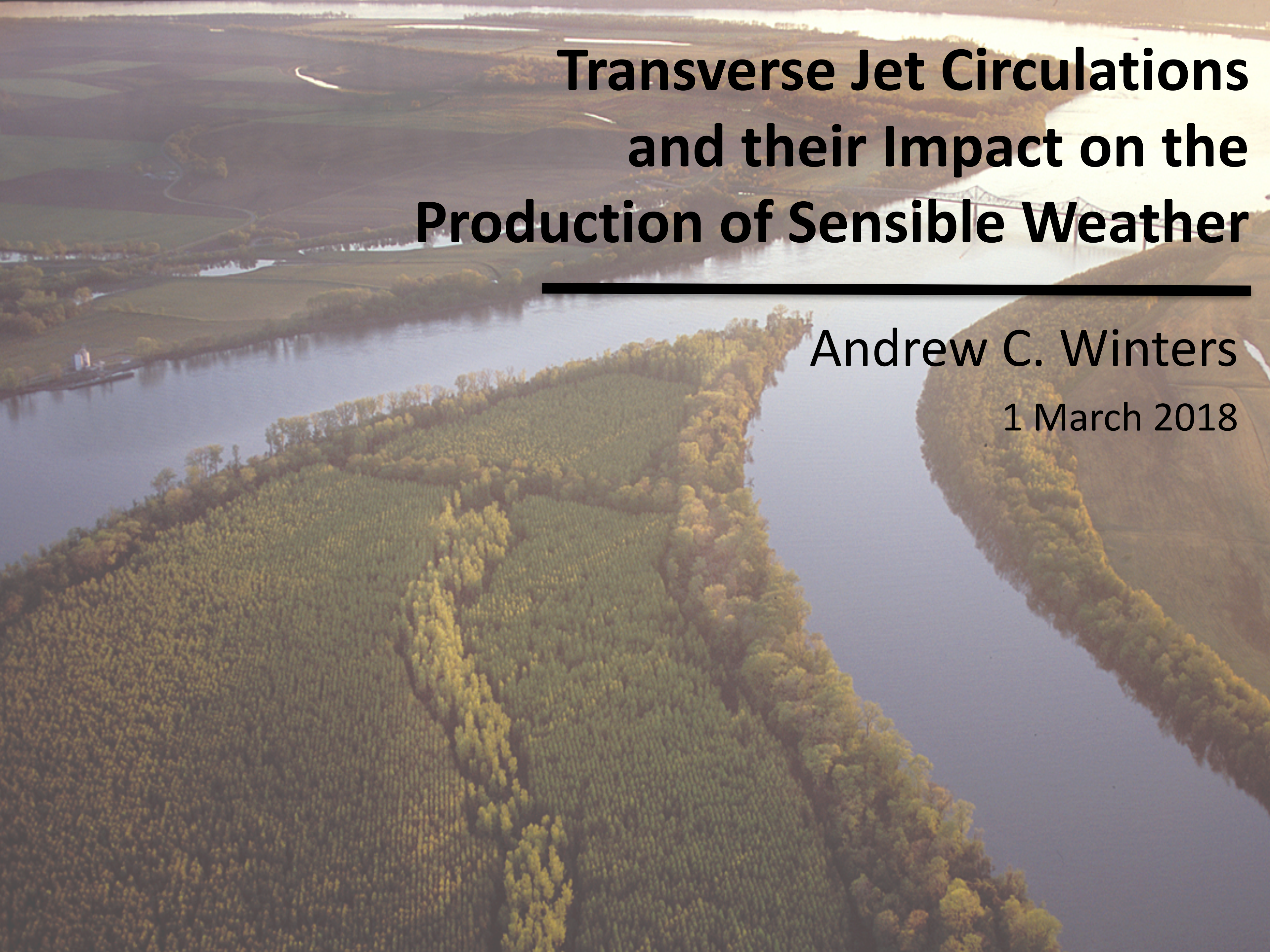

Transverse Jet Circulations and their Impact on the Production of Sensible Weather

Andrew C. Winters

1 March 2018


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Learning Objectives

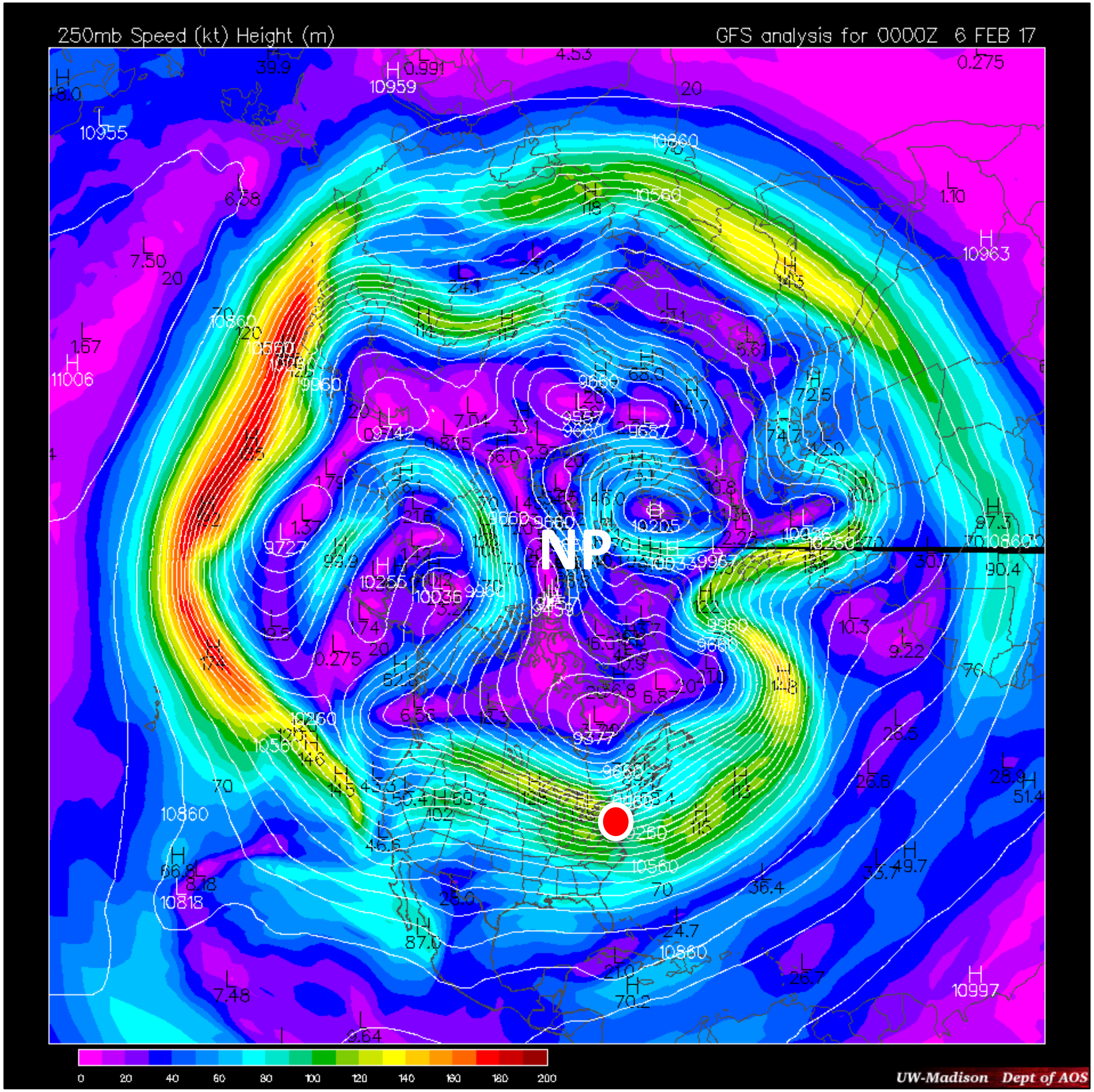
1) What are the characteristics of the Jet Stream?

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



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NP North Pole

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250-hPa Wind Speed

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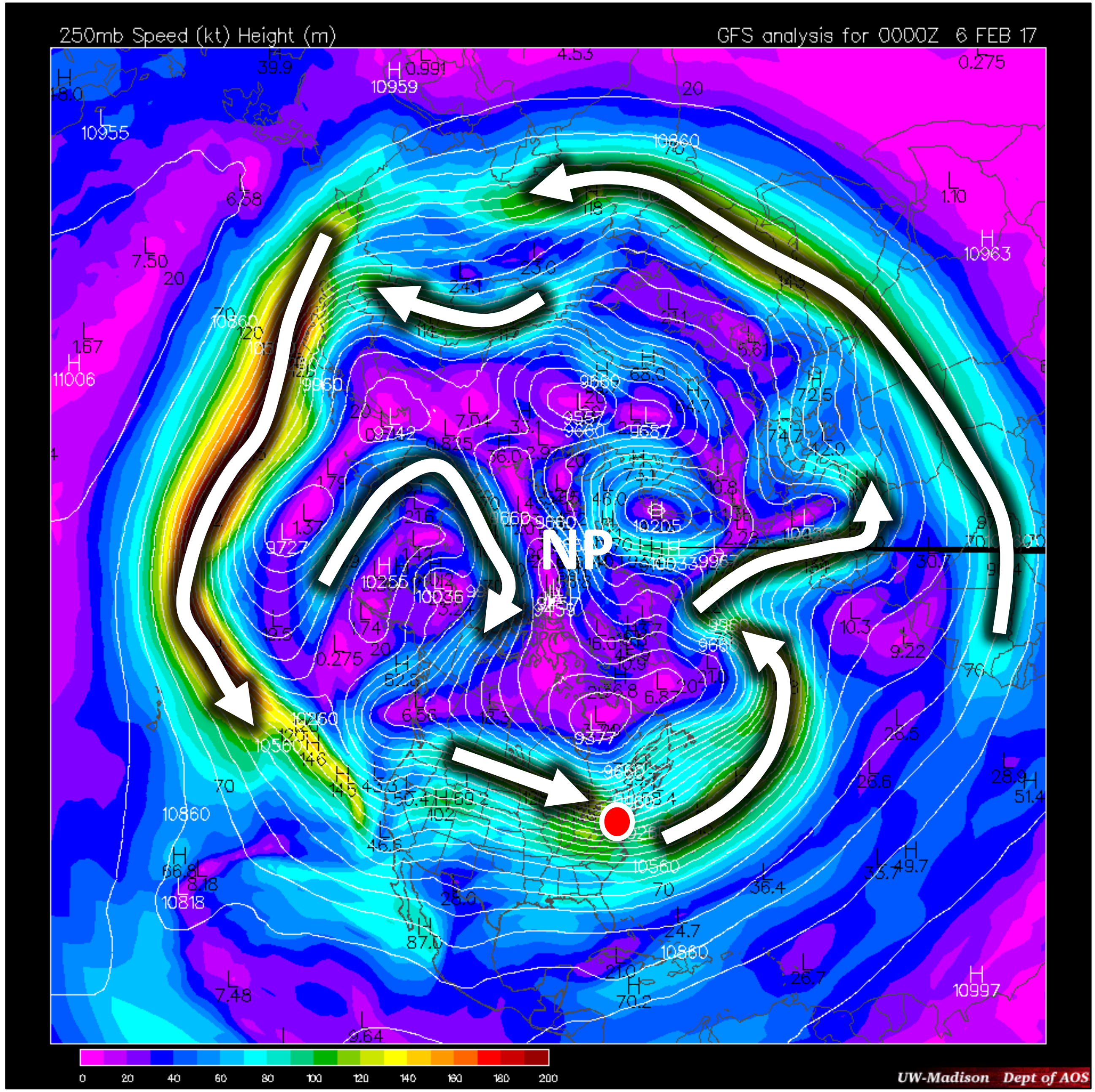

Jet Stream

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850-hPa Temperature

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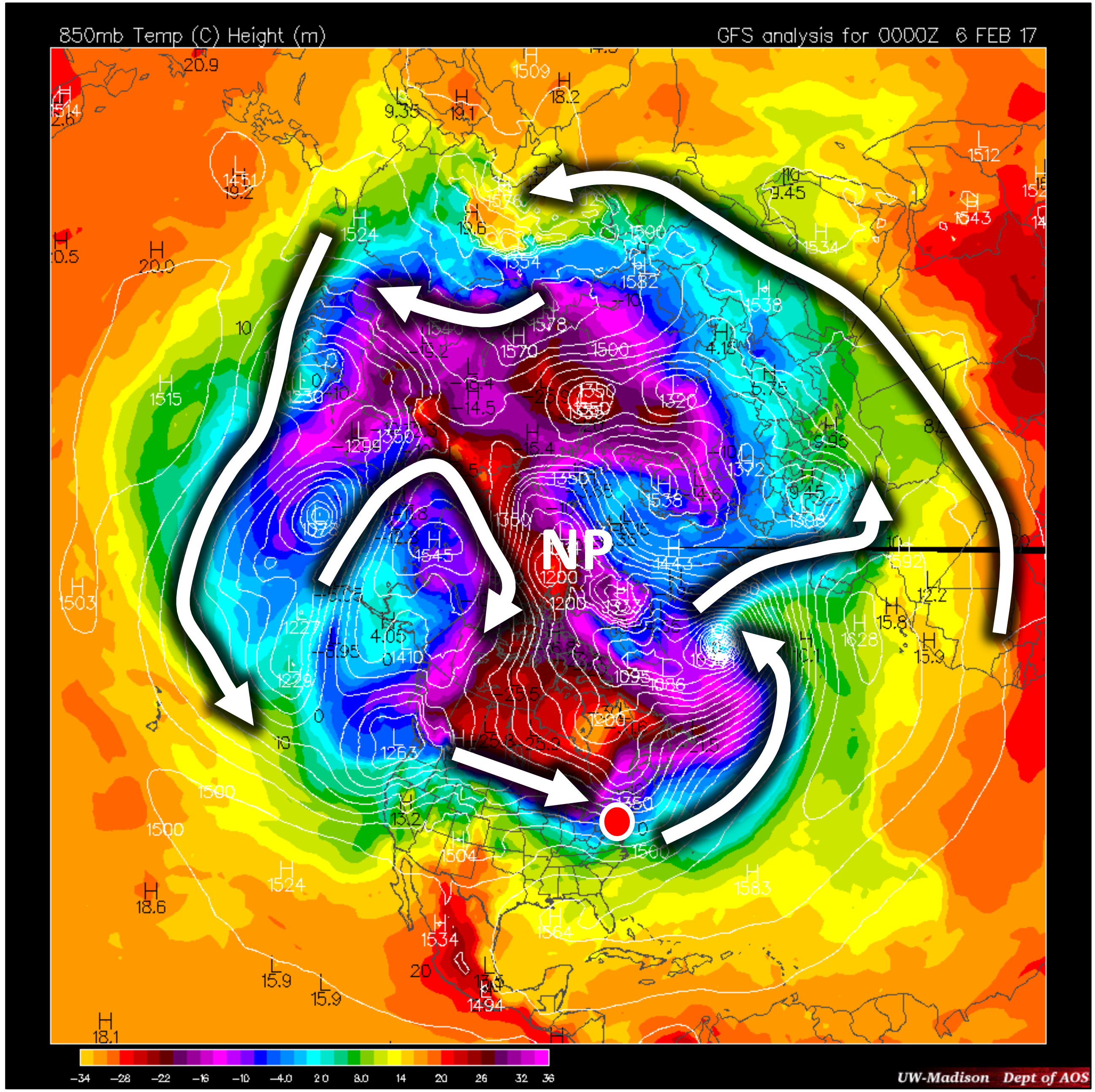

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Tropopause Potential Temperature

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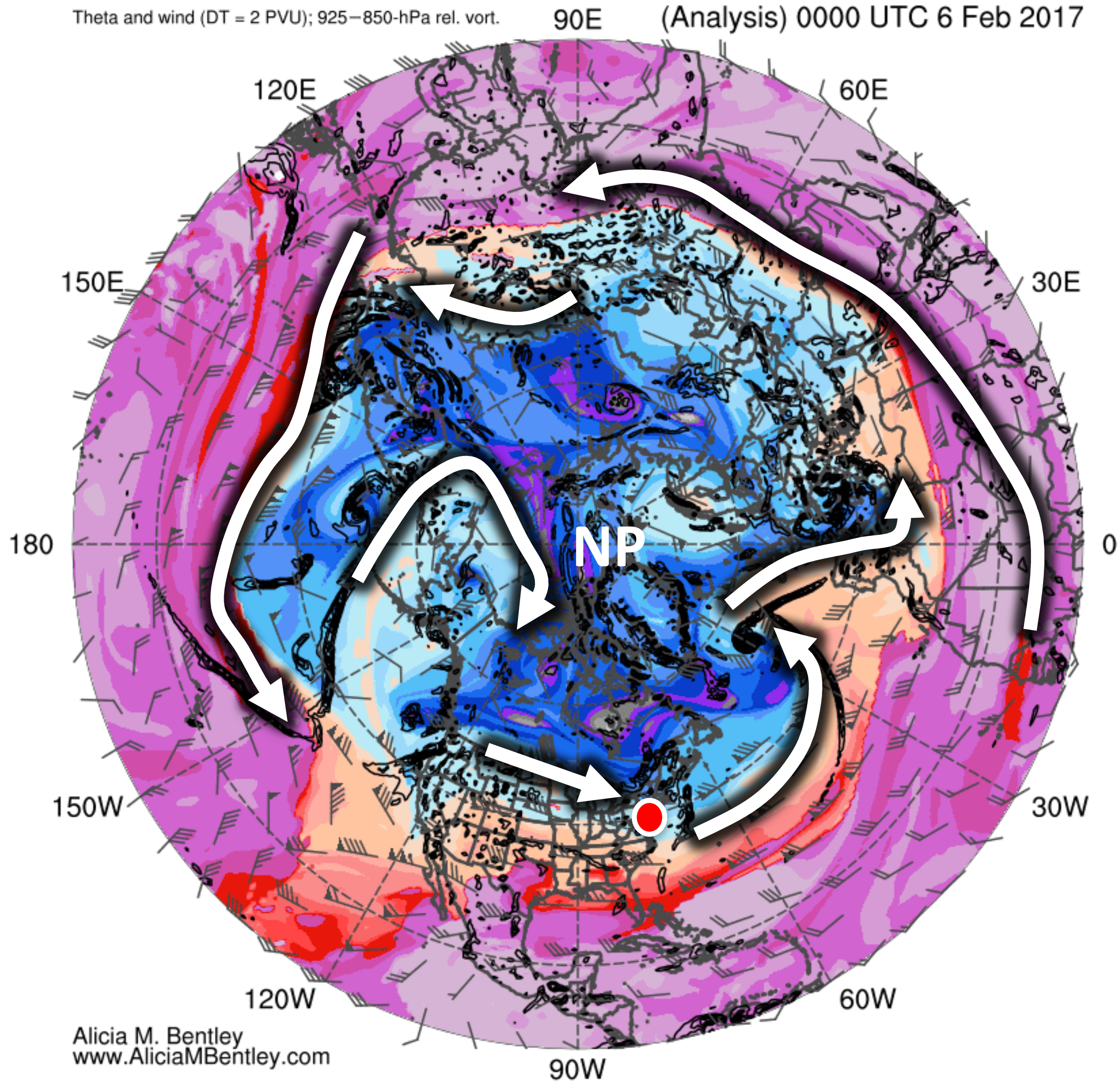

