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

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University Park, PA
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Background

Modified from Defant and Taba (1957)

Mean Meridional Cross-Section of θ

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

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.
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
Background

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2) North America
3) Northern Africa
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).

Moore et al. (2012)
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- Jet superposition was associated with a rapidly deepening East Coast cyclone (Winters and Martin 2016; 2017).
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• Jet superposition over the West Pacific preceded the development of an intense Midwest U.S. cyclone.
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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)
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)
Jet Superposition Conceptual Model

1a) Remote production of a cyclonic PV anomaly

1b) Remote production of an anticyclonic PV anomaly

2) Both PV anomalies are advected towards middle latitudes

3) Local dynamics can aid in the development of superposition

Winters and Martin (2017)
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
Jet Superposition Event Identification

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

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0000 UTC 27 April 2010

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250-hPa wind speed

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

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

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Integrated 400–100-hPa wind speed must exceed 30 m s⁻¹

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Criteria for both the polar and subtropical jets satisfied within the same grid column.

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

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

Mean Position of 2–PVU on the:
- 320-K surface
- 350-K surface
- +/- 0.5σ

0000 UTC 1 January
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• Polar Dominant
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- Polar Dominant
- Subtropical Dominant
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- Polar Dominant
- Subtropical Dominant
- Hybrid
Jet Superposition Event Classification

Number of Cases

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

<table>
<thead>
<tr>
<th>Month</th>
<th>All events</th>
<th>Polar dominant</th>
<th>Subtropical dominant</th>
<th>Hybrid events</th>
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<tbody>
<tr>
<td>Nov</td>
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<td>20</td>
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<tr>
<td>Mar</td>
<td>50</td>
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<td>15</td>
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<tr>
<td>Dec</td>
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Jet Superposition Event Classification

Number of Cases

Jet Superposition Event Classification

[Bar chart showing the number of cases for different months with categories: All events (N=326), Polar dominant (N=80), Subtropical dominant (N=129), Hybrid events (N=117).]
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

N = 80

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

Legend
- Centroid of all events
- Composite movement of superposition

Number of events
Jet Superposition Event Classification

Frequency of Subtropical Dominant Jet Superposition Events

West: N = 53
East: N = 76

Legend:
- Centroid of all events
- Composite movement of superposition

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

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

1 Day Prior to Jet Superposition

N=80
Polar Dominant Jet Superposition Events

0 Days Prior to Jet Superposition

N=80

<table>
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<tr>
<th>250-hPa Jet, Geo. Height, &amp; Geo. Height Anom., &amp; 300-hPa Geo. Temp Adv.</th>
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<td>MSLP Anom.</td>
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</tbody>
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m s^{-1}

mm
Polar Dominant Jet Superposition Events

0 Days Prior to Jet Superposition

N=80
Polar Dominant Jet Superposition Events

0 Days Prior to Jet Superposition

N=80
Polar Dominant Jet Superposition Events

12 Hours Prior to Jet Superposition

Legend

- 1.5,-,2-, 3-PVU
- θ
- + pert. θ
- − pert. θ

Legend

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

12 Hours Prior to Jet Superposition

- Warm and cold anomalies indicative of a strong positive PV anomaly
- Subsidence directly beneath and poleward of the jet core

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

Legend

- 1.5-, 2-, 3-PVU
- \( \theta \)
- + pert. \( \theta \)
- - pert. \( \theta \)
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
E. Subtropical Dominant Jet Superposition Events

12 Hours Prior to Jet Superposition

Ascent directly beneath the jet core

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

Legend

- 1.5-, 2-, 3-PVU
- \(\theta\)
- + pert. \(\theta\)
- - pert. \(\theta\)
E. Subtropical Dominant Jet Superposition Events

0 Hours Prior to Jet Superposition

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

0 Hours Prior to Jet Superposition

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

Subsidence directly beneath and poleward of the jet core

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

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

Polar Dominant

E. Subtropical Dominant
Summary

Polar Dominant Events:

1a) Remote production of a cyclonic PV anomaly

1b) Remote production of an anticyclonic PV anomaly
Summary

Polar Dominant Events:

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

1a) Remote production of a cyclonic PV anomaly

1b) Remote production of an anticyclonic PV anomaly

East Subtropical Dominant Events:
Summary

**East Subtropical Dominant Events:**

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

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

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

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

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

Legend

- Centroid of all events
- Composite movement of superposition

N = 53
Jet Superposition Event Classification

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

- Event Classification:
  - Jet Superposition

- Months:
  - Nov
  - Dec
  - Jan
  - Feb
  - Mar

- Frequency Scale:
  - 0 to 250
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
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

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