-hPa Geo. Height Anomalies
- 500-hPa Descent
- Avg. Location of Superposition

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

Jet Superposition Event Composites

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

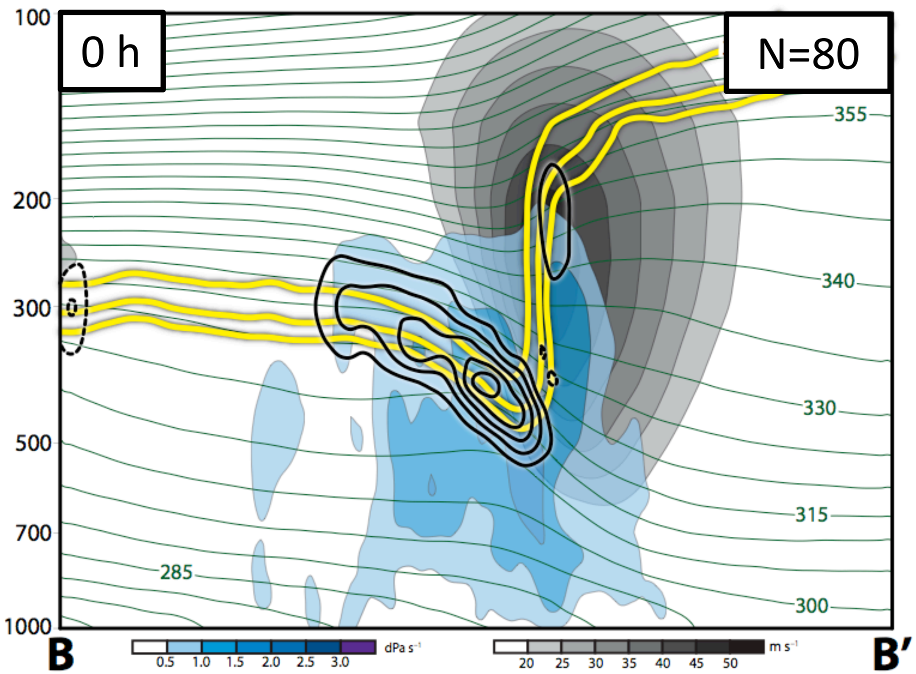


- 250-hPa Geo. Height
- 250-hPa Geo. Height Anomalies
- 500-hPa Descent
- Avg. Location of Superposition

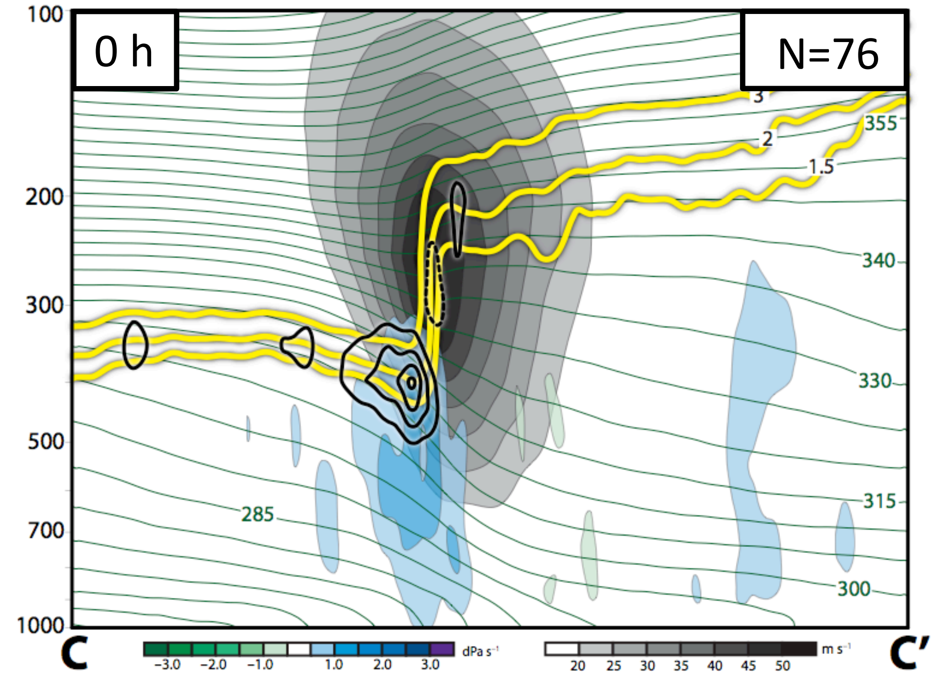
Descent within the jet-entrance region is a common element among the jet superposition event composites.

The Consistent Role of Descent

Polar Dominant Events



East Subtropical Dominant Events



1.5-, 2-, 3-PVU contours

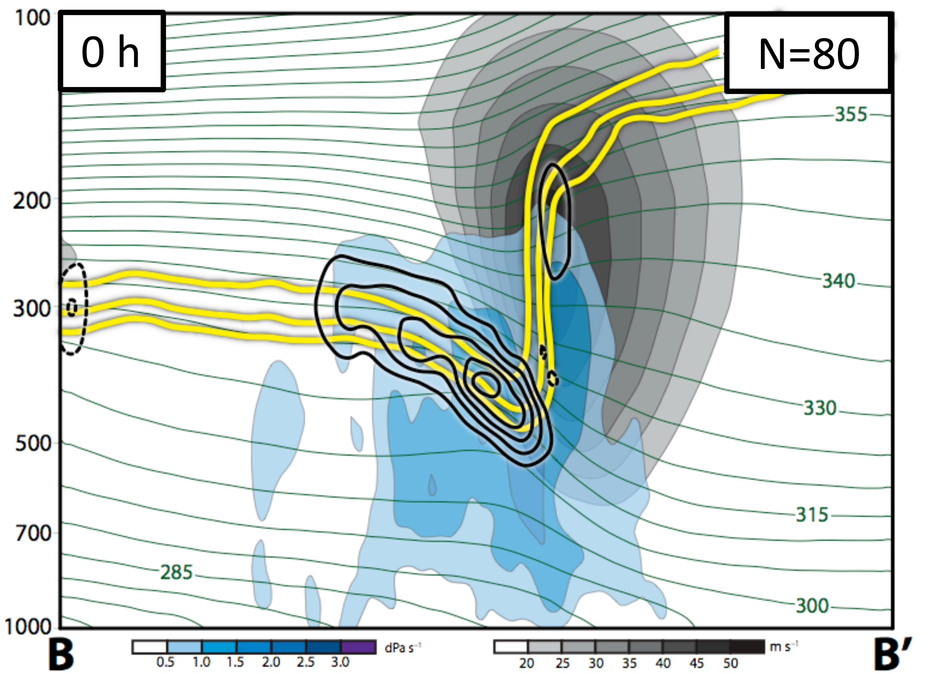
Potential Temperature

Positive PV advection

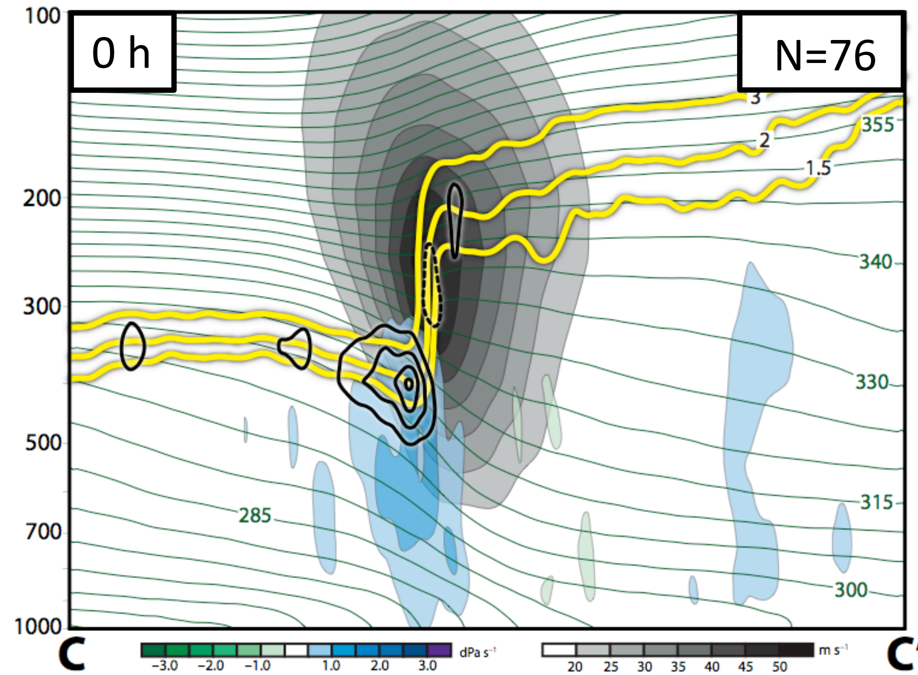
Negative PV advection

The Consistent Role of Descent

Polar Dominant Events



East Subtropical Dominant Events



1.5-, 2-, 3-PVU contours

Potential Temperature

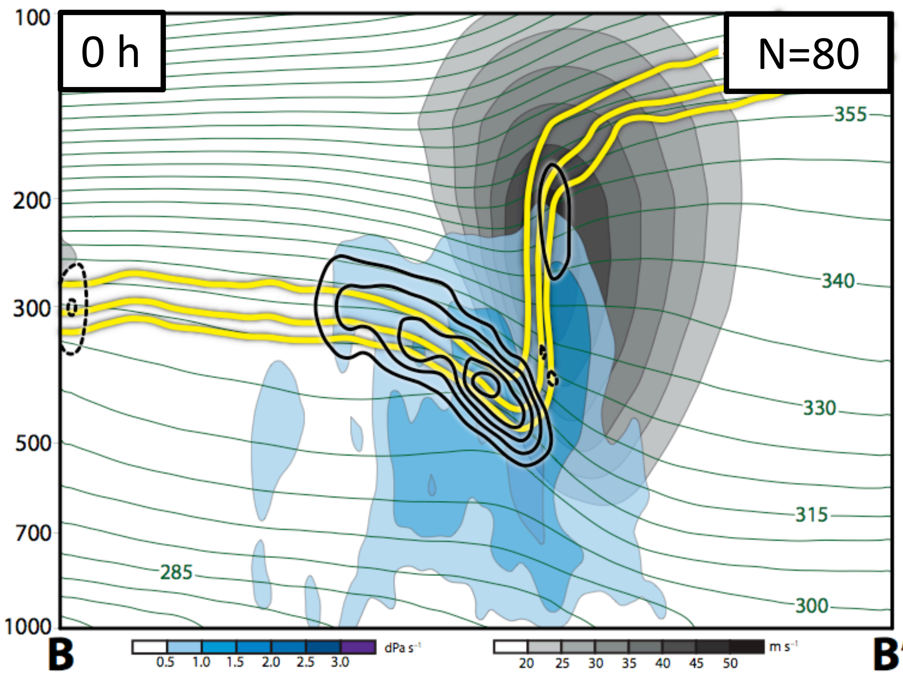
Positive PV advection

Negative PV advection

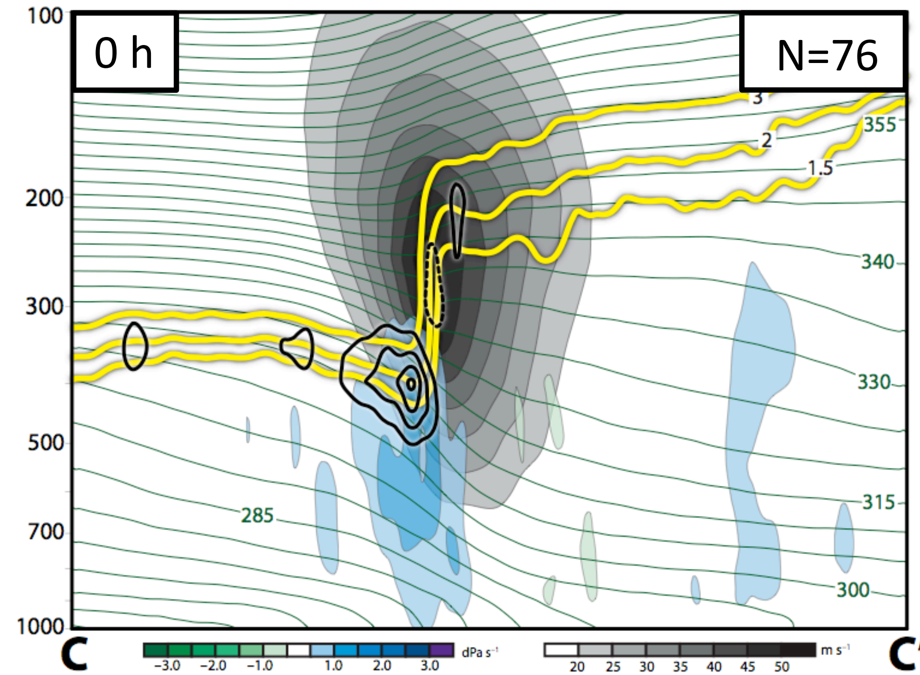
Descent results in downward PV advection within the developing tropopause fold, which acts to steepen the tropopause.

The Consistent Role of Descent

Polar Dominant Events



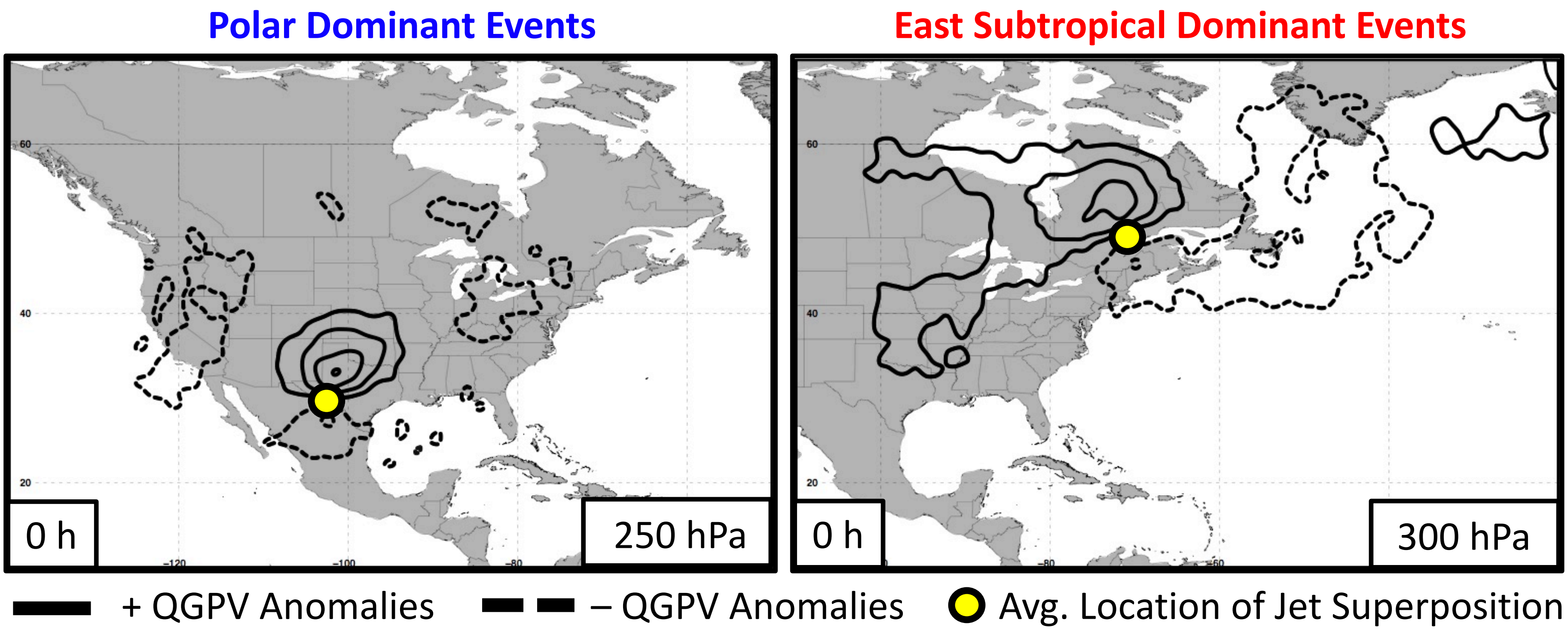
East Subtropical Dominant Events



- 1.5-, 2-, 3-PVU contours
- Potential Temperature
- Positive PV advection
- Negative PV advection

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

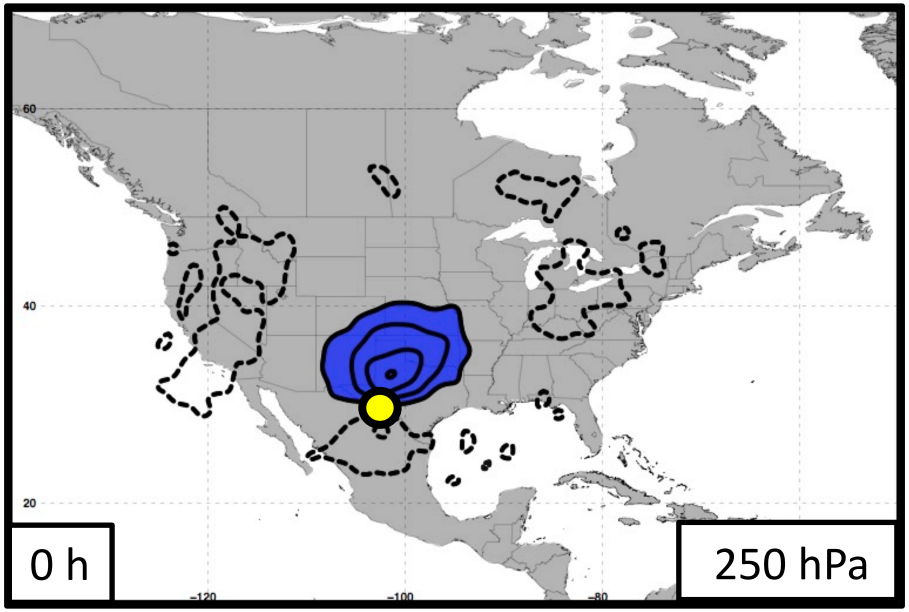
QGPV Inversions



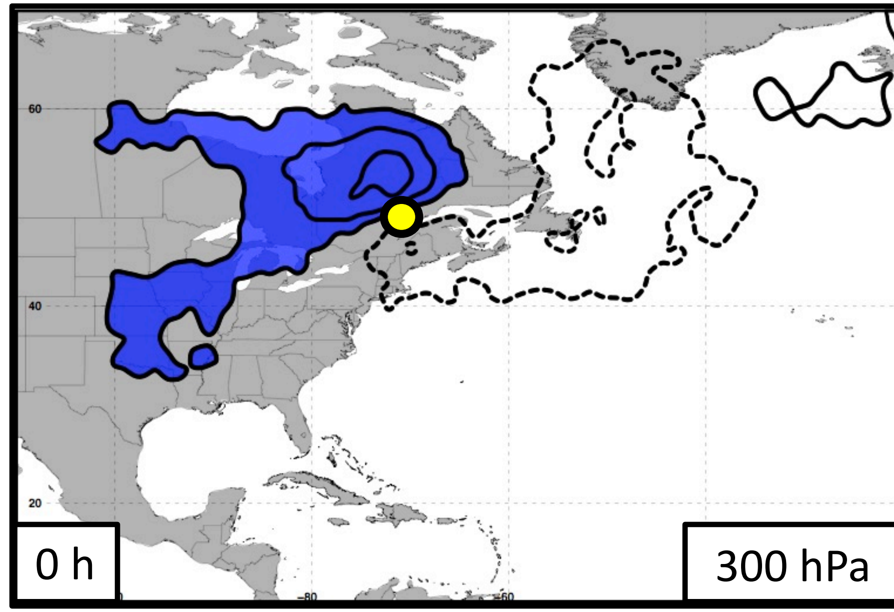
The descent characterizing each jet superposition event composite is examined further by isolating quasi-geostrophic (QG) PV anomalies in the vicinity of the jet superposition.

QGPV Inversions

Polar Dominant Events



East Subtropical Dominant Events

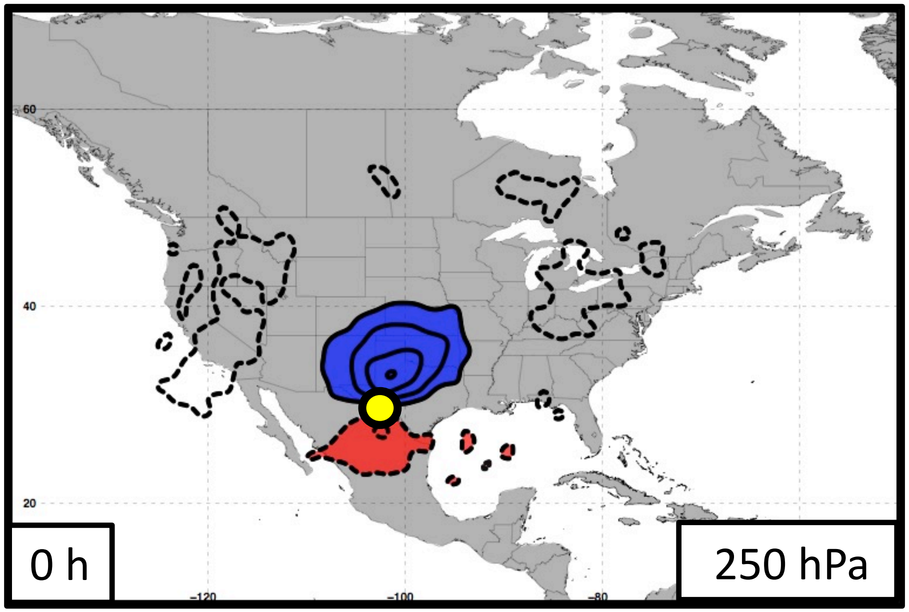


Polar Cyclonic QGPV Anomalies

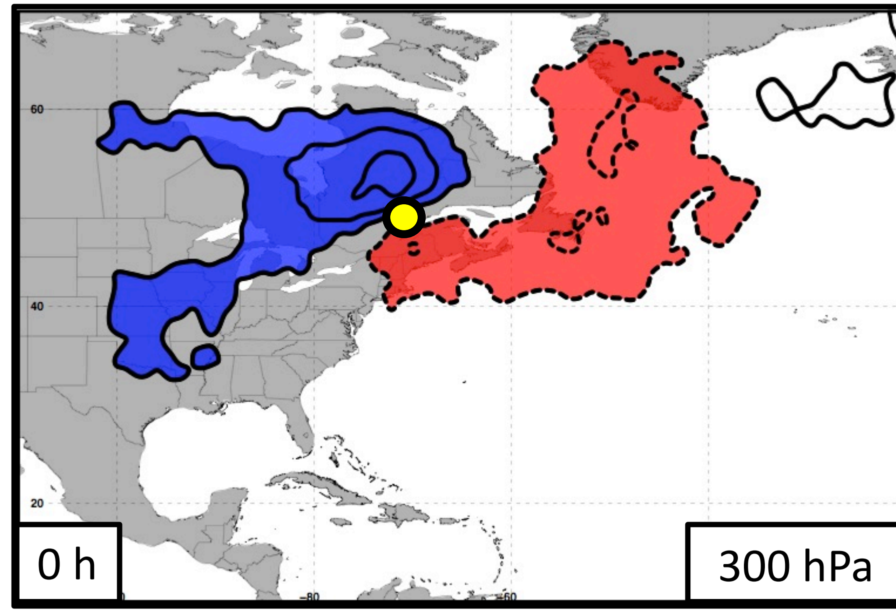
Avg. Location of Jet Superposition

QGPV Inversions

Polar Dominant Events



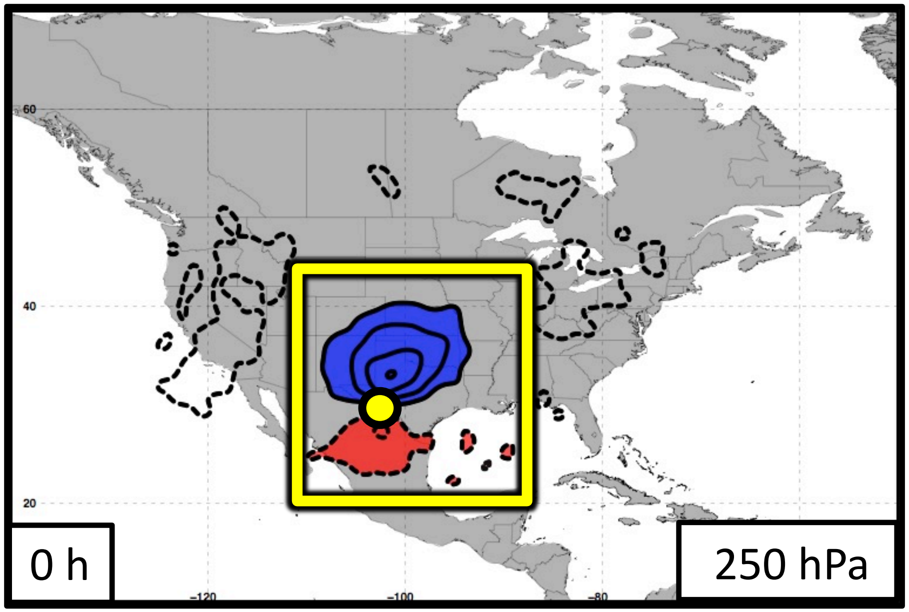
East Subtropical Dominant Events



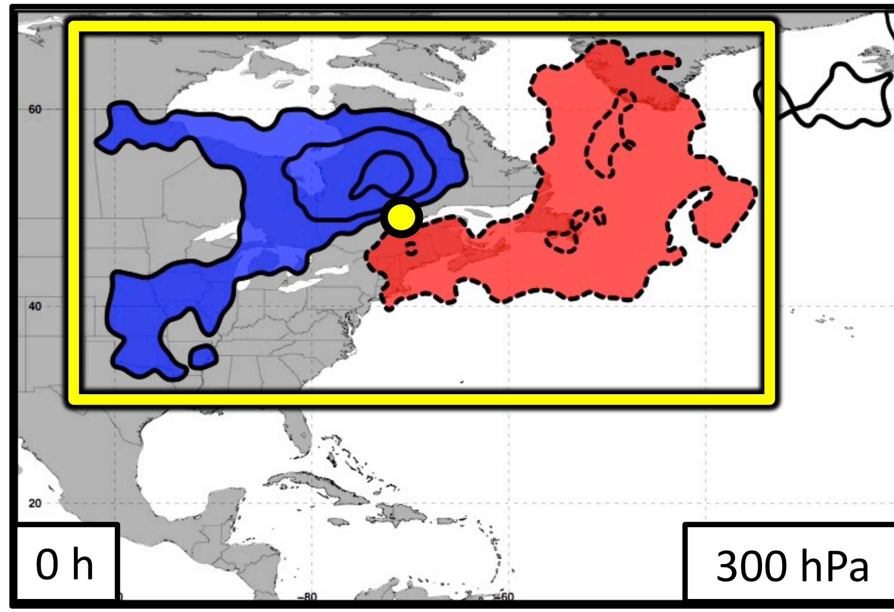
- Polar Cyclonic QGPV Anomalies
- Tropical Anticyclonic QGPV Anomalies
- Avg. Location of Jet Superposition

