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

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Background

Mean Meridional Cross-Section of $\theta$

- **Polar Tropopause**
- **Tropical Tropopause**
- **Subtropical Tropopause**
- **Polar Frontal Zone**

Modified from Defant and Taba (1957)
Background

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STJ  Subtropical Jet

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

Modified from Defant and Taba (1957)
The pole-to-equator baroclinicity is combined into a much narrower zone of contrast in the vicinity of a jet superposition.

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

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

1) Western Pacific

2) North America

3) Northern Africa
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1) Western Pacific
2) North America
3) Northern Africa

Climatological frequency of Northern Hemisphere jet superposition events per cold season (Nov–Mar) 1960–2010
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).
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How do these structures develop?
Jet Superposition Conceptual Model

1a) Remote production of a cyclonic PV anomaly

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

1a) Remote production of a cyclonic PV anomaly

1b) Remote production of an anticyclonic PV anomaly

Winters and Martin (2017)
Jet Superposition Conceptual Model

1a) Remote production of a cyclonic PV anomaly

1b) Remote production of an anticyclonic PV anomaly

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

1a) Remote production of a cyclonic PV anomaly

2) Both PV anomalies are advected towards middle latitudes

1b) Remote production of an anticyclonic PV anomaly

Winters and Martin (2017)
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2) Both PV anomalies are advected towards middle latitudes
3) Local dynamics can aid in the development of superposition
Jet Superposition Conceptual Model

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

Winters and Martin (2017)
Goal: To determine the characteristic types of interaction that exist between upper-tropospheric PV anomalies during a jet superposition event.

Winters and Martin (2017)
Jet Superposition Event
Identification and Classification
Isolated grid points over North America in the CFSR (Saha et al. 2014) characterized by polar and subtropical jets during Nov–Mar 1979–2010.

Jet Superposition Event Identification

0000 UTC 27 April 2010

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

250-hPa wind speed

A

STJ

PJ

A'

Winters and Martin (2014, 2016, 2017); Christenson et al. (2017); Handlos et al. (2016)
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Isolated grid points over North America in the CFSR (Saha et al. 2014) characterized by polar and subtropical jets during Nov–Mar 1979–2010.

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

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Potential Temp.
1,2,3-PVU contours

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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.
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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.

3. Filtered retained analysis times to group together jet superpositions that are < 30 h and < 1500 km of one another.
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
- Subtropical Dominant
Jet Superposition Event Classification

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- Polar Dominant
- Subtropical Dominant
- Hybrid
Jet Superposition Event Classification

Number of Cases

<table>
<thead>
<tr>
<th>Month</th>
<th>All events (N=326)</th>
<th>Polar dominant (N=80)</th>
<th>Subtropical dominant (N=129)</th>
<th>Hybrid events (N=117)</th>
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<tr>
<td>Nov</td>
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Number of Cases

- All events (N=326)
- Polar dominant (N=80)
- Subtropical dominant (N=129)
- Hybrid events (N=117)

Bar chart showing the number of cases for different months and event classifications.
Jet Superposition Event Classification

Frequency of Polar Dominant Jet Superposition Events

Legend

- Centroid of all events
- Composite movement of superposition

N = 80

Number of events
Jet Superposition Event Classification

Frequency of Polar Dominant Jet Superposition Events

Legend
- Centroid of all events
- Composite movement of superposition

Number of events
Jet Superposition Event Classification

Frequency of Hybrid Jet Superposition Events

N = 117

Legend
- Centroid of all events
- Composite movement of superposition

Number of events
Jet Superposition Event Classification

Frequency of Hybrid Jet Superposition Events

Legend
- Centroid of all events
- Composite movement of superposition

N = 117

Number of events
Jet Superposition Event Classification

Frequency of Subtropical Dominant Jet Superposition Events

Number of events

Legend
- Centroid of all events
- Composite movement of superposition

N = 129
Jet Superposition Event Classification

Frequency of Subtropical Dominant Jet Superposition Events

Legend
- Centroid of all events
- Composite movement of superposition

N = 129

West: N = 53

East: N = 76

Number of events
Jet Superposition Event Classification

Frequency of Subtropical Dominant Jet Superposition Events

Legend
- Centroid of all events
- Composite movement of superposition

West: N = 53
East: N = 76

N = 129

Number of events
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

N=80

1 Day Prior to Jet Superposition

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

250-hPa Jet, MSLP Anom., PWAT Anom., & −OLR Anom.
Polar Dominant Jet Superposition Events

0 Days Prior to Jet Superposition

N=80
Polar Dominant Jet Superposition Events

0 Days Prior to Jet Superposition

Jet

Superposition Centroid

N=80

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

250-hPa Geo. Height
250-hPa Geo. Height Anom.
300-hPa Geo. WAA
300-hPa Geo. CAA

200-500 m s⁻¹

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

MSLP Anom.
Neg. OLR Anom.