Jet Stream

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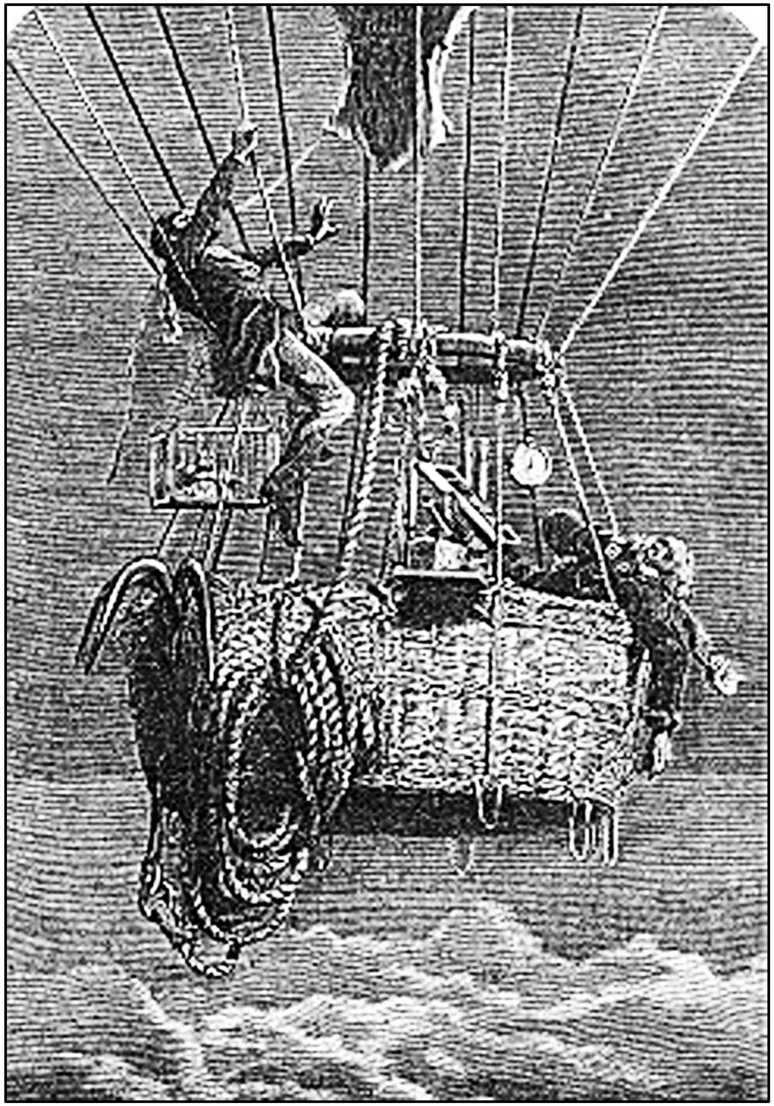
Building Blocks to Jet Stream "Discovery"

Coxwell and Glaischer (1862)

The Flight of a Lifetime!

Manned balloon ascent to ~29000 feet.



Illustrated London News

Building Blocks to Jet Stream "Discovery"

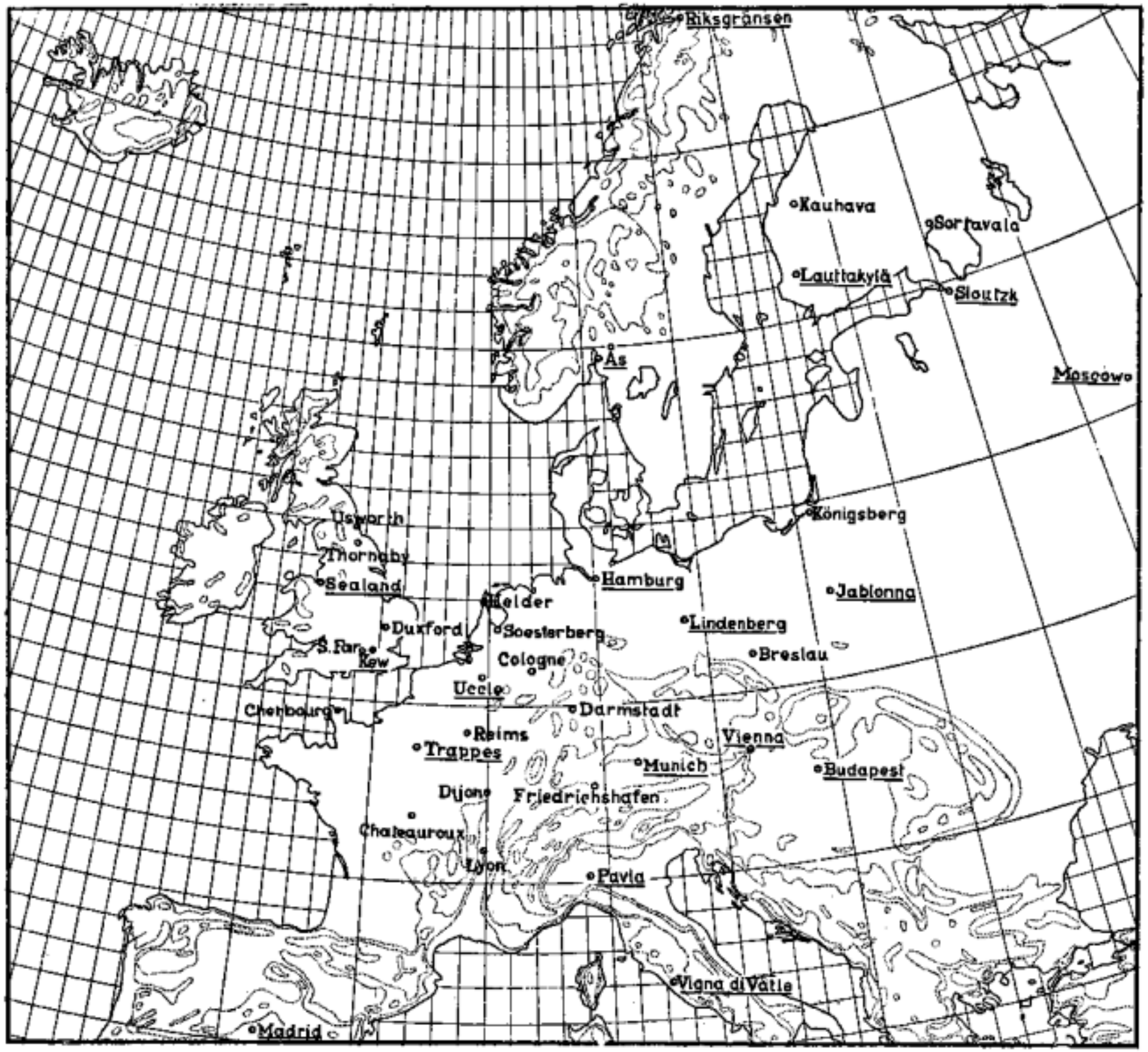
Teisserenc de Bort (1902)

Discovery of the stratosphere

Temperature stops decreasing at a particular distance above the Earth's surface.

Nature

Building Blocks to Jet Stream "Discovery"

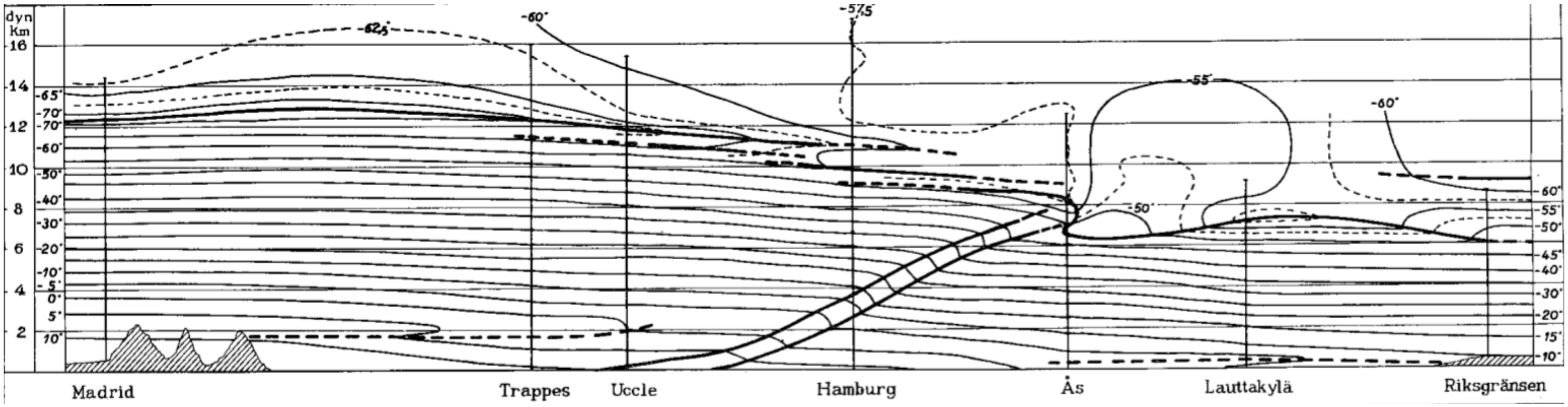


Bjerknes and Palmén (1937)

Coordinated **"swarm ascents"** at 18 different locations across Europe.

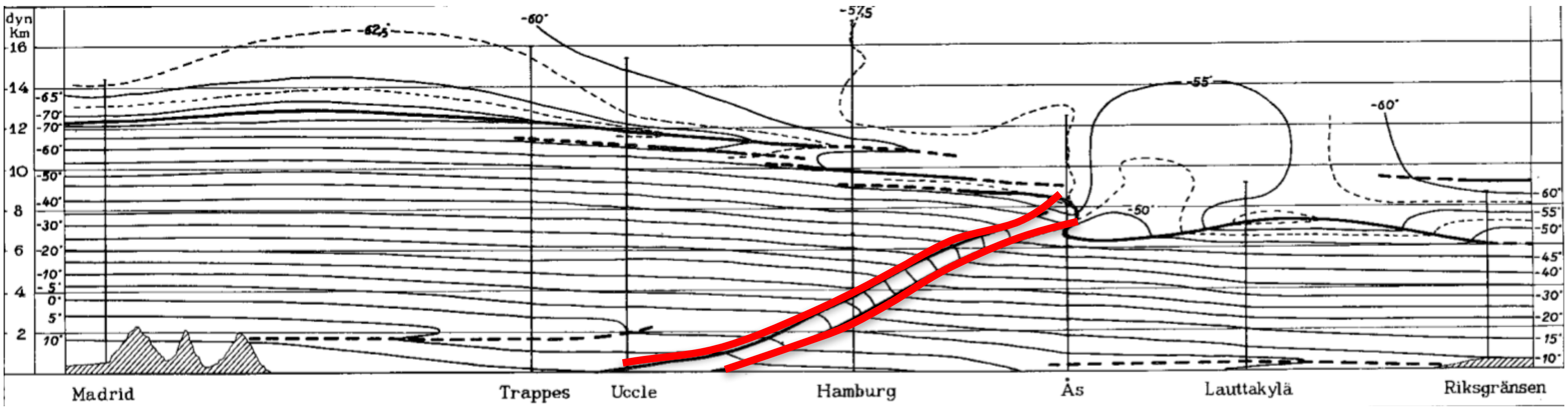
Building Blocks to Jet Stream "Discovery"

Bjerknes and Palmén (1937)



Building Blocks to Jet Stream "Discovery"

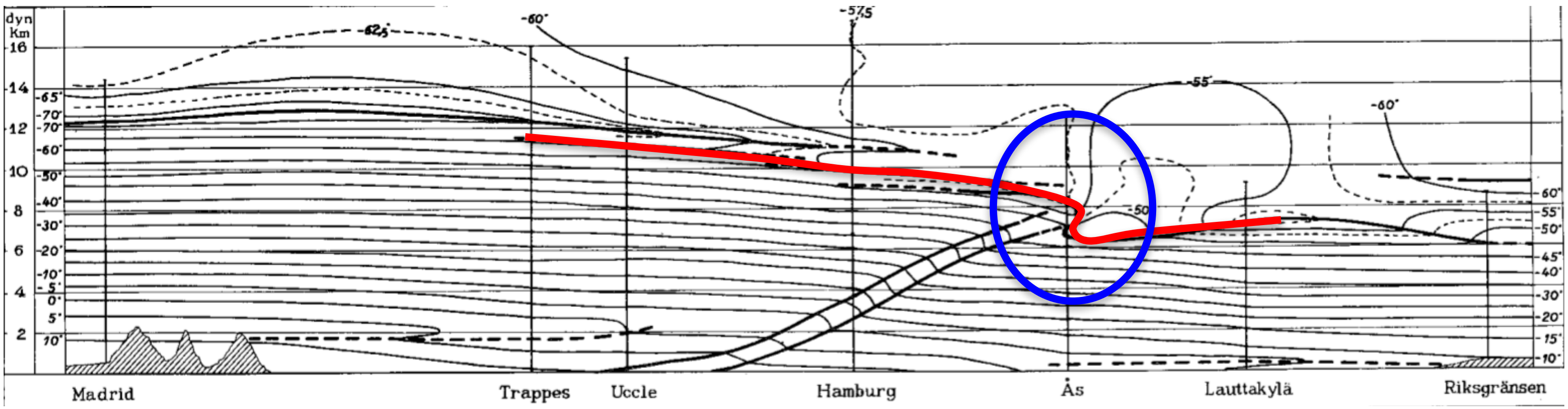
Bjerknes and Palmén (1937)



- The front is a **transition zone** across which the temperature gradient is discontinuous.

Building Blocks to Jet Stream "Discovery"

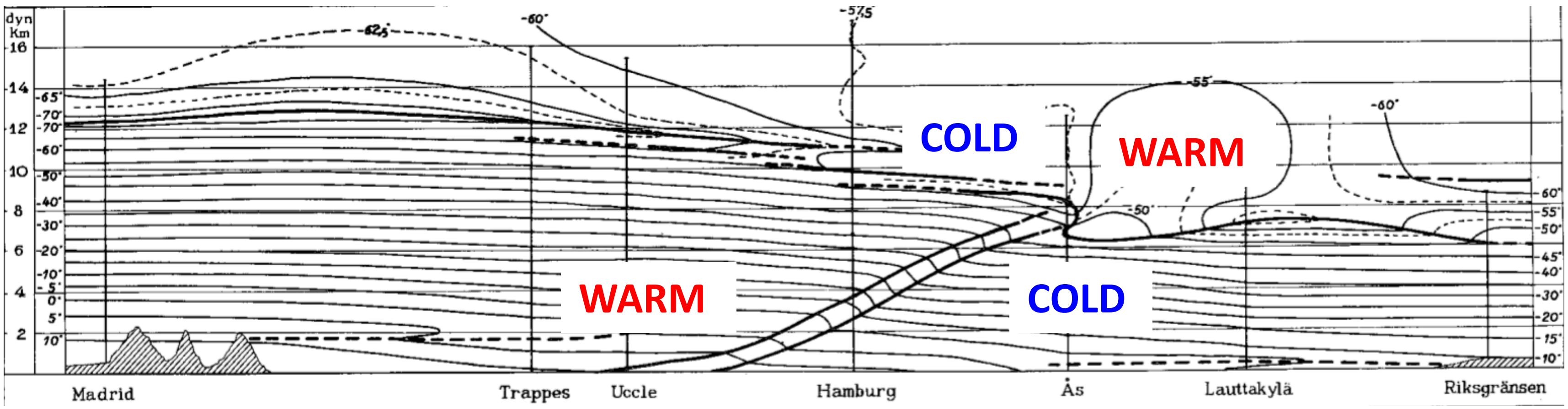
Bjerknes and Palmén (1937)



- 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.

Building Blocks to Jet Stream "Discovery"

Bjerknes and Palmén (1937)



- 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).

CCR

“Discovery” of the Jet Stream

Reid Bryson and Bill Plumley – Weather Officers in the Pacific during World War II (1944) (Bryson 1994).

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).

Cliff Mass

“Discovery” of the Jet Stream

Reid Bryson and Bill Plumley – Weather Officers in the Pacific during World War II (1944) (Bryson 1994).

Heinrich Seilkopf – “die Strahlströmung”, Which translates to “jet flow” (1939) (Reiter 1963, p. 3).

Wasaburo Ooishi – observed and documented large climatological wind speeds over Japan (1926).