QGPV Inversions

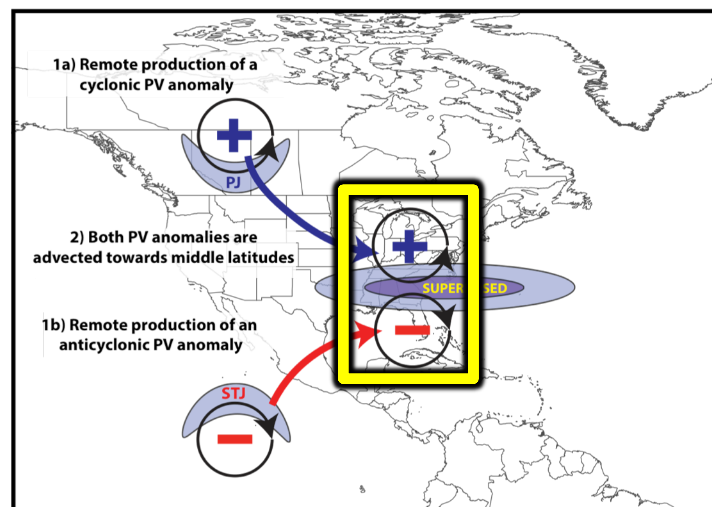
Polar Dominant Events



East Subtropical Dominant Events

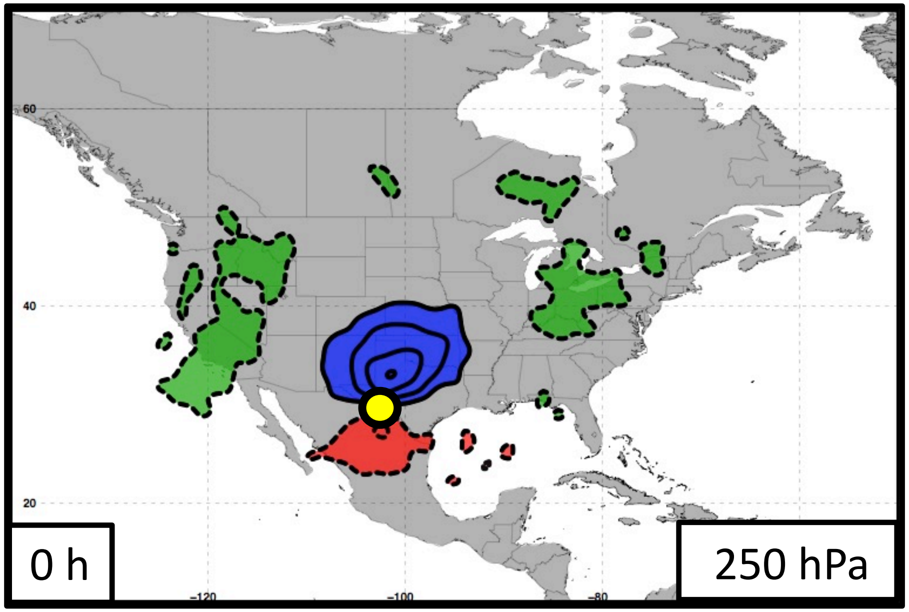


- Polar Cyclonic QGPV Anomalies (blue)
- Tropical Anticyclonic QGPV Anomalies (red)
- Avg. Location of Jet Superposition (yellow dot)

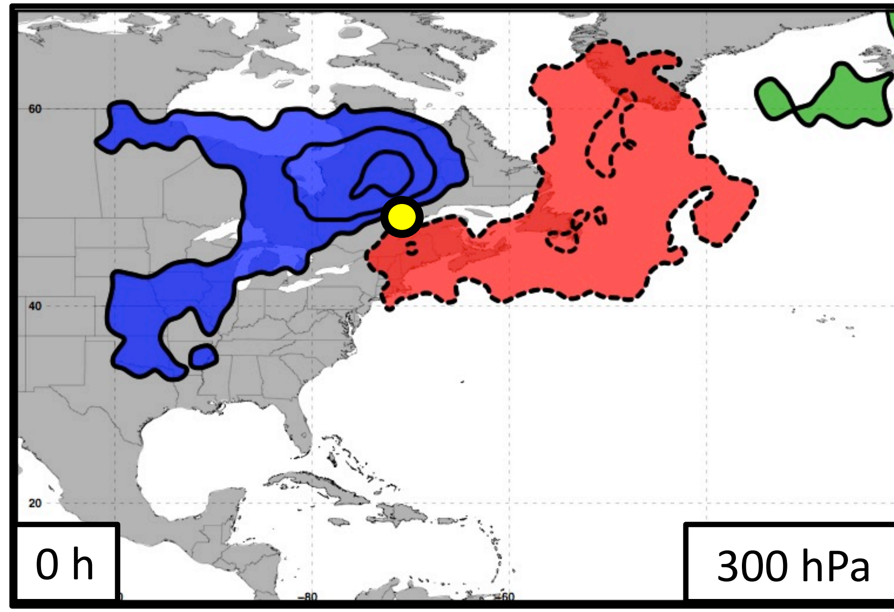


QGPV Inversions

Polar Dominant Events



East Subtropical Dominant Events

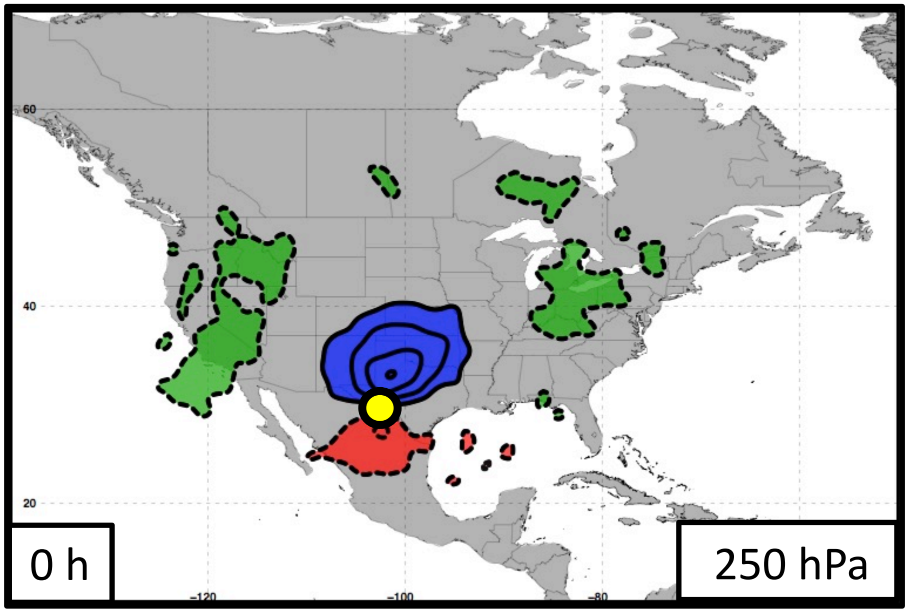


Polar Cyclonic QGPV Anomalies
Tropical Anticyclonic QGPV Anomalies
Residual Upper-Tropospheric QGPV Anomalies

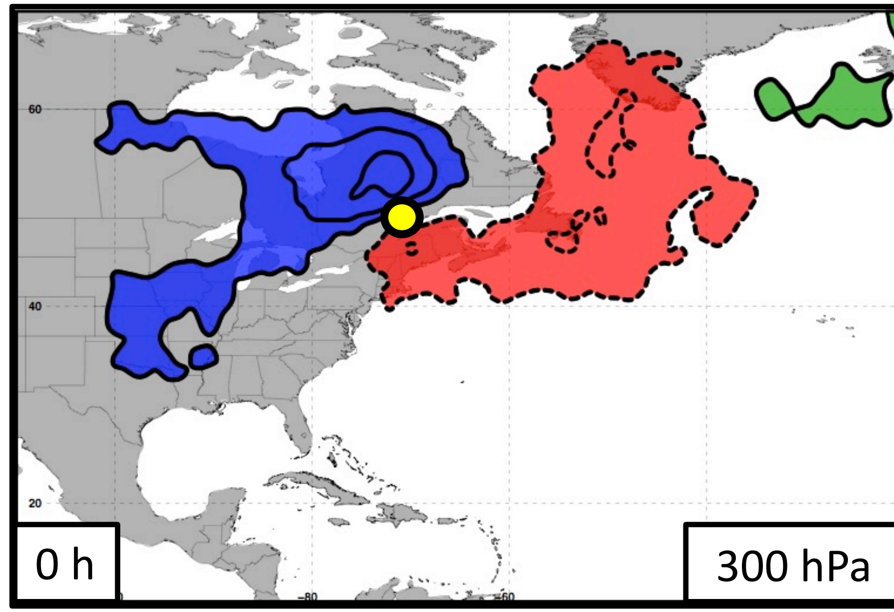
Avg. Location of Jet Superposition

QGPV Inversions

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 Jet Superposition

QGPV Inversions

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.*

QGPV Inversions

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:

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

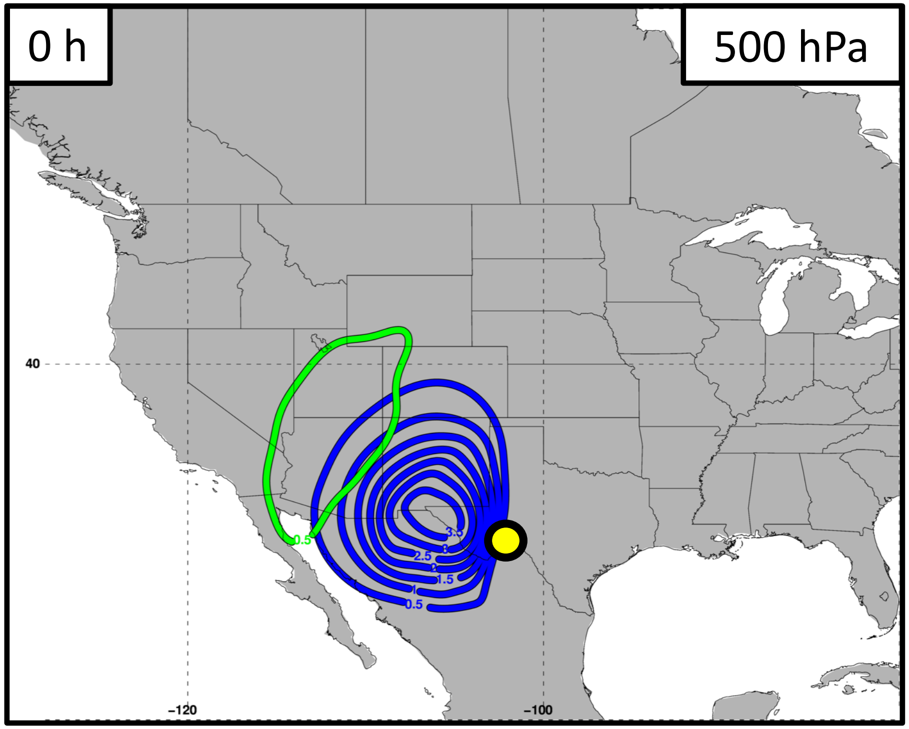
where

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

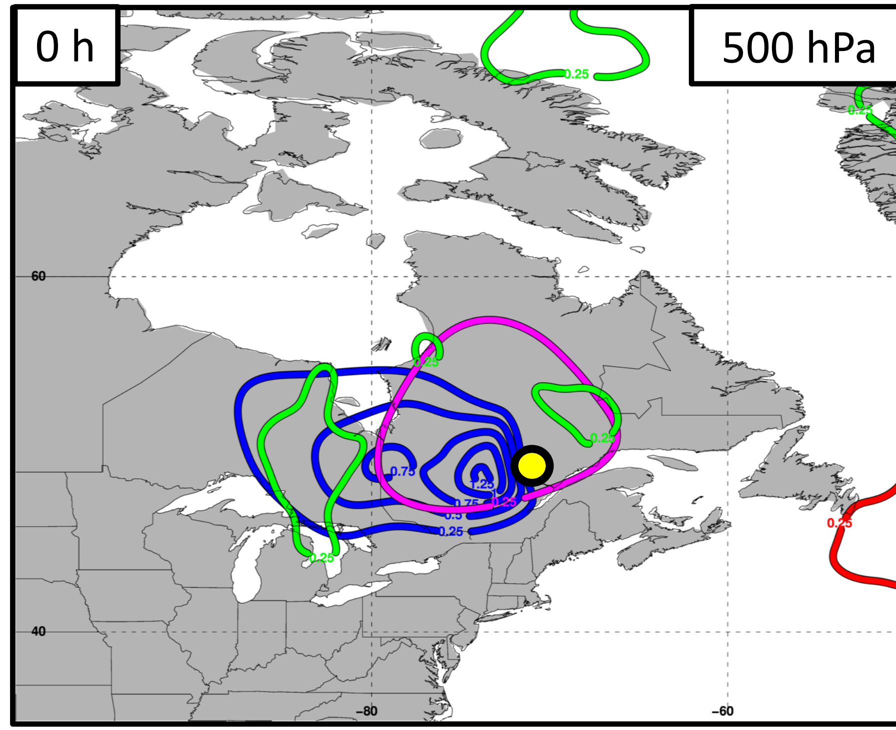
$$\vec{Q} = -\frac{R}{p}\left[\left(\frac{\partial\overrightarrow{V_g'}}{\partial x}\cdot\nabla T\right),\left(\frac{\partial\overrightarrow{V_g'}}{\partial y}\cdot\nabla T\right)\right]$$

QG Descent

Polar Dominant Events



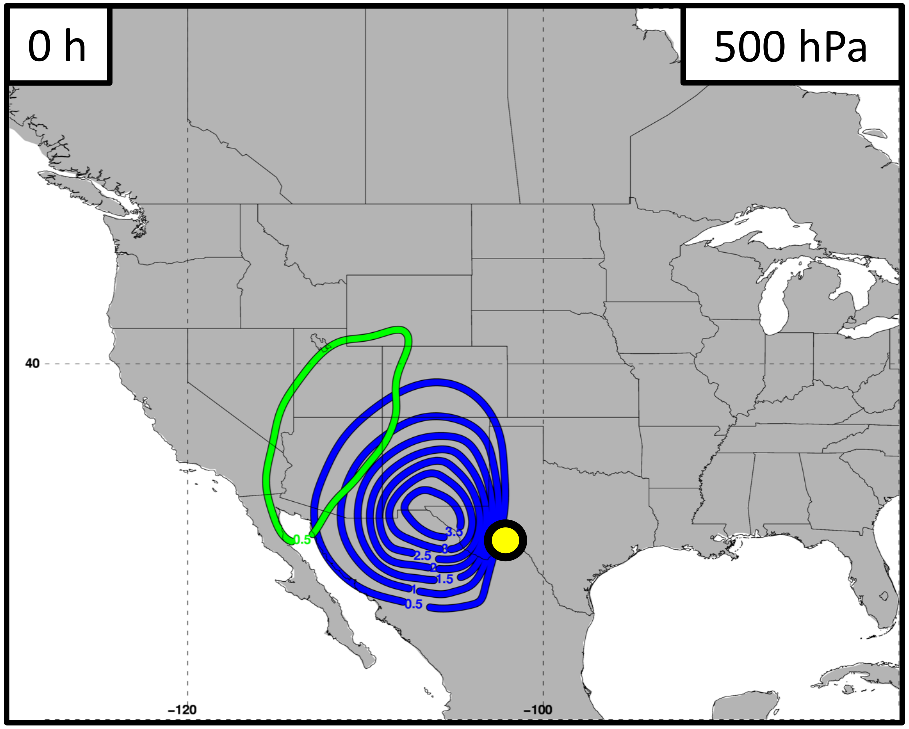
East Subtropical Dominant Events



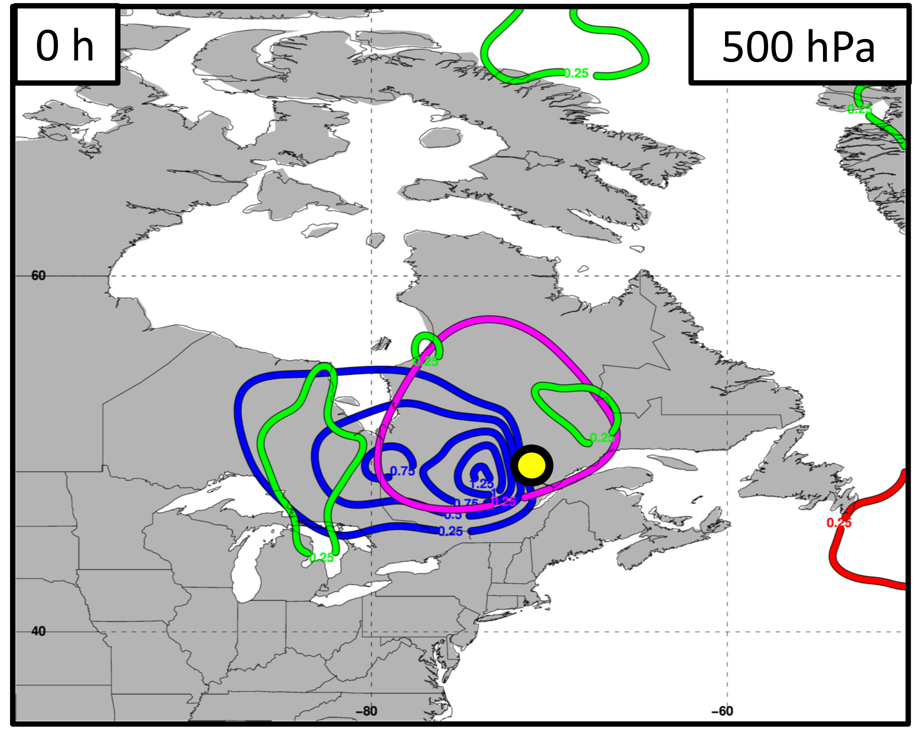
- Polar Cyclonic QGPV Anomalies
- Tropical Anticyclonic QGPV Anomalies
- Residual Upper-Tropospheric QGPV Anomalies
- Lower-Tropospheric QGPV Anomalies
- Avg. Location of Jet Superposition

QG 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 Jet Superposition

Descent is primarily associated with polar cyclonic QGPV anomalies.

Summary

- Jet superpositions typify a dynamical and thermodynamic environment that is particularly conducive to high-impact weather.
- Descent within the jet-entrance region is a common element among jet superpositions, regardless of the event type.
- Descent is primarily associated with the geostrophic flow attributed to polar cyclonic QGPV anomalies.
- The latter result underscores the critical role that polar cyclonic QGPV anomalies play during jet superpositions.

Contact: acwinters@albany.edu

Supplementary Slides

References

Cavallo, S. M., and G. J. Hakim, 2010: Composite structure of tropopause polar cyclones. *Mon. Wea. Rev.*, **138,** 3840–3857.

Christenson, C. E., J. E. Martin, and Z. J. Handlos, 2017: A synoptic-climatology of Northern Hemisphere, cold season polar and subtropical jet superposition events. *J. Climate*, **30**, 7231-7246.

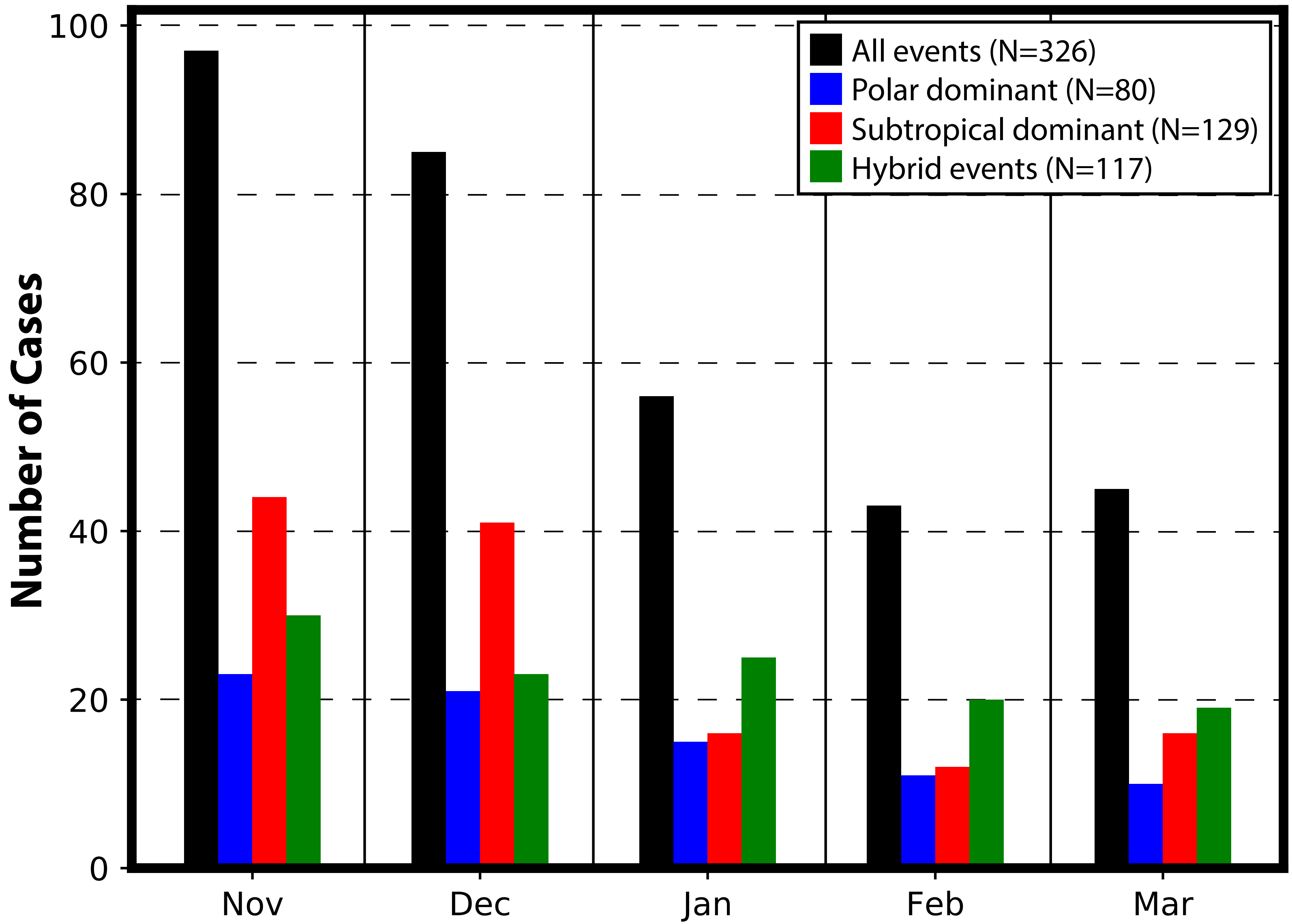
Pyle, M. E., D. Keyser, and L. F. Bosart, 2004: A diagnostic study of jet streaks: Kinematic signatures and relationship to coherent tropopause disturbances. *Mon. Wea. Rev.*, **132,** 297–319.

Saha, S. and co-authors, 2014: The NCEP Climate Forecast System Version 2. *J. Climate*, **27,** 2185–2208.

Winters, A. C., and J. E. Martin, 2017: Diagnosis of a North American polar/subtropical jet superposition employing piecewise potential vorticity inversion. *Mon. Wea. Rev.*,**145**, 1853-1873.

