The 25-27 December 2010 Snowstorm: A case study of the associated Upper-Level Jet-Front Systems

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Source: NASA/Goddard Space Flight System
Overview of ULJF Systems
Upper-Level Jet-Front System

Theta contours solid lines; wind speed (m/s) dashed lines; magnitude of theta gradient (K/100km) shaded
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Upper-Tropospheric Front

Jet streak
Upper-Level Jet-Front System

Theta contours solid lines; wind speed (m/s) dashed lines; magnitude of theta gradient (K/100km) shaded

Lower-Stratospheric Front

Upper-Tropospheric Front

Jet streak
Upper-Level Jet-Front System

Fronts characterized by larger than background:
- vertical and horizontal shear
- static stability
- temperature gradient

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Upper-Level Jet-Front System

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Upper-Level Jet-Front System

Lower-Stratospheric Front

Upper-Tropospheric Front

Commonly observed in Northwesterly and Southwesterly flow during the winter season

Theta contours solid lines; wind speed (m/s) dashed lines; magnitude of theta gradient (K/100km) shaded
Upper-Level Jet-Front System

Influence the life-cycle of surface cyclones

Lower-Stratospheric Front

Jet streak

Upper-Tropospheric Front

Theta contours solid lines; wind speed (m/s) dashed lines; magnitude of theta gradient (K/100km) shaded
Mix stratospheric air (characterized by high values of potential vorticity and low values of water vapor) into the troposphere.
Upper-Level Jet-Front System

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25-27 December 2010
East Coast Snowstorm
Previous Studies

• Mike Soltow, HPC Meteorologist: *Event Review: December 25-27, 2010 Winter Storm, Eastern United States*
  – Overview of event including: synoptic set up and mesoscale features

• Kocin et al: *The Blizzard of 25-27 December 2010: Forecast Assessment*
  – Assessed predictability issues associated with the storm

• Independent Case Studies
Overview of Storm

• Significant snowfall event for all of the East Coast
  – Blizzard conditions in some locations:
    • Wind speeds of at least 30 kts
    • Visibilities reduced to <¼ mile due to falling or blowing snow
    • These conditions lasting for at least 3 hours

• The storm occurred during the Christmas Season during peak travel making this a high impact event
Synoptic Overview
0000 UTC 21 December 2010

Theta on 2 PVU Surface [Shaded]; Sea Level Pressure [Contoured, dashed < 1000 hPa]
Theta on 2 PVU Surface [Shaded]; Sea Level Pressure [Contoured, dashed < 1000 hPa]
0000 UTC 22 December 2010

Theta on 2 PVU Surface [Shaded]; Sea Level Pressure [Contoured, dashed < 1000 hPa]
1200 UTC 22 December 2010

Theta on 2 PVU Surface [Shaded]; Sea Level Pressure [Contoured, dashed < 1000 hPa]
Theta on 2 PVU Surface [Shaded]; Sea Level Pressure [Contoured, dashed < 1000 hPa]
1200 UTC 23 December 2010

Theta on 2 PVU Surface [Shaded]; Sea Level Pressure [Contoured, dashed < 1000 hPa]
Theta on 2 PVU Surface [Shaded]; Sea Level Pressure [Contoured, dashed < 1000 hPa]
Theta on 2 PVU Surface [Shaded]; Sea Level Pressure [Contoured, dashed < 1000 hPa]
0000 UTC 25 December 2010

Theta on 2 PVU Surface [Shaded]; Sea Level Pressure [Contoured, dashed < 1000 hPa]
Theta on 2 PVU Surface [Shaded]; Sea Level Pressure [Contoured, dashed < 1000 hPa]
Theta on 2 PVU Surface [Shaded]; Sea Level Pressure [Contoured, dashed < 1000 hPa]
1200 UTC 26 December 2010

Theta on 2 PVU Surface [Shaded]; Sea Level Pressure [Contoured, dashed < 1000 hPa]
0000 UTC 27 December 2010