MIT

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

"Discovery" of the Jet Stream

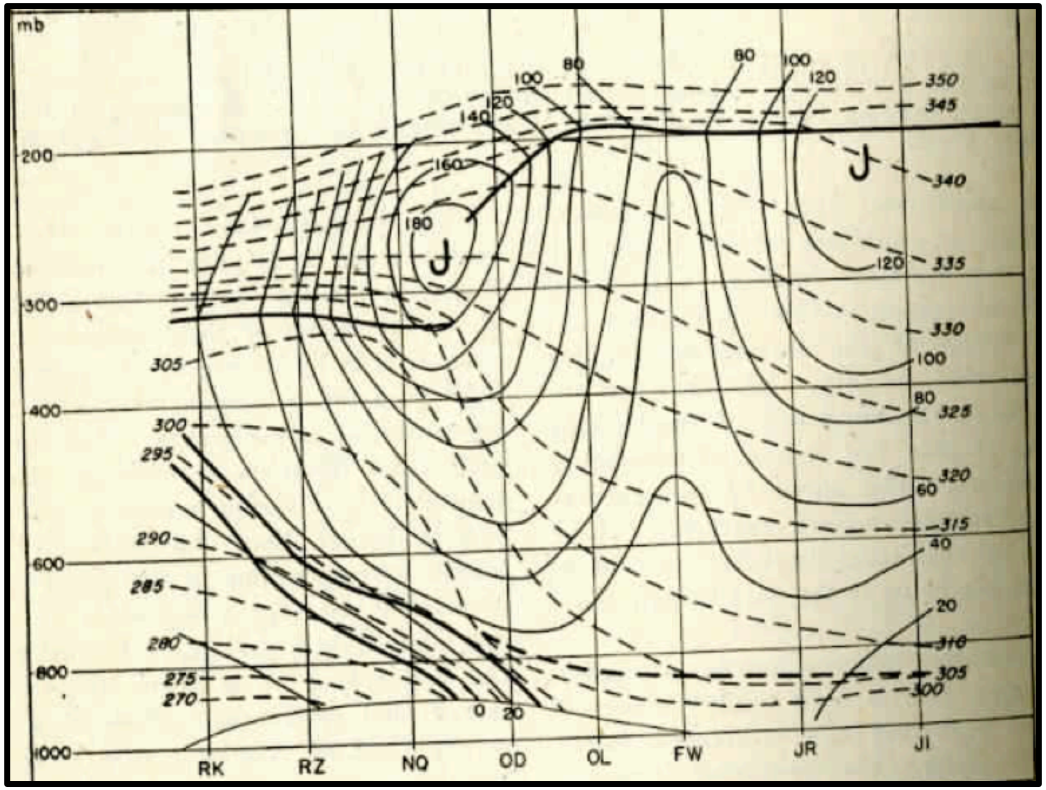
University of Chicago (1947)

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.

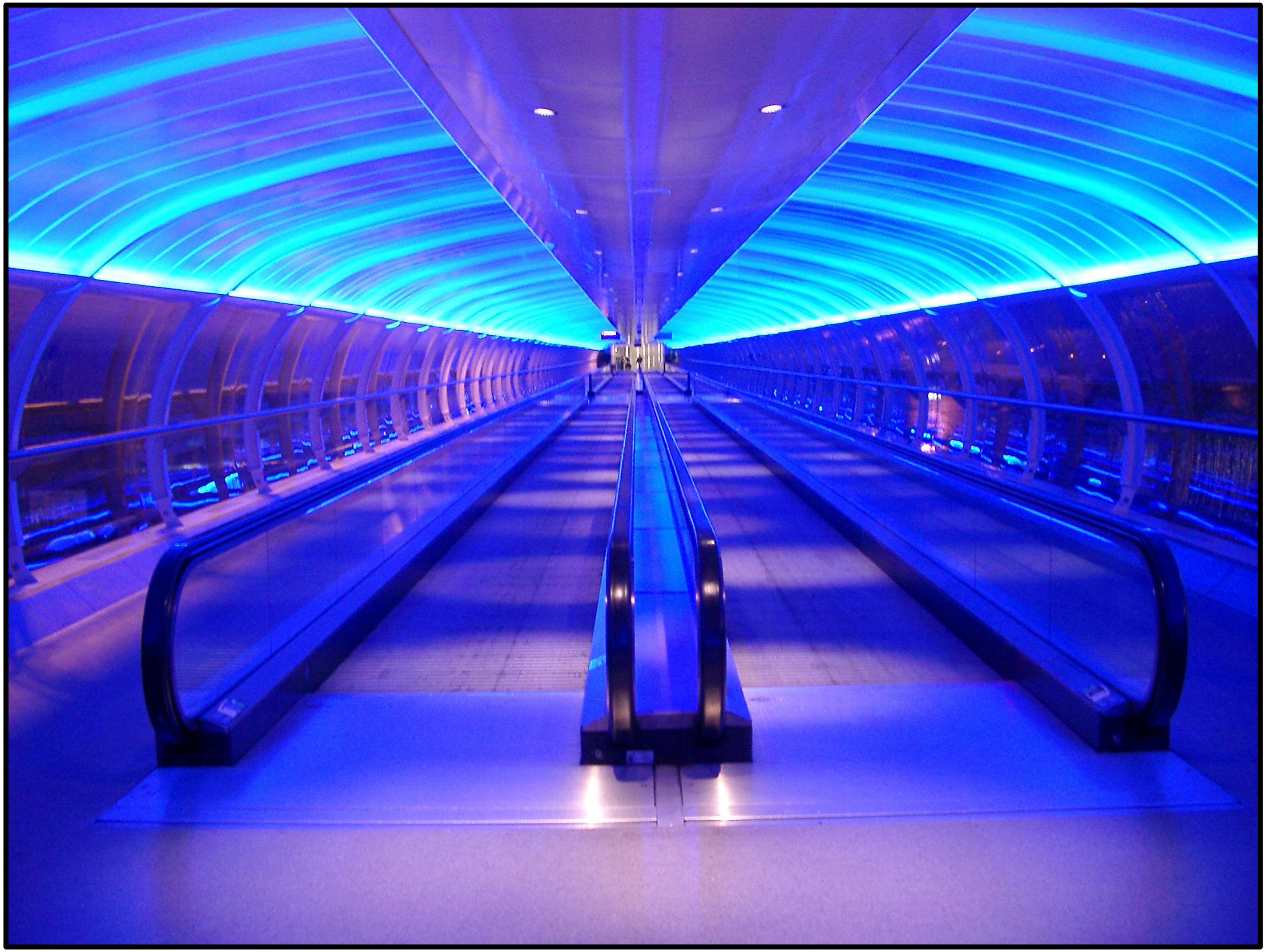
2) The jet sat atop the strongly baroclinic polar front.

3) The jet was nestled squarely in a tropopause break.



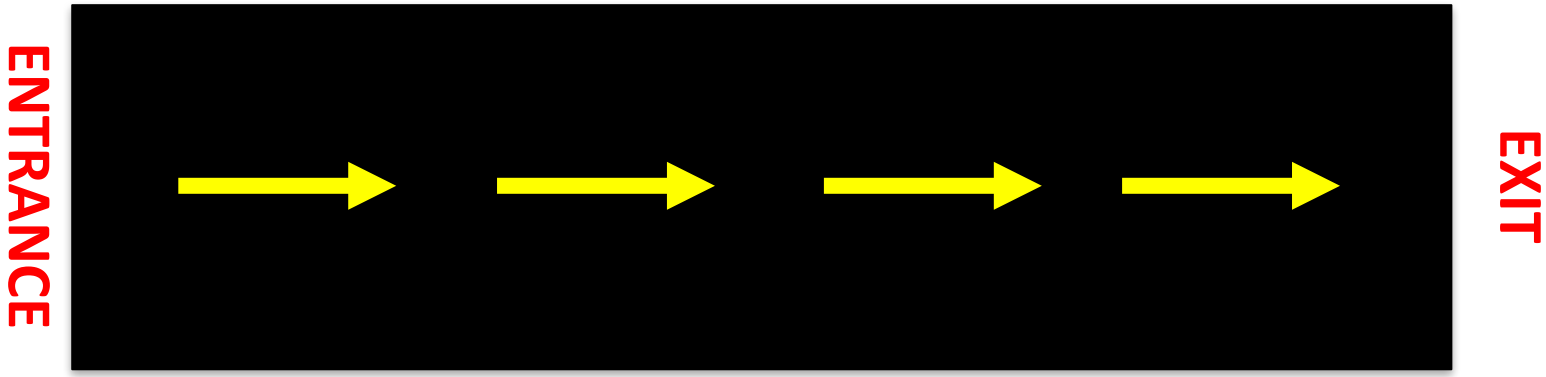
How do Jet Streams Impact the Weather?

How do Jet Streams Impact the Weather?



Photoeverywhere.co.uk

How do Jet Streams Impact the Weather?



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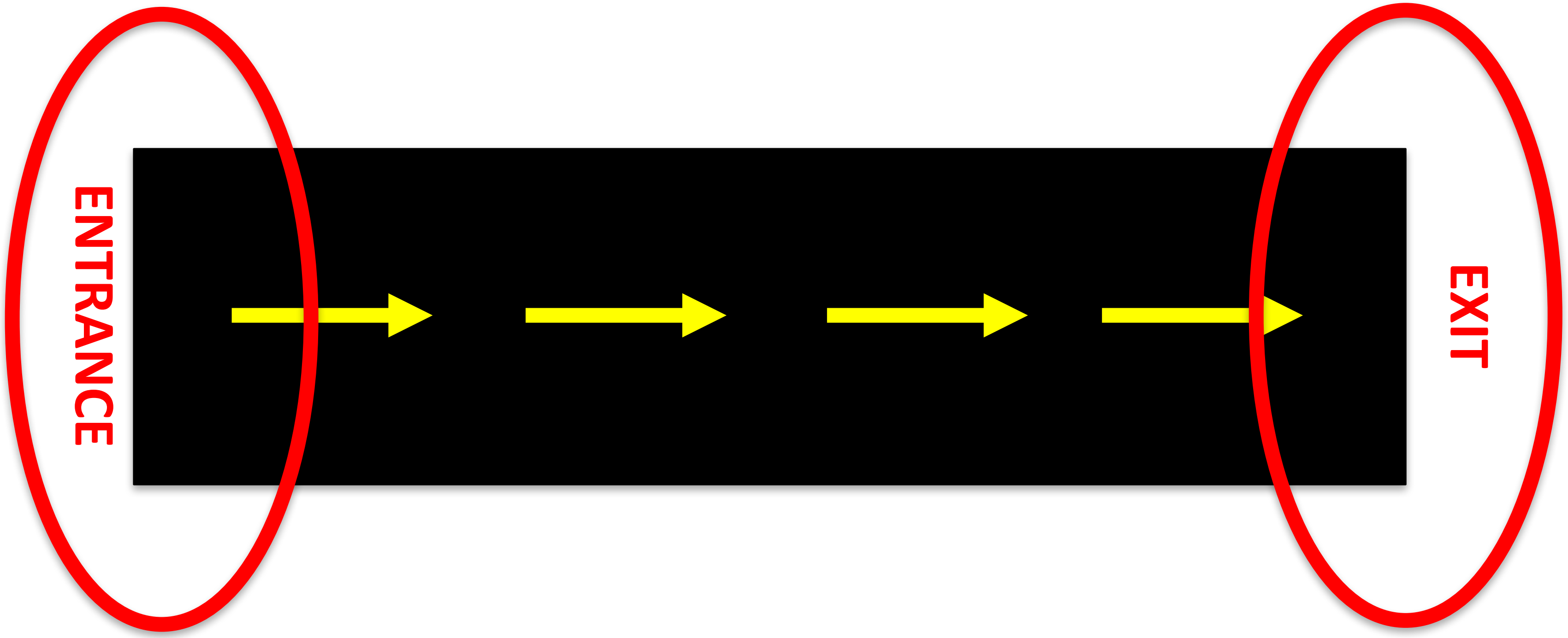
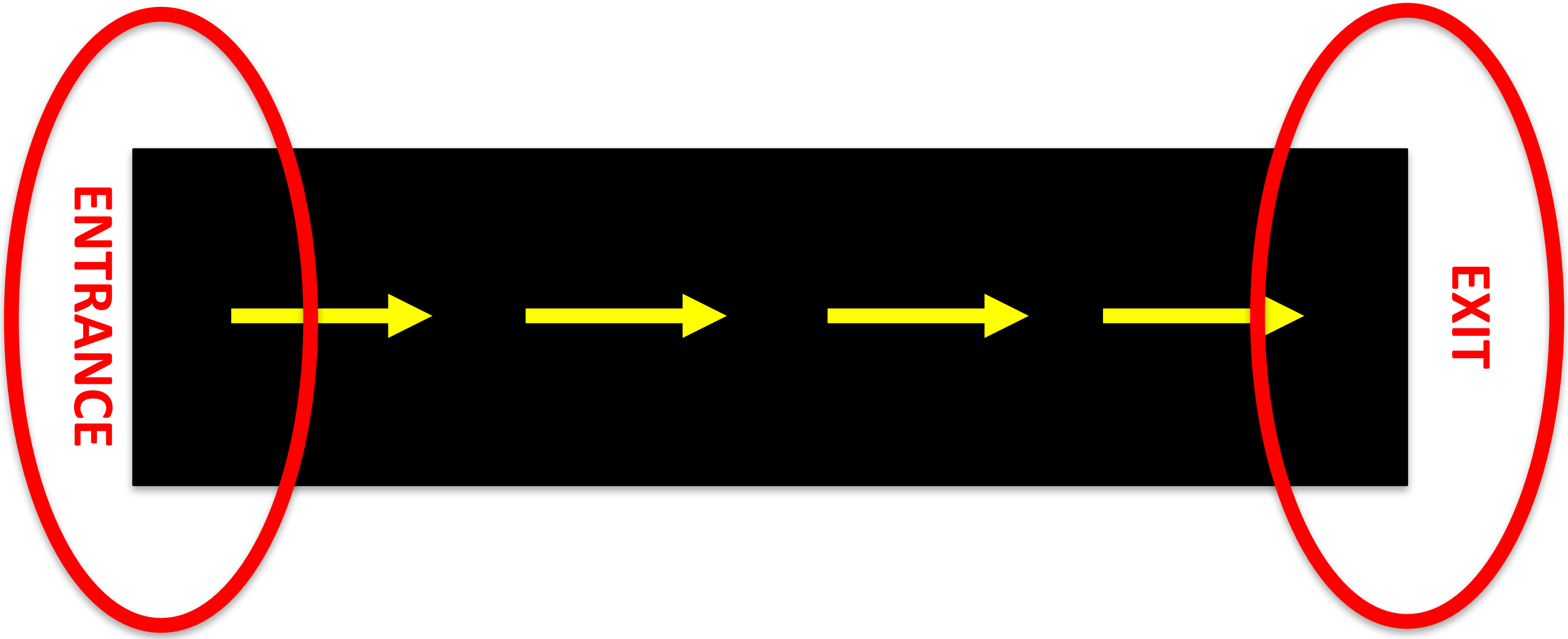
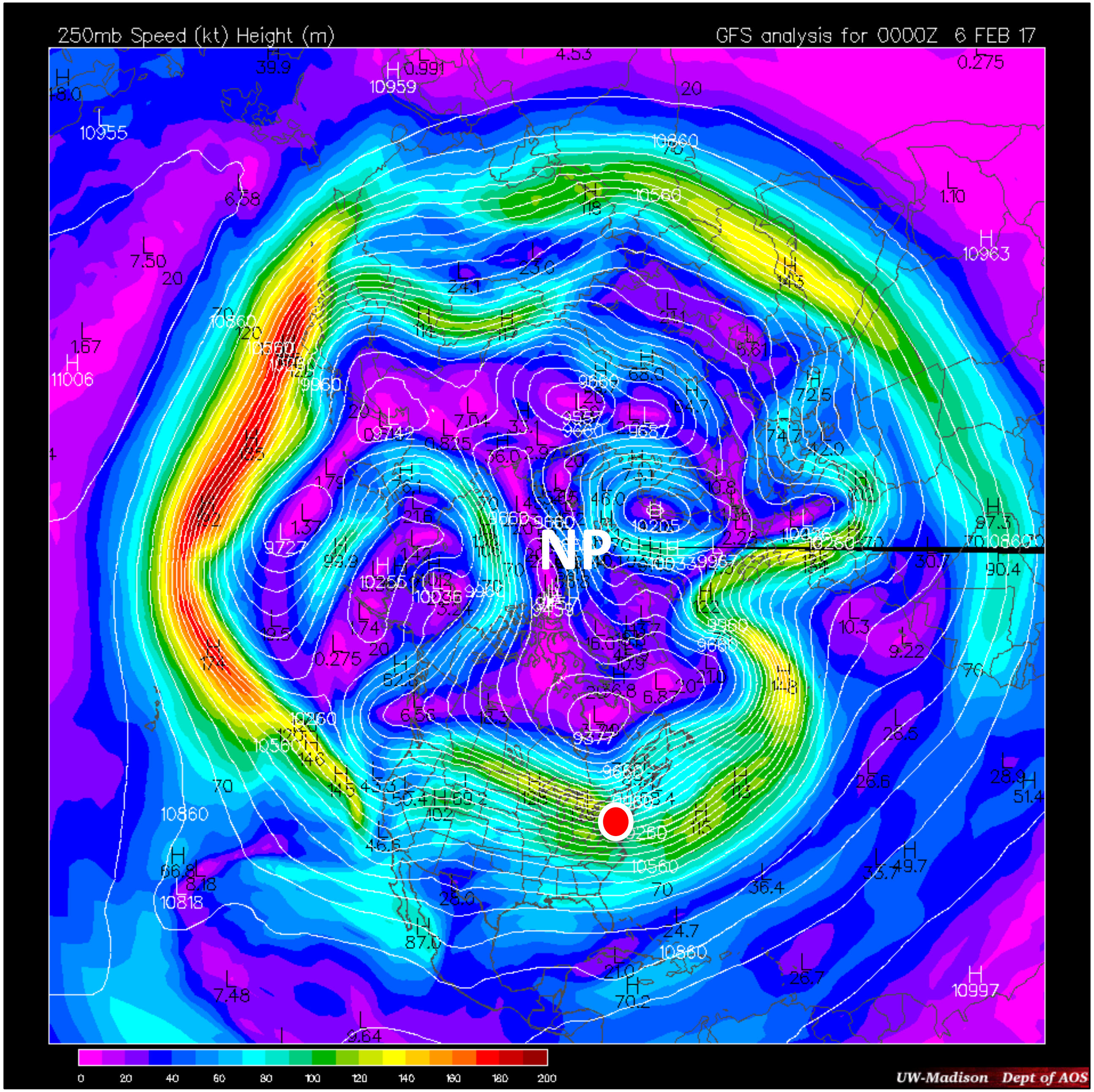


How do Jet Streams Impact the Weather?



