Precipitation Processes Associated with Jet-Induced Vertical Circulations

Andrew C. Winters
ATM 409/509
10 November 2016
250-hPa Wind Speed

0000 UTC
7 Nov 2016

Albany, NY

North Pole
250-hPa Wind Speed

0000 UTC 7 Nov 2016

Jet Streams

Albany, NY

NP North Pole
850-hPa Temperature

0000 UTC
7 Nov 2016

Jet Streams
- Albany, NY
- NP North Pole

UW-Madison AOS
Teisserenc de Bort (1902)

Discovery of the stratosphere

Temperature stops decreasing when you get far enough away from the Earth’s surface
Building Blocks to Jet Stream “Discovery”

Bjerknes and Palmén (1937)

Coordinated “swarm ascents” at 18 different locations across Europe.
The front is a **transition zone** across which the temperature gradient is discontinuous.

Note that the tropopause **abruptly lowers** at the location where the polar front intersects the tropopause.

**Reversal** in the sign of the meridional temperature gradient above the tropopause break.
“Discovery” of the Jet Stream

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Carl-Gustaf Rossby – First to refer to the phenomenon as the “jet stream” (1947).
“Discovery” of the Jet Stream

University of Chicago (1947)

One of the first hemispheric examinations of the midlatitude circulation in the literature.

1) A nearly continuous band of strong zonal wind speeds.

2) Sat atop the strongly baroclinic polar front.

3) The jet was nestled squarely in a tropopause break.
How do Jet Streams Impact the Weather?
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Areas where there is an acceleration or deceleration are important for generating clumsiness.
How do Jet Streams Impact the Weather?

- No wind speed
- Slow wind speed
- Fast wind speed
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Areas where the wind is accelerating or decelerating are important for generating weather.
Cross-Stream Vertical Circulations

Cross-stream vertical circulations serve as a dynamical mechanism to maintain thermal wind balance.

Namias and Clapp (1949)
Cross-Stream Vertical Circulations

Only ageostrophic motions can account for the production of convergence and vorticity characteristic of a front.

The Sawyer (1956)–Eliassen (1962) Circulation Equation retains across-front ageostrophic advections of temperature and momentum and provides a way to diagnose the transverse circulations associated with active fronts.
Sawyer–Eliassen Circulation Equation

\[
(\gamma \frac{\partial \theta}{\partial p}) \frac{\partial^2 \psi}{\partial y^2} + (2 \frac{\partial M}{\partial p}) \frac{\partial^2 \psi}{\partial p \partial y} + (- \frac{\partial M}{\partial y}) \frac{\partial^2 \psi}{\partial p^2} = Q_g - \gamma \frac{\partial}{\partial y} \left( \frac{d\theta}{dt} \right)
\]

Where:

\[
\omega = \frac{\partial \psi}{\partial y}, \quad Q_g = 2\gamma \left( \frac{\partial U_g}{\partial y} \frac{\partial \theta}{\partial x} + \frac{\partial V_g}{\partial y} \frac{\partial \theta}{\partial y} \right)
\]

\[
\nu_{age} = -\frac{\partial \psi}{\partial p}
\]

Shearing

Confluence

\(X\)

\(Y\)

\(\Delta z_1'\) \(\Delta z_2'\) \(\Delta z_3'\) \(\Delta z_4'\)
Sawyer–Eliassen Circulation Equation

\[
\left(-\gamma \frac{\partial \theta}{\partial p}\right) \frac{\partial^2 \psi}{\partial y^2} + \left(2 \frac{\partial M}{\partial p}\right) \frac{\partial^2 \psi}{\partial p \partial y} + \left(- \frac{\partial M}{\partial y}\right) \frac{\partial^2 \psi}{\partial p^2} = Q_g - \gamma \frac{\partial}{\partial y} \left(\frac{d\theta}{dt}\right)
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Static Stability
Across-Front Baroclinicity
Horizontal Relative Vorticity