1 2 3 4 5 6 mm
Polar Dominant Jet Superposition Events

0 Days Prior to Jet Superposition

Jet
Superposition Centroid

N=80
Polar Dominant Jet Superposition Events

12 Hours Prior to Jet Superposition

Legend
- 1.5-, 2-, 3-PVU
- $\theta$
- + pert. PV
- - pert. PV
Polar Dominant Jet Superposition Events

12 Hours Prior to Jet Superposition

Strong cyclonic PV anomaly poleward of the developing jet superposition

Legend
- 1.5-, 2-, 3-PVU
- θ
- + pert. PV
- − pert. PV
Polar Dominant Jet Superposition Events

12 Hours Prior to Jet Superposition

Subsidence directly beneath and poleward of the jet core

Legend
- 1.5-, 2-, 3-PVU
- \( \theta \)
- + pert. PV
- - pert. PV

\( \omega \) wind speed

Subsidence directly beneath and poleward of the jet core
Subsidence acts to steepen the tropopause
Polar Dominant Jet Superposition Events

0 Hours Prior to Jet Superposition

Subsidence acts to steepen the tropopause
Polar Dominant Jet Superposition Events

0 Hours Prior to Jet Superposition

Cyclonic PV anomaly intensifies poleward of the jet superposition

Legend
- 1.5-, 2-, 3-PVU
- $\theta$
- + pert. PV
- - pert. PV

wind speed
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

12 Hours Prior to Jet Superposition

Legend

- 1.5-, 2-, 3-PVU
- $\theta$
- + pert. PV
- − pert. PV
E. Subtropical Dominant Jet Superposition Events

12 Hours Prior to Jet Superposition

Legend

- 1.5-,2-, 3-PVU
- $\theta$
- + pert. PV
- − pert. PV

Juxtaposition of cyclonic and anticyclonic PV anomalies near the tropopause.
E. Subtropical Dominant Jet Superposition Events

12 Hours Prior to Jet Superposition

Ascent directly beneath the jet core

Legend
- 1.5-, 2-, 3-PVU
- $\theta$
- $+$ pert. PV
- $-$ pert. PV

$\omega$ wind speed

Legend
- 1.5-, 2-, 3-PVU
- $\theta$
- $+$ pert. PV
- $-$ pert. PV

Ascent directly beneath the jet core
E. Subtropical Dominant Jet Superposition Events

12 Hours Prior to Jet Superposition

Ascent and the diabatic destruction of PV act to steepen the tropopause

Legend
- 1.5-, 2-, 3-PVU
- \( \theta \)
- + PV adv.
- – PV adv.
E. Subtropical Dominant Jet Superposition Events

0 Hours Prior to Jet Superposition

Subsidence develops beneath the jet core and acts to further steepen the tropopause.
E. Subtropical Dominant Jet Superposition Events

0 Hours Prior to Jet Superposition

The intensification of both PV anomalies is associated with an acceleration of jet wind speeds.

Legend

- 1.5-, 2-, 3-PVU
- $\theta$
- + pert. PV
- − pert. PV

$\omega$ wind speed

Legend

- 1.5-, 2-, 3-PVU
- $\theta$
- + pert. PV
- − pert. PV

wind speed
Summary

- MSLP Anomaly < −1σ
- 300-hPa Geo. CAA
- OLR Anomaly < −10 W m⁻²
- Prcp. Water Anomaly > 10 mm

Polar Dominant
E. Subtropical Dominant
Polar Dominant Events:

1a) Remote production of a cyclonic PV anomaly

1b) Remote production of an anticyclonic PV anomaly
Summary

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

1a) Remote production of a cyclonic PV anomaly

1b) Remote production of an anticyclonic PV anomaly

East Subtropical Dominant Events:
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
References


Jet Superposition Event Identification

90th percentile for superposition grid points at a time: 18 grid points
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

- Used for calculation
- Not used for calculation
- Jet superposition centroid

\[ d > 1000 \text{ km} \]
Jet Superposition Event Identification

Frequency of East Subtropical Dominant Jet Superposition Events

Legend

- Centroid of all events
- Composite movement of superposition

N = 76
Jet Superposition Event Identification

Frequency of West Subtropical Dominant Jet Superposition Events

N = 53

Legend

Centroid of all events
Composite movement of superposition
Jet Superposition Event Classification

Frequency

- All times (N=717)
- Polar dominant (N=158)
- Subtropical dominant (N=295)
- Hybrid events (N=264)

Month: Nov, Dec, Jan, Feb, Mar
### 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

Dynamic Tropopause
Potential Temperature

Pyle et al. (2004)
Jet Superposition Conceptual Model

Dynamic Tropopause
Potential Temperature

Heather Archambault
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.

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.