Areas where you accelerate or decelerate with respect to the walkway are important for generating clumsiness

250-hPa Wind Speed



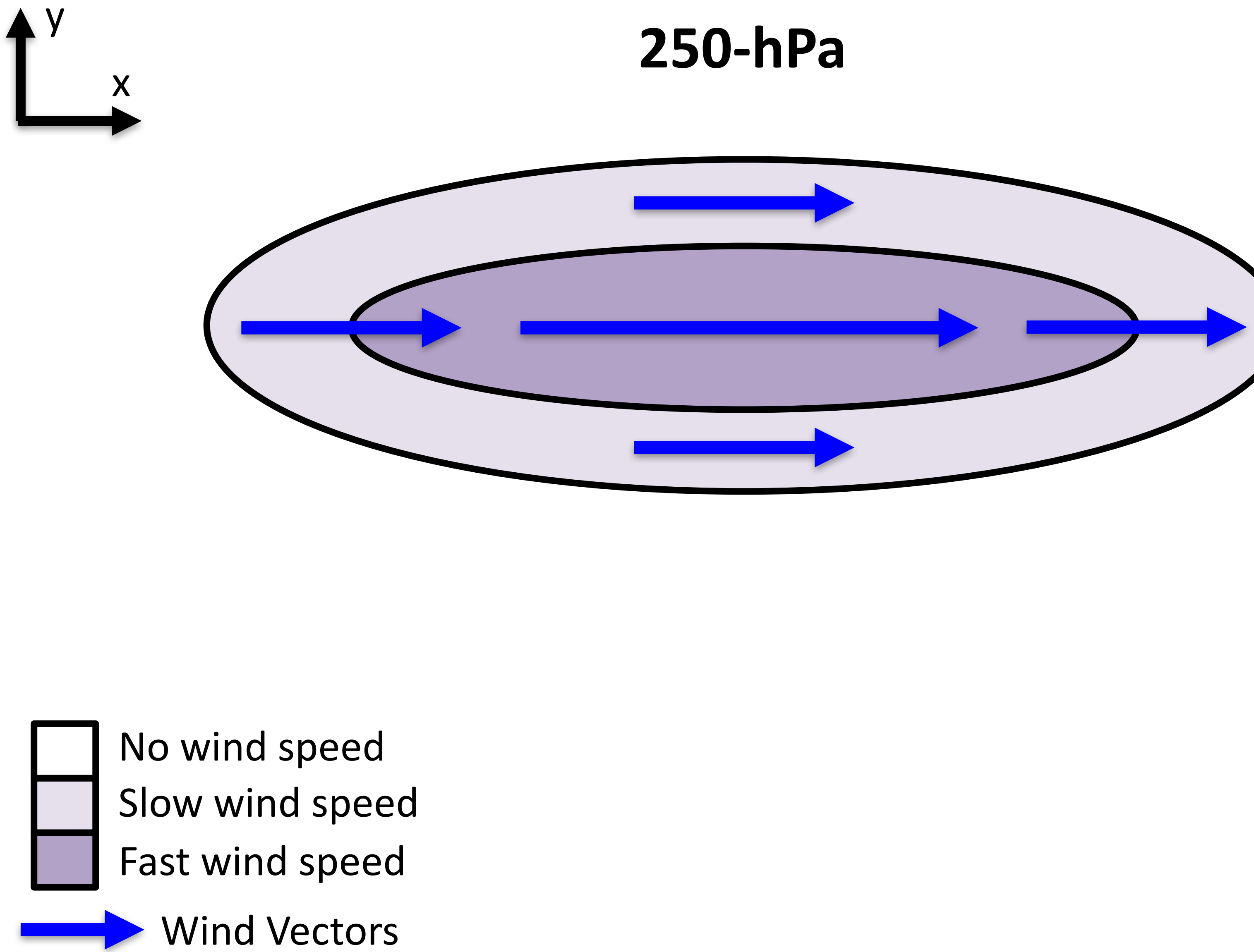
0000 UTC
6 Feb 2017

State College, PA

NP North Pole

UW-Madison AOS

How do Jet Streams Impact the Weather?



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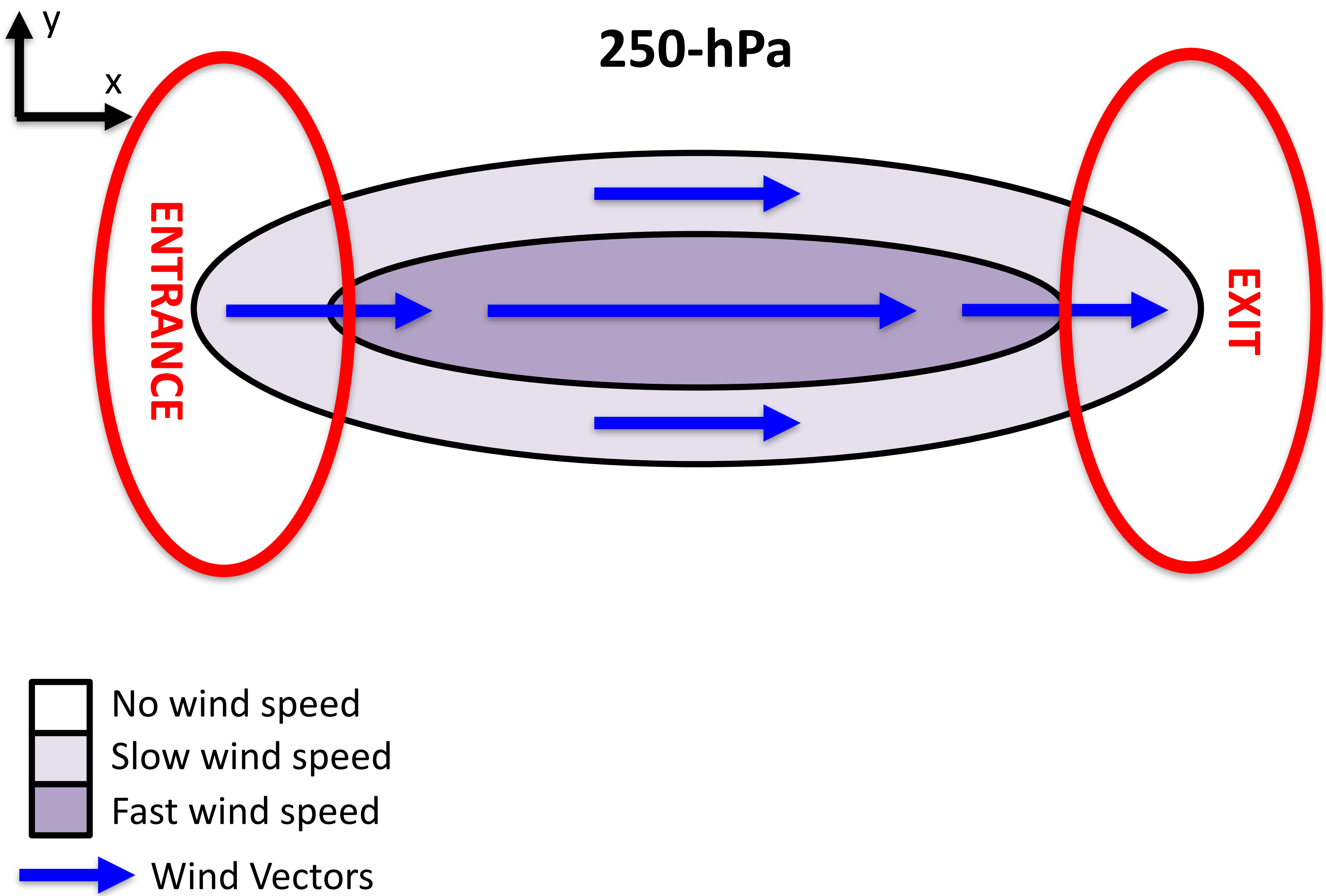

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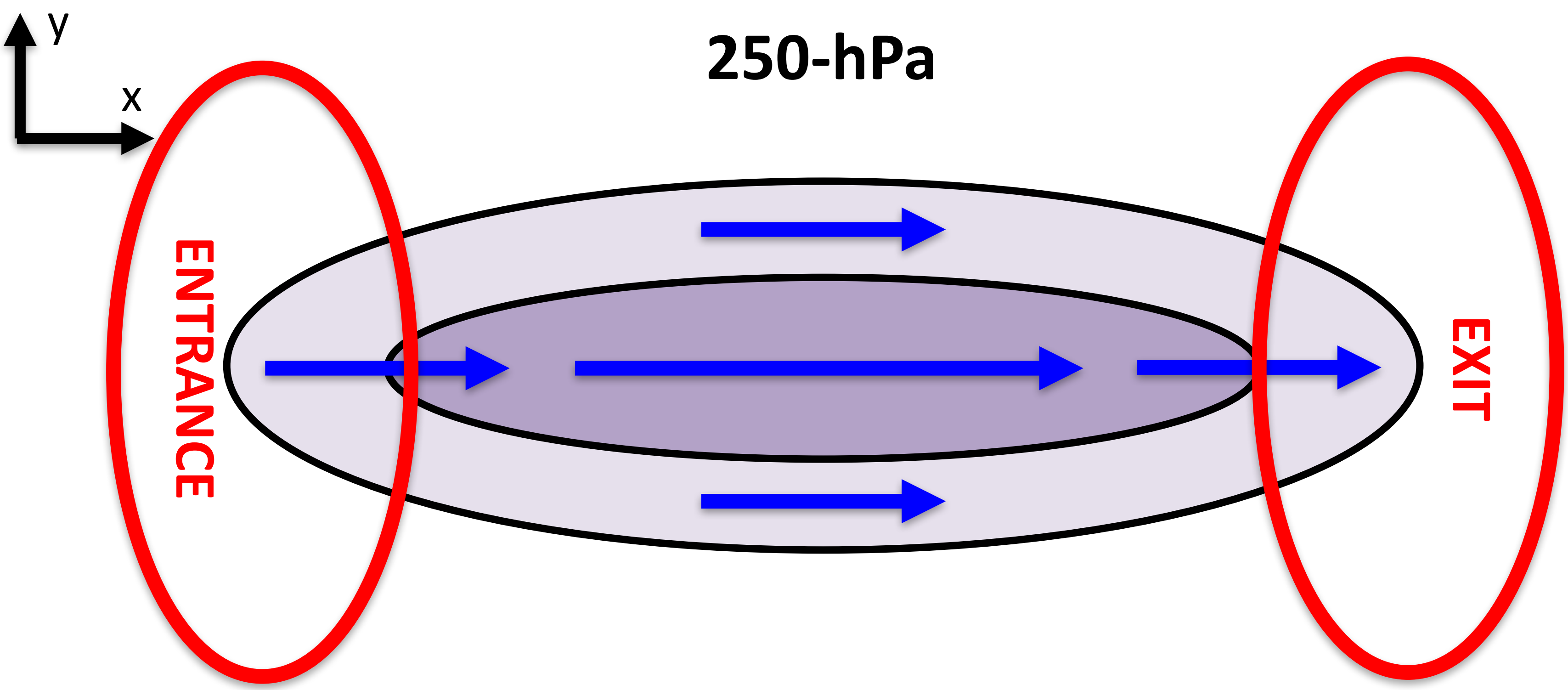
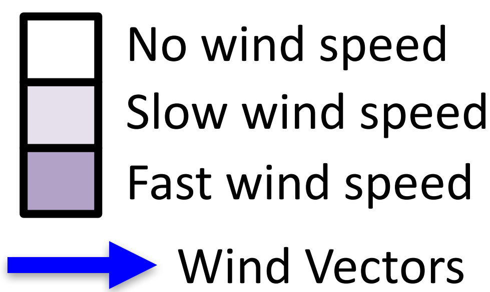
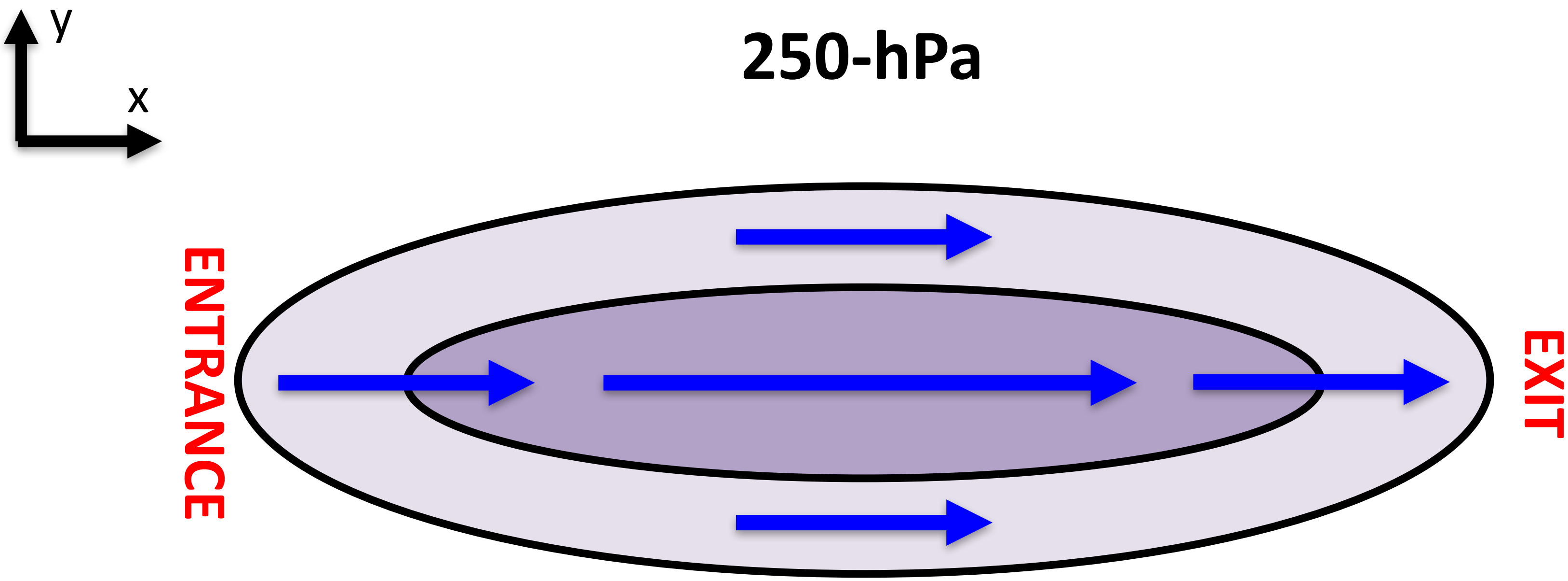
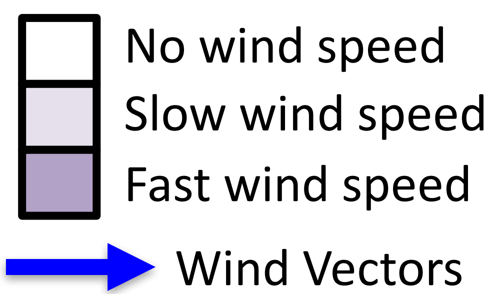




Areas where the wind accelerates or decelerates are important for generating weather

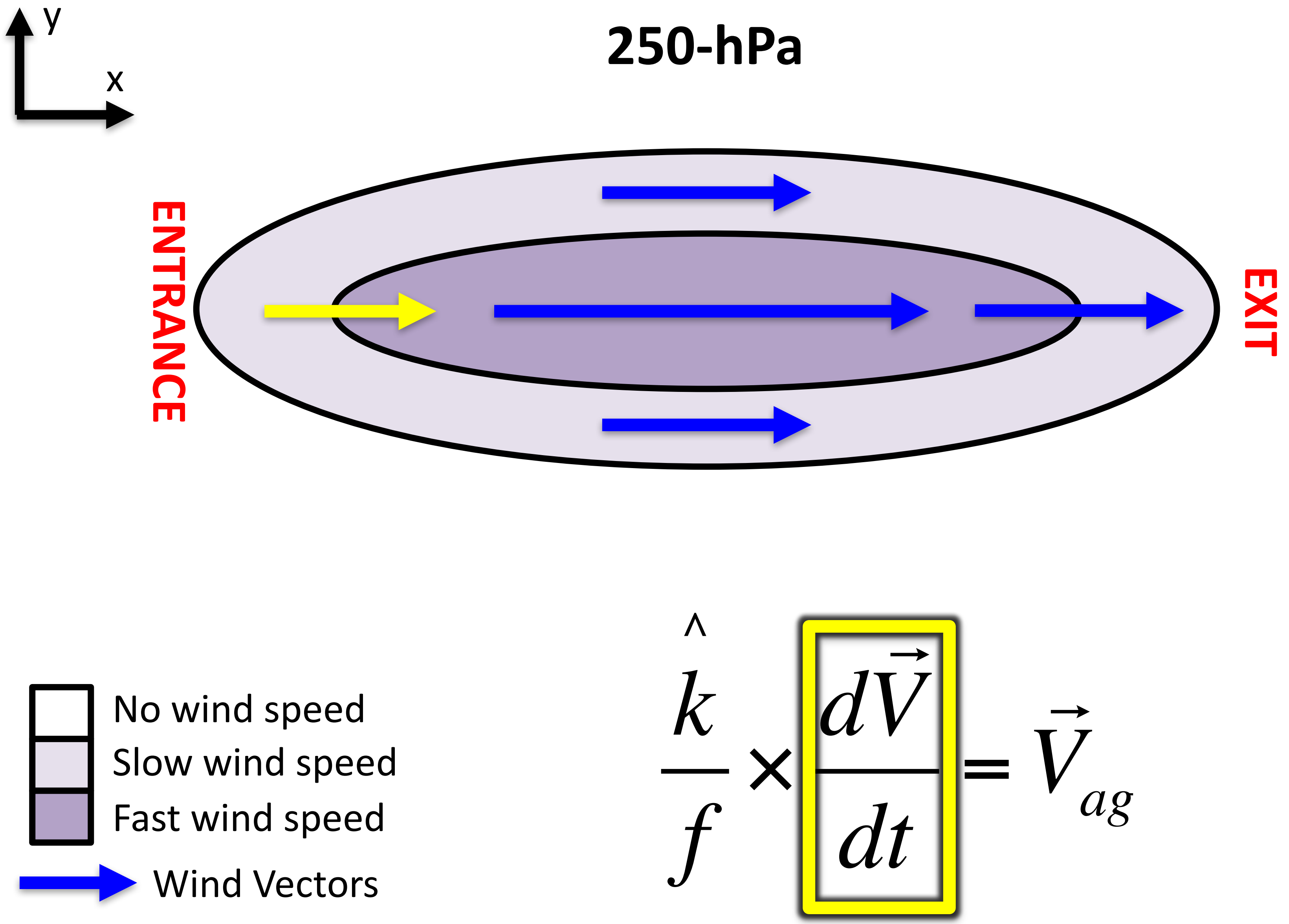
How do Jet Streams Impact the Weather?





$$\frac{\hat{k}}{f} \times \frac{d\vec{V}}{dt} = \vec{V}_{ag}$$

How do Jet Streams Impact the Weather?



