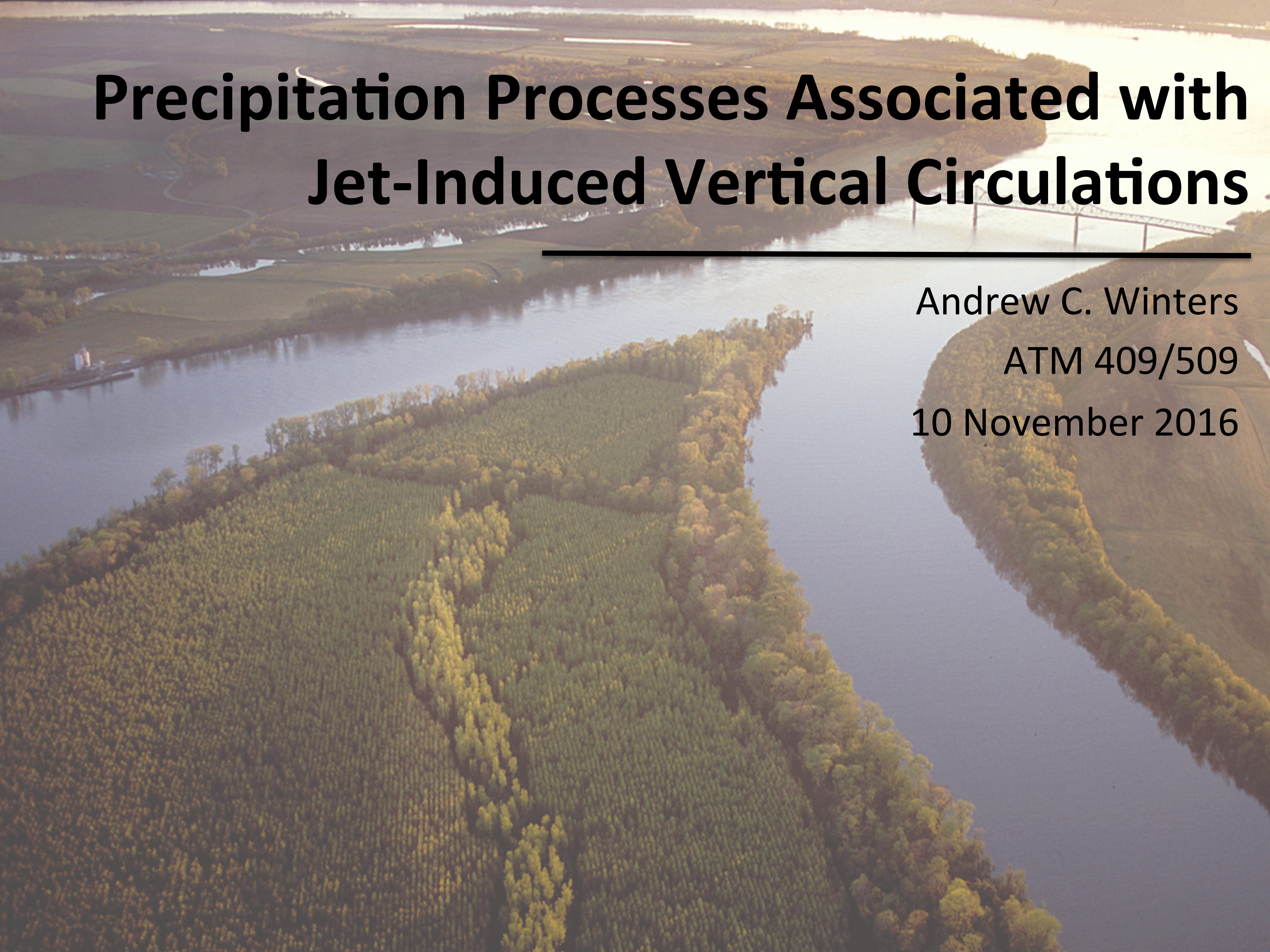


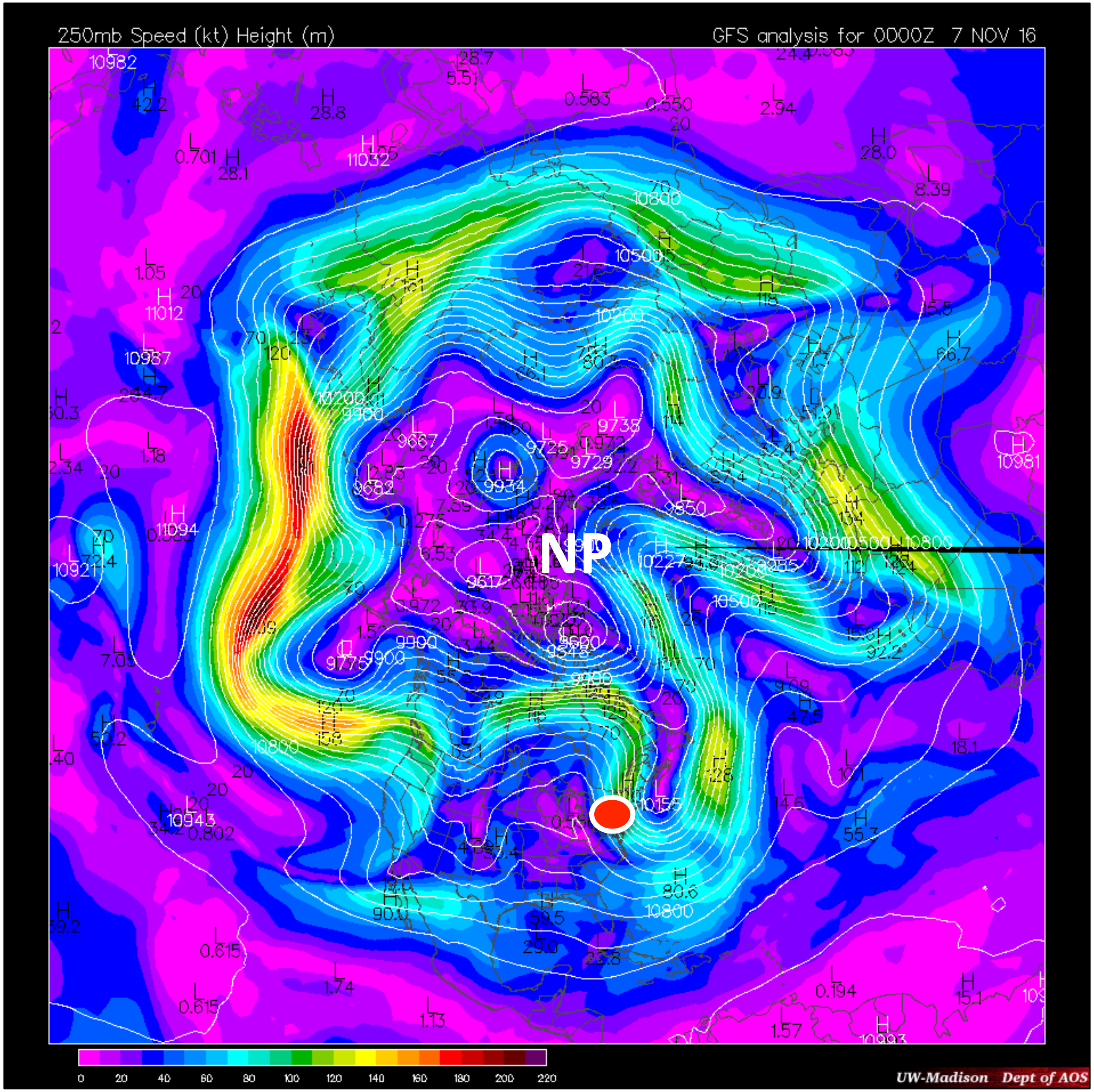
Precipitation Processes Associated with Jet-Induced Vertical Circulations

