Transverse Jet Circulations and their Impact on the Production of Sensible Weather

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Learning Objectives

1) What are the characteristics of the Jet Stream?

1) How was the Jet Stream “discovered”?

1) How do transverse jet circulations impact the production of sensible weather?
250-hPa Wind Speed

0000 UTC
6 Feb 2017

State College, PA

North Pole

UW-Madison AOS
250-hPa Wind Speed

0000 UTC
6 Feb 2017

Jet Stream
State College, PA
NP North Pole
850-hPa Temperature

0000 UTC
6 Feb 2017

Jet Stream

State College, PA
North Pole
Building Blocks to Jet Stream “Discovery”

Coxwell and Glaischer (1862)

The Flight of a Lifetime!

Manned balloon ascent to ~29000 feet.

Illustrated London News
Teisserenc de Bort (1902)

Discovery of the stratosphere

Temperature stops decreasing at a particular distance above the Earth’s surface.
Building Blocks to Jet Stream “Discovery”

Bjerknes and Palmén (1937)

Coordinated “swarm ascents” at 18 different locations across Europe.
Building Blocks to Jet Stream “Discovery”

Bjerknes and Palmén (1937)
The front is a transition zone across which the temperature gradient is discontinuous.
• The front is a **transition zone** across which the temperature gradient is discontinuous.

• The tropopause **abruptly lowers** at the location where the polar front intersects the tropopause.
• The front is a transition zone across which the temperature gradient is discontinuous.

• The tropopause abruptly lowers at the location where the polar front intersects the tropopause.

• The meridional temperature gradient reverses directly above the tropopause break.
“Discovery” of the Jet Stream

Reid Bryson and Bill Plumley – Weather Officers in the Pacific during World War II (1944) (Bryson 1994).
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Heinrich Seilkopf – “die Strahlströmung”, Which translates to “jet flow” (1939) (Reiter 1963, p. 3).
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Wasaburo Ooishi – observed and documented large climatological wind speeds over Japan (1926).
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Wasaburo Ooishi – observed and documented large climatological wind speeds over Japan (1926).

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.

1) The jet was characterized by a nearly continuous band of strong zonal wind speeds.

2) The jet 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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How do Jet Streams Impact the Weather?

Areas where you accelerate or decelerate with respect to the walkway are important for generating clumsiness.
250-hPa Wind Speed

0000 UTC
6 Feb 2017

State College, PA
North Pole

UW-Madison AOS
How do Jet Streams Impact the Weather?

250-hPa

No wind speed
Slow wind speed
Fast wind speed

Wind Vectors
How do Jet Streams Impact the Weather?

250-hPa

No wind speed
Slow wind speed
Fast wind speed

Wind Vectors
How do Jet Streams Impact the Weather?

Areas where the wind accelerates or decelerates are important for generating weather.
How do Jet Streams Impact the Weather?

\[ \frac{k}{f} \times \frac{d\vec{V}}{dt} = \vec{V}_{ag} \]
How do Jet Streams Impact the Weather?

\[ \frac{k}{f} \times \frac{d\vec{V}}{dt} = \vec{V}_{ag} \]

- No wind speed
- Slow wind speed
- Fast wind speed
- Wind Vectors
How do Jet Streams Impact the Weather?

\[ \frac{k}{f} \times \frac{d\vec{V}}{dt} = \vec{V}_{ag} \]

Wind Vectors

- No wind speed
- Slow wind speed
- Fast wind speed
How do Jet Streams Impact the Weather?

\[ \frac{k}{f} \times \frac{d\vec{V}}{dt} = \vec{V}_{ag} \]

- No wind speed
- Slow wind speed
- Fast wind speed

Wind Vectors
How do Jet Streams Impact the Weather?

250-hPa

No wind speed
Slow wind speed
Fast wind speed

Wind Vectors

\[
\vec{V} = \frac{k}{f} \cdot \frac{d\vec{V}}{dt}
\]

\(\vec{V}_{ag}\)
How do Jet Streams Impact the Weather?

\[
\frac{k}{f} \cdot \frac{d\vec{V}}{dt} = \vec{V}_{ag}
\]

- No wind speed
- Slow wind speed
- Fast wind speed

Wind Vectors

CONV
DIV
ENTRANCE
EXIT

250-hPa

CONV
DIV

No wind speed
Slow wind speed
Fast wind speed
Wind Vectors
How do Jet Streams Impact the Weather?

250-hPa

SINKING

ENTRANCE

RISING

EXIT

No wind speed
Slow wind speed
Fast wind speed

Wind Vectors

\[ \frac{k}{f} \times \frac{d\vec{V}}{dt} = \vec{V}_{ag} \]
How do Jet Streams Impact the Weather?

Areas where the wind accelerates or decelerates are important for generating weather.

No wind speed
Slow wind speed
Fast wind speed
Wind Vectors

250-hPa

SINKING

ENTRANCE

EXIT
Transverse Jet Circulations

The Sawyer (1956)–Eliassen (1962) Circulation Equation provides a way to diagnose the transverse circulations associated with active fronts.
Sawyer–Eliassen Circulation Equation

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

Where:

\[
\omega = \frac{\partial \psi}{\partial y}
\]

\[
\nu_{age} = -\frac{\partial \psi}{\partial p}
\]
Sawyer–Eliassen Circulation Equation

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

Where:

\[\omega = \frac{\partial \psi}{\partial y}\]
\[\nu_{age} = -\frac{\partial \psi}{\partial p}\]
Sawyer–Eliassen Circulation Equation