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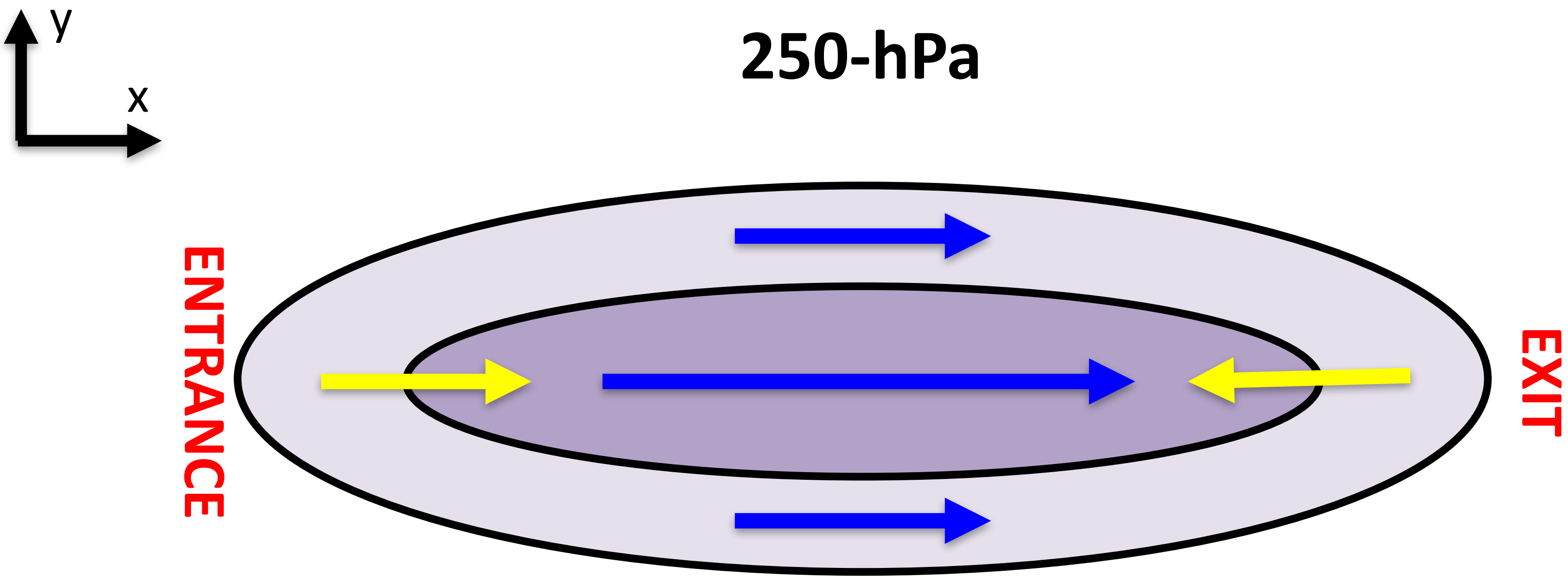

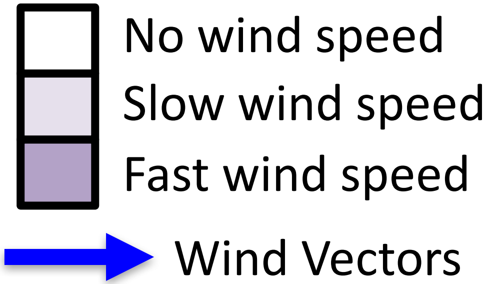

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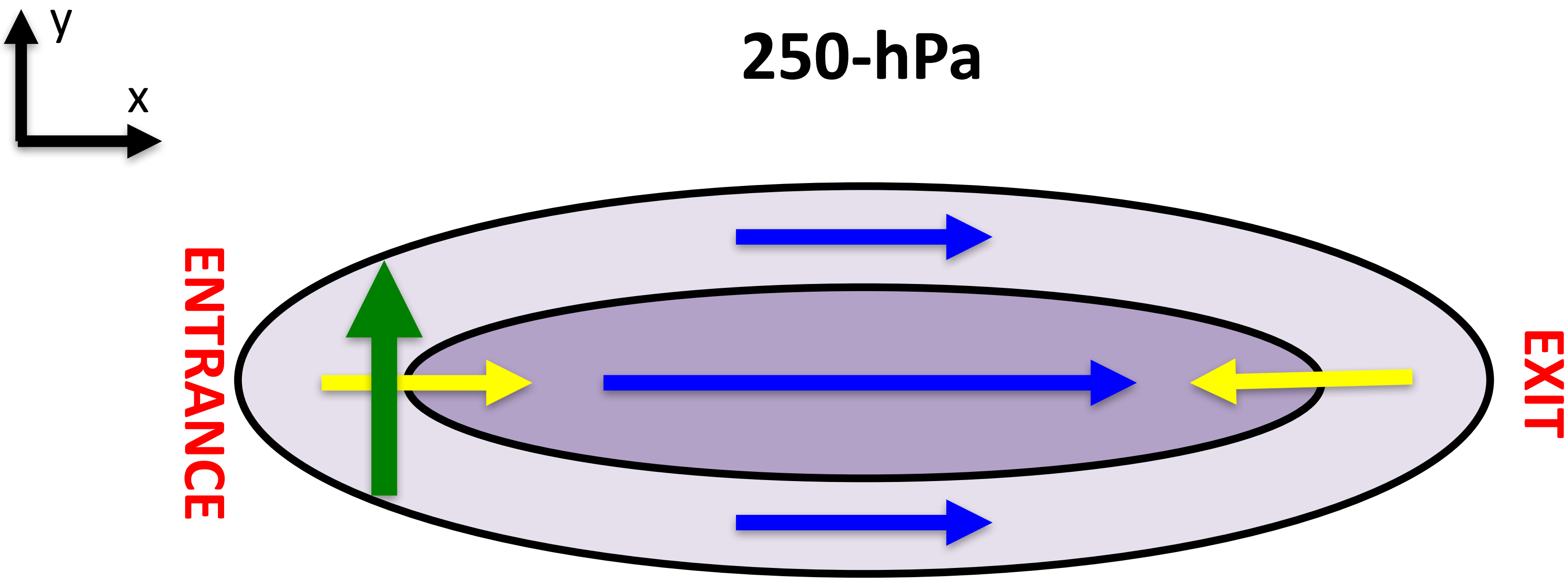
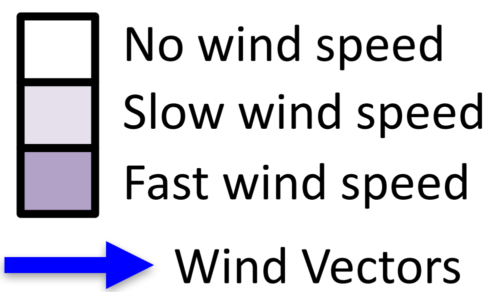
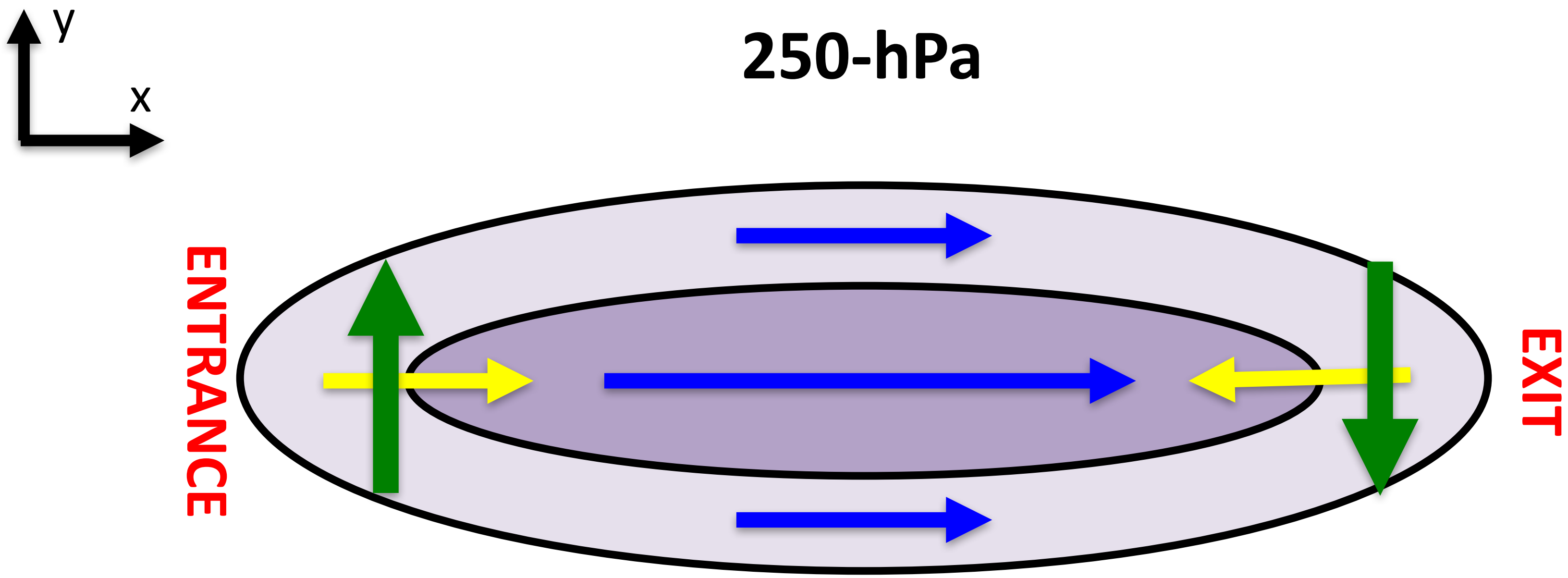
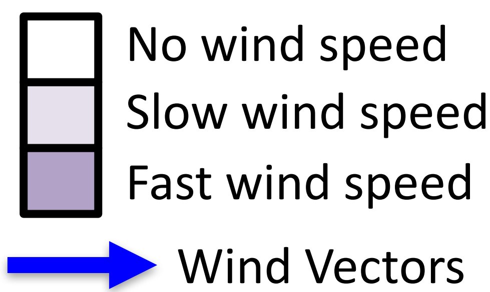




$$\frac{\hat{k}}{f} \times \frac{d\vec{V}}{dt} = \vec{V}_{ag}$$

How do Jet Streams Impact the Weather?





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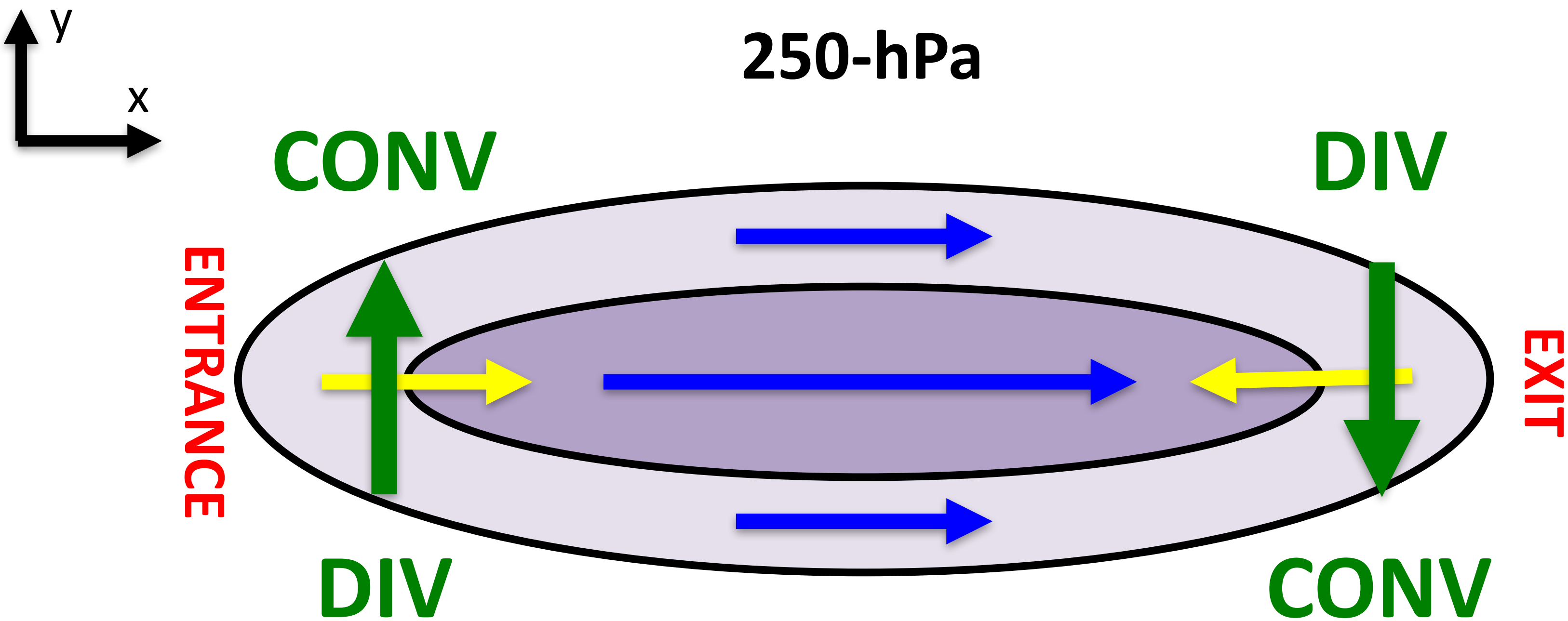