Andrew C. Winters

ATM 409/509

10 November 2016

250-hPa Wind Speed



0000 UTC
7 Nov 2016

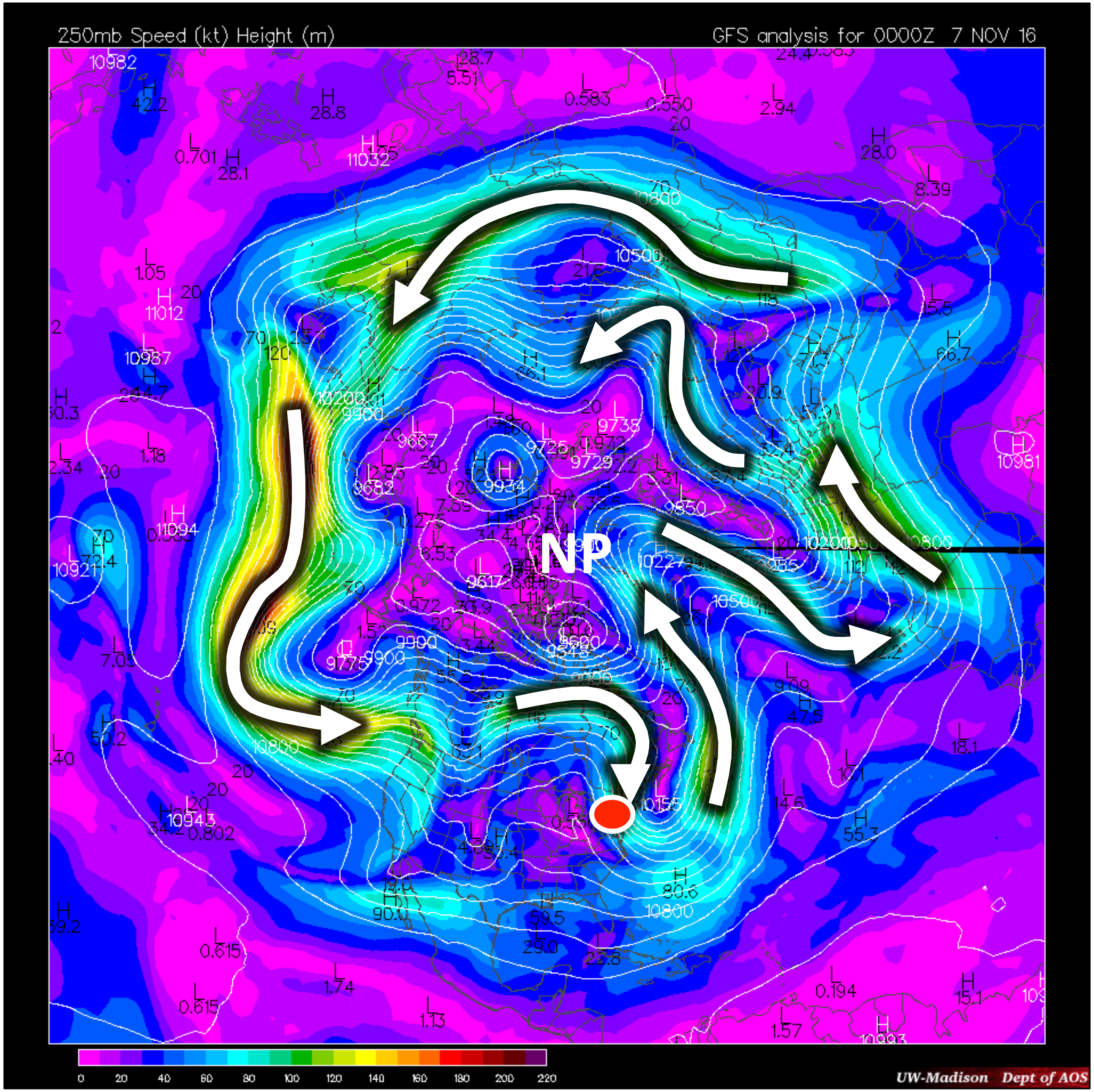
● Albany, NY

NP North Pole

UW-Madison AOS

250-hPa Wind Speed

0000 UTC
7 Nov 2016



→ Jet Streams