Uccellini and Kocin (1987)
Sawyer–Eliassen Circulation Equation

\[
(-\gamma \frac{\partial \theta}{\partial p}) \frac{\partial^2 \psi}{\partial y^2} + (2\gamma \frac{\partial \theta}{\partial y}) \frac{\partial^2 \psi}{\partial p \partial y} + (- \frac{\partial u_g}{\partial y} + f) \frac{\partial^2 \psi}{\partial p^2} = Q_g - \gamma \frac{\partial}{\partial y} \left( \frac{d\theta}{dt} \right)
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Where:

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\omega = \frac{\partial \psi}{\partial y}
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Sawyer–Eliassen Circulation Equation

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

Static Stability

Where:

\[\omega = \frac{\partial \psi}{\partial y}\]

\[\nu_{age} = -\frac{\partial \psi}{\partial p}\]
Sawyer–Eliassen Circulation Equation

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

Static Stability
Across-Front Baroclinicity

Where:

\[
\omega = \frac{\partial \psi}{\partial y}
\]

\[
v_{age} = -\frac{\partial \psi}{\partial p}
\]
Sawyer–Eliassen Circulation Equation

\[
\begin{align*}
(-\gamma \frac{\partial \theta}{\partial p}) \frac{\partial^2 \psi}{\partial y^2} + (2\gamma \frac{\partial \theta}{\partial y}) \frac{\partial^2 \psi}{\partial p \partial y} + (-\frac{\partial u_g}{\partial y} + f) \frac{\partial^2 \psi}{\partial p^2} &= Q_g - \gamma \frac{\partial}{\partial y} \left( \frac{d\theta}{dt} \right)
\end{align*}
\]

Static Stability
Across-Front Baroclinicity
Horizontal Absolute Vorticity

Where:

\[
\omega = \frac{\partial \psi}{\partial y}
\]

\[
\nu_{age} = -\frac{\partial \psi}{\partial p}
\]
Sawyer–Eliassen Circulation Equation

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

Static Stability
Across-Front Baroclinicity
Horizontal Absolute Vorticity

Where:

\[
\omega = \frac{\partial \psi}{\partial y}
\]

\[
\nu_{age} = -\frac{\partial \psi}{\partial p}
\]
Hakim and Keyser (2001)

How do the coefficients of the Sawyer–Eliassen Equation modulate the resultant circulation?

\[
\begin{align*}
\left(-\gamma \frac{\partial \theta}{\partial p}\right) \frac{\partial^2 \psi}{\partial y^2} + \left(2\gamma \frac{\partial \theta}{\partial y}\right) \frac{\partial ^2 \psi}{\partial p \partial y} + \left(-\frac{\partial u_g}{\partial y} + f\right) \frac{\partial^2 \psi}{\partial p^2} &= Q_g - \gamma \frac{\partial}{\partial y} \left(\frac{d \theta}{dt}\right)
\end{align*}
\]
Sawyer–Eliassen Circulation Equation

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

Static Stability
Across-Front Baroclinicity
Horizontal Absolute Vorticity

Where:
\[
\omega = \frac{\partial \psi}{\partial y} \quad Q_g = 2\gamma \left( \frac{\partial U_g}{\partial y} \frac{\partial \theta}{\partial x} + \frac{\partial V_g}{\partial y} \frac{\partial \theta}{\partial y} \right)
\]
\[
v_{age} = -\frac{\partial \psi}{\partial p}
\]

Shearing
Confluence

Geostrophic and Diabatic Forcing

Frontal Characteristics

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

\[
(-\gamma \frac{\partial \theta}{\partial p}) \frac{\partial^2 \psi}{\partial y^2} + (2\gamma \frac{\partial \theta}{\partial y}) \frac{\partial^2 \psi}{\partial p \partial y} + (- \frac{\partial u_g}{\partial y} + f) \frac{\partial^2 \psi}{\partial p^2} = Q_g - \gamma \frac{\partial}{\partial y} \left( \frac{\partial \theta}{\partial t} \right)
\]

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

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

\[
Q_g = 2\gamma \left( \frac{\partial U_g}{\partial y} \frac{\partial \theta}{\partial x} + \frac{\partial V_g}{\partial y} \frac{\partial \theta}{\partial y} \right)
\]
The absence of any along-jet temperature advection returns the traditional four-quadrant model.
Sawyer–Eliassen Circulation Equation

\[
(-\gamma \frac{\partial \theta}{\partial p}) \frac{\partial^2 \psi}{\partial y^2} + (2\gamma \frac{\partial \theta}{\partial y}) \frac{\partial^2 \psi}{\partial p \partial y} + (-\frac{\partial u_g}{\partial y} + f) \frac{\partial^2 \psi}{\partial p^2} = Q_g
\]

No Temp. Advection

Geo. CAA

Geo. WAA

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

Lang and Martin (2012)
Sawyer–Eliassen Circulation Equation

Geo. CAA in the jet entrance region

Geo. WAA in the jet exit region
The result is a thermally direct circulation.

**Subsidence** is present slightly poleward of the jet core.
Sawyer–Eliassen Circulation Equation

Geo. CAA in the jet entrance region

Geo. WAA in the jet exit region
The result is a thermally indirect circulation.

Ascent is present slightly poleward of the jet core.
How do Jet Streams Impact the Weather?

Impacts of Transverse Jet 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)
How do Jet Streams Impact the Weather?

Impacts of Transverse Jet 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)
How do Jet Streams Impact the Weather?

Impacts of Transverse Jet Circulations on the Production of Sensible Weather

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  (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)
How do Jet Streams Impact the Weather?

1) Severe Weather Outbreaks

Uccellini and Kocin (1987)
How do Jet Streams Impact the Weather?

1) Severe Weather Outbreaks

2) Cyclogenesis

Uccellini and Kocin (1987)
How do Jet Streams Impact the Weather?

1) Severe Weather Outbreaks
2) Cyclogenesis
3) Moisture Transport

Uccellini and Kocin (1987)
References


References


References