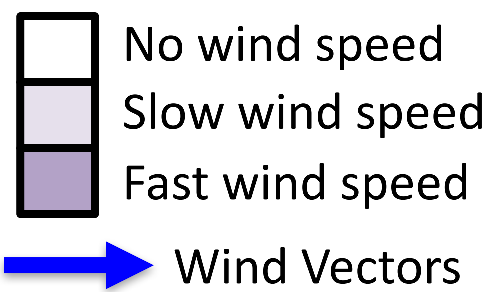

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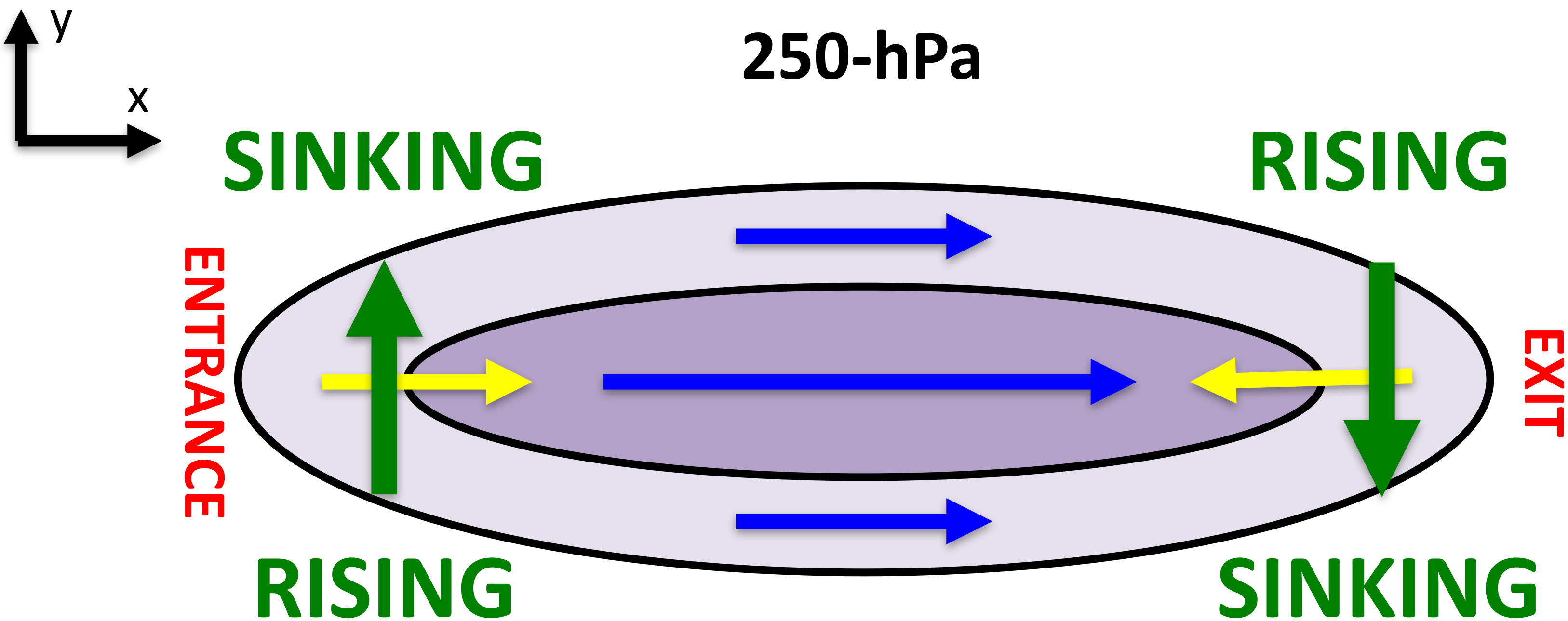
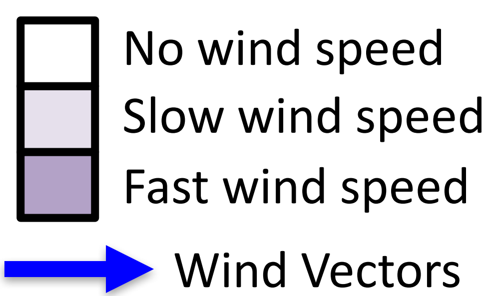
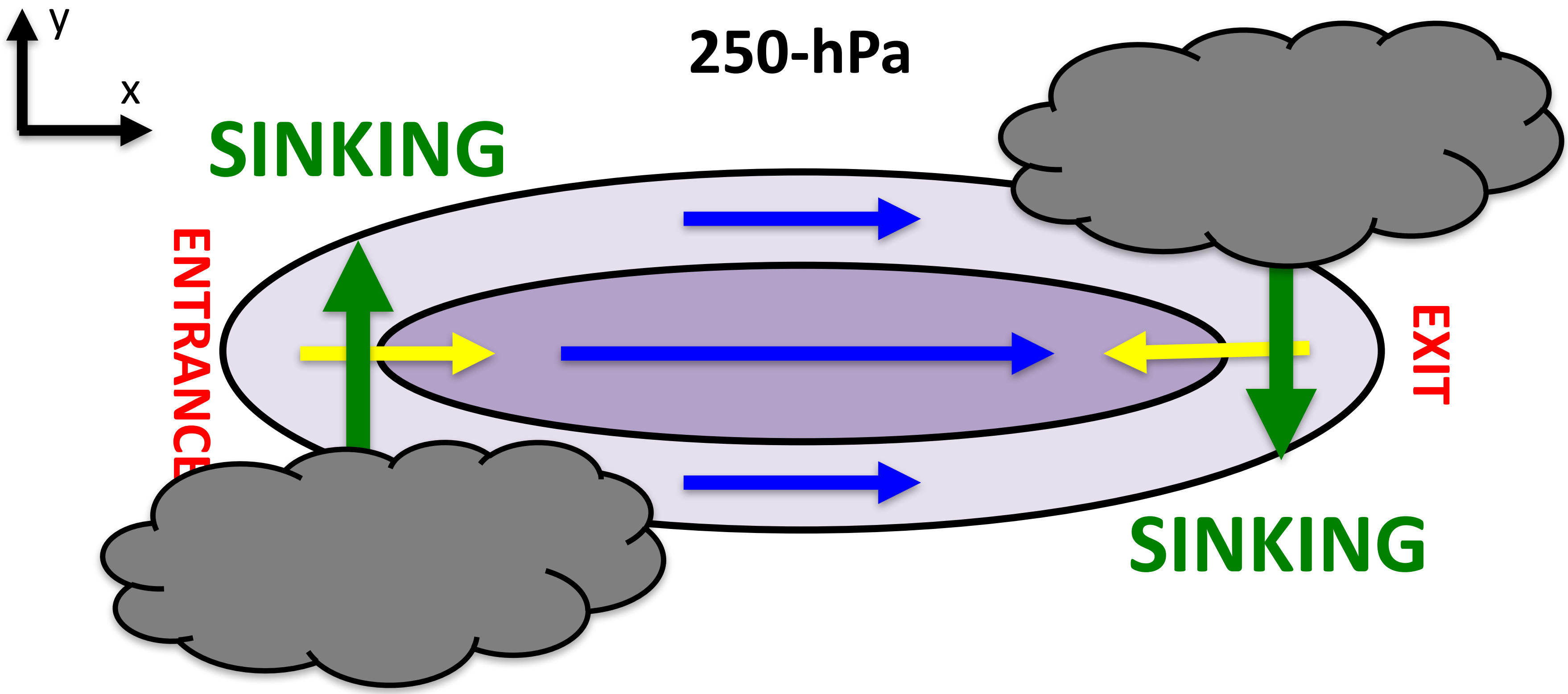




$$\frac{\hat{k}}{f} \times \frac{d\vec{V}}{dt} = \vec{V}_{ag}$$

How do Jet Streams Impact the Weather?



No wind speed
Slow wind speed
Fast wind speed
Wind Vectors

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

Transverse Jet Circulations

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

Arnt Eliassen

Norwegian Encyclopedia

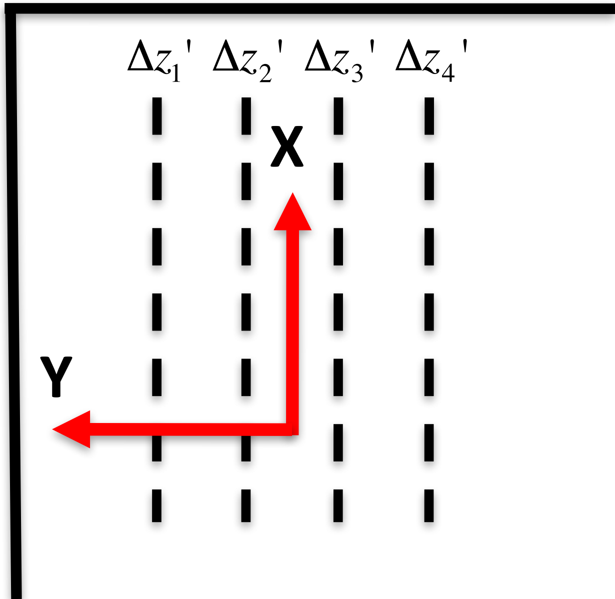
Sawyer–Eliassen Circulation Equation

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

Where:

$$\omega=\frac{\partial\psi}{\partial y}$$

$$v_{age}=-\frac{\partial\psi}{\partial p}$$



Sawyer–Eliassen Circulation Equation

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Where:

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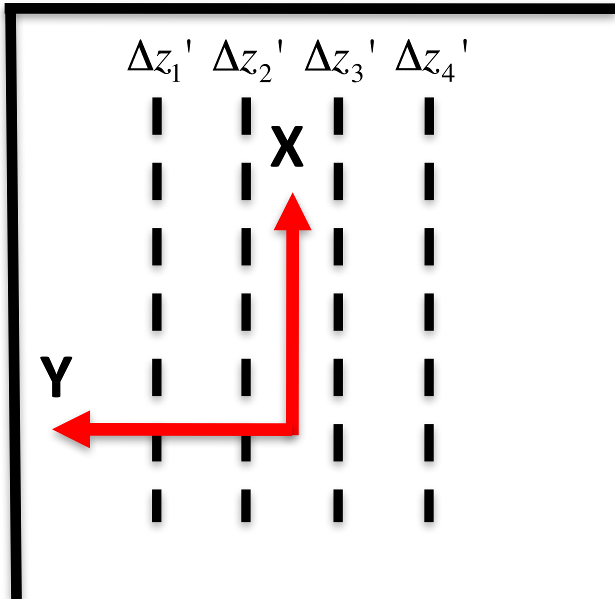
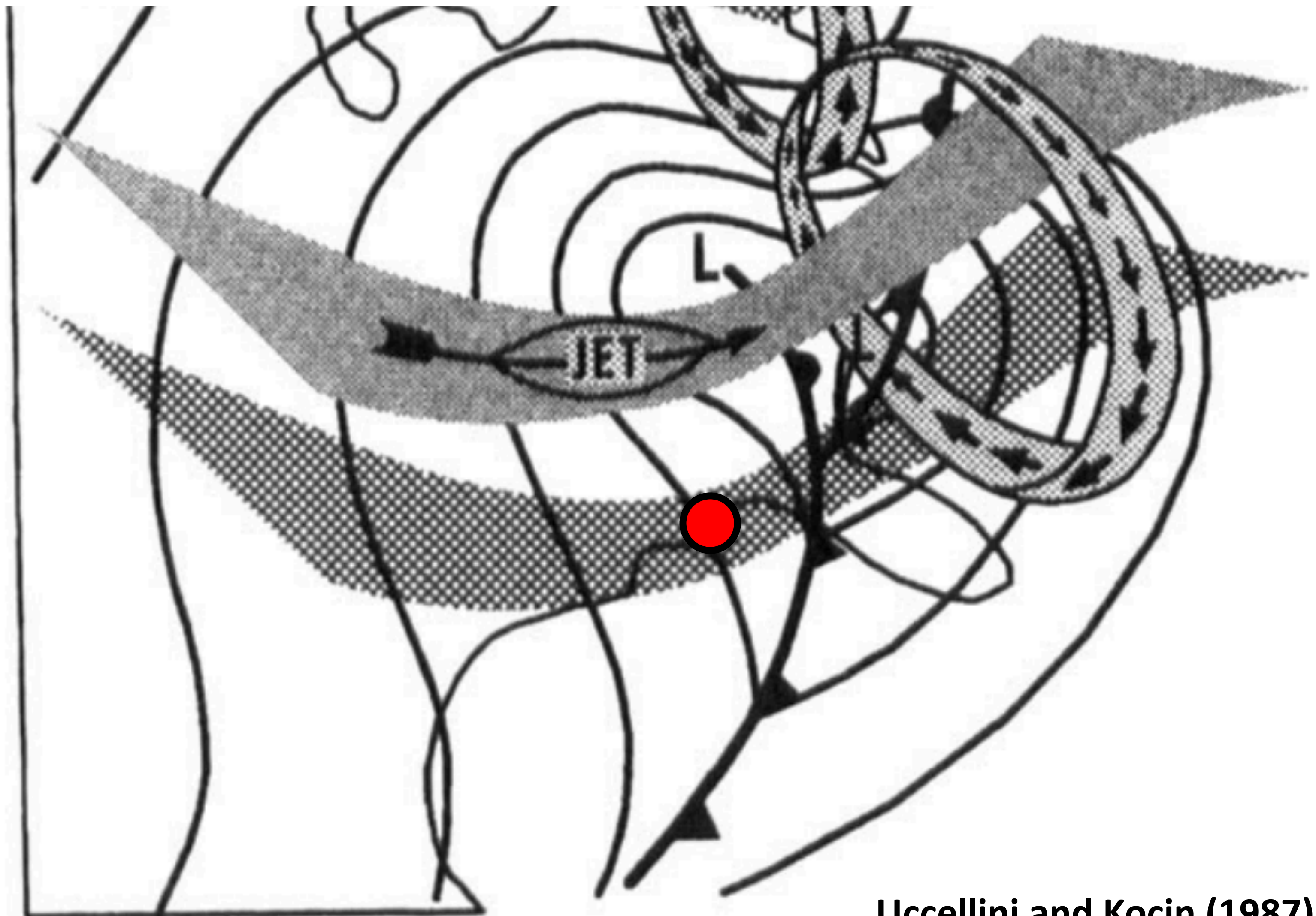


Sawyer–Eliassen Circulation Equation



Uccellini and Kocin (1987)

Sawyer–Eliassen Circulation Equation

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

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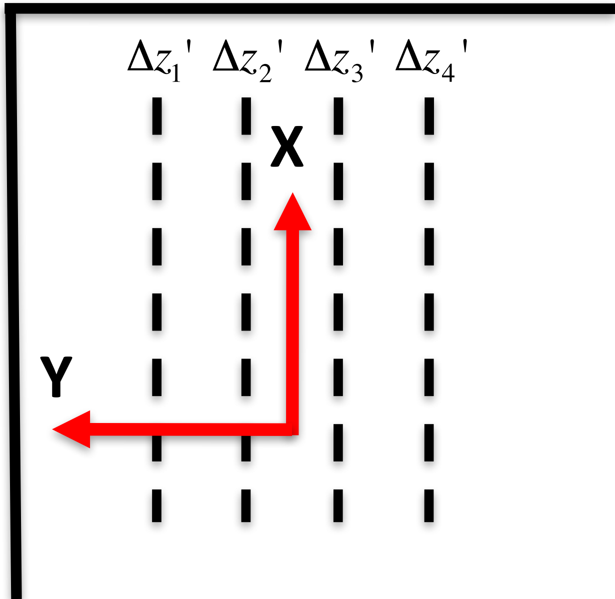

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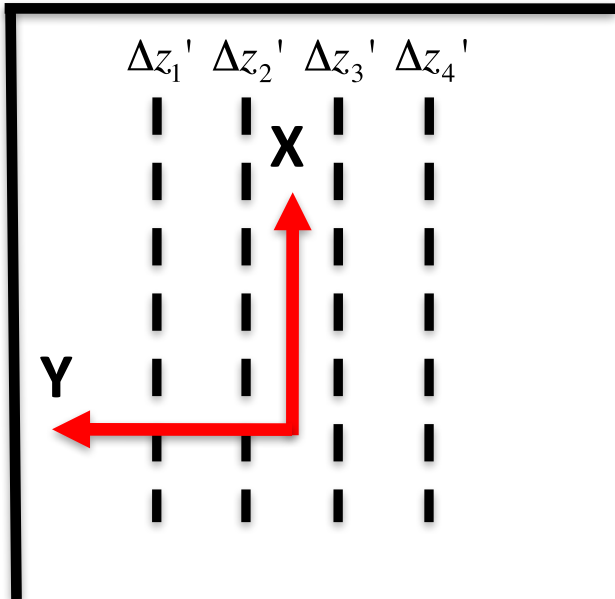
Static Stability

Where:

$$\omega=\frac{\partial\psi}{\partial y}$$

$$v_{age}=-\frac{\partial\psi}{\partial p}$$



Sawyer–Eliassen Circulation Equation

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

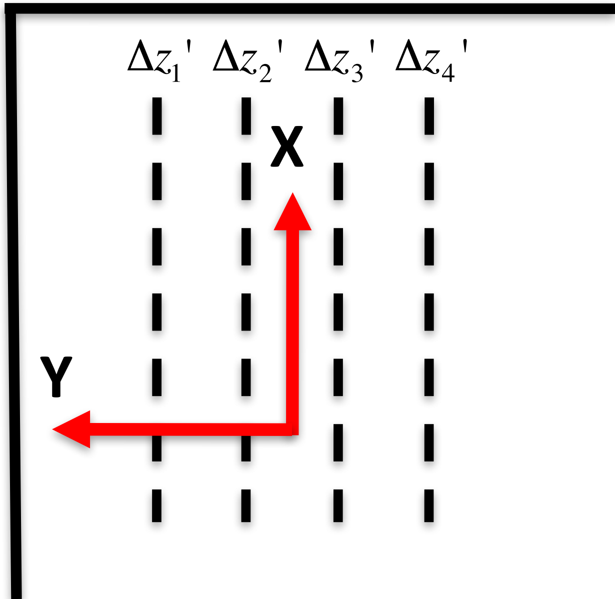
Static Stability

Across-Front Baroclinicity

Where:

$$\omega=\frac{\partial\psi}{\partial y}$$

$$v_{age}=-\frac{\partial\psi}{\partial p}$$



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

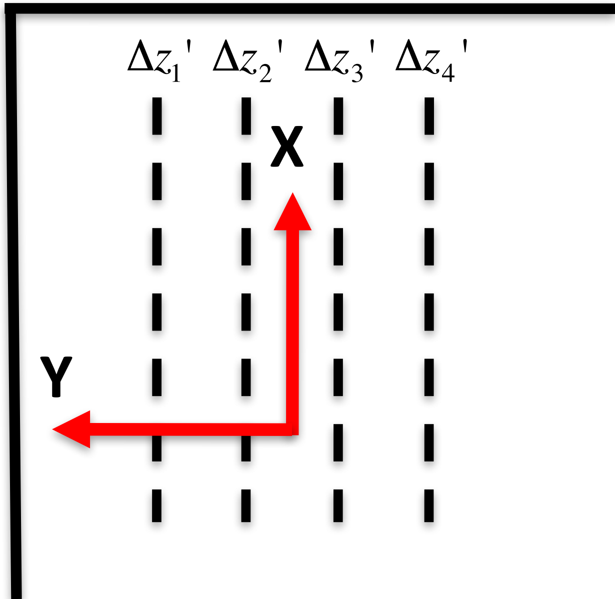
Across-Front Baroclinicity

Horizontal Absolute Vorticity

Where:

$$\omega = \frac{\partial\psi}{\partial y}$$

$$v_{age} = -\frac{\partial\psi}{\partial p}$$



Sawyer–Eliassen Circulation Equation

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

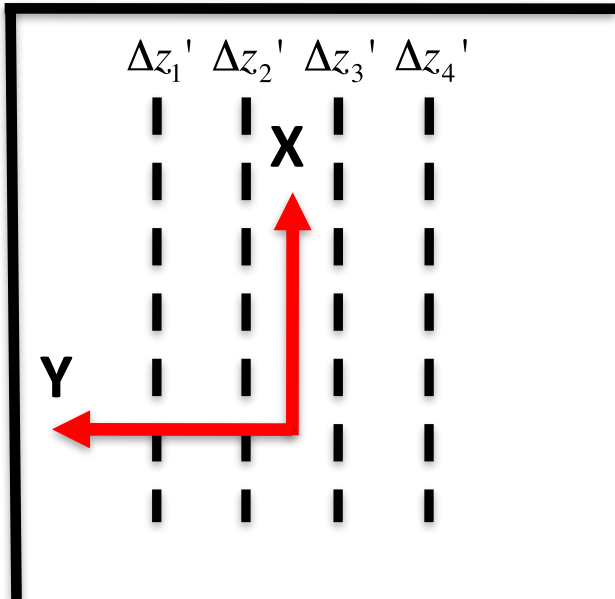
Static Stability
Across-Front Baroclinicity
Horizontal Absolute Vorticity