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Shearing
Confluence
Hakim and Keyser (2001)

How does modulating the coefficients to the Sawyer–Eliassen Equation impact the resultant circulation?

\[
\left(-\gamma \frac{\partial \theta}{\partial p}\right) \frac{\partial^2 \psi}{\partial y^2} + \left(2 \frac{\partial M}{\partial p}\right) \frac{\partial^2 \psi}{\partial p \partial y} + \left(-\frac{\partial M}{\partial y}\right) \frac{\partial^2 \psi}{\partial p^2} = Q_g - \gamma \frac{\partial}{\partial y} \left(\frac{d \theta}{dt}\right)
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Sawyer–Eliassen Circulation Equation

\[ (-\gamma \frac{\partial \theta}{\partial p}) \frac{\partial^2 \psi}{\partial y^2} + \left(2 \frac{\partial M}{\partial p}\right) \frac{\partial^2 \psi}{\partial p \partial y} + \left(-\frac{\partial M}{\partial y}\right) \frac{\partial^2 \psi}{\partial p^2} = Q_g - \gamma \frac{\partial}{\partial y} \left(\frac{d\theta}{dt}\right) \]

**Static Stability**

**Across-Front Baroclinicity**

**Horizontal Relative Vorticity**

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\[ Q_g = 2\gamma \left( \frac{\partial U_g}{\partial y} \frac{\partial \theta}{\partial x} + \frac{\partial V_g}{\partial y} \frac{\partial \theta}{\partial y} \right) \]
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\[
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\]

The absence of any along-jet temperature advection returns the traditional four-quadrant model.

Lang and Martin (2012)
Sawyer–Eliassen Circulation Equation

\[
(-\gamma \frac{\partial \theta}{\partial p}) \frac{\partial^2 \psi}{\partial y^2} + (2 \frac{\partial M}{\partial p}) \frac{\partial^2 \psi}{\partial p \partial y} + (- \frac{\partial M}{\partial y}) \frac{\partial^2 \psi}{\partial p^2} = Q_g
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Q_g = 2\gamma \left( \frac{\partial U_g}{\partial y} \frac{\partial \theta}{\partial x} + \frac{\partial V_g}{\partial y} \frac{\partial \theta}{\partial y} \right)
\]

Shearing
Confluence

Along-jet temperature advection acts to “shift” the circulations relative to the jet axis.

Lang and Martin (2012)
Sawyer–Eliassen Circulation Equation

1200 UTC 22 Dec 2013

Geo. CAA in the jet entrance region

Geo. WAA in the jet exit region
Sawyer–Eliassen Circulation Equation

Subsidence is present slightly poleward of the jet core in association with a thermally direct circulation.
Sawyer–Eliassen Circulation Equation

Shearing Term

Confluence Term
Sawyer–Eliassen Circulation Equation

1200 UTC 22 Dec 2013

Geo. CAA in the jet entrance region

Geo. WAA in the jet exit region
Ascent is present slightly poleward of the jet core in association with a thermally indirect circulation.
Sawyer–Eliassen Circulation Equation

Shearing Term

Confluence Term
Case Study: 1–3 May 2010 Nashville Flood

Winters and Martin 2014
Several repeated rounds of rainfall beginning during the early morning hours of 1 May

Record Setting Rainfall: 1–3 May 2010

Select Precip Totals:
Camden, TN: 19.41 in.
Fairview, TN: 18.04 in.
Belle Meade, TN: 17.67 in.
Nashville, TN: 13.57 in.
1–3 May 2010 Nashville Flood

Heavy Impacts on the Area

26 flood related fatalities

~ $2 billion in property damage in the greater Nashville area alone

Record crests of area rivers

80 confirmed tornadoes over the two-day period
Atmospheric river helped to transport anomalously high Precipitable Water values into the eastern US (Moore et al. 2012)