Theta on 2 PVU Surface [Shaded]; Sea Level Pressure [Contoured, dashed < 1000 hPa]
1200 UTC 27 December 2010

Theta on 2 PVU Surface [Shaded]; Sea Level Pressure [Contoured, dashed < 1000 hPa]
Theta on 2 PVU Surface [Shaded]; Sea Level Pressure [Contoured, dashed < 1000 hPa]
1200 UTC 28 December 2010

Theta on 2 PVU Surface [Shaded]; Sea Level Pressure [Contoured, dashed < 1000 hPa]
Motivation for This Research Study

• Kocin et al. concluded that the trough merger that occurred on 25 December was difficult to forecast

• How did ULJF systems impact the upper level flow pattern?
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• How did ULJF systems impact the upper level flow pattern?

• **Focus on the evolution of one of the ULJF systems**
Thermal Wind in the Troposphere

\[ \frac{\partial u_g}{\partial p} = \frac{R}{f_0 p} \left( \frac{\partial T}{\partial y} \right)_p \]
Thermal Wind in the Troposphere

\[ \frac{\partial u_g}{\partial p} = R f_0 p \left( \frac{\partial T}{\partial y} \right)_p \]
Thermal Wind in the Troposphere

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Thermal Wind in the Troposphere

\[ \partial \frac{u_g}{\partial p} = R \left( \frac{\partial T}{\partial y} \right)_p \]

(-) \quad (+) \quad (-) \quad (+) \quad \partial u_g \\
(-) \quad \partial p \\

COLD \quad \nabla T \quad WARM
Thermal Wind in the Troposphere

\[ \partial u_g \partial p = R f_0 p \left( \frac{\partial T}{\partial y} \right)_p \]
Thermal Wind in the Troposphere

We expect a jet ABOVE this temperature gradient

\[ \partial u_g \frac{\partial T}{\partial y} = R \frac{\partial p}{f_0 p \left( \frac{\partial T}{\partial y} \right)_p} \]
Upper-Tropospheric Jet

\[ \nabla T \]

JET

\[ 30, 309, 312, 315, 321, 321, 321, 5600 \]
Thermal Wind in the Stratosphere

\[ \partial u_g \frac{\partial T}{\partial y} = R \left( \frac{\partial T}{\partial y} \right)_p \]

\[ \begin{align*}
(+) \quad \frac{\partial u_g}{\partial p} &= R \left( \frac{\partial T}{\partial y} \right)_p \\
(-) \quad \frac{\partial T}{\partial y} &= \frac{\partial p}{\partial p} \\
(-) \quad \frac{\partial p}{\partial p} &= \frac{\partial T}{\partial p}
\end{align*} \]
Thermal Wind in the Stratosphere

\[ \partial u = R f_{0} p \left( \frac{\partial T}{\partial y} \right) \]
Potential Vorticity

\[ PV = (\xi + f) \left( -g \frac{\partial \theta}{\partial p} \right) \]
Potential Vorticity

\[ PV = (\xi + f) \left( -g \frac{\partial \theta}{\partial p} \right) \]

- Absolute Vorticity
- Static Stability
0600 UTC 25 December 2010

200 hPa Geopotential Height contoured every 200 meters [solid contours]
Theta contoured every 3K [dashed contours]
Magnitude of the Theta Gradient every 1K (100km)$^{-1}$ starting at 2K (100km)$^{-1}$ [shaded]
300 hPa Geopotential Height contoured every 100 meters [solid contours]
Magnitude of the wind every 10 m/s starting at 40 m/s [shaded]
500 hPa Geopotential Height contoured every 100 meters [solid contours]
Theta contoured every 3K [dashed contours]
Magnitude of the Theta Gradient every 1K (100km)$^{-1}$ starting at 2K (100km)$^{-1}$ [shaded]
Evolution of ULJF
25 December 2010