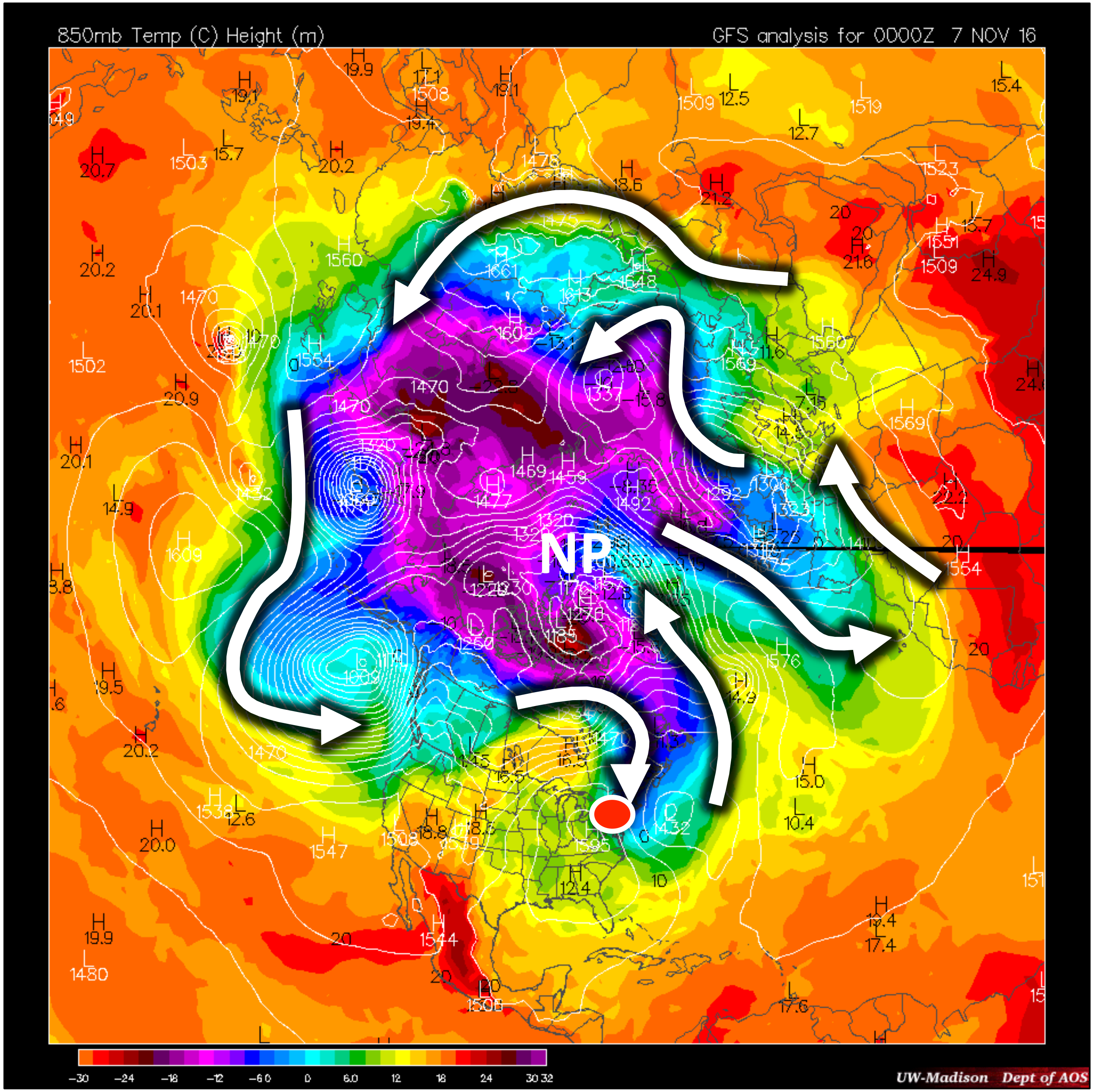
● Albany, NY

NP North Pole

UW-Madison AOS

850-hPa Temperature

0000 UTC
7 Nov 2016



→ Jet Streams

● Albany, NY

NP North Pole

UW-Madison AOS

Building Blocks to Jet Stream "Discovery"