Frontal Characteristics

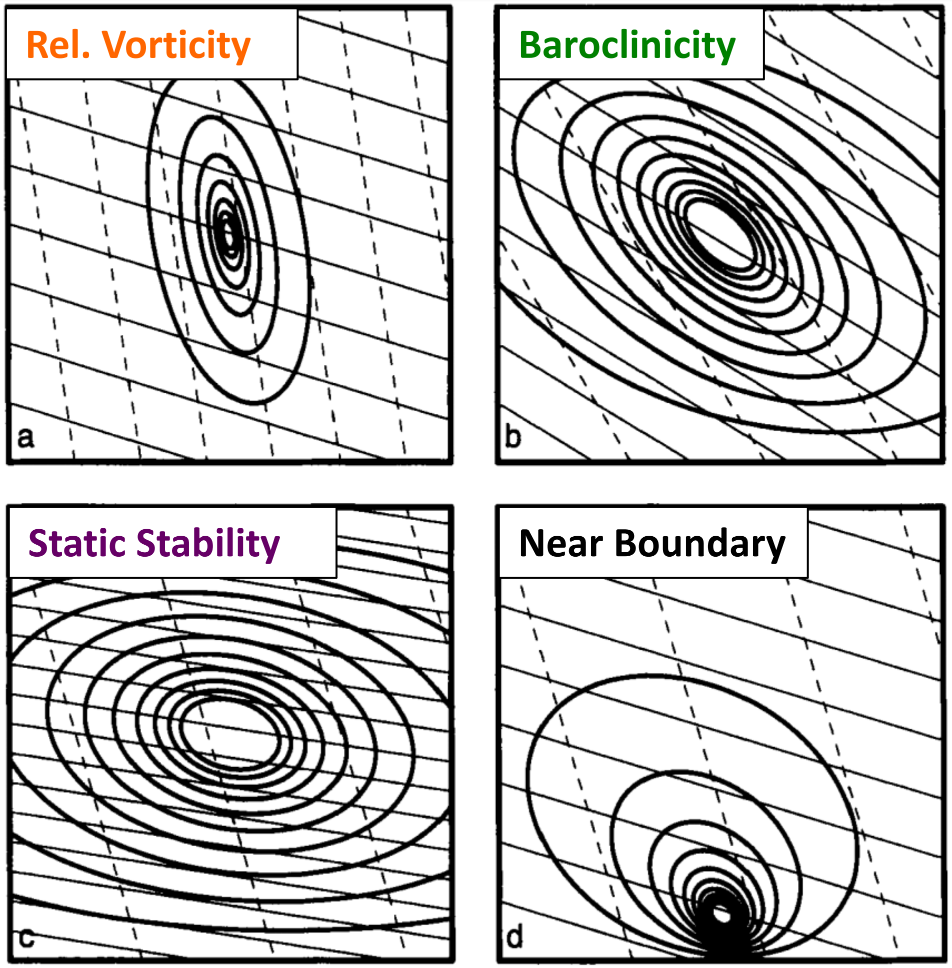
Where:

$$\omega = \frac{\partial\psi}{\partial y}$$

$$v_{age} = -\frac{\partial\psi}{\partial p}$$



Sawyer–Eliassen Circulation Equation



Hakim and Keyser (2001)

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

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

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
Horizontal Absolute Vorticity

Frontal Characteristics

Geostrophic and Diabatic Forcing

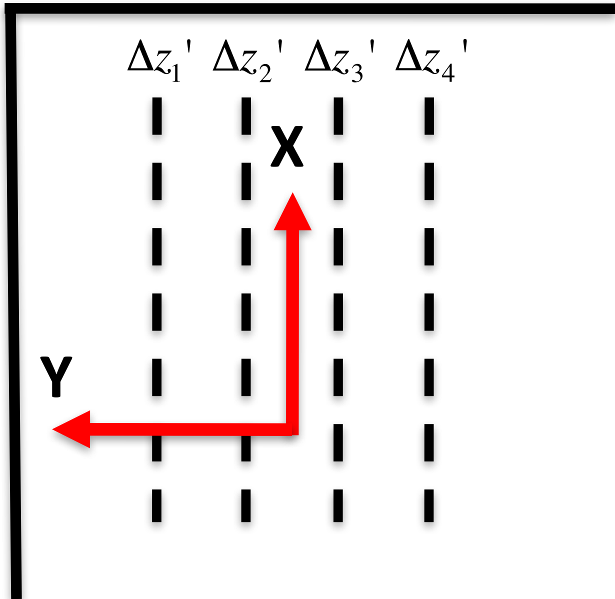
Where:

$$\omega=\frac{\partial\psi}{\partial y}$$

$$v_{age}=-\frac{\partial\psi}{\partial p}$$

$$Q_g=2\gamma(\frac{\partial U_g}{\partial y}\frac{\partial\theta}{\partial x}+\frac{\partial V_g}{\partial y}\frac{\partial\theta}{\partial y})$$

Shearing **Confluence**



Sawyer–Eliassen Circulation Equation

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

$$Q_g=2\gamma(\underbrace{\frac{\partial U_g}{\partial y}\frac{\partial\theta}{\partial x}}_{\text{Shearing}}+\underbrace{\frac{\partial V_g}{\partial y}\frac{\partial\theta}{\partial y}}_{\text{Confluence}})$$

Sawyer–Eliassen Circulation Equation

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

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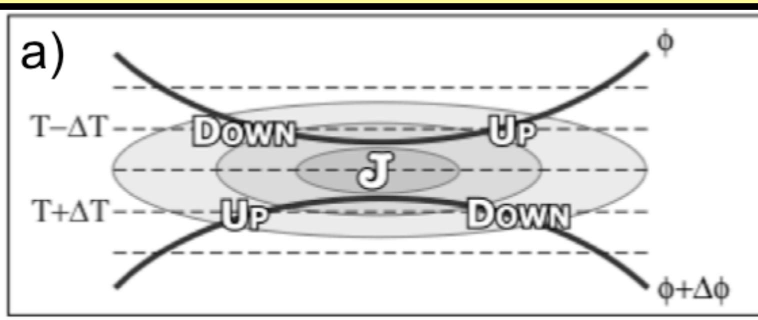
Shearing Confluence

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



$$Q_g = 2\gamma \qquad \frac{\partial V_g}{\partial y}\frac{\partial\theta}{\partial y})$$

Shearing — Confluence

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

Lang and Martin (2012)

Sawyer–Eliassen Circulation Equation

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

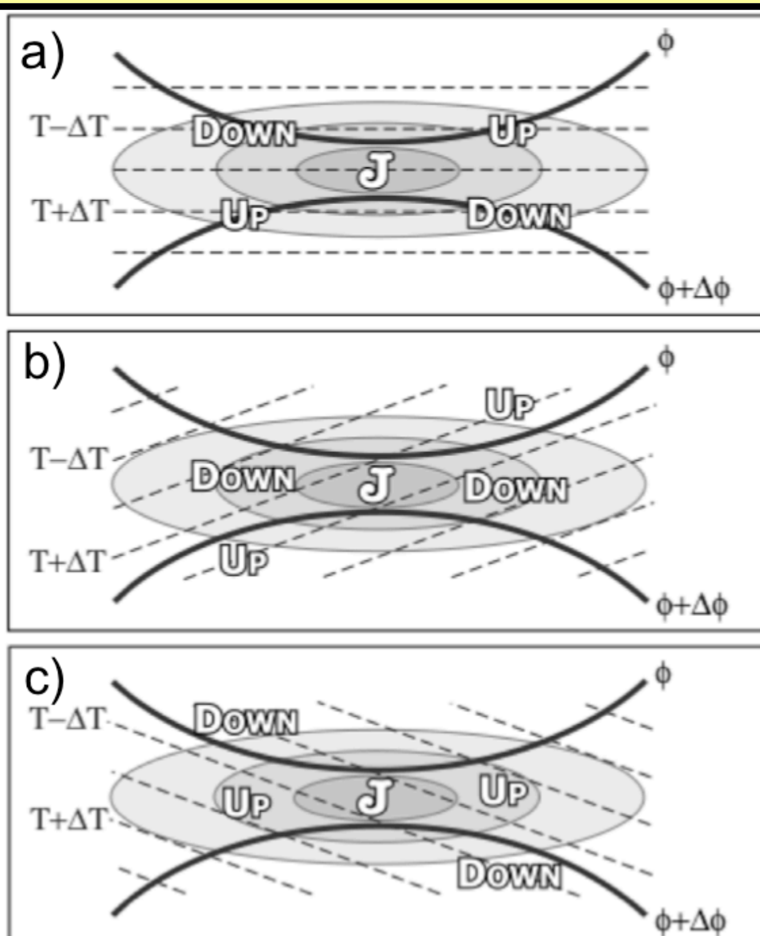
$$Q_g = 2\gamma(\frac{\partial U_g}{\partial y}\frac{\partial \theta}{\partial x} + \frac{\partial V_g}{\partial y}\frac{\partial \theta}{\partial y})$$

Shearing — Confluence

No Temp. Advection

Geo. CAA

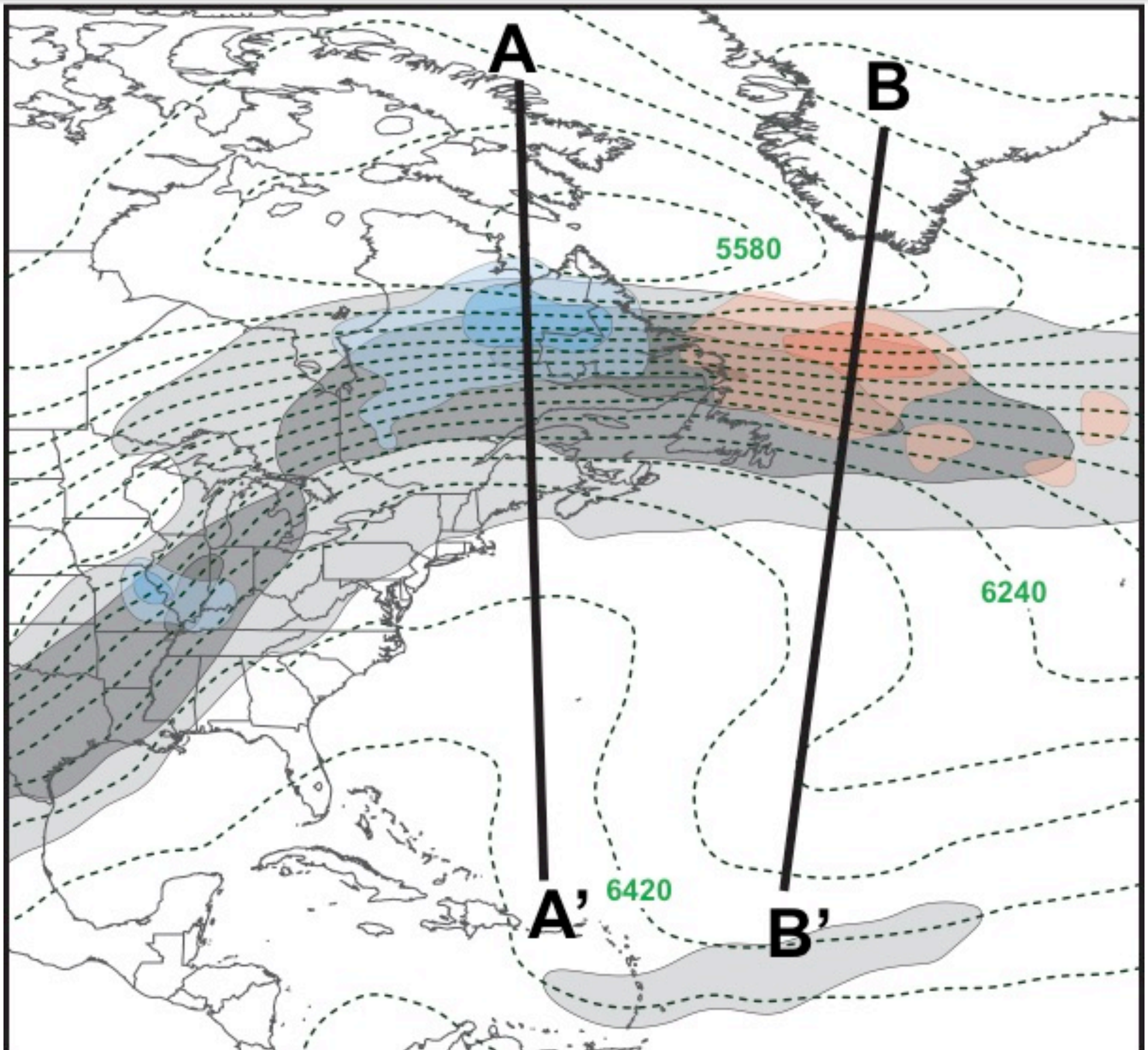
Geo. WAA



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

Lang and Martin (2012)

Sawyer–Eliassen Circulation Equation

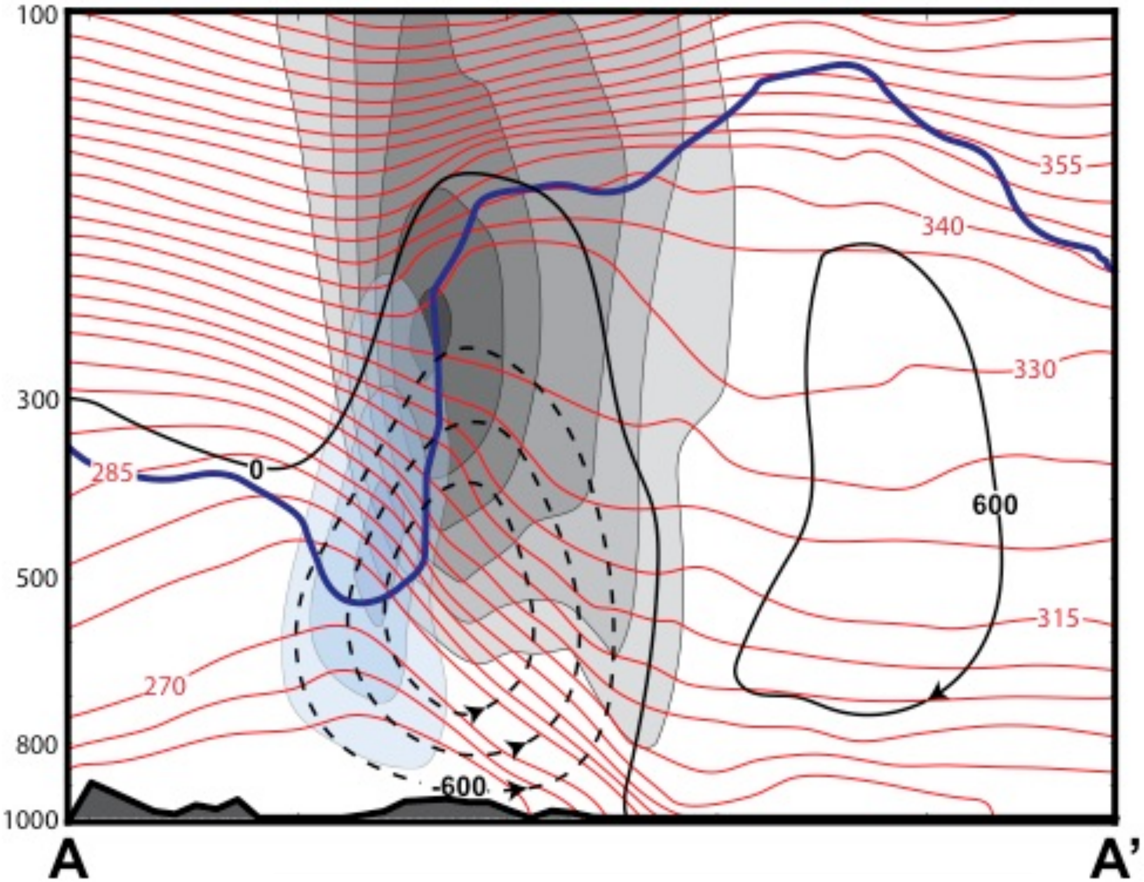


1200 UTC
22 Dec 2013

Geo. CAA in the jet entrance region

Geo. WAA in the jet exit region

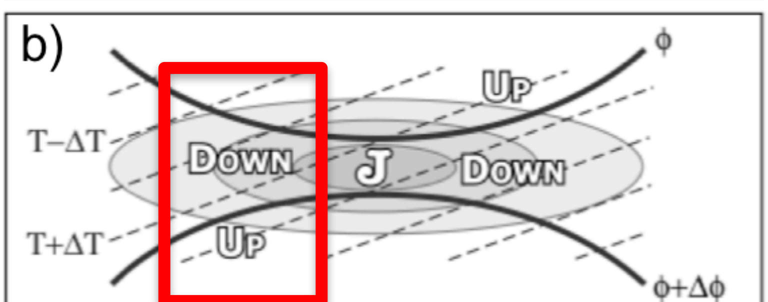
Sawyer–Eliassen Circulation Equation



1200 UTC
22 Dec 2013

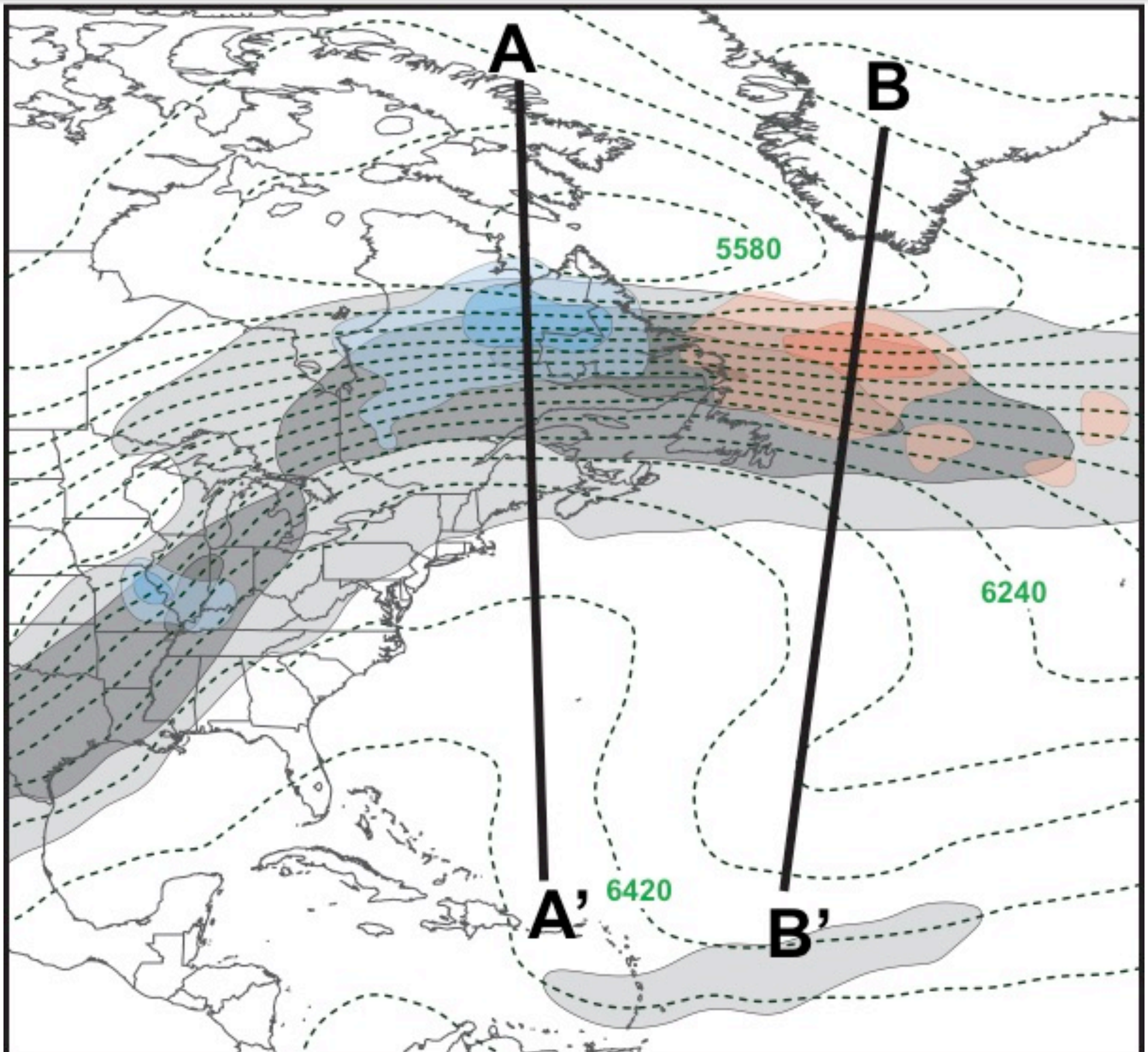
The result is a **thermally direct circulation**.