Front 2

200 hPa

0600 UTC

500 hPa

1200 UTC

Geopotential Height every 200 m (100m) at 200 hPa (500hPa) [solid]
Theta every 3K [dashed]
Magnitude of theta gradient every 1K (100km)$^{-1}$ starting at 2K (100km)$^{-1}$ [shaded]
200 hPa  26 December 2010  500 hPa

0000 UTC

1200 UTC
0600 UTC 25 December 2010
0600 UTC 25 December 2010

200 hPa

500 hPa

Cross section from A to A’

Theta [solid lines]

Magnitude of the wind every 10 m/s starting at 20 m/s [dashed]

Magnitude of the theta gradient every 1K (100 km)^{-1} starting at 2 K (100 km)^{-1} [shaded]

1.5 PVU [red line]
0600 UTC 25 December 2010

200 hPa

500 hPa

Cross section from A to A’

Theta [solid lines]

Magnitude of the wind every 10 m/s starting at 20 m/s [dashed]

Omega every $2 \times 10^{-3}$ hPa s$^{-1}$ starting at $2 (-2) \times 10^{-3}$ hPa s$^{-1}$ [shaded]

Geostrophic Temperature Advection every $3 \times 10^{-4}$ K s$^{-1}$ starting at $3 (-3) \times 10^{-4}$ K s$^{-1}$ [solid (dashed)]

1.5 PVU [red line]
Upper Tropospheric Jet Circulations
(below the jet core)

From Lang and Martin (2010)
Upper Tropospheric Jet Circulations (below the jet core)

Geostrophic CAA Jet Circulation

From Lang and Martin (2010)
0600 25 December Conclusions

• The ULJF system and associated subsidence are amplifying the vorticity in the trough
• Increased slope of the tropopause leads to a more intense jet streak
• The ULJF circulations and amplification of the northern trough are associated with the merger of the shortwave trough to the south
0000 UTC 27 December 2010
0000 UTC 27 December 2010

200 hPa

500 hPa

Front 2

Cross section from A to A'

Theta [solid lines]

Magnitude of the wind every 10 m/s starting at 20 m/s [dashed]

Magnitude of the theta gradient every 1K (100 km)$^{-1}$ starting at 2 K (100 km)$^{-1}$ [shaded]

1.5 PVU [red line]
Intense UTF associated with local maxima in: vorticity, stability, and temperature gradient
500 hPa Geopotential Height contoured every 100 meters [solid contours]
Sea Level Pressure every 5 hPa [dashed]
Vorticity every $2 \times 10^{-5}$ s$^{-1}$ starting at $10 \times 10^{-5}$ s$^{-1}$ [shaded]
Forcings for Ascent above Surface Cyclone

1. Divergence of ageostrophic wind (downstream of trough axis)
Forcings for Ascent above Surface Cyclone

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2. Strong Vorticity due to:
Forcings for Ascent above Surface Cyclone

1. Divergence of ageostrophic wind (downstream of trough axis)

2. Strong Vorticity due to:
   1. Curvature Vorticity
   2. Shear Vorticity
   3. Upper tropospheric frontogenesis
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Positive Vorticity Advection downstream of trough

Strong Ascent
Forcings for Ascent above Surface Cyclone

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   Positive Vorticity Advection downstream of trough
   → Strong Ascent

Deep Surface Cyclone!
0000 27 December Conclusions

• High PV air is being brought into the troposphere from the stratosphere
• High vorticity in the location of the UTF
  large vorticity advection  
  increase strength of the surface cyclone
Conclusions

• Upper level fronts significantly influence the strength and location of the jet streaks (thermal wind)

• The tropopause fold associated with the UTF gives high PV stratospheric air a pathway into the troposphere

• High PV \rightarrow high vorticity \rightarrow large vorticity advection \rightarrow significant ascent \rightarrow deepening of cyclone
Future Work

• Better understand ULJF systems, specifically LSFs
• How frontogenesis of LSFs influences ULJF systems
• Create a climatology of LSFs during North American winters