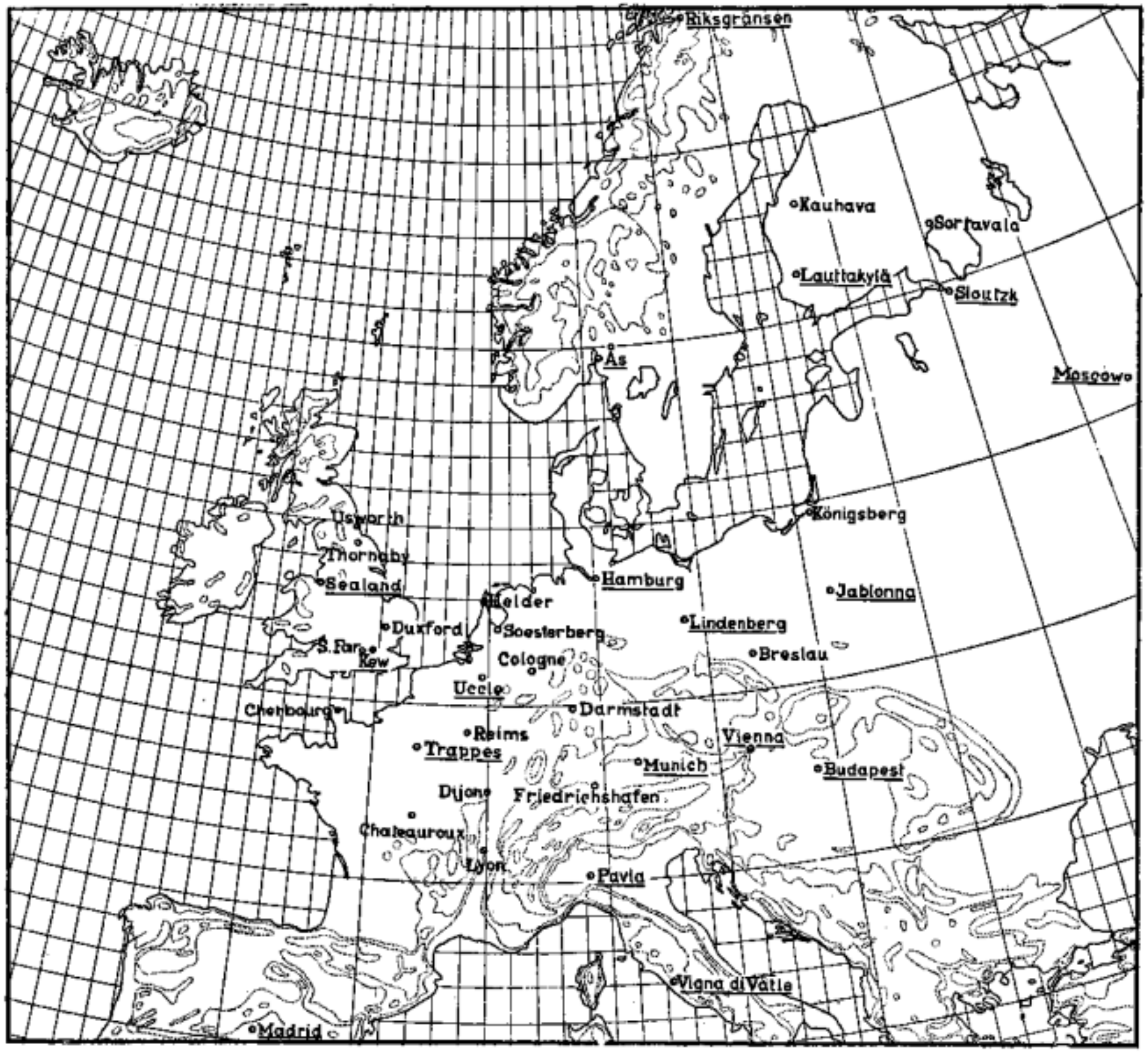
Teisserenc de Bort (1902)

Discovery of the stratosphere

Temperature stops decreasing when you get far enough away from the Earth's surface

Building Blocks to Jet Stream "Discovery"