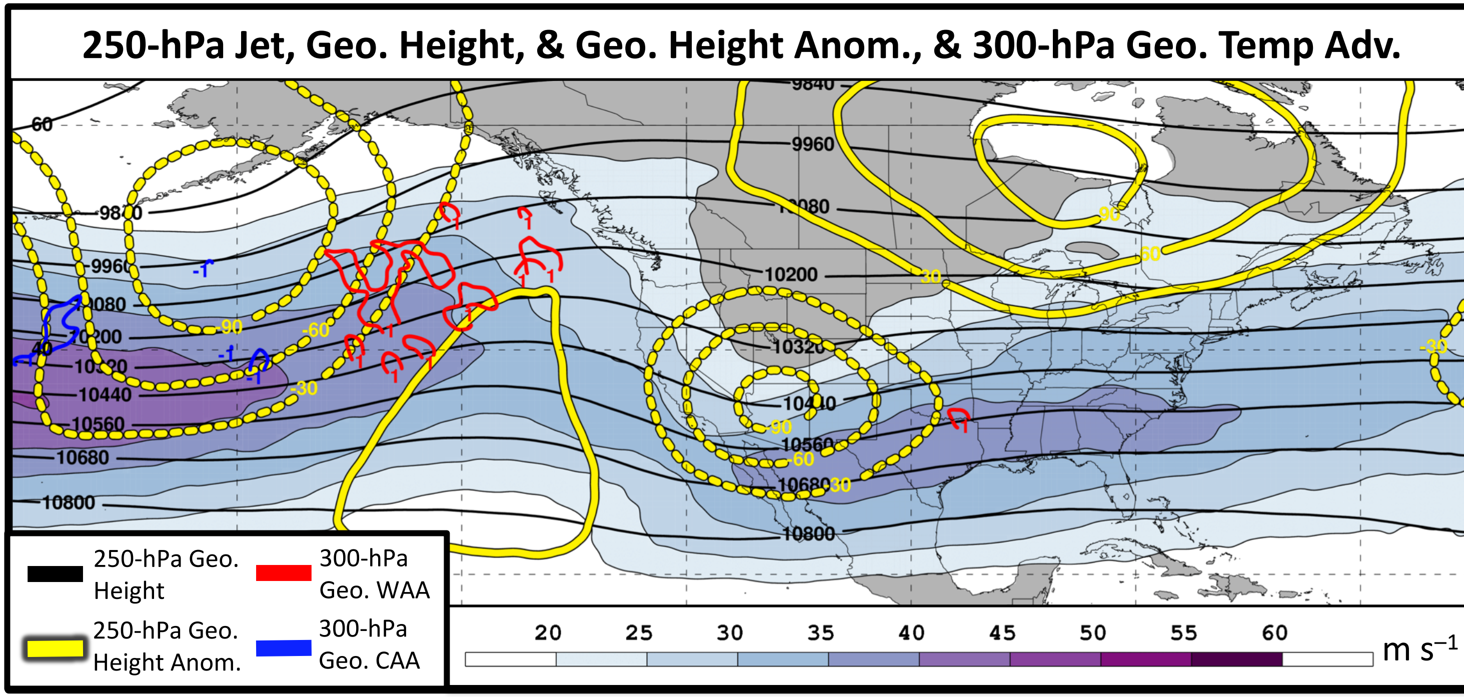
Composite Characteristics

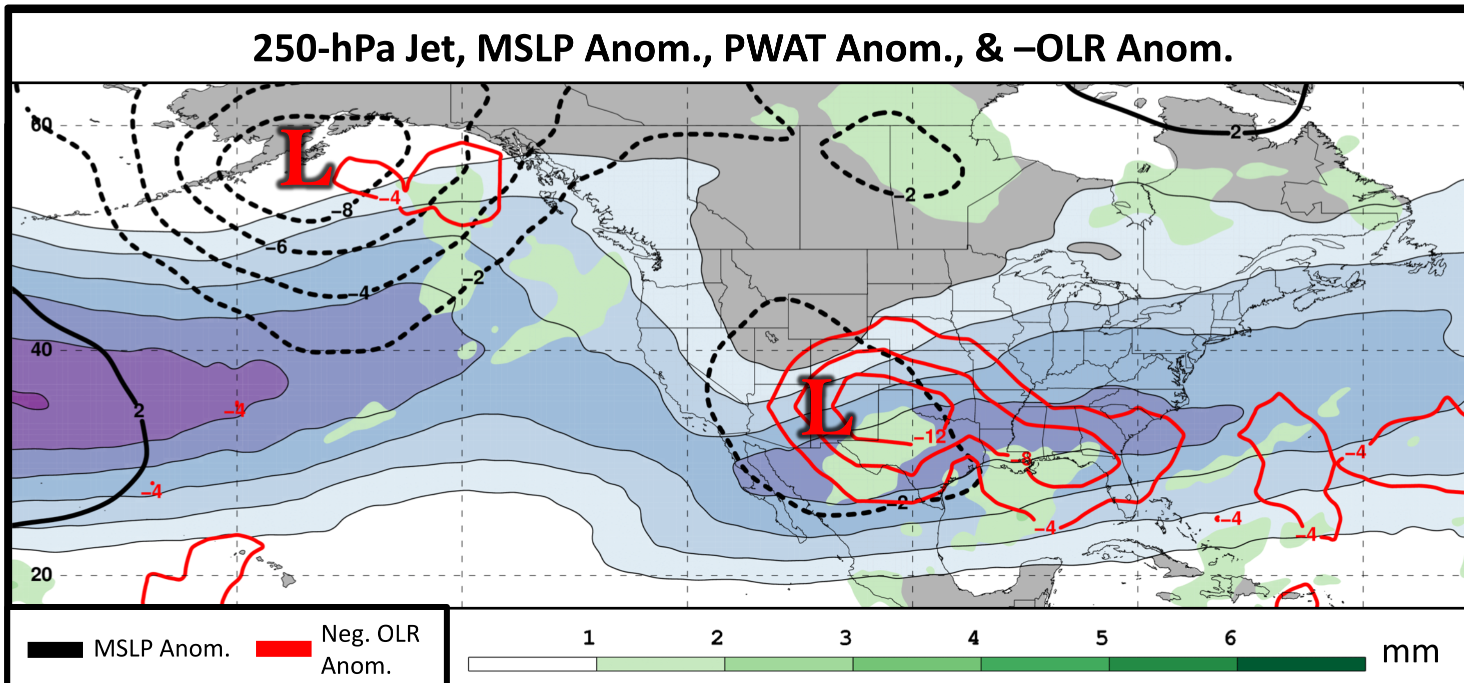
Jet Superposition Event Characteristics



Polar Dominant Jet Superposition Events

2 Days Prior to Jet Superposition

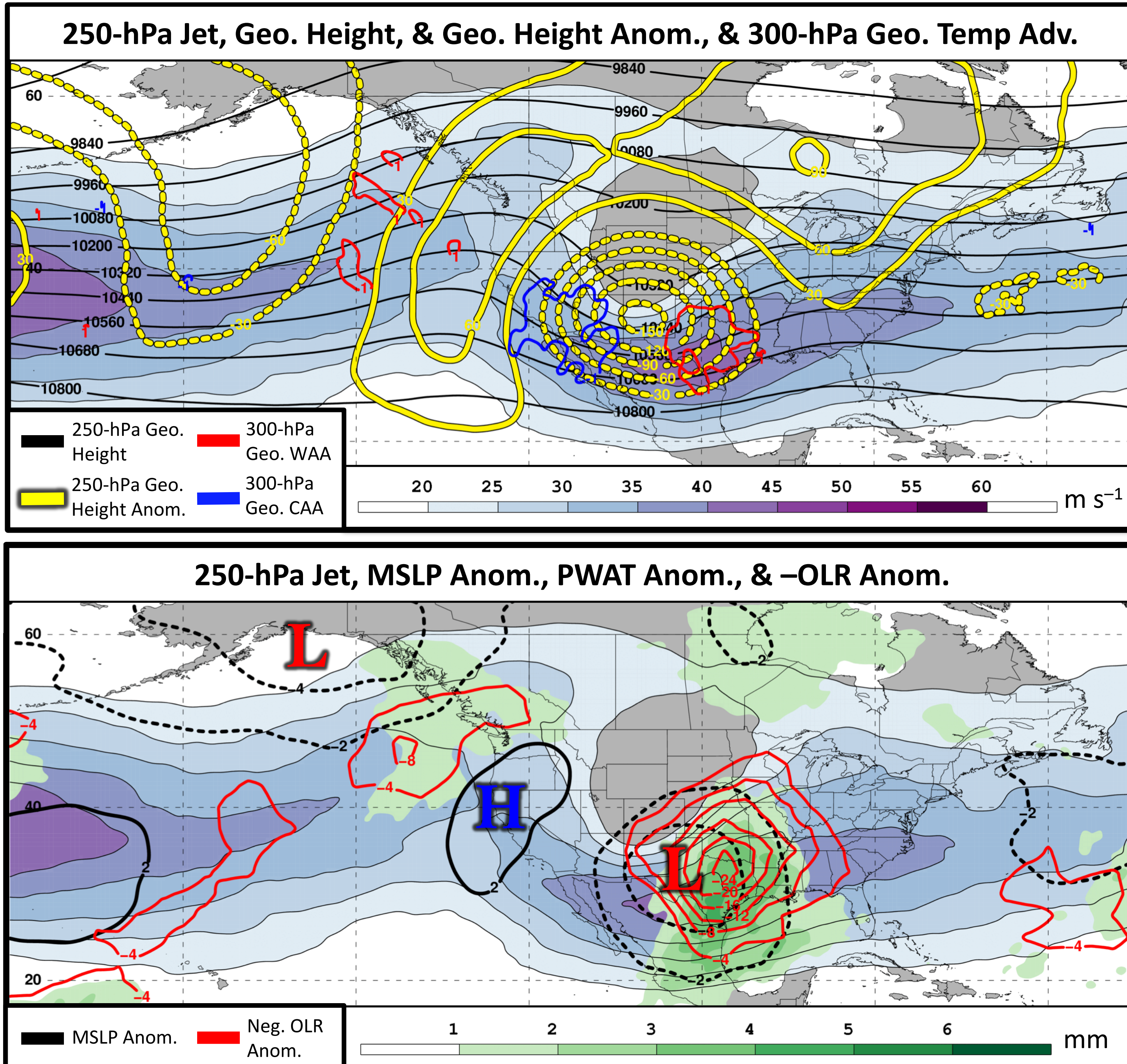




N=80

Polar Dominant Jet Superposition Events

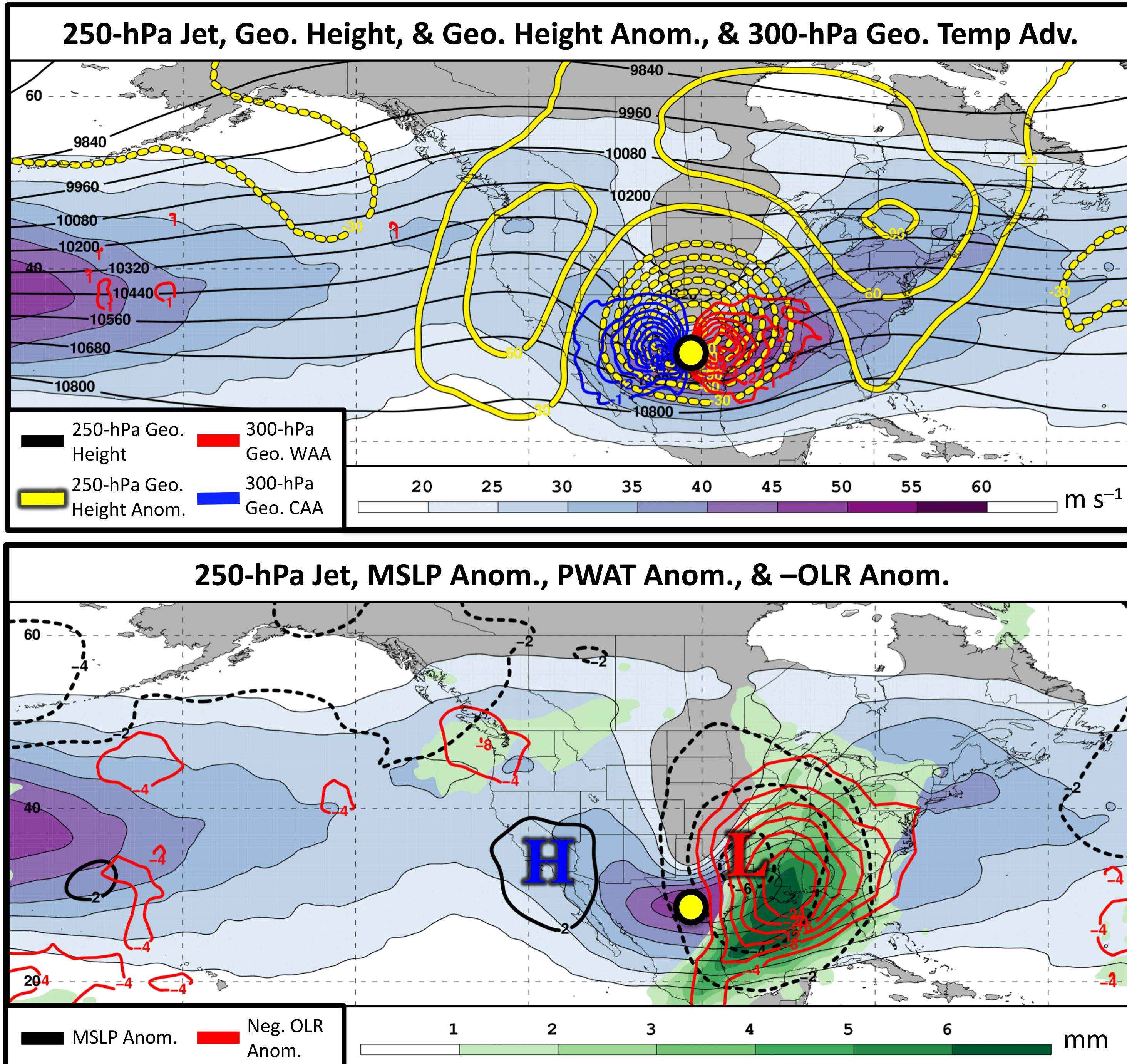
1 Day Prior to Jet Superposition



N=80

Polar Dominant Jet Superposition Events

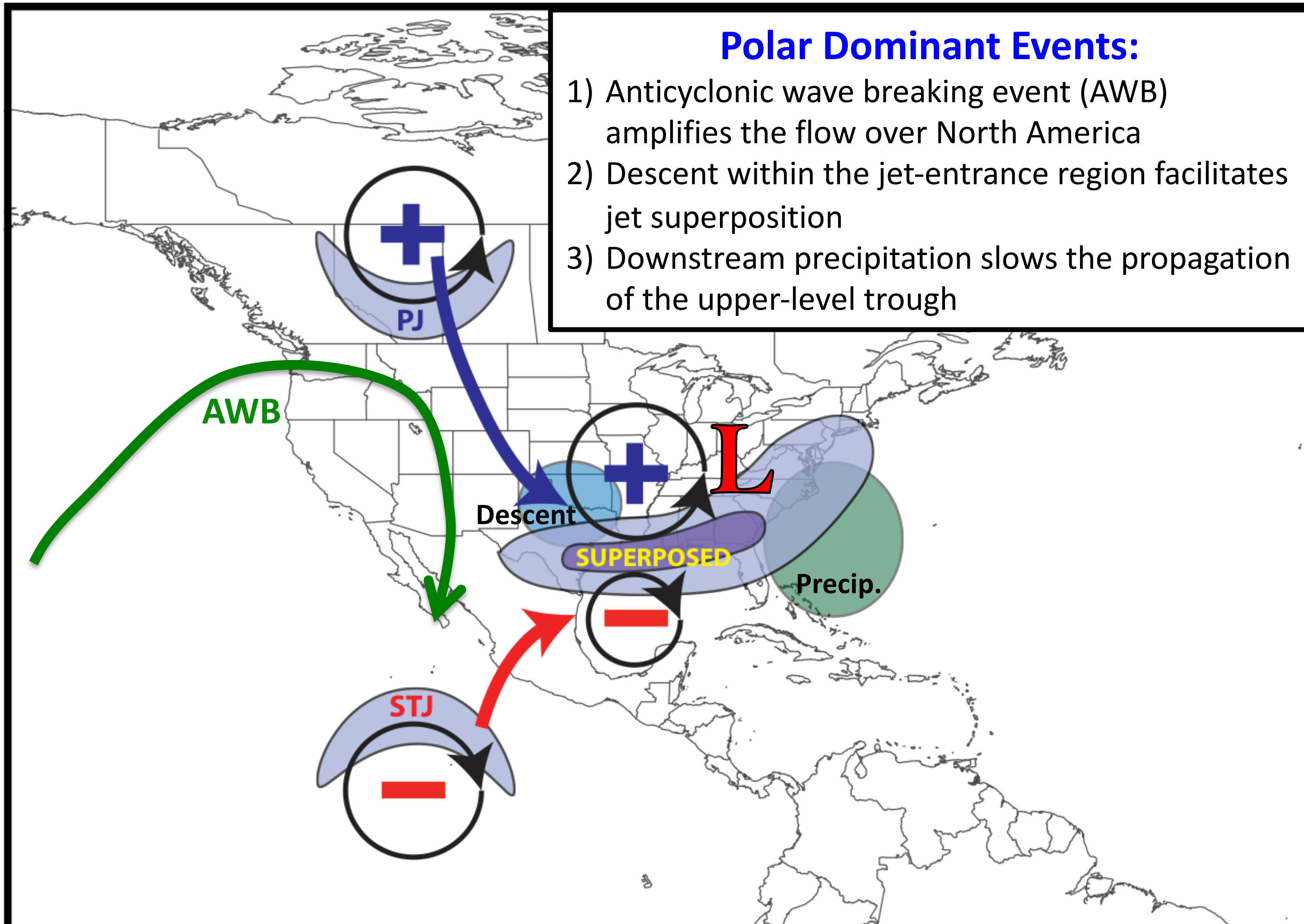
0 Days Prior to Jet Superposition



Jet Superposition Centroid

N=80

Jet Superposition Event Composites

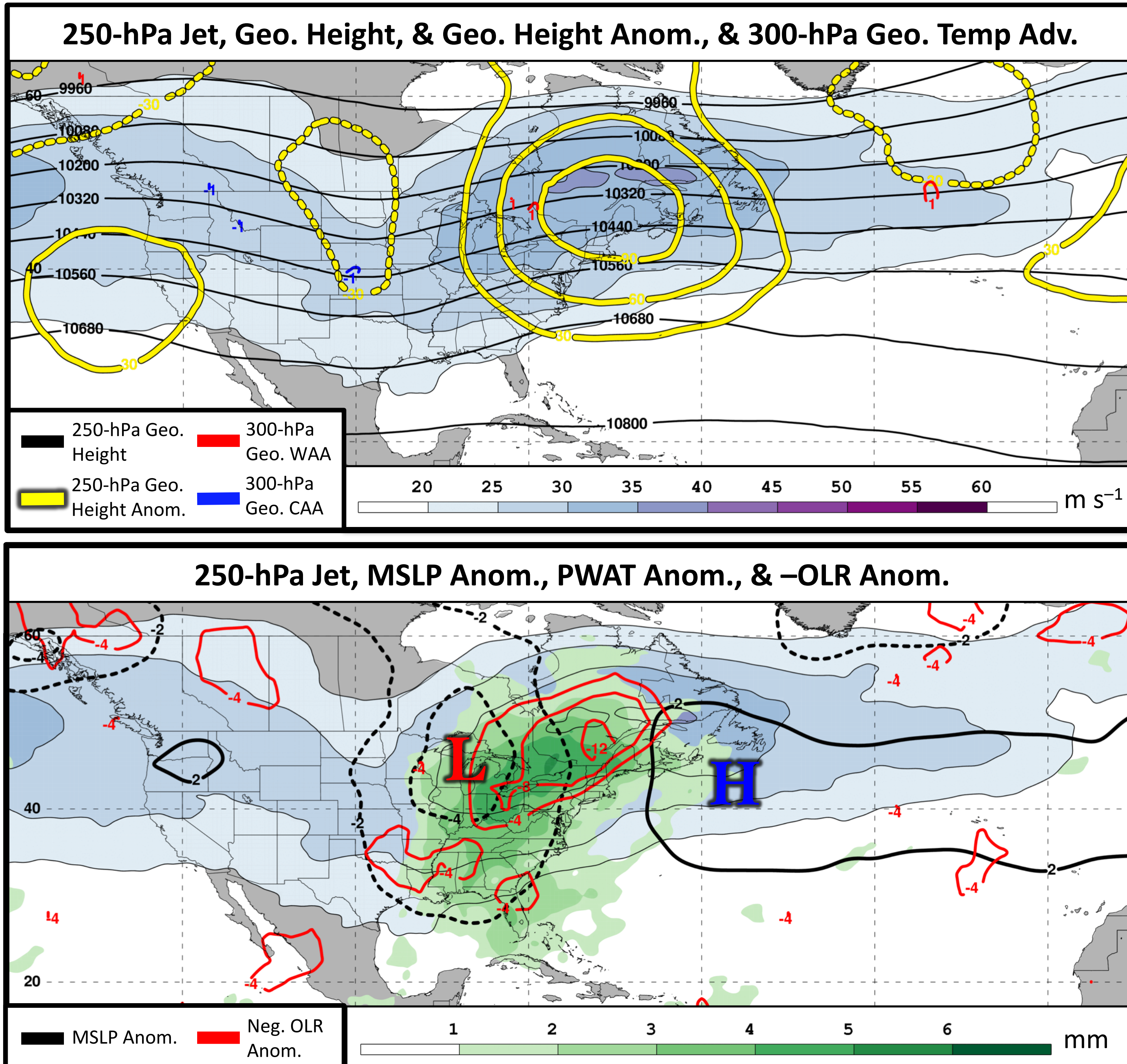


Polar Dominant Events:

1) Anticyclonic wave breaking event (AWB) amplifies the flow over North America
2) Descent within the jet-entrance region facilitates jet superposition
3) Downstream precipitation slows the propagation of the upper-level trough

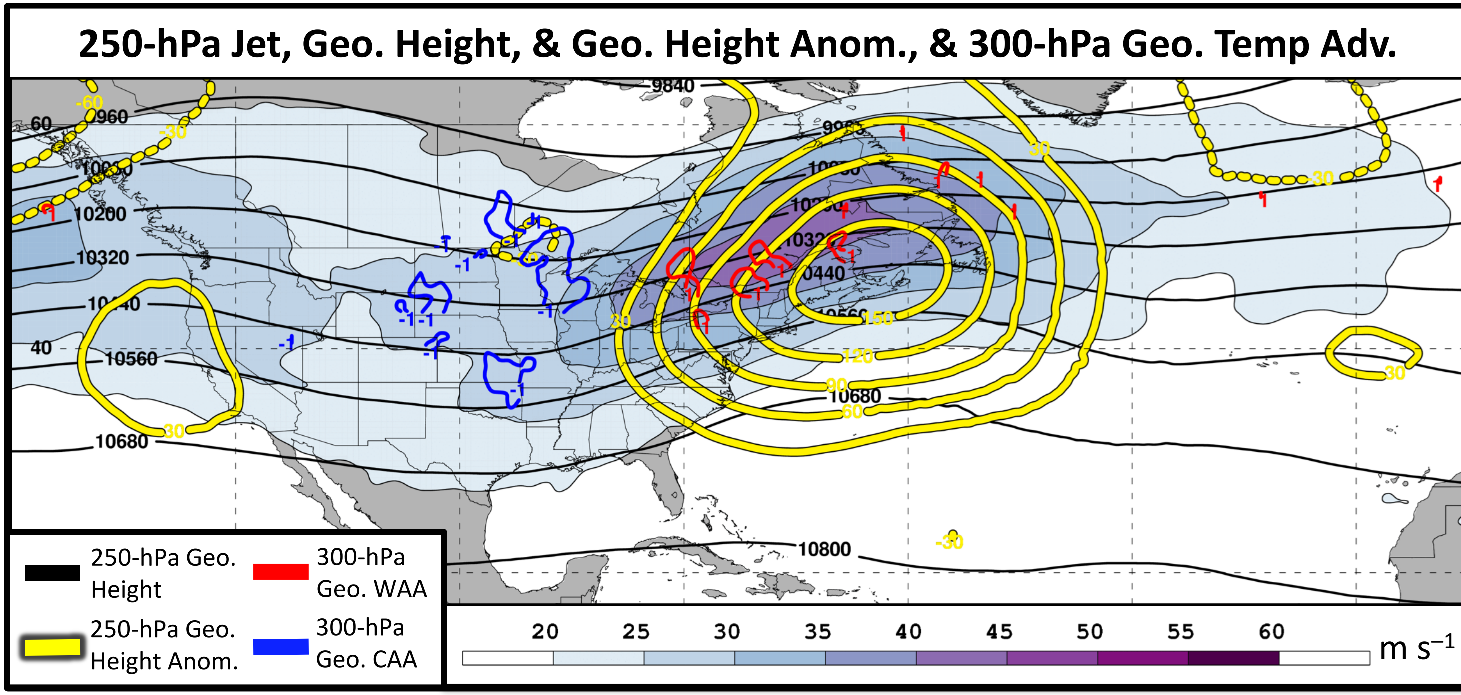
E. Subtropical Dominant Jet Superposition Events