Subsidence is present slightly poleward of the jet core.



Geo. CAA

Sawyer–Eliassen Circulation Equation

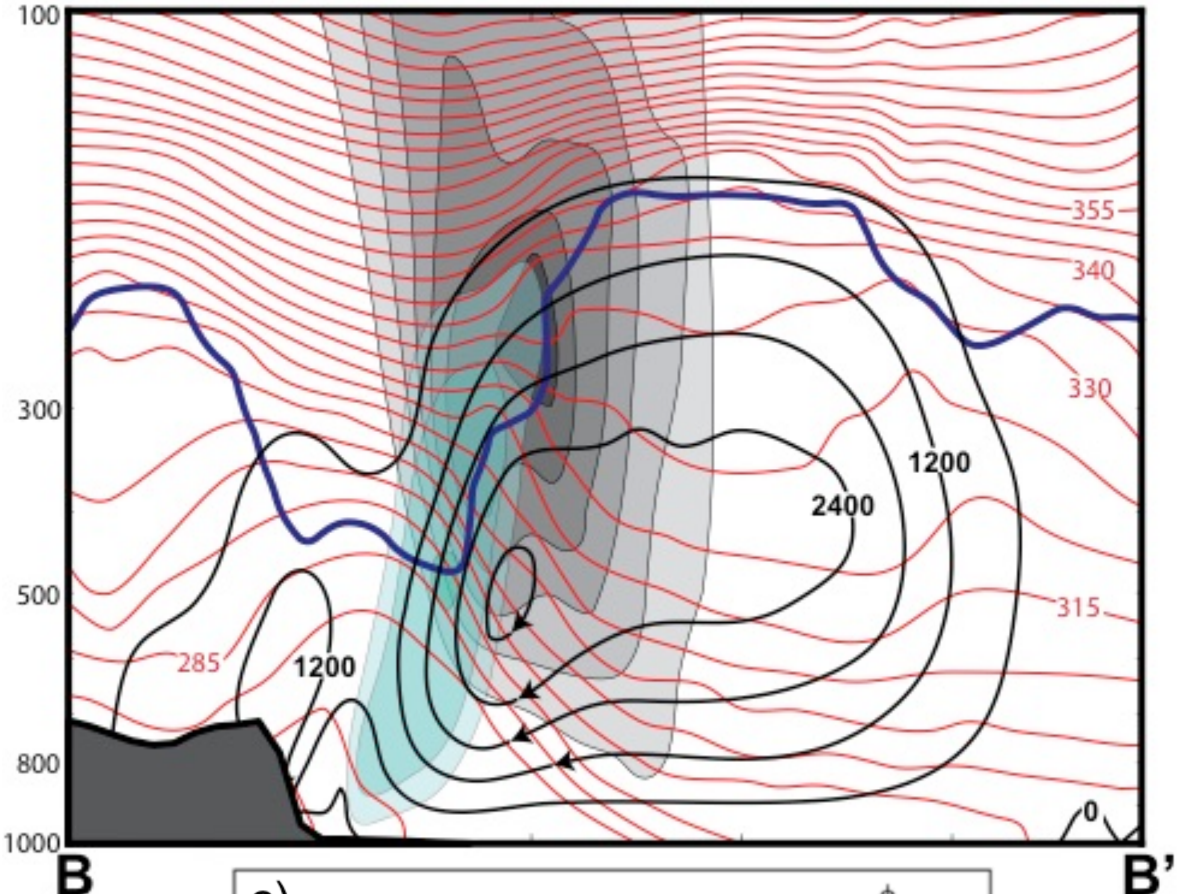


1200 UTC
22 Dec 2013

Geo. CAA in the jet entrance region

Geo. WAA in the jet exit region

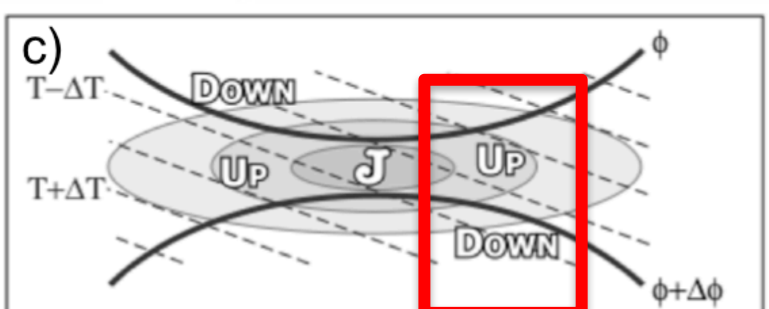
Sawyer–Eliassen Circulation Equation



1200 UTC
22 Dec 2013

The result is a **thermally indirect circulation**.

Ascent is present slightly poleward of the jet core.



Geo. WAA

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?

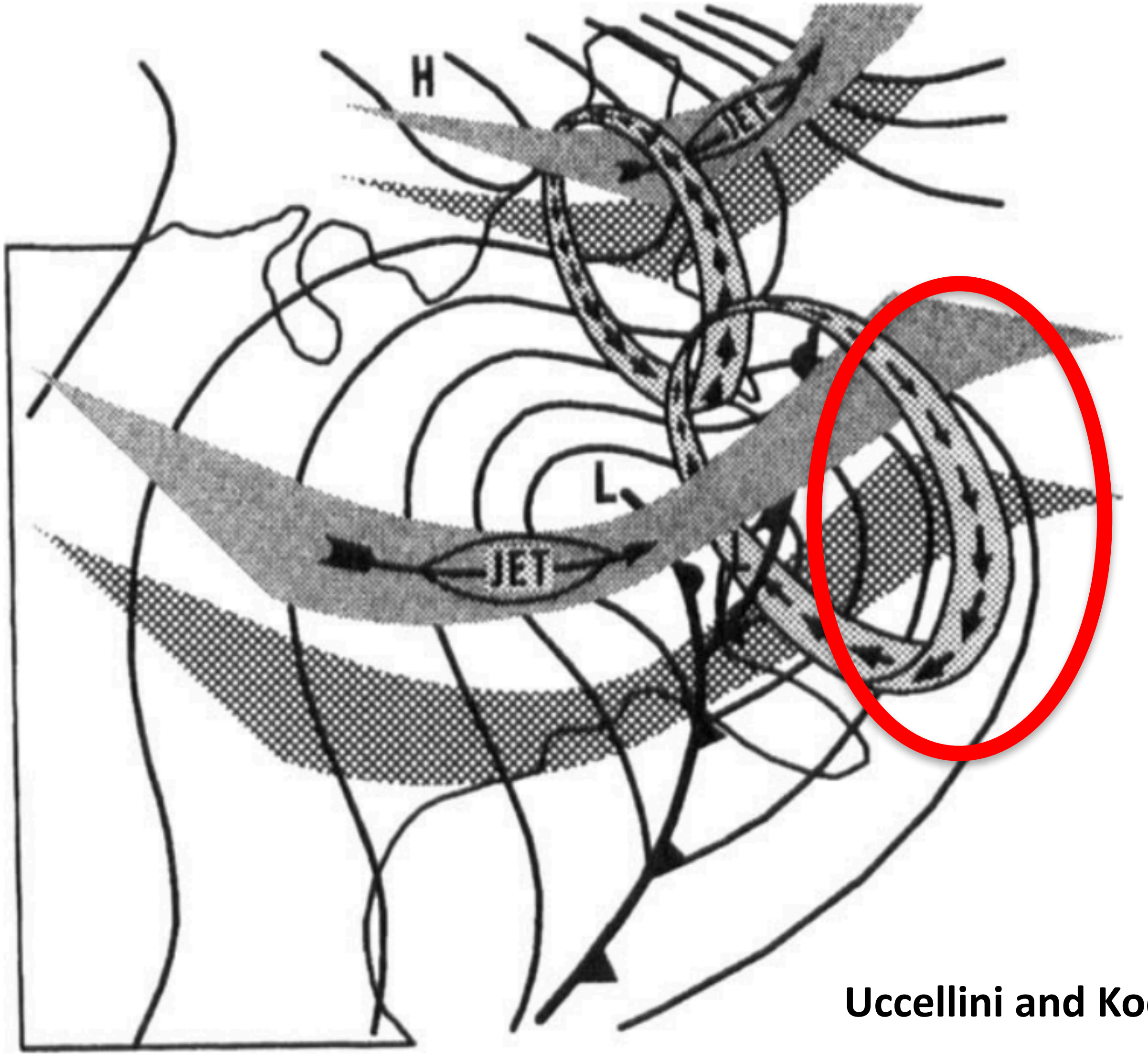
Impacts of Transverse Jet Circulations on the Production of Sensible Weather

- **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)

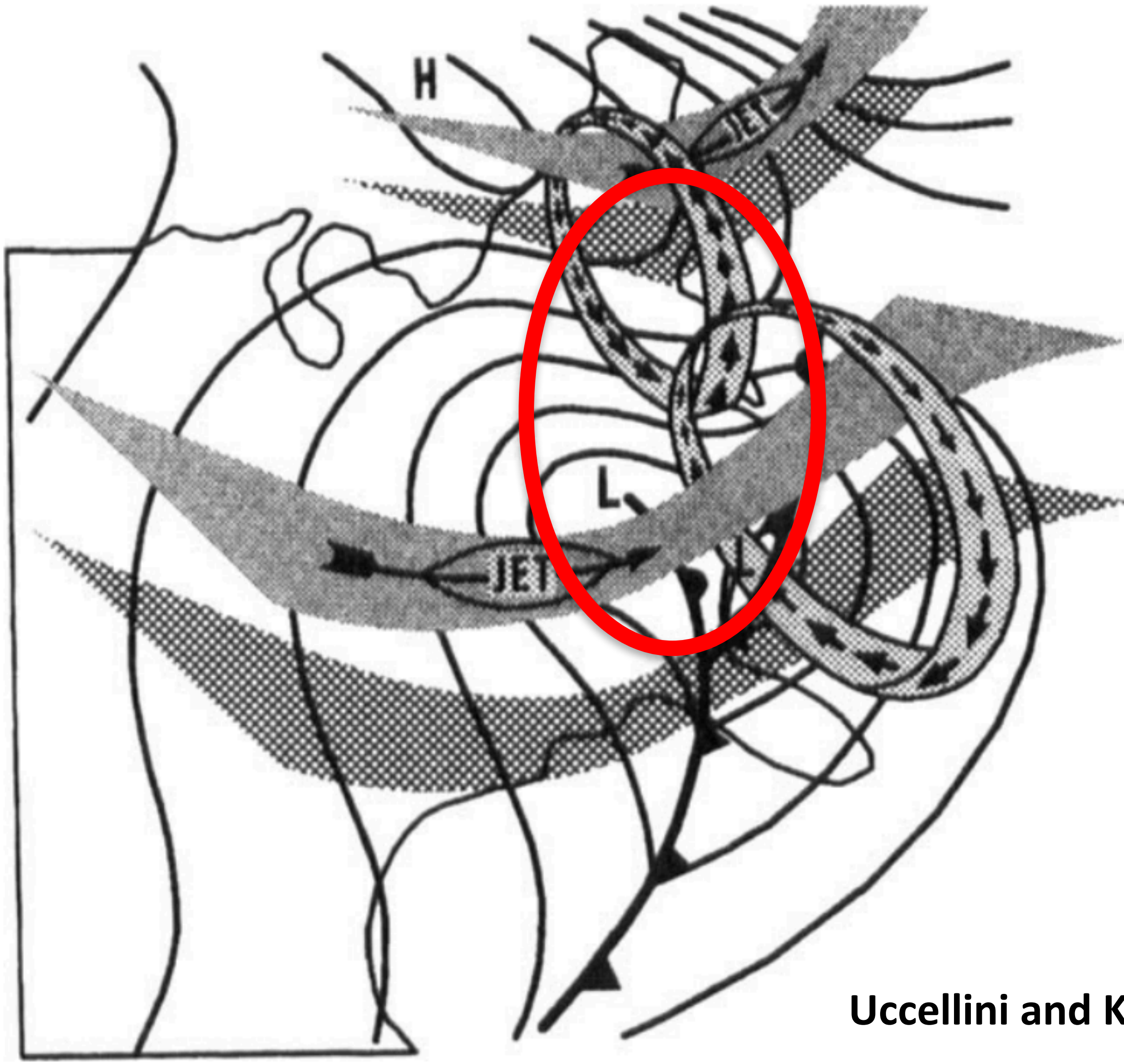
How do Jet Streams Impact the Weather?



1) **Severe Weather Outbreaks**

Uccellini and Kocin (1987)

How do Jet Streams Impact the Weather?

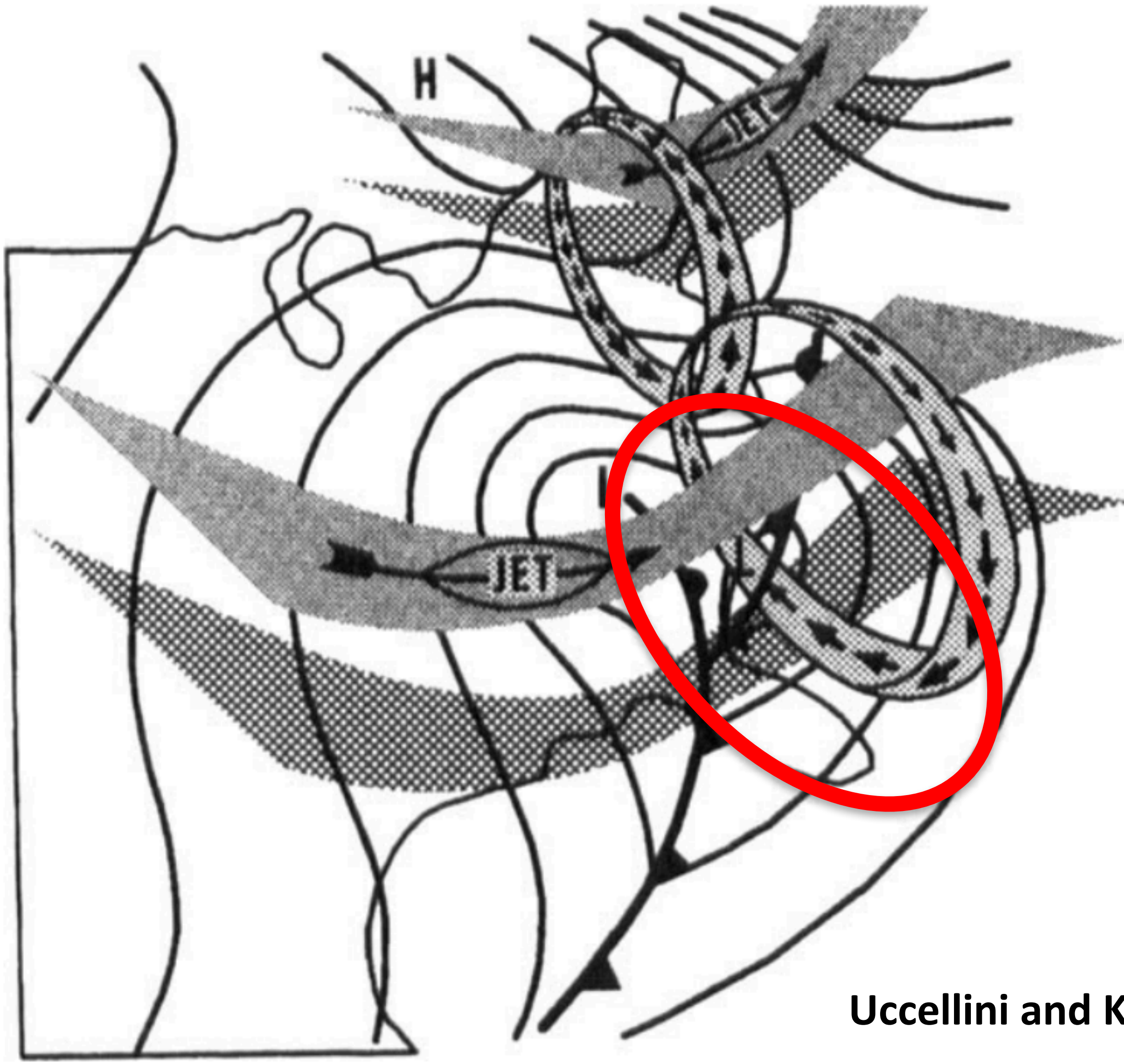


1) Severe Weather Outbreaks

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)

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