PWAT: 2.02 in. (00Z 5/2/10) Registers well above the 99th percentile for this time of year in Nashville (NOAA)
1–3 May 2010 Nashville Flood

250 hPa Isotachs, Sea Level Pressure, 925 hPa Moisture Flux, POL and STJ, and Surface Frontal boundaries
1–3 May 2010 Nashville Flood

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1 May 2010 – Subtropical Jet Circulation

Streamlines (m hPa s\(^{-1}\))

- negative omega (dPa)
- moisture flux every 3 cm s\(^{-1}\)

Max moisture flux \(~ 5\) cm s\(^{-1}\)
1–3 May 2010 Nashville Flood

250 hPa Isotachs, Sea Level Pressure, 925 hPa Moisture Flux, POL and STJ, and Surface Frontal boundaries
1–3 May 2010 Nashville Flood

2 May 2010 – Superposed Jet Circulation

Streamlines (m hPa s\(^{-1}\))

- negative omega (dPa)
- moisture flux every 3 cm s\(^{-1}\)

Max Moisture Flux ~ 15 cm s\(^{-1}\)
1–3 May 2010 Nashville Flood

00Z 2 May

250 hPa Isotachs, Sea Level Pressure, 925 hPa Moisture Flux, POL and STJ, and Surface Frontal boundaries

Contribution to Moisture Flux
~ 11 cm s\(^{-1}\) (120% increase)
24-h change in poleward moisture flux between 0000 UTC 2 May and 0000 UTC 1 May

Fig. 9. Change in the magnitude of the 925-hPa (a) total, (b) geostrophic, and (c) ageostrophic poleward moisture fluxes over the Southeast United States during the 24-h period from 0000 UTC 1 May to 0000 UTC 2 May. Changes in the moisture flux greater than (less than) 3 \((-3\) cm s\(^{-1}\)) are shaded in the green (red/brown) fill pattern every 3 cm s\(^{-1}\), with 0 cm s\(^{-1}\) contoured in black. The blue (red) dashed line represents the axis of maximum poleward moisture flux at 0000 UTC 1 May (2 May), as indicated in Fig. 7.
1–3 May 2010 Nashville Flood

2 May 2010 – Superposed Jet Circulation

Streamlines (m hPa s$^{-1}$) negative omega (dPa) moisture flux every 3 cm s$^{-1}$

Max Moisture Flux ~ 15 cm s$^{-1}$
1–3 May 2010 Nashville Flood

Streamlines (m hPa s\(^{-1}\))

negative omega (dPa)

moisture flux every 3 cm s\(^{-1}\)
1–3 May 2010 Nashville Flood

Diabatically Forced Circulation

Streamlines (m hPa s⁻¹)

negative omega (dPa)

moisture flux every 3 cm s⁻¹

Diabatic heating (2x10⁻⁴ K s⁻¹)
1–3 May 2010 Nashville Flood

2 May 2010 – Superposed Jet Circulation

Streamlines (m hPa s\(^{-1}\))

negative omega (dPa)
momentum flux every 3 cm s\(^{-1}\)

Max Moisture Flux
~ 15 cm s\(^{-1}\)
1–3 May 2010 Nashville Flood

Shapiro 1982
a) Geostrophic Circ.

Shapiro 1982

Diabatic Circ.

Shapiro 1982
Cross Stream Vertical Circulations

Impacts of Transverse Circulations on the Production of Sensible Weather

– **Severe Weather Outbreaks**
  (e.g., Omoto 1965; Uccellini and Johnson 1979; Hobbs et al. 1990; Martin et al. 1993)

– **Cyclogenesis**
  (e.g., Uccellini et al. 1984; Uccellini et al. 1985; Uccellini and Kocin 1987; Whitaker et al. 1988; Barnes and Colman 1993; Lackmann et al. 1997)

– **Moisture Transport**
  (e.g., Uccellini and Johnson 1979; Uccellini et al. 1984; Uccellini and Kocin 1987; Winters and Martin 2014)
References


References