2 Days Prior to Jet Superposition

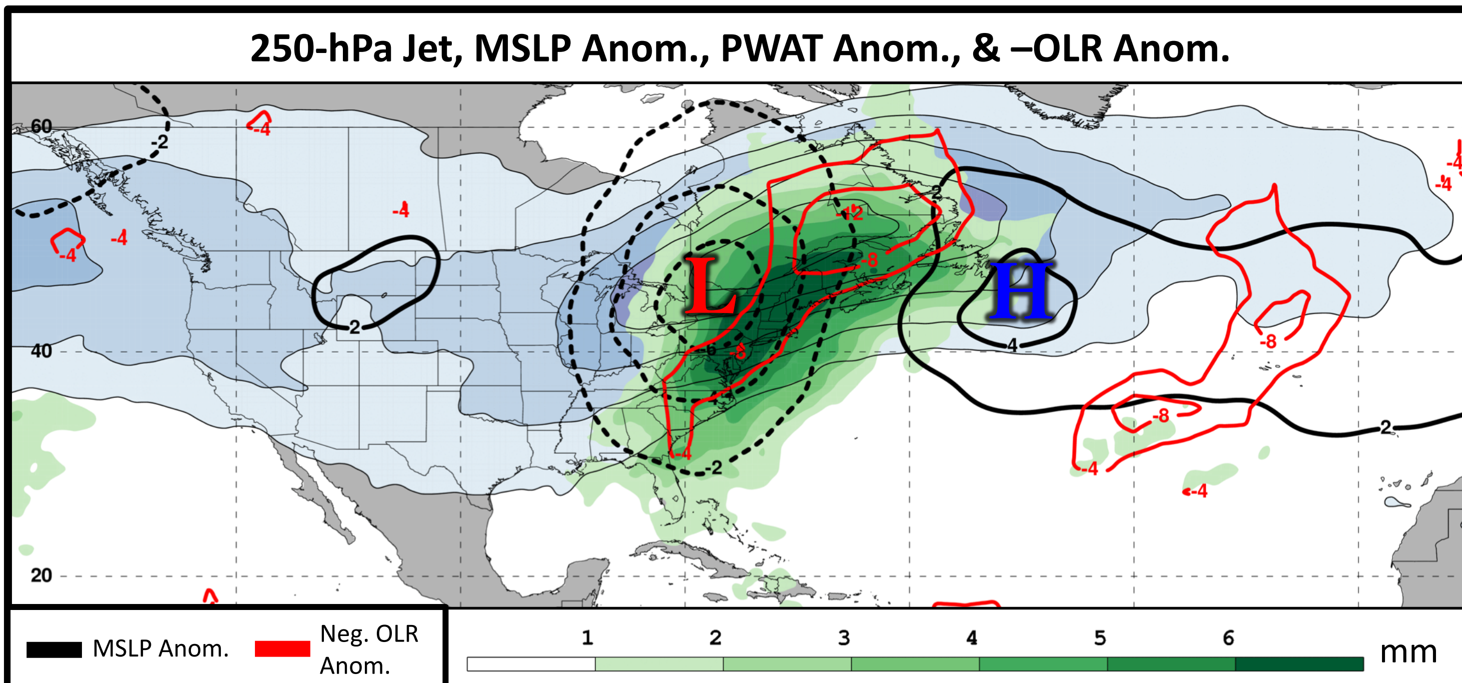


N=76

E. Subtropical Dominant Jet Superposition Events

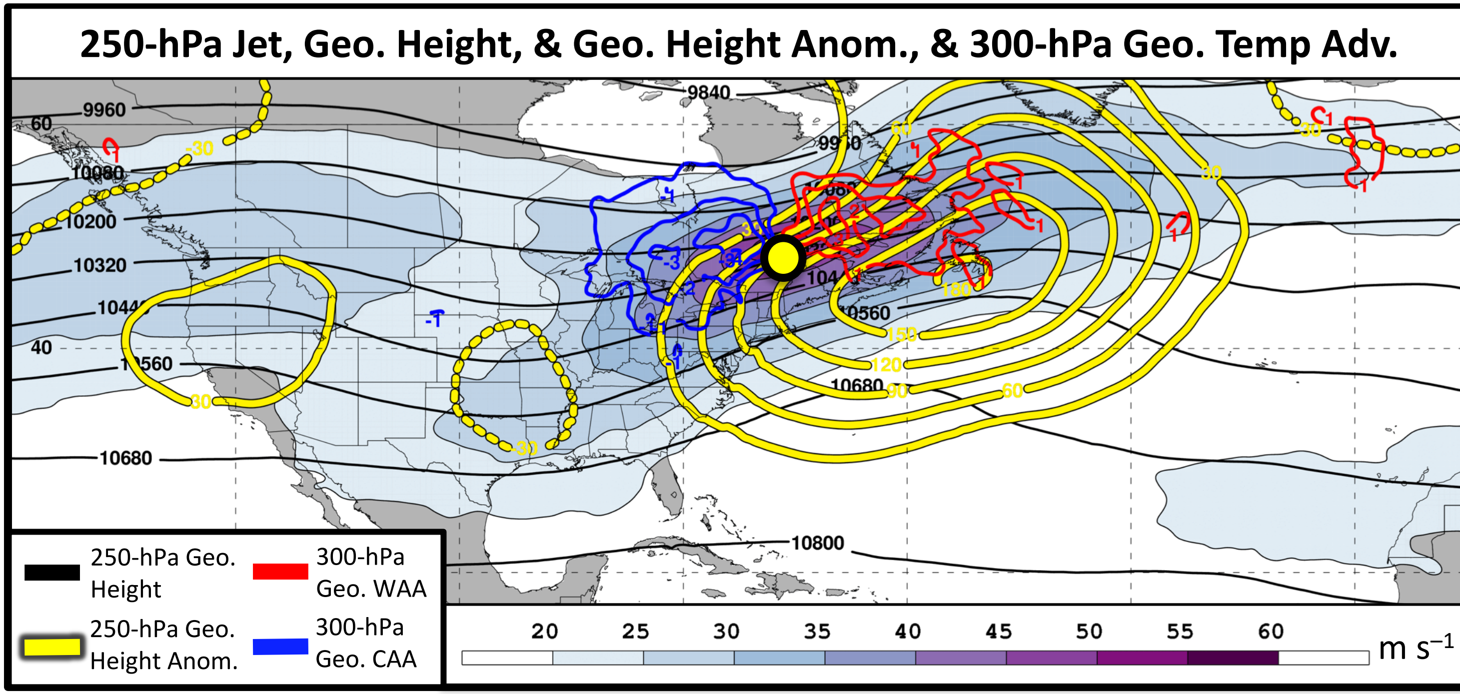


1 Day Prior to Jet Superposition

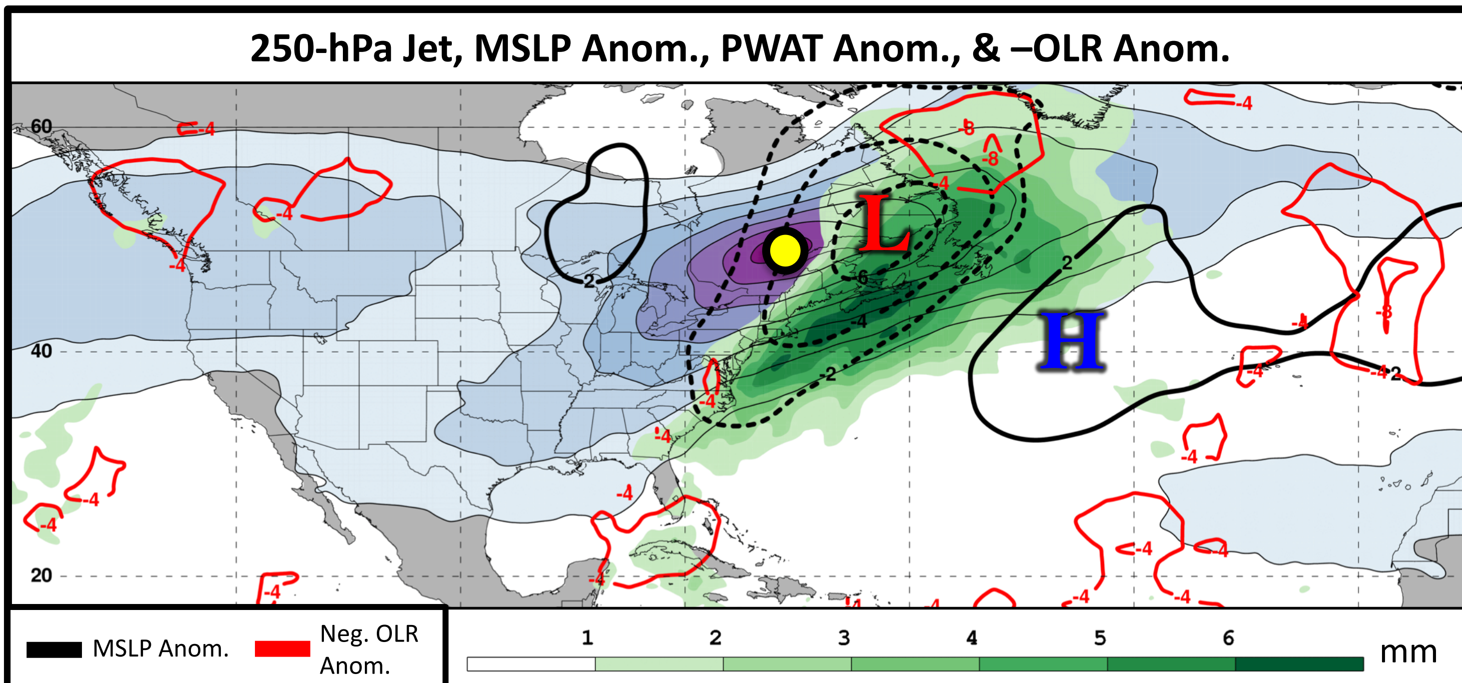


N=76

E. Subtropical Dominant Jet Superposition Events



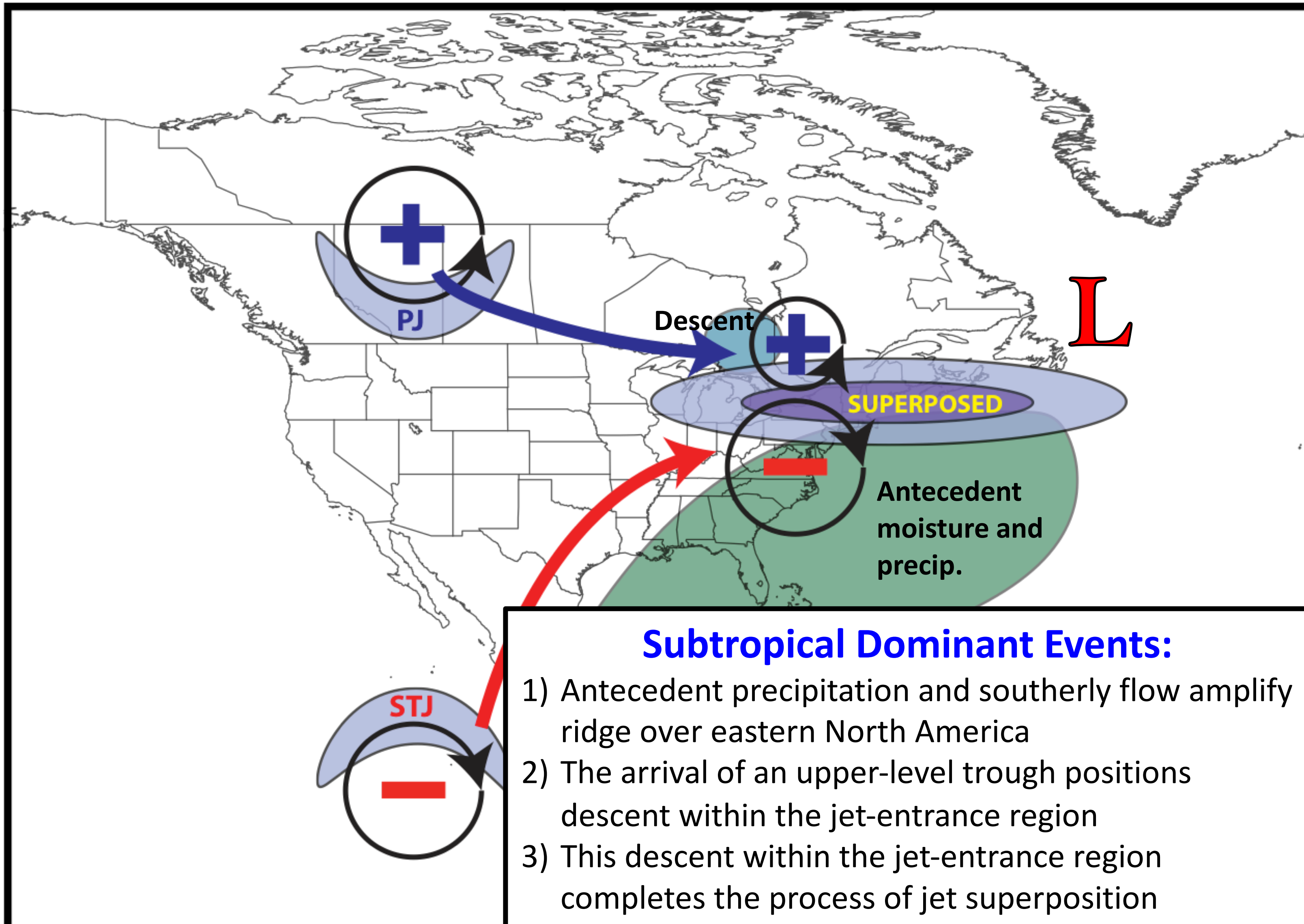
0 Days Prior to Jet Superposition



Jet Superposition Centroid

N=76

Jet Superposition Event Composites

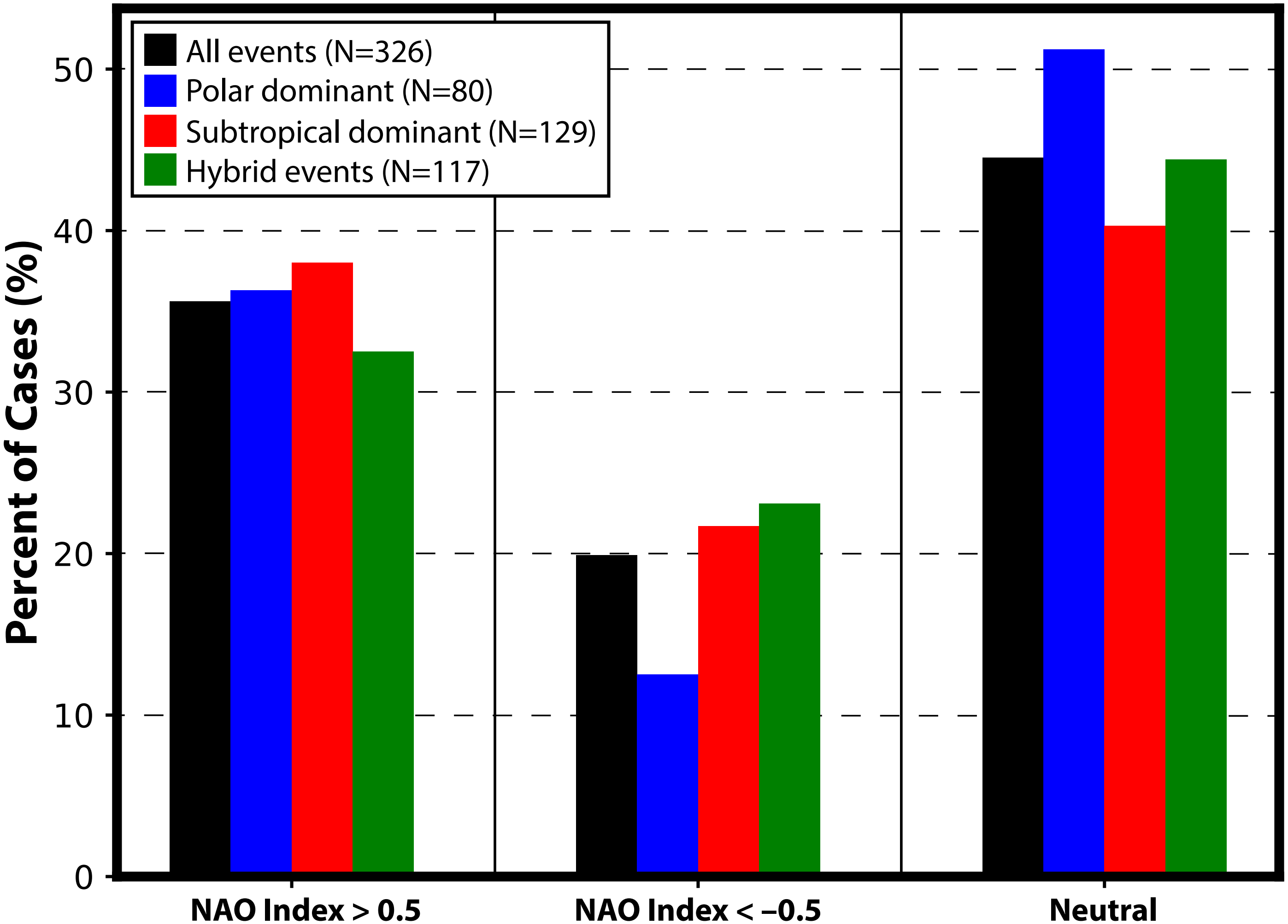


Subtropical Dominant Events:

1) Antecedent precipitation and southerly flow amplify ridge over eastern North America
2) The arrival of an upper-level trough positions descent within the jet-entrance region
3) This descent within the jet-entrance region completes the process of jet superposition

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

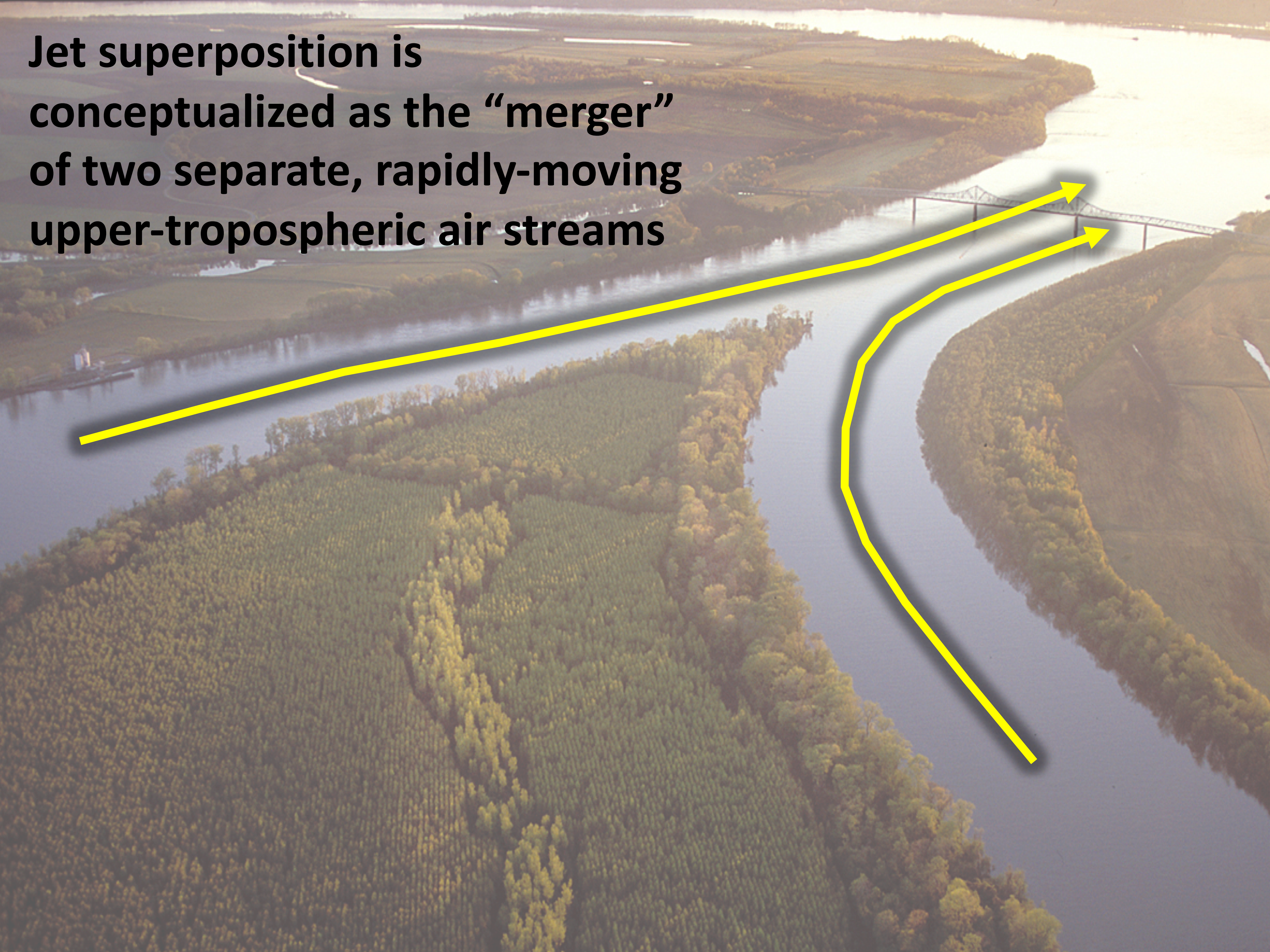
QGPV and QG Omega Inversions

QGPV Category	Physical Interpretation
Polar Cyclonic QGPV Anomalies	Circulation associated with near-jet cyclonic QGPV anomalies
Tropical Anticyclonic QGPV Anomalies	Circulation associated with near-jet anticyclonic QGPV anomalies
Residual Upper-Tropospheric QGPV Anomalies	Circulation associated with the background upper-tropospheric flow
Lower-Tropospheric QGPV Anomalies	Circulation associated with surface cyclones and anticyclones
Mean QGPV	Circulation associated with the climatological mean flow

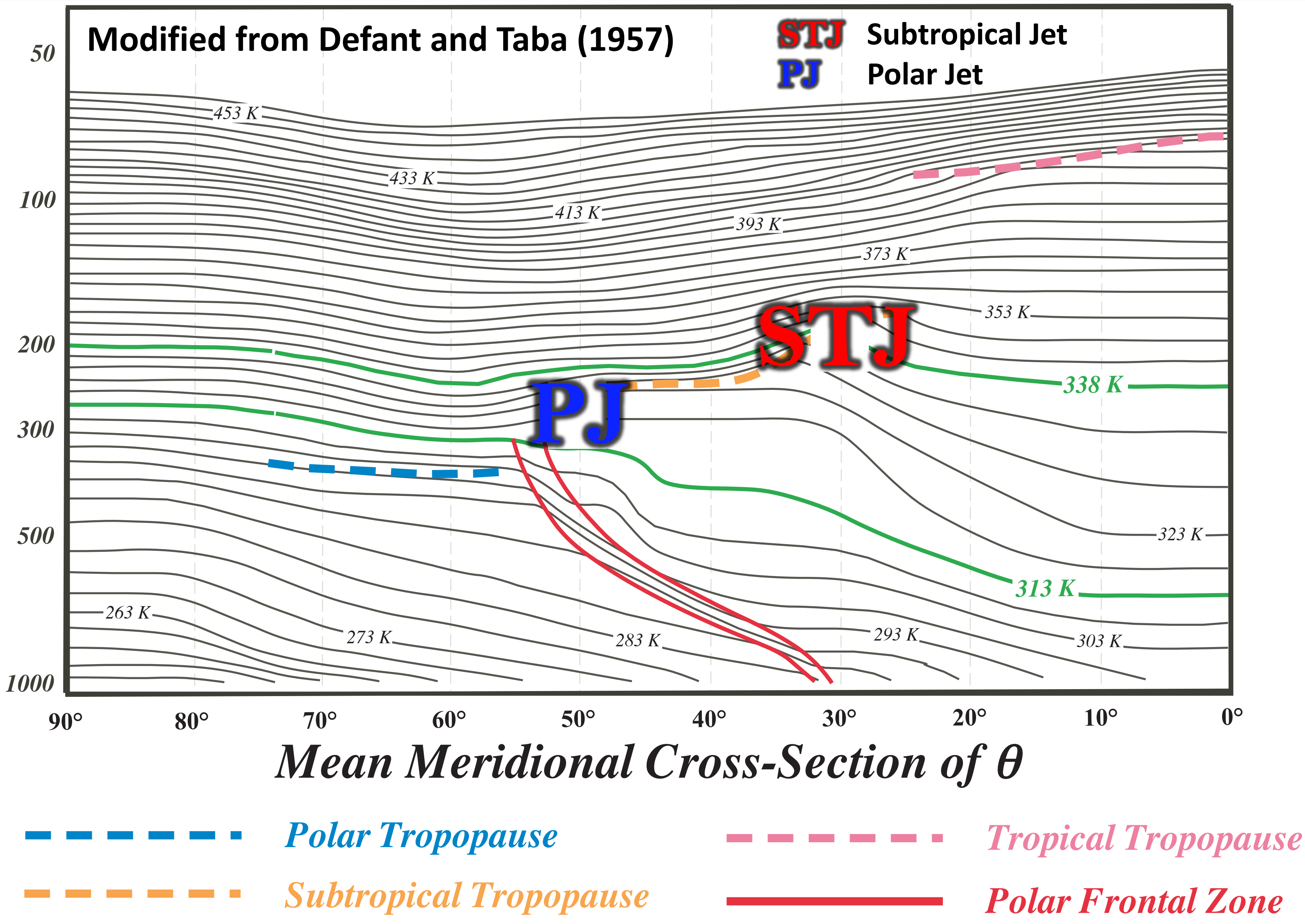
The descent characterizing each jet superposition event composite is examined further by isolating quasi-geostrophic (QG) PV anomalies in the vicinity of the jet superposition.

Background Material

Jet superposition is conceptualized as the "merger" of two separate, rapidly-moving upper-tropospheric air streams

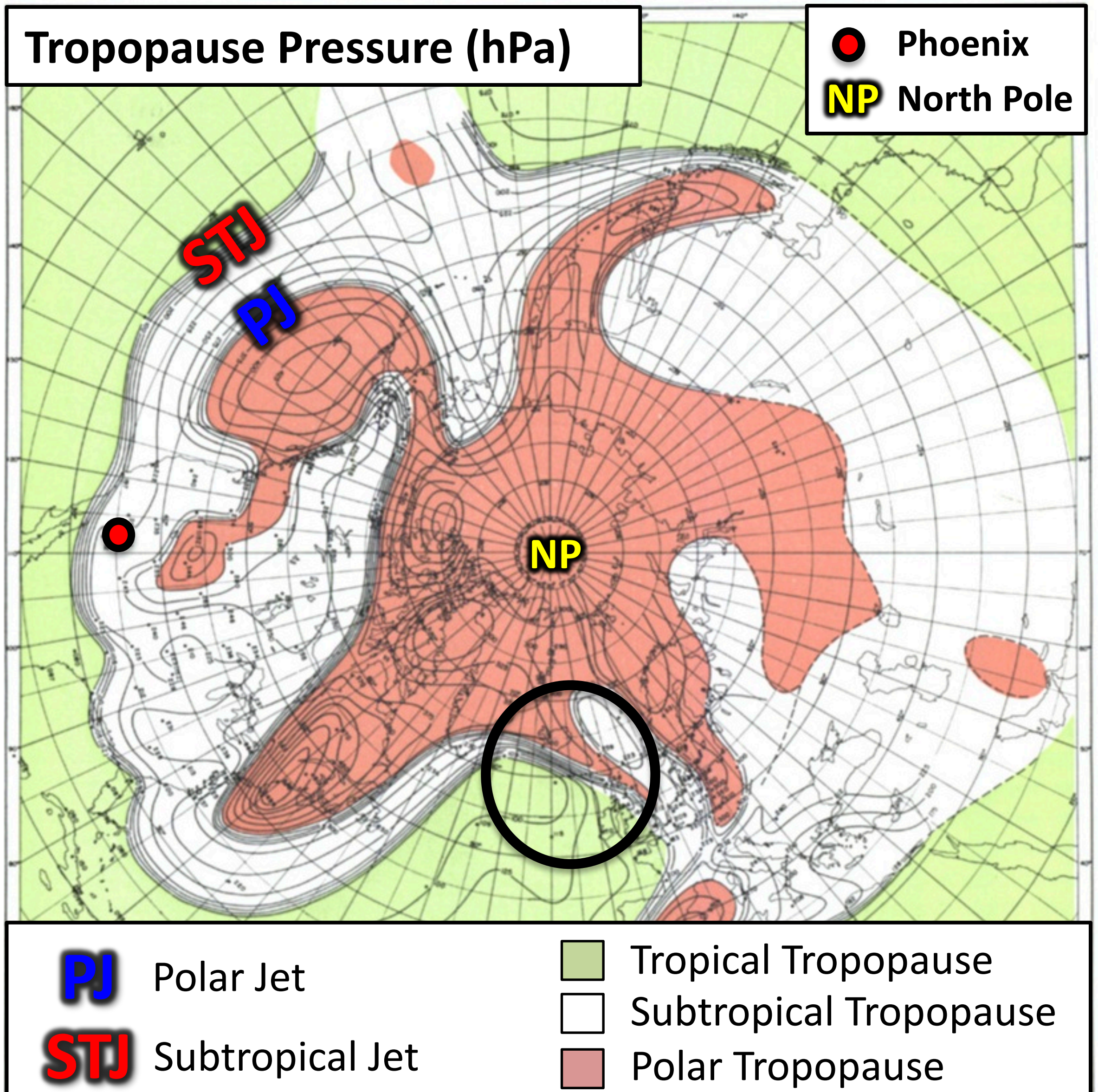


Background



Modified from Defant and Taba (1957)
STJ Subtropical Jet
PJ Polar Jet
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
STJ
PJ
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



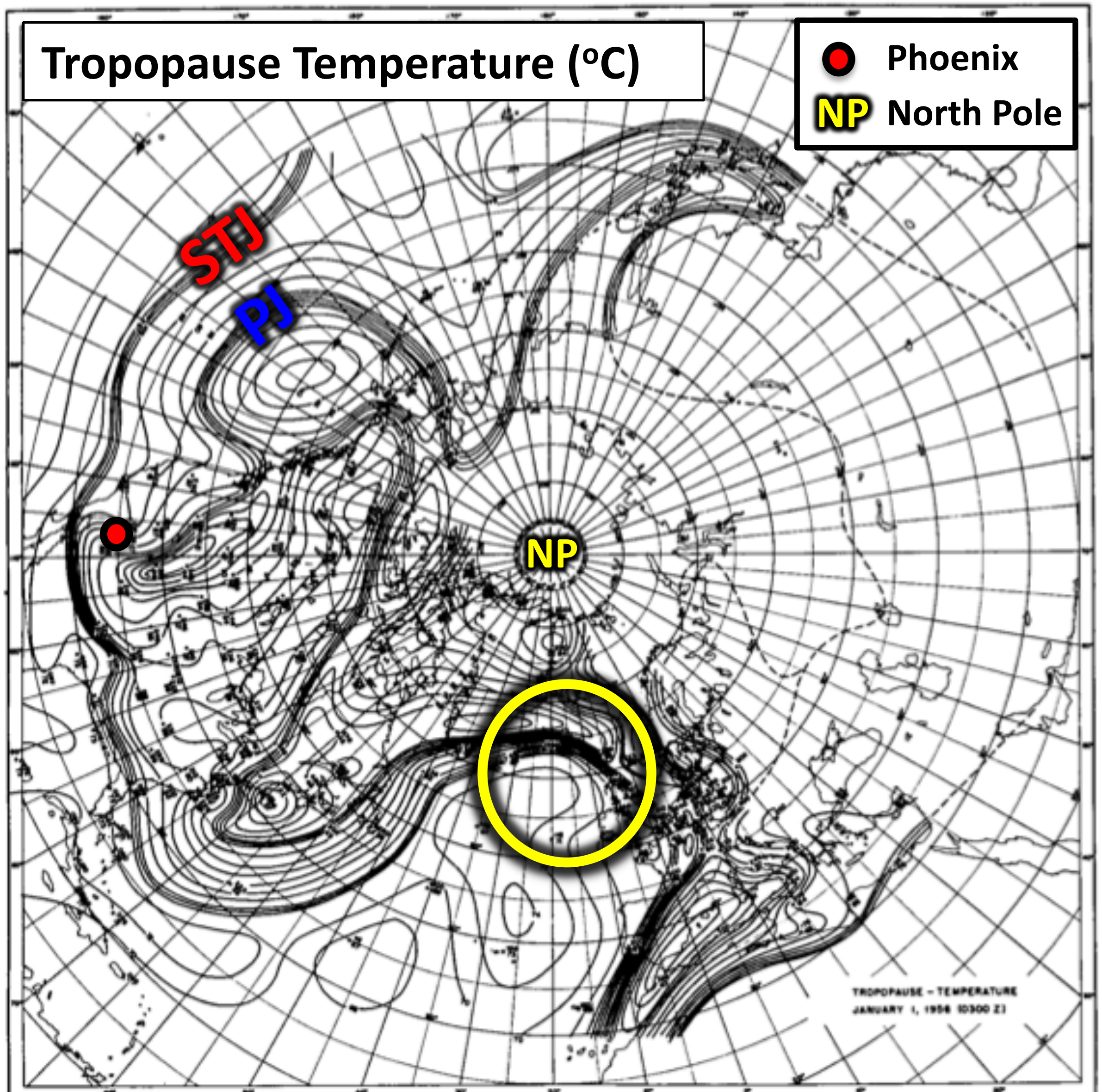
Maps of tropopause pressure help to identify the location of the jets.

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**.

Modified from Defant and Taba (1957)

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

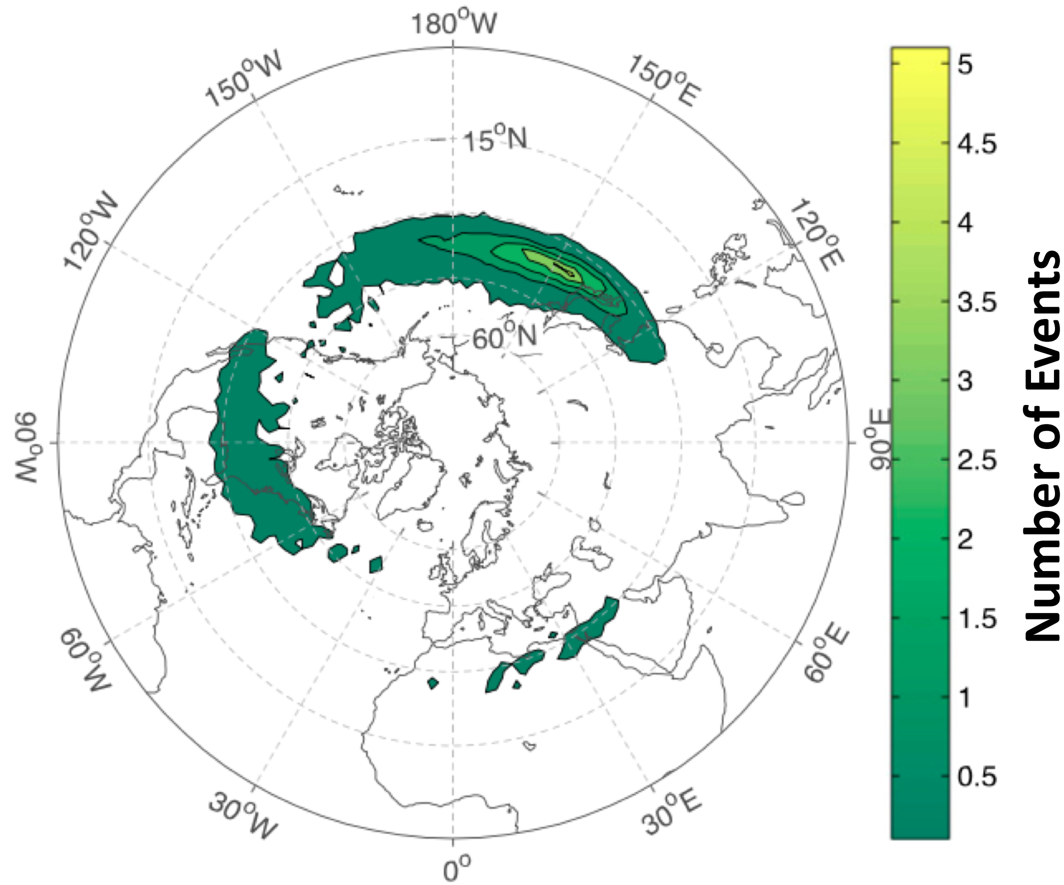
Christenson et al. (2017) highlight three locations that experience the greatest frequency of jet superpositions:

1) Western Pacific

2) North America

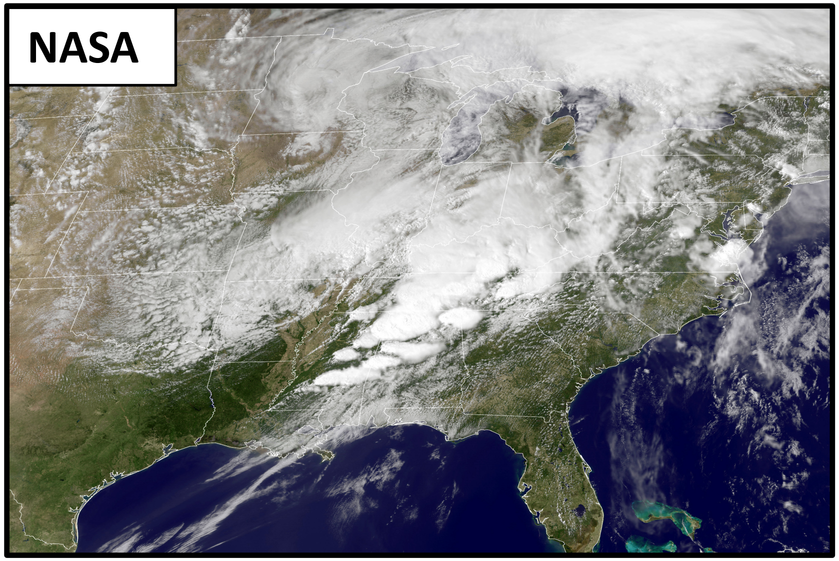
3) Northern Africa

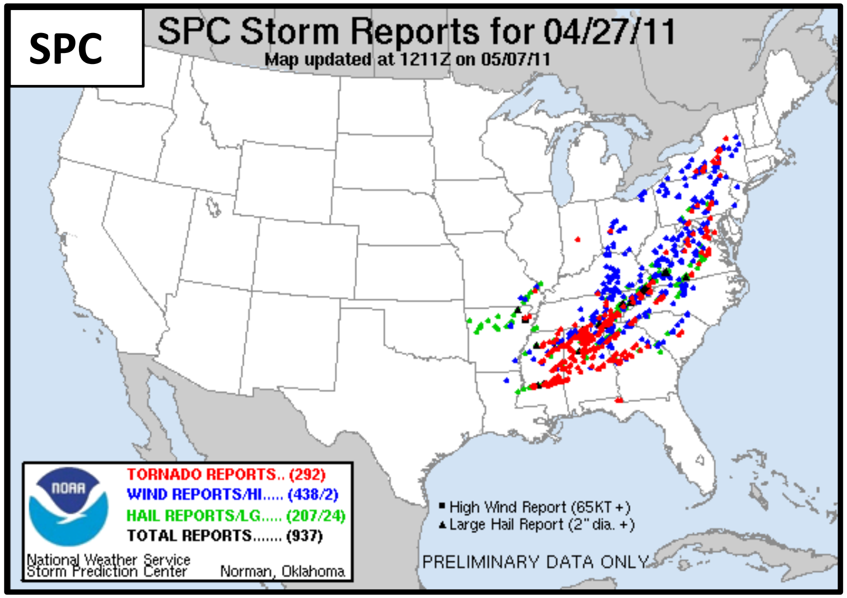
Climatological frequency of Northern Hemisphere jet superposition events per cold season (Nov–Mar) 1960–2010



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).

18–20 December 2009 Mid-Atlantic Blizzard

- Jet superposition was associated with a rapidly deepening East Coast cyclone (Winters and Martin 2016; 2017).

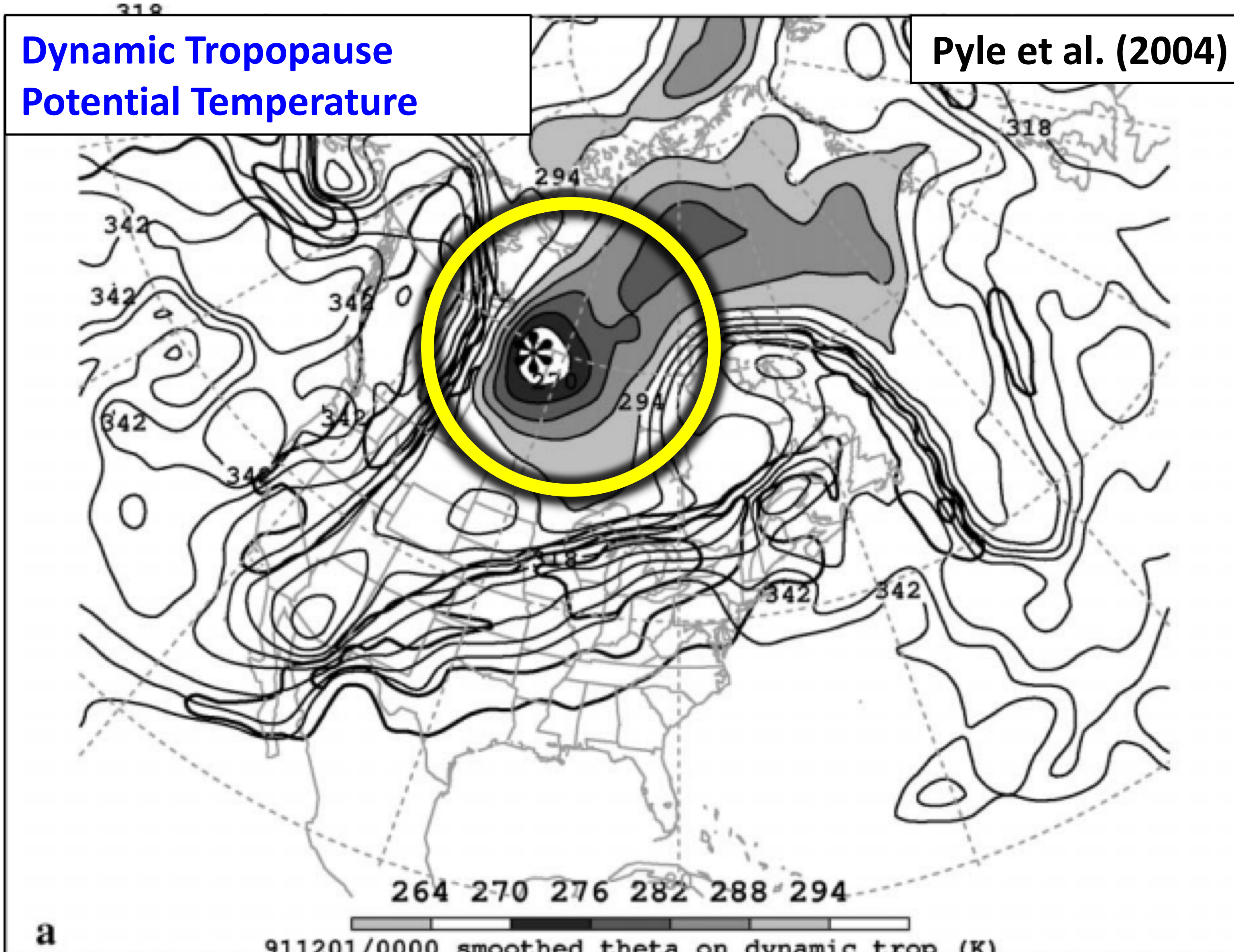
26 October 2010: Explosive Cyclogenesis Event

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

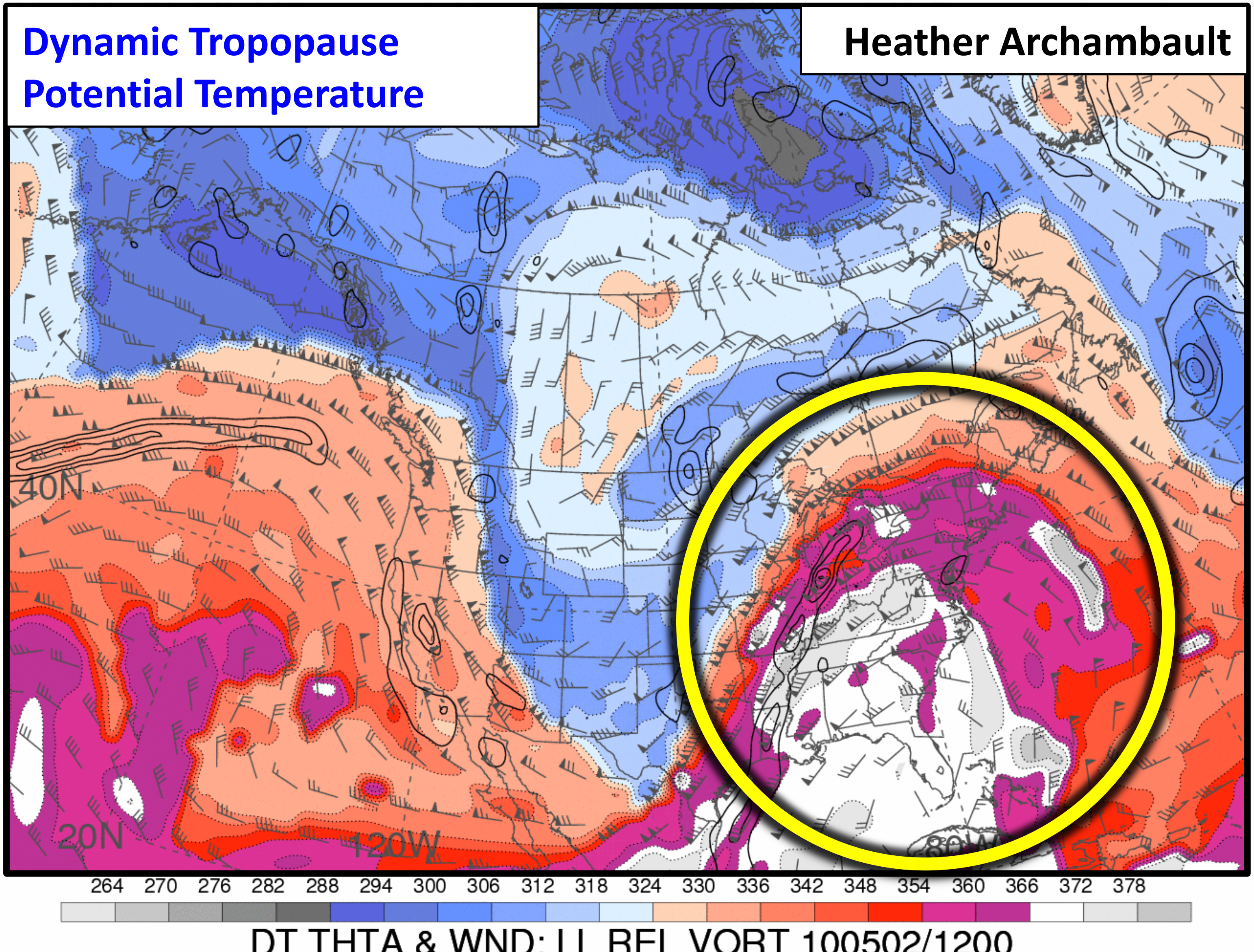
25–28 April 2011 Tornado Outbreak

- Jet superposition occurred over the West Pacific prior to the outbreak (Knupp et al. 2014; Christenson and Martin 2012).

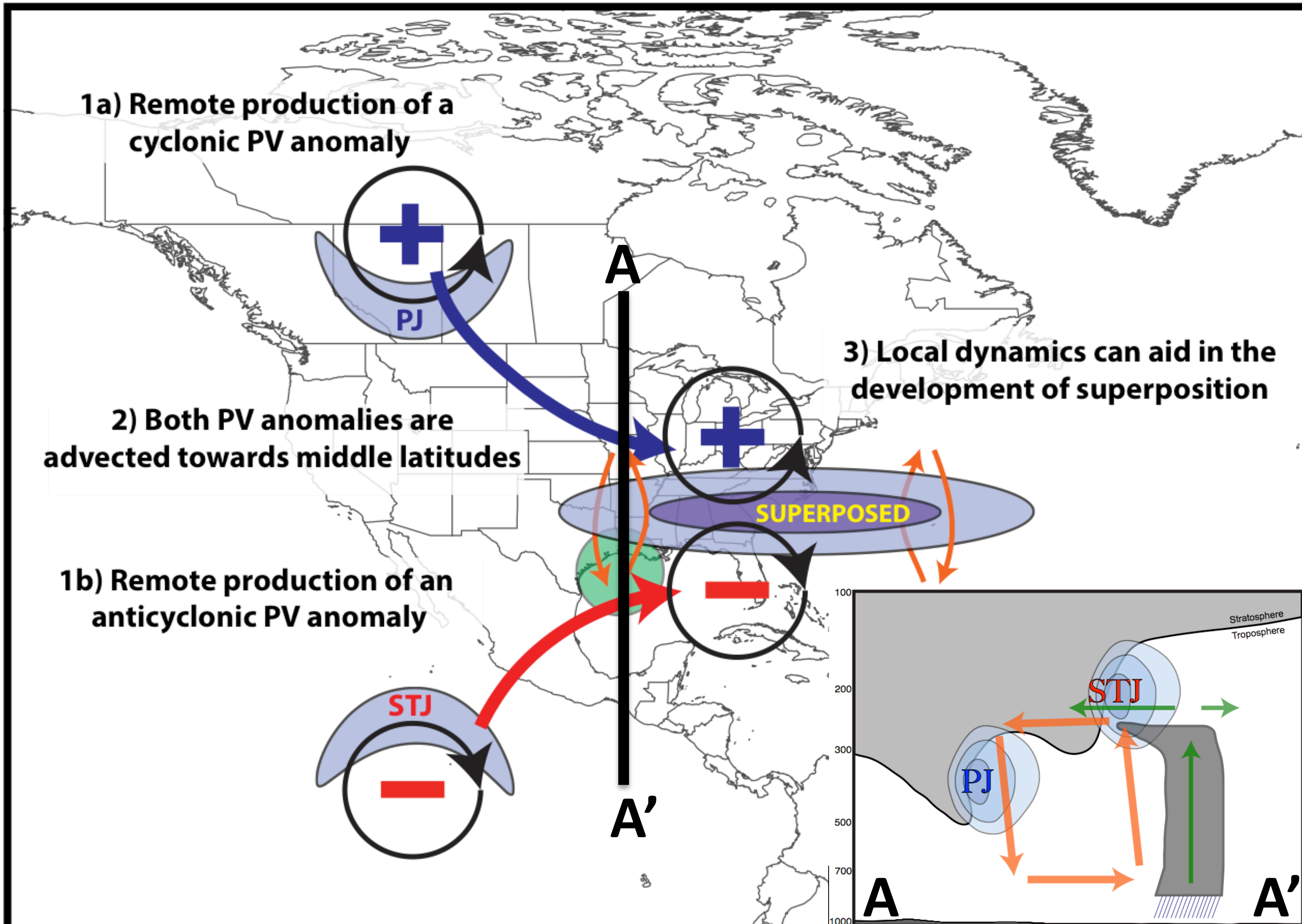
Jet Superposition Conceptual Model



Jet Superposition Conceptual Model



Jet Superposition Conceptual Model

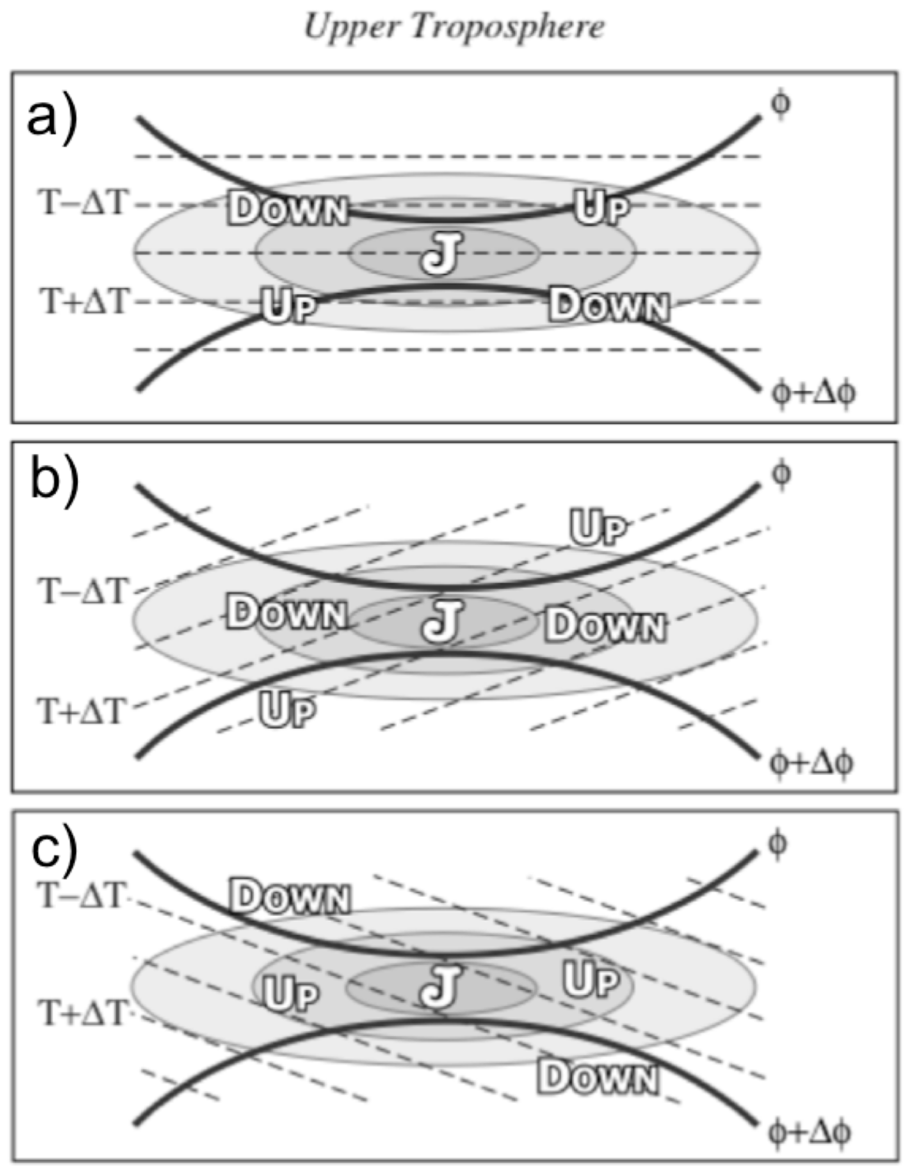


Ageostrophic Transverse Jet Circulations

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)

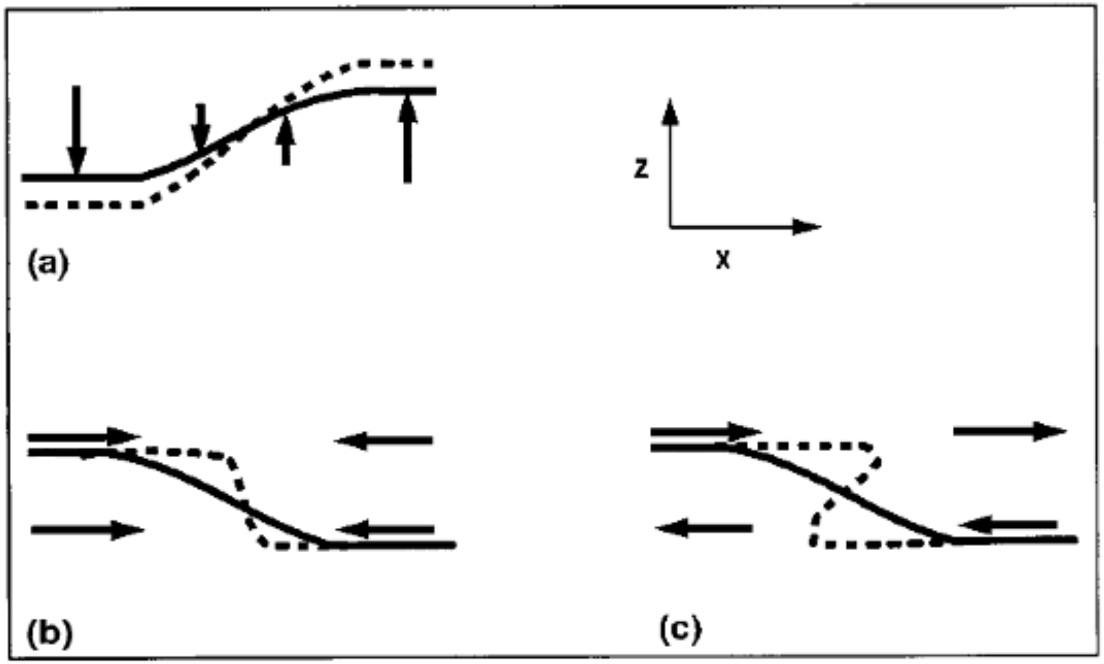
Background

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.



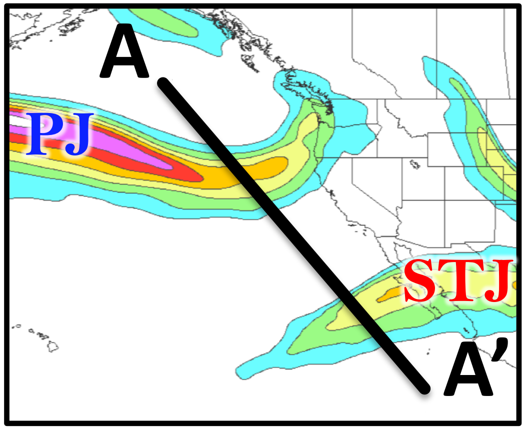
Wandishin et al. 2000

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

Jet Identification

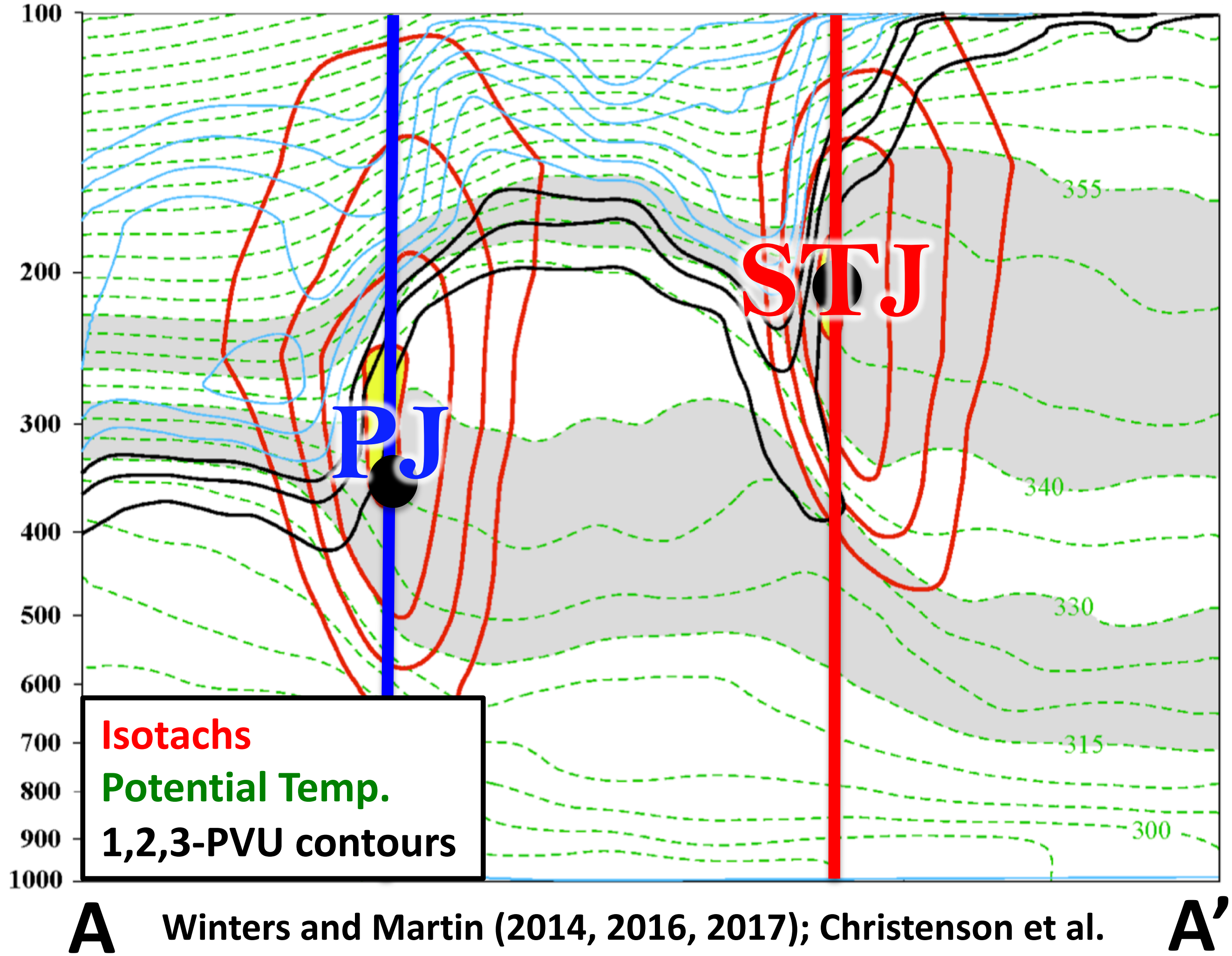
Jet Superposition Event Identification

0000 UTC 27 April 2010



250-hPa wind speed

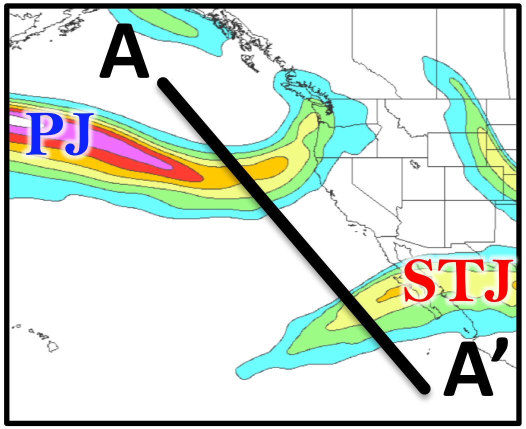
Isolated grid points over North America in the CFSR (Saha et al. 2014) characterized by polar and subtropical jets during Nov–Mar 1979–2010.



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

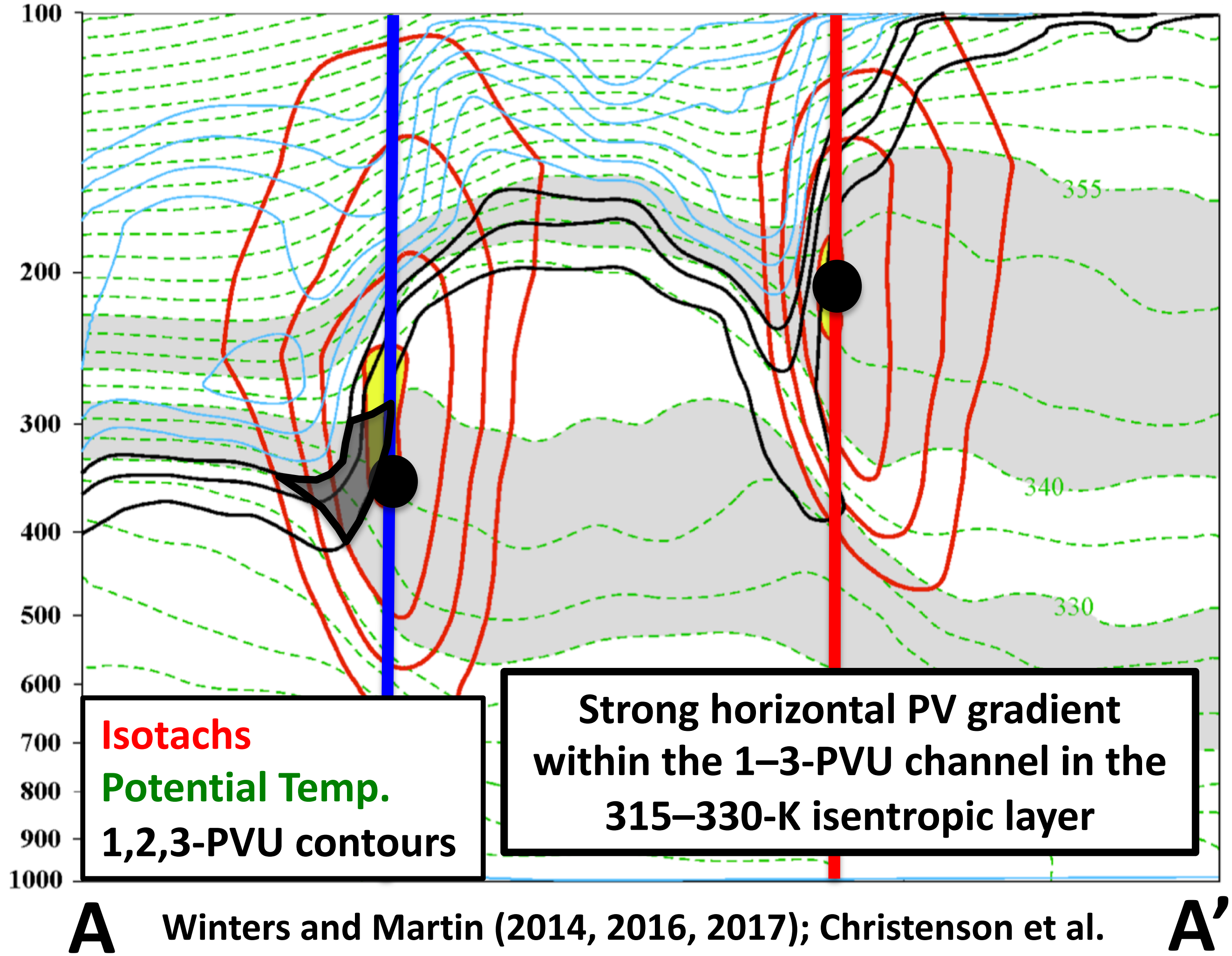
Jet Superposition Event Identification

0000 UTC 27 April 2010



250-hPa wind speed

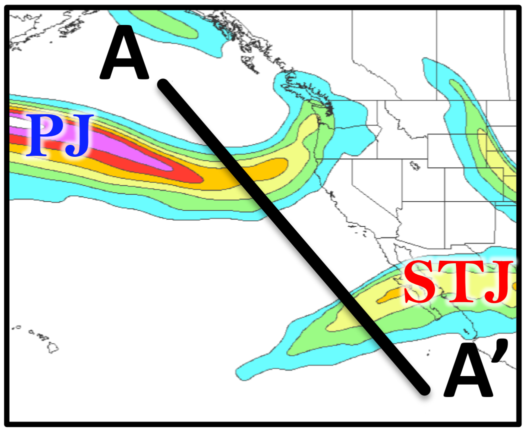
Isolated grid points over North America in the CFSR (Saha et al. 2014) characterized by polar and subtropical jets during Nov–Mar 1979–2010.



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

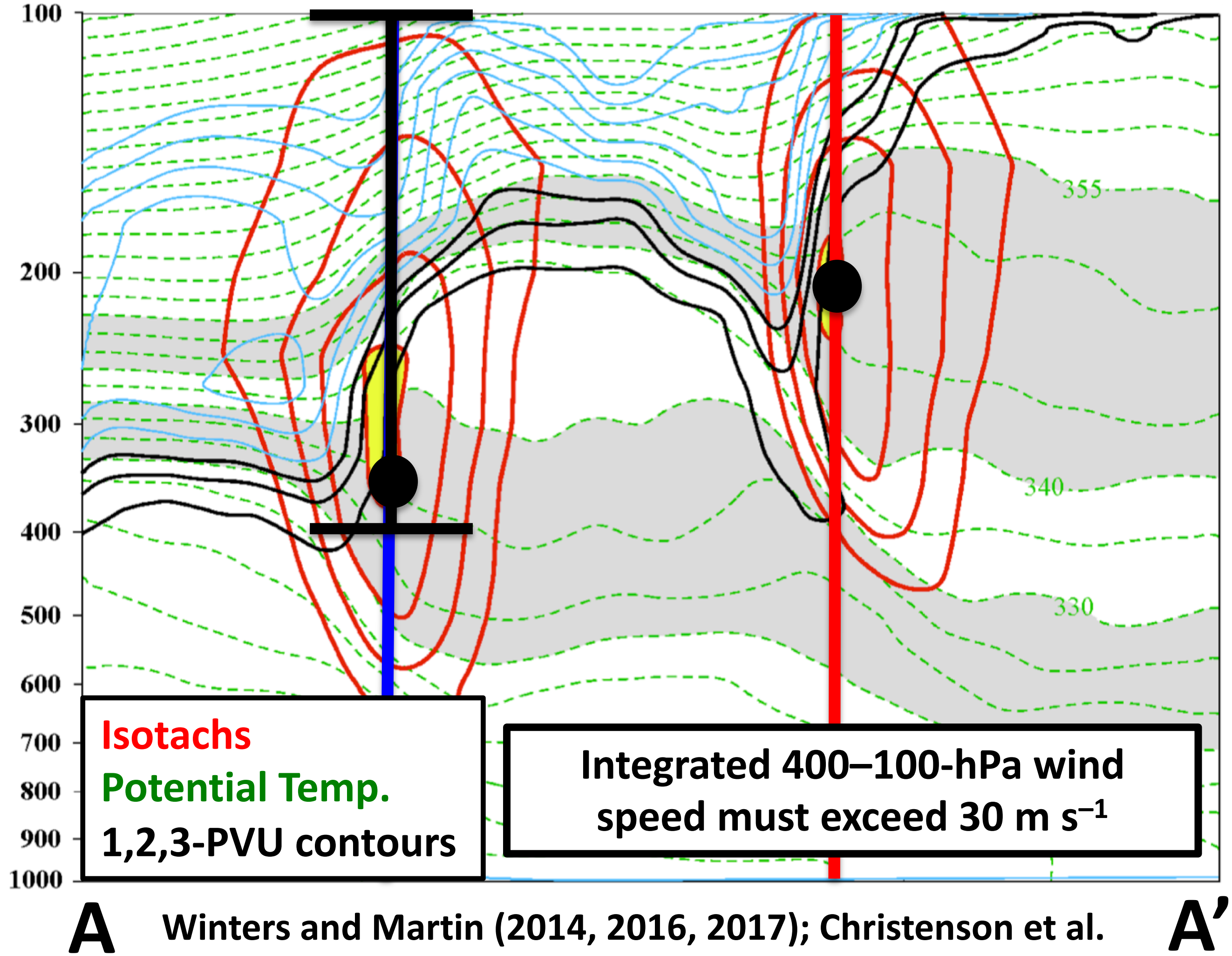
Jet Superposition Event Identification

0000 UTC 27 April 2010



250-hPa wind speed

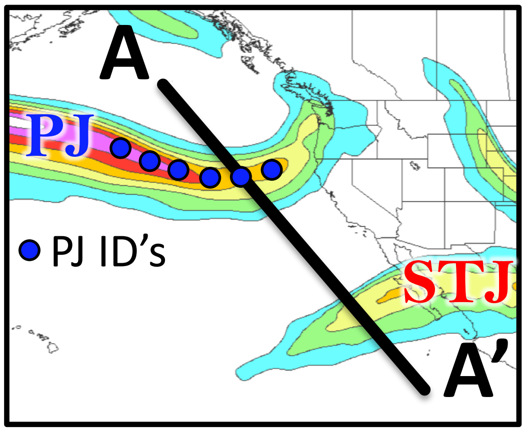
Isolated grid points over North America in the CFSR (Saha et al. 2014) characterized by polar and subtropical jets during Nov–Mar 1979–2010.



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

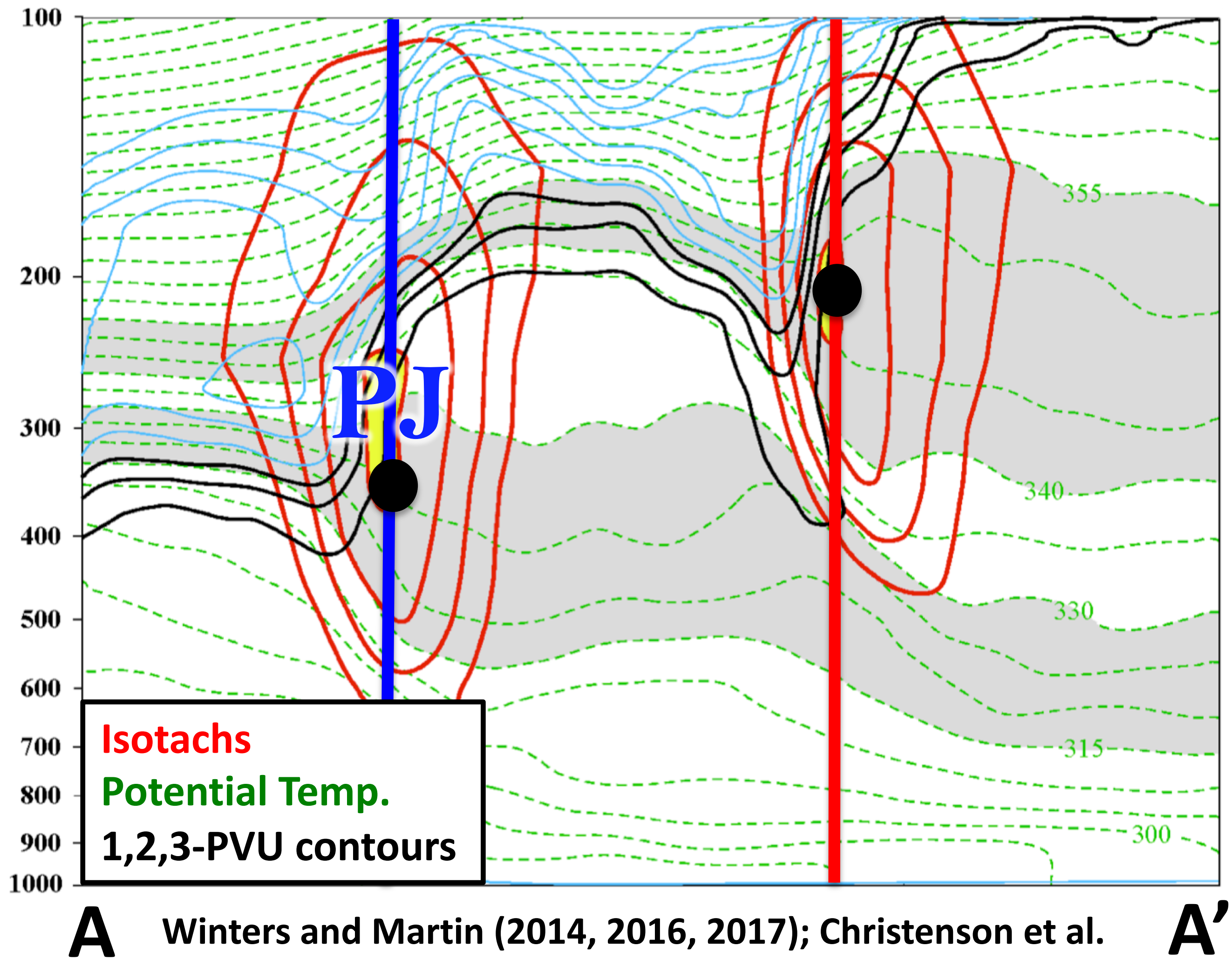
Jet Superposition Event Identification

0000 UTC 27 April 2010



250-hPa wind speed

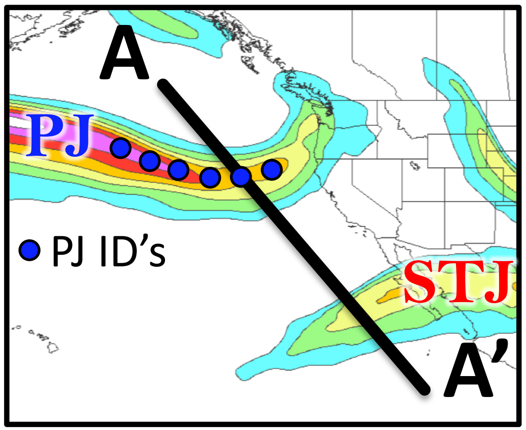
Isolated grid points over North America in the CFSR (Saha et al. 2014) characterized by polar and subtropical jets during Nov–Mar 1979–2010.



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

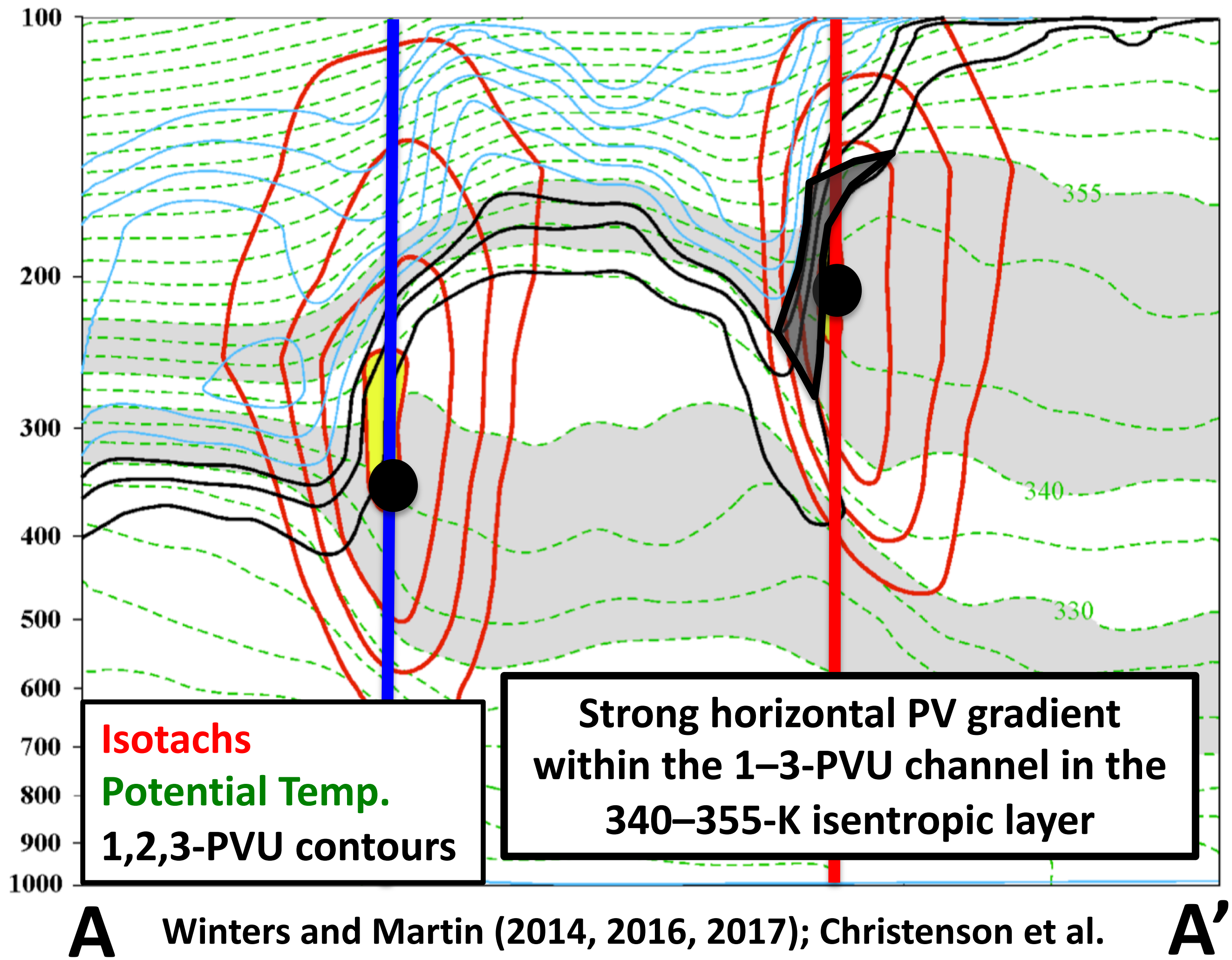
Jet Superposition Event Identification

0000 UTC 27 April 2010



250-hPa wind speed

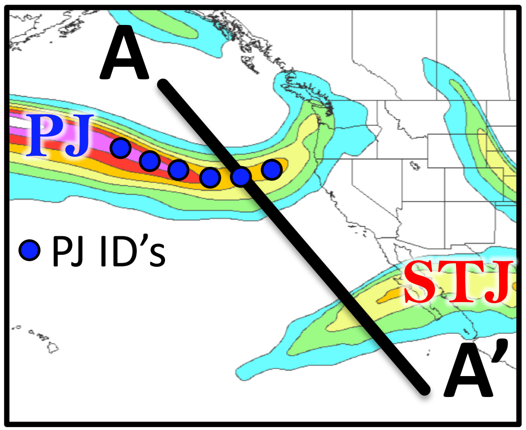
Isolated grid points over North America in the CFSR (Saha et al. 2014) characterized by polar and subtropical jets during Nov–Mar 1979–2010.



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

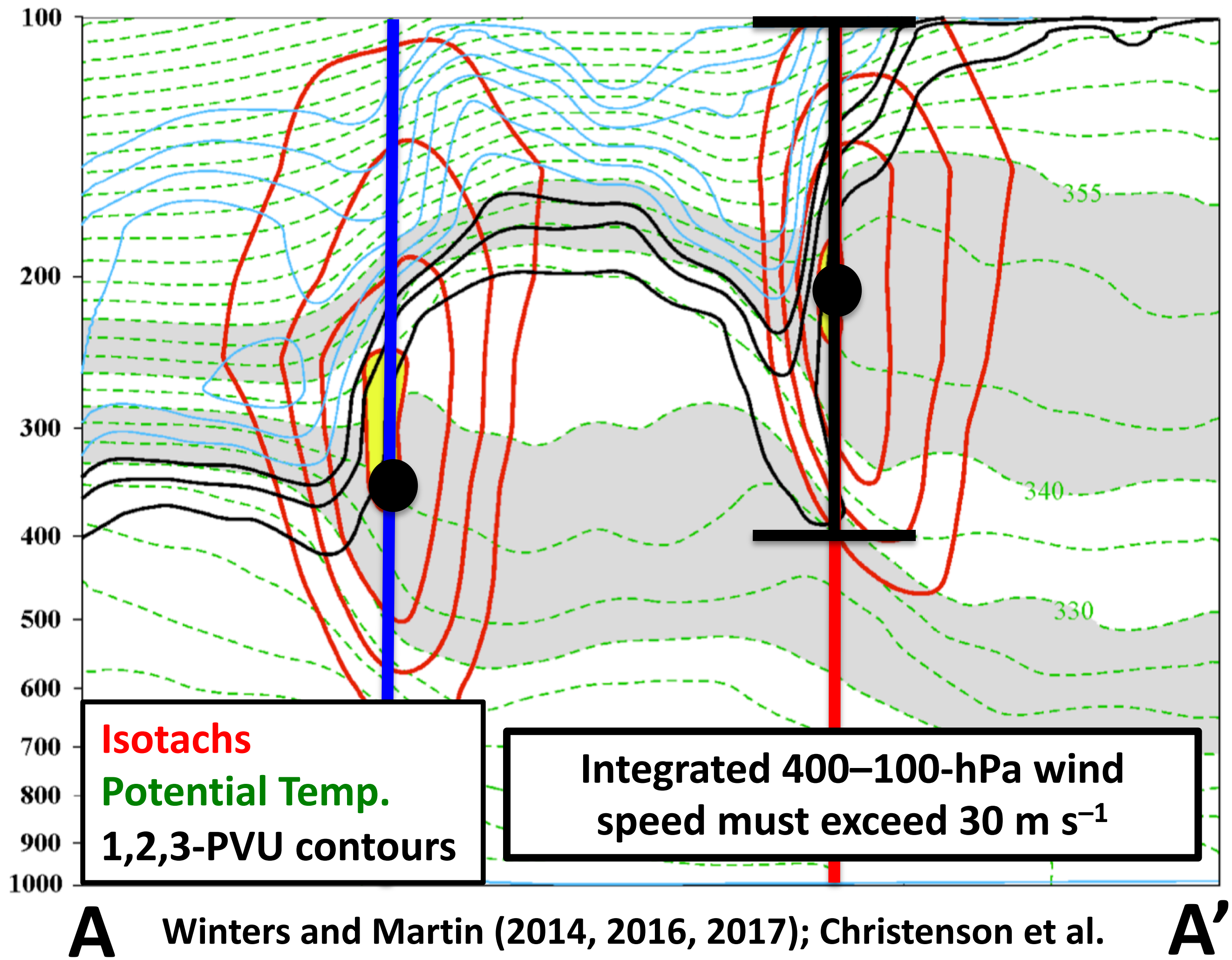
Jet Superposition Event Identification

0000 UTC 27 April 2010



250-hPa wind speed

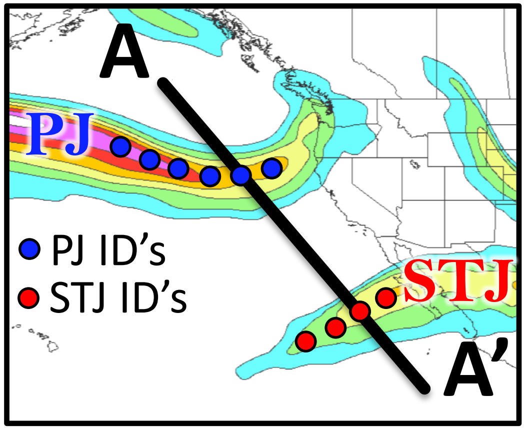
Isolated grid points over North America in the CFSR (Saha et al. 2014) characterized by polar and subtropical jets during Nov–Mar 1979–2010.



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

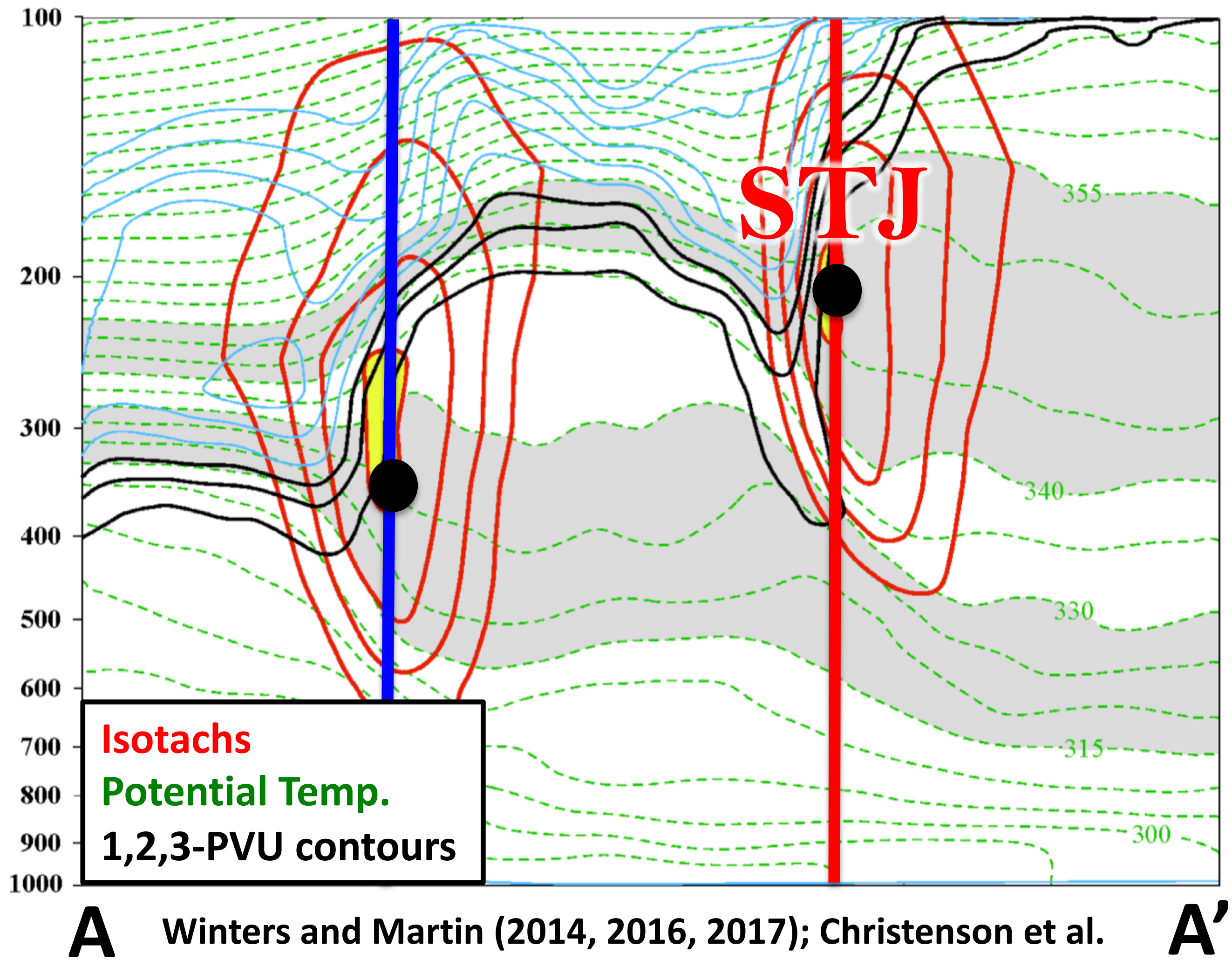
Jet Superposition Event Identification

0000 UTC 27 April 2010



250-hPa wind speed

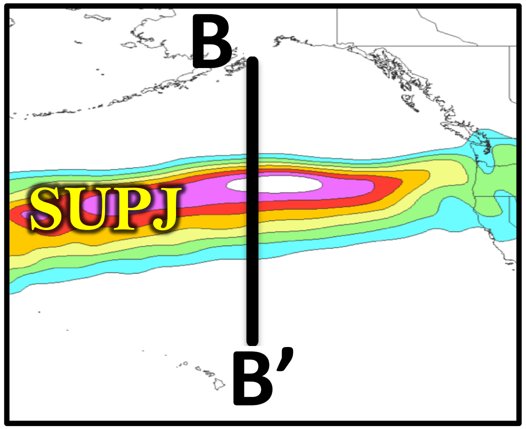
Isolated grid points over North America in the CFSR (Saha et al. 2014) characterized by polar and subtropical jets during Nov–Mar 1979–2010.



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

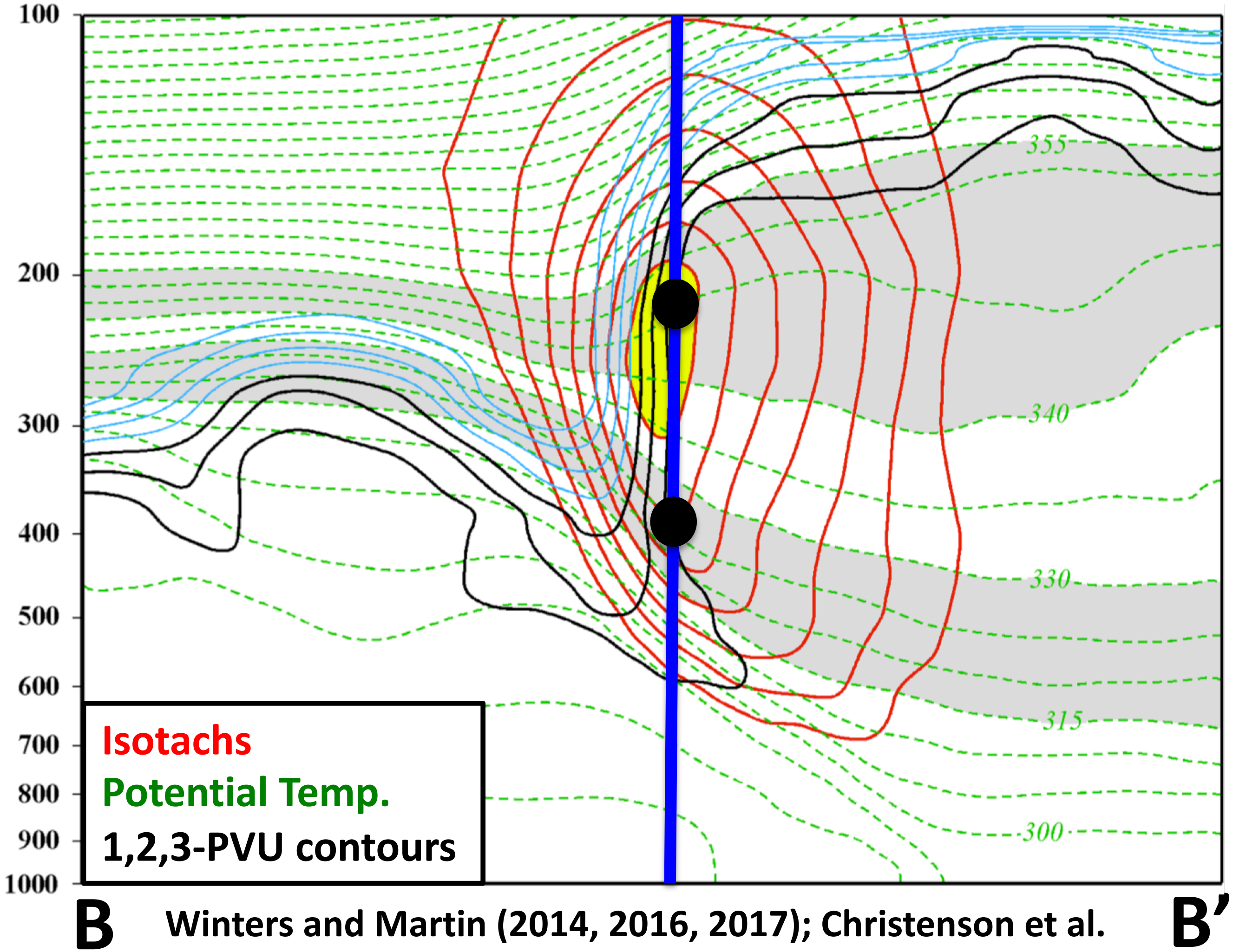
Jet Superposition Event Identification

0000 UTC 24 October 2010



250-hPa wind speed

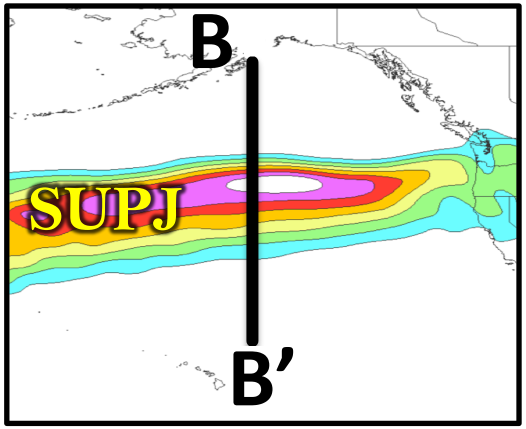
Isolated grid points over North America in the CFSR (Saha et al. 2014) characterized by a jet superposition during Nov–Mar 1979–2010.



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

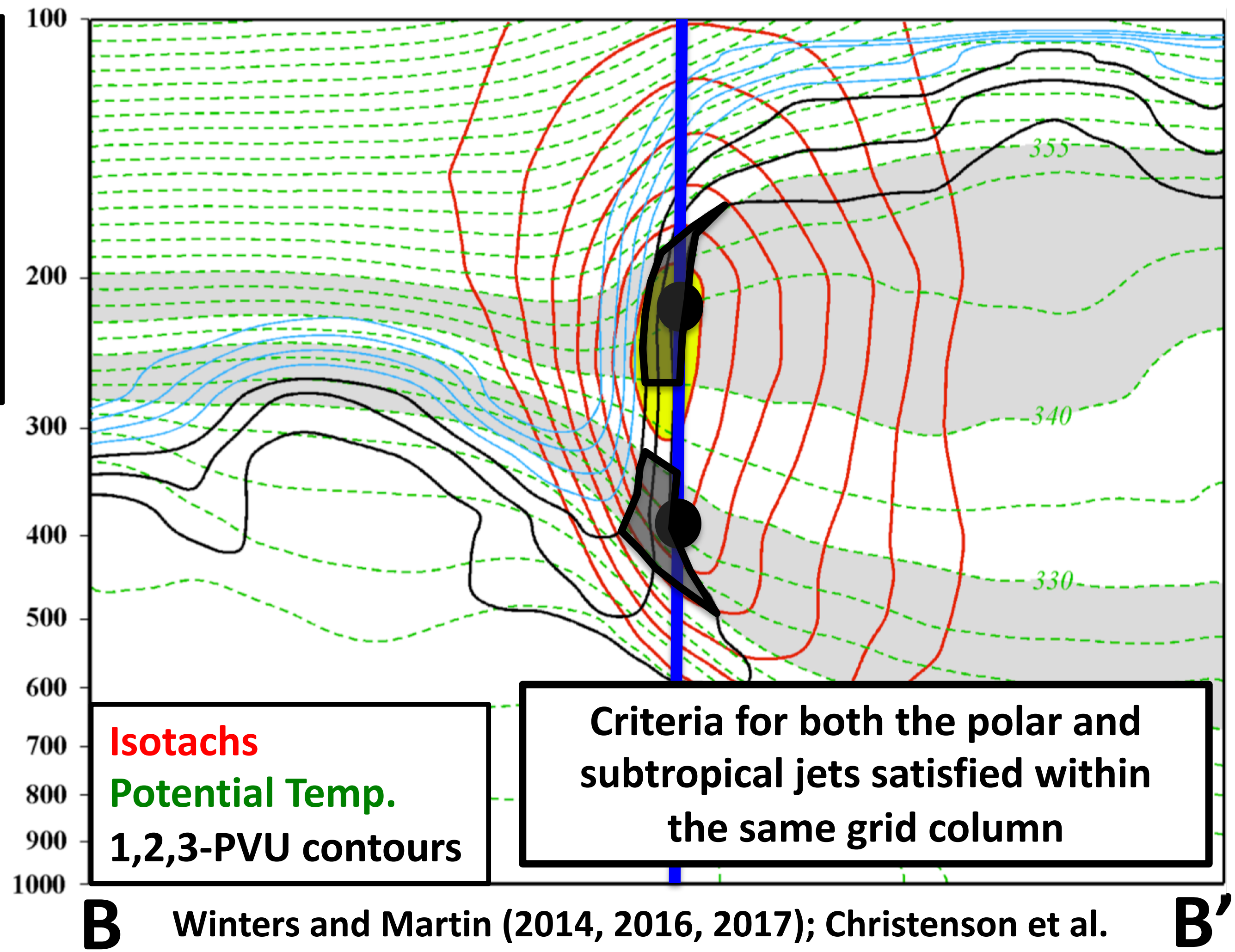
Jet Superposition Event Identification

0000 UTC 24 October 2010



250-hPa wind speed

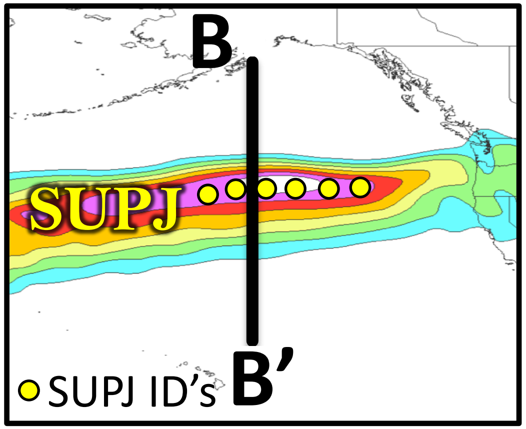
Isolated grid points over North America in the CFSR (Saha et al. 2014) characterized by a jet superposition during Nov–Mar 1979–2010.



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

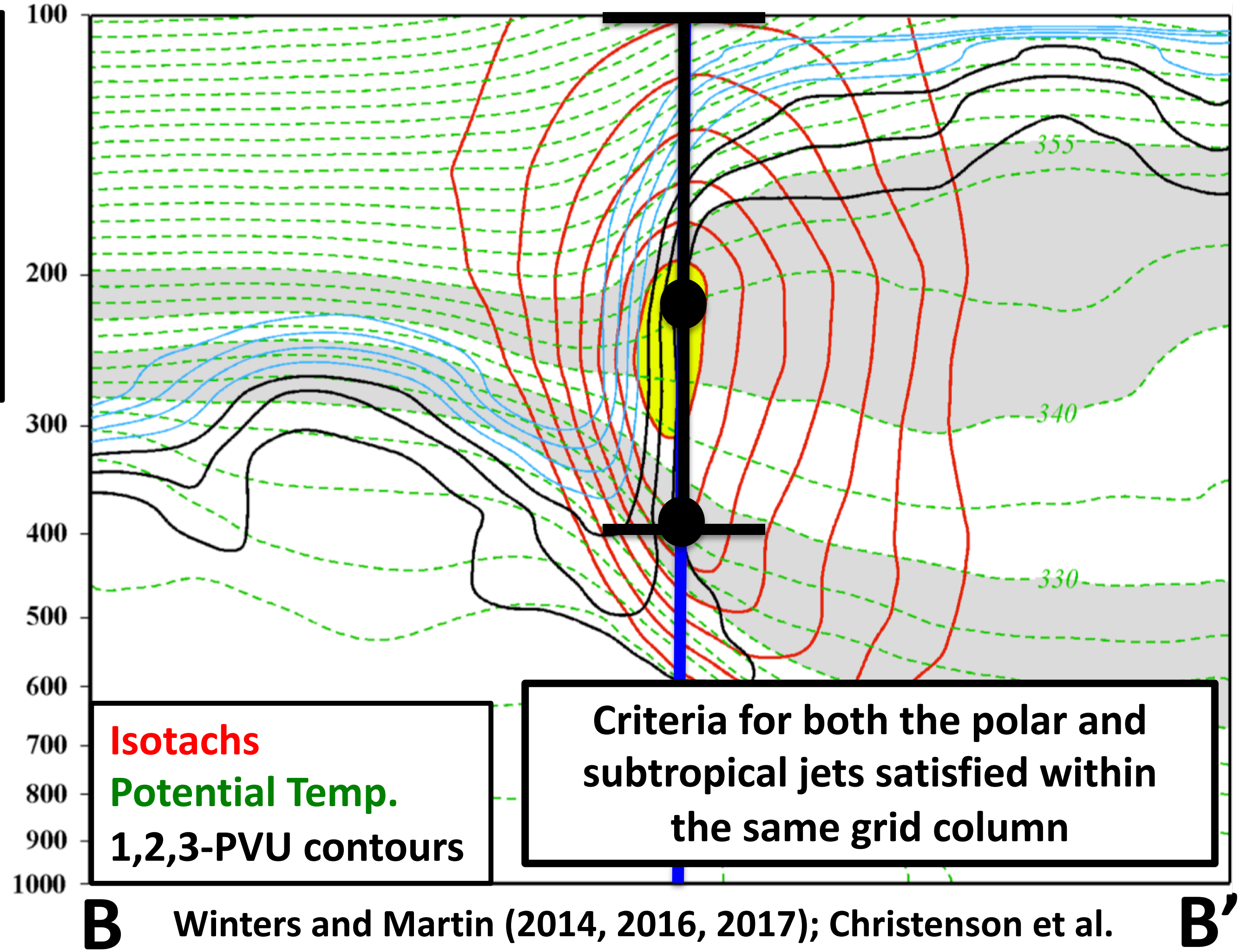
Jet Superposition Event Identification

0000 UTC 24 October 2010



250-hPa wind speed

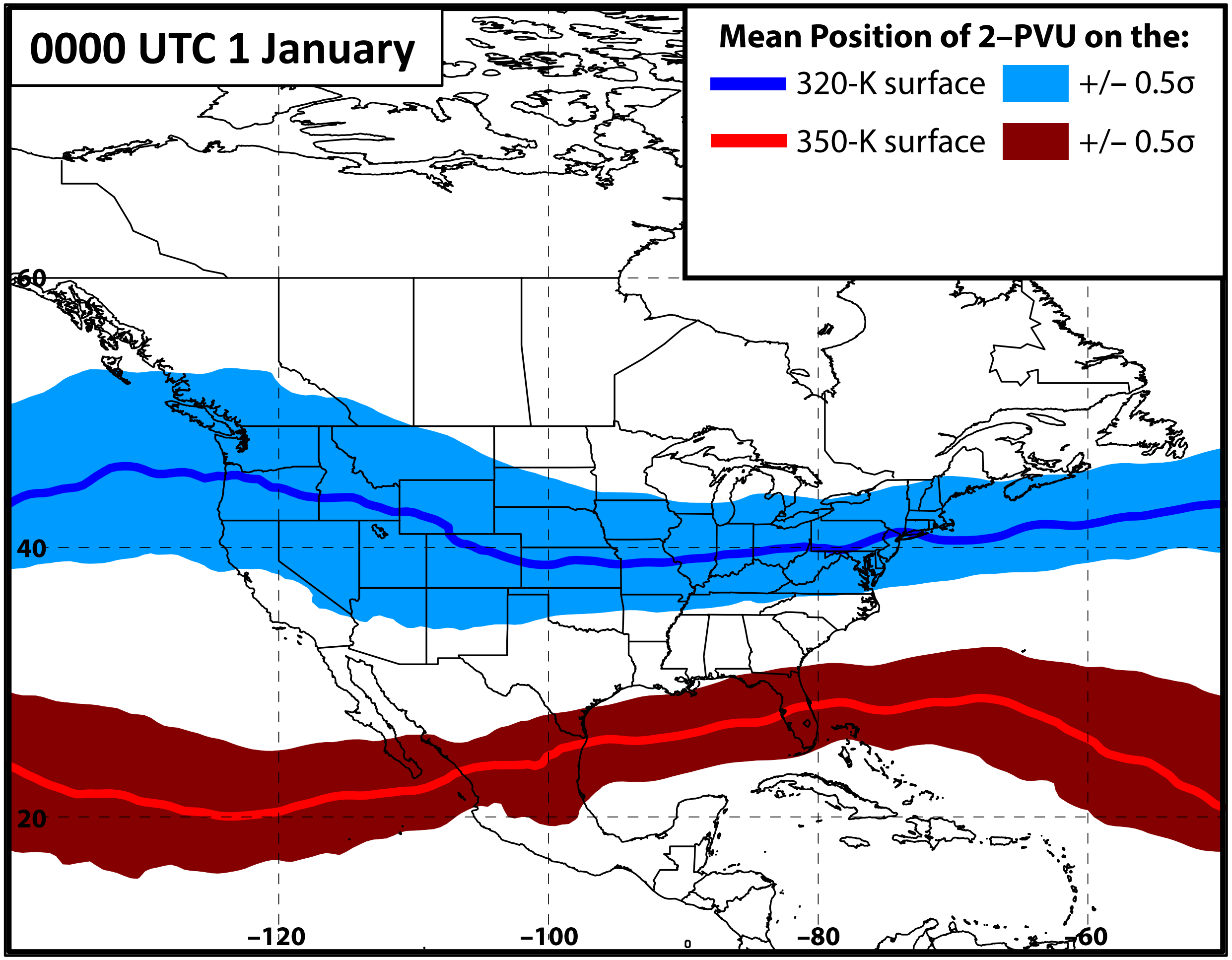
Isolated grid points over North America in the CFSR (Saha et al. 2014) characterized by a jet superposition during Nov–Mar 1979–2010.



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

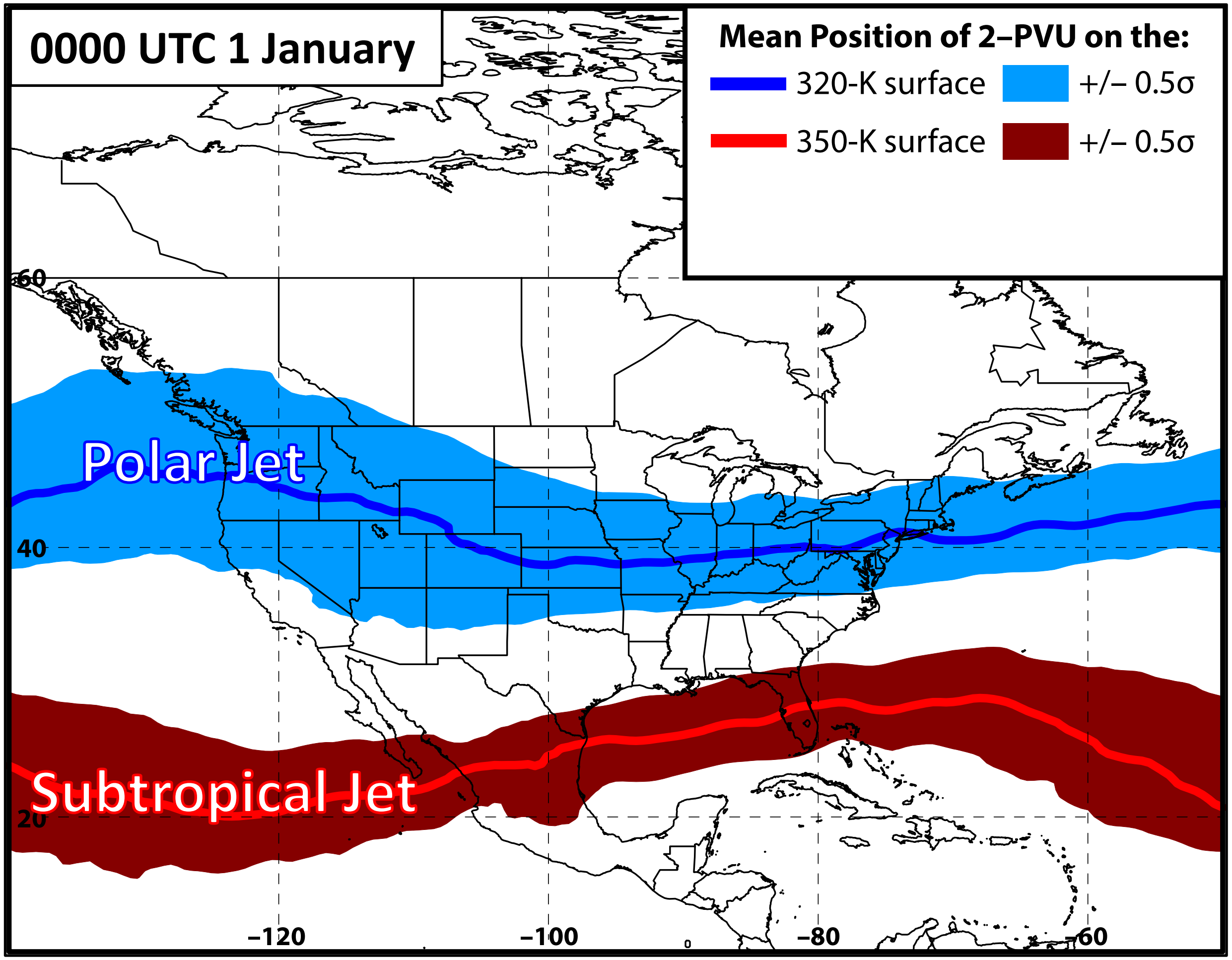
Jet Superposition Event Classification

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

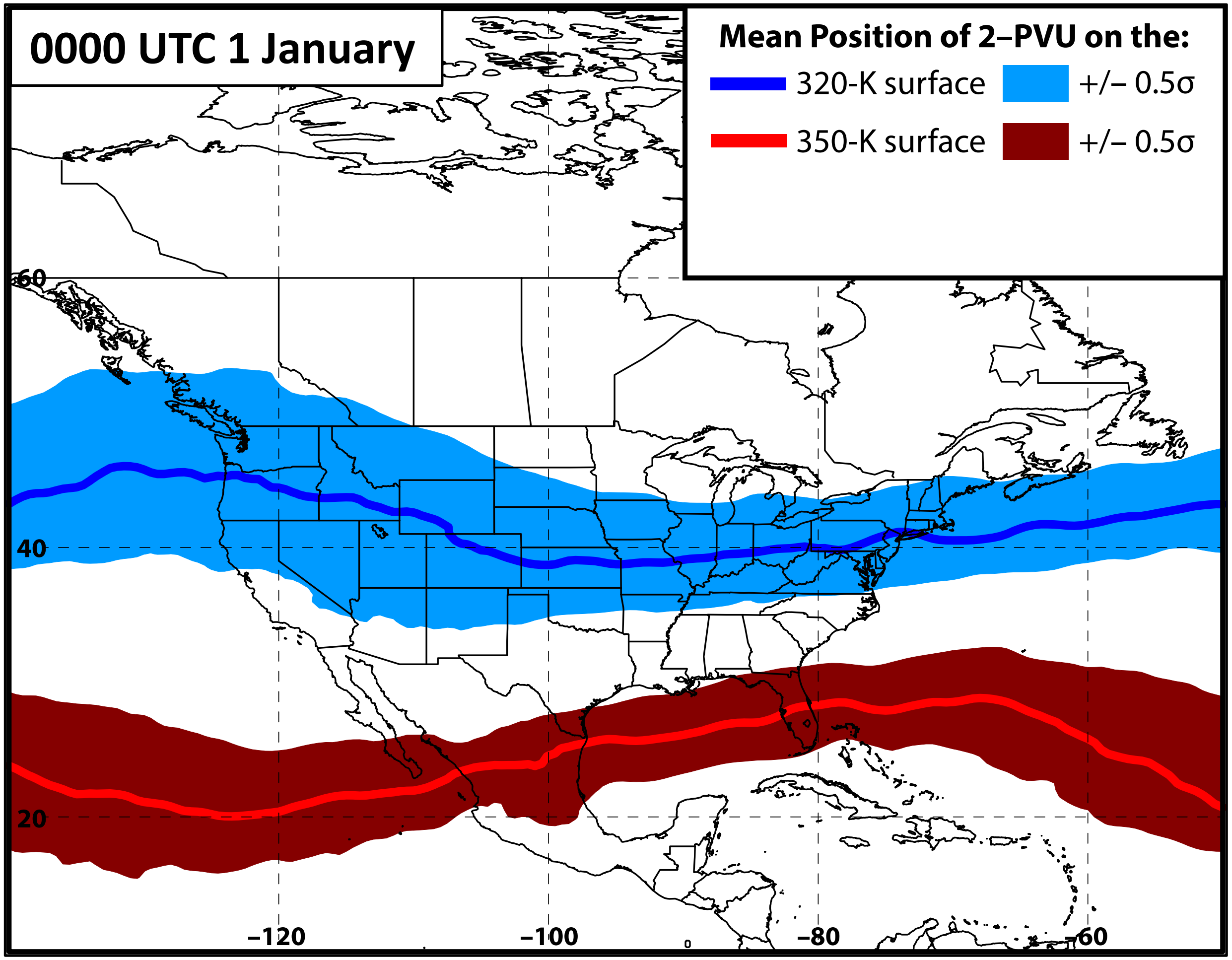
1. Determined the mean position of the 2-PVU contour on the 320-K and 350-K surfaces at each analysis time in the CFSR.



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.

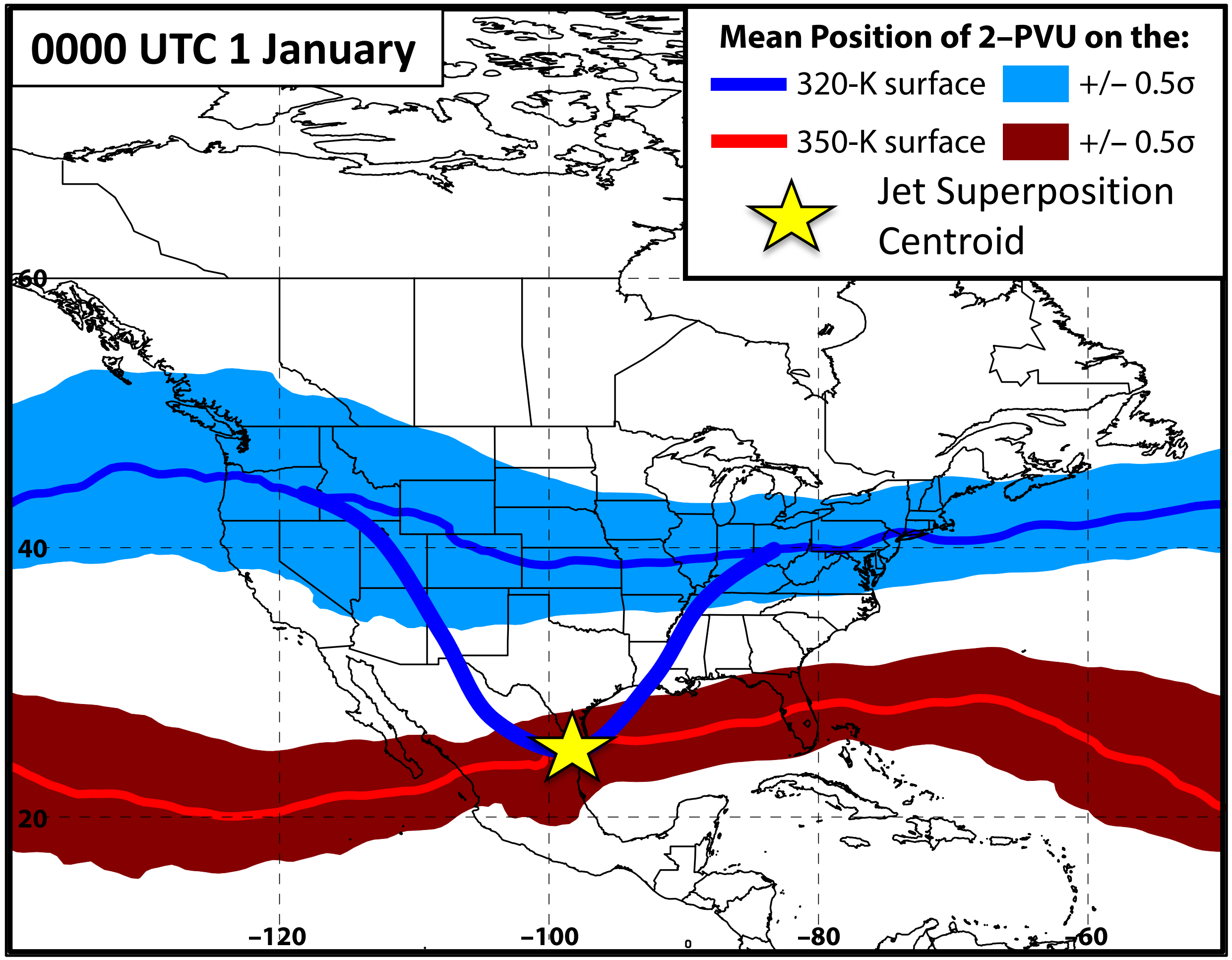


Jet Superposition Event Classification

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.

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**

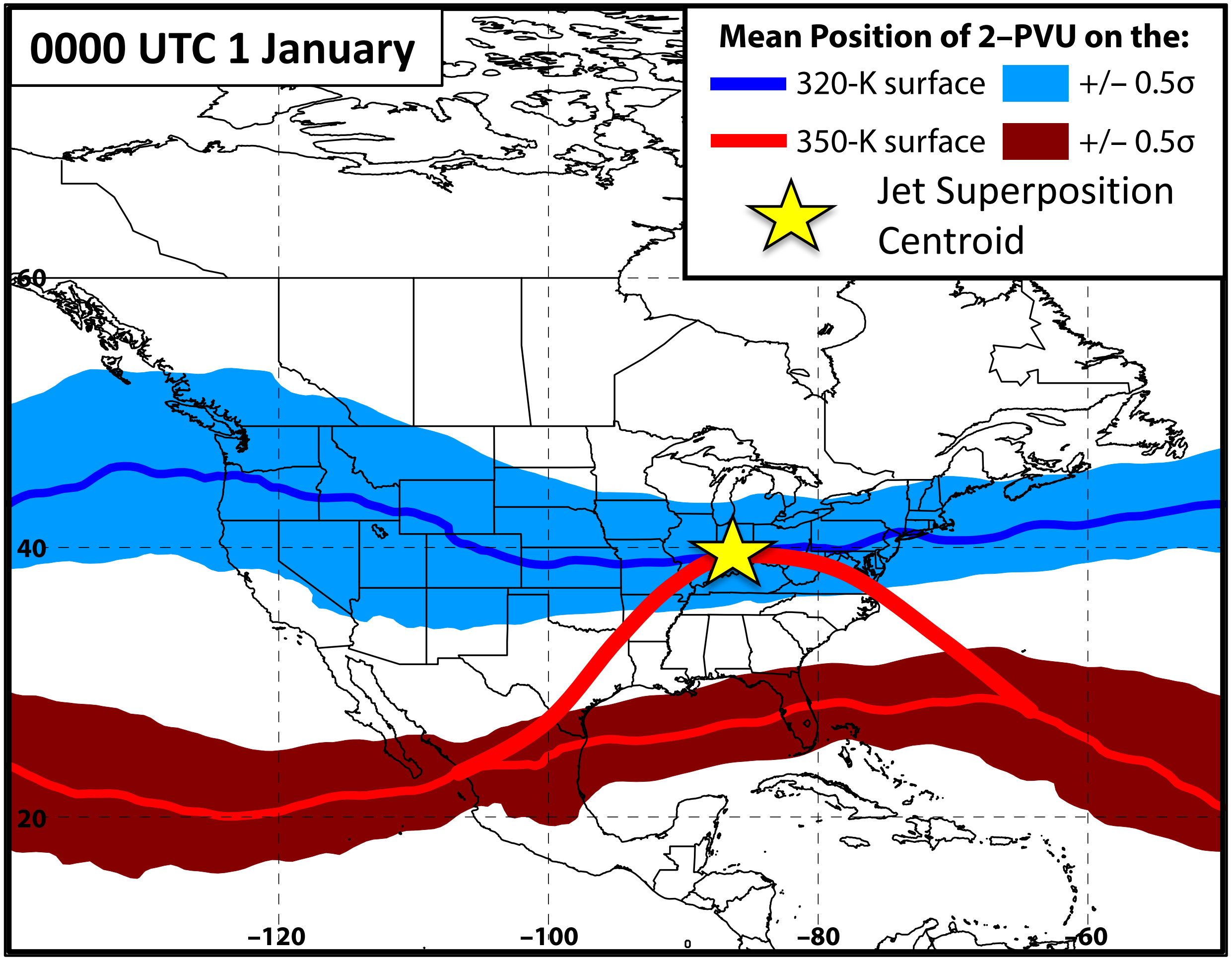


Jet Superposition Event Classification

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**

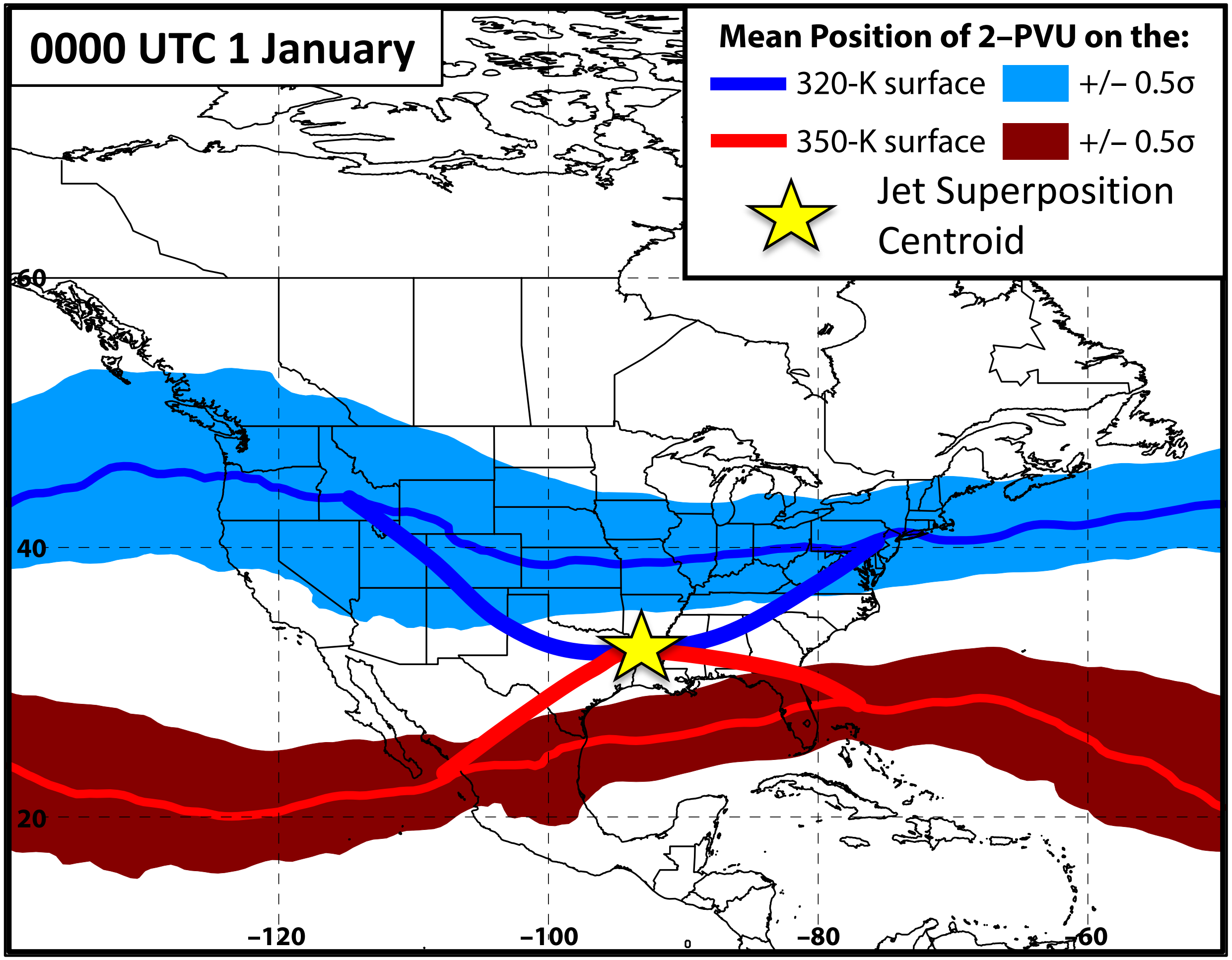


Jet Superposition Event Classification

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**



Background

Christenson et al. (2017)

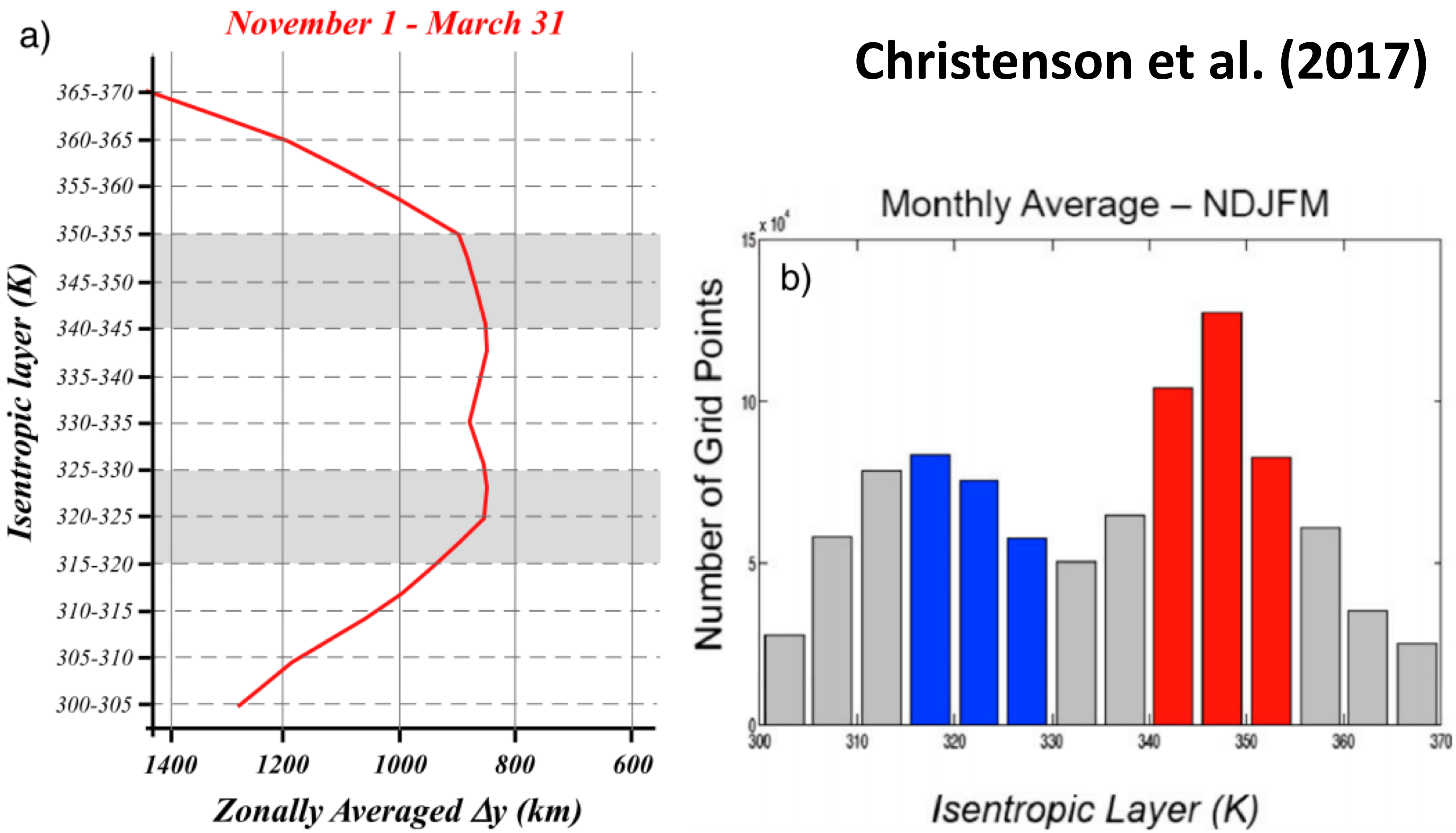
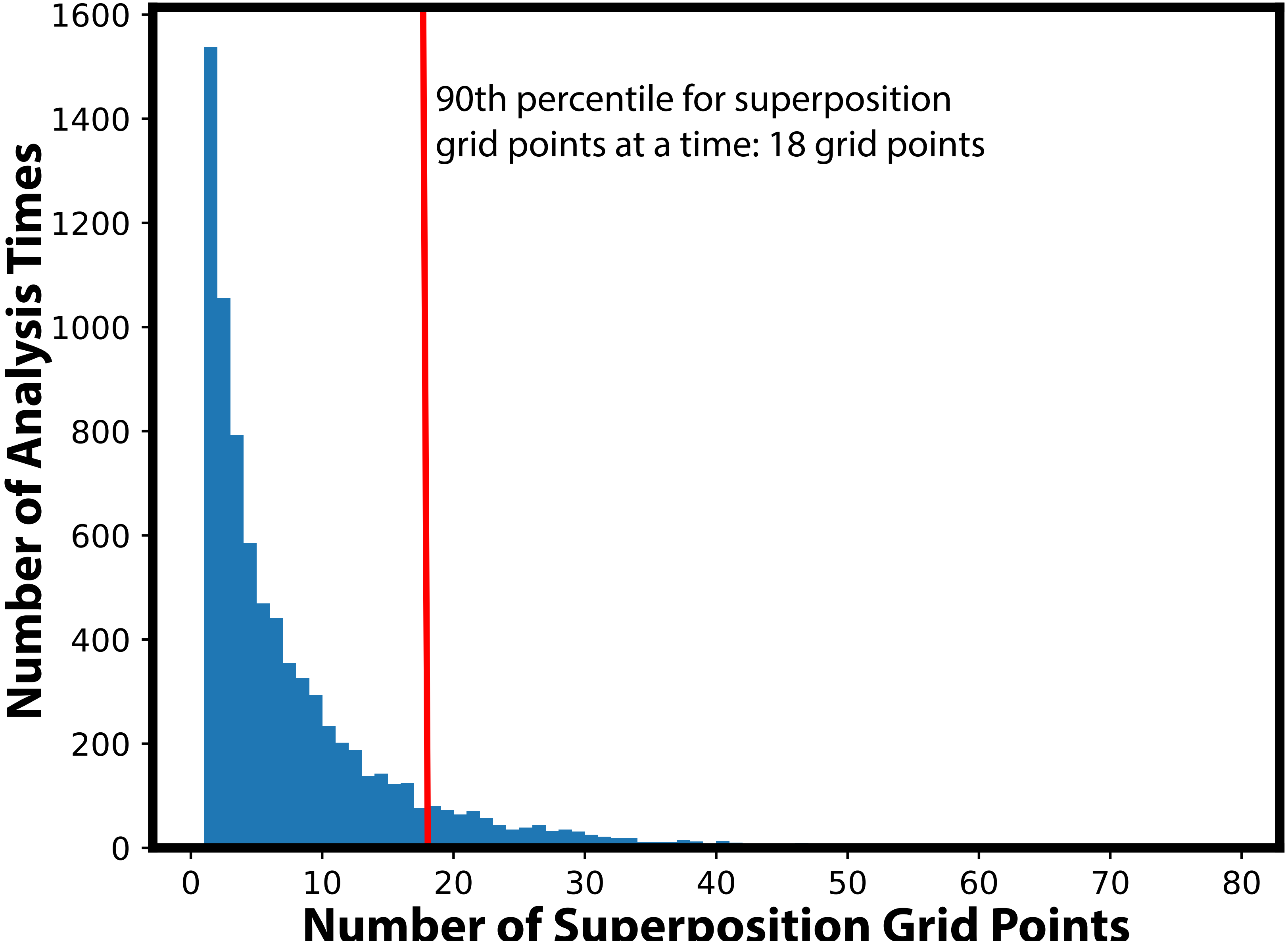


FIG. 2. (a) Cold season average of zonally averaged Δ*y* (km) for 5-K isentropic layers ranging from 300–305 to 365–370 K. The 315–330- and 340–355-K layers are highlighted in light gray shading. (b) The average frequency of occurrence of grid points with a maximum wind speed value within the 5-K isentropic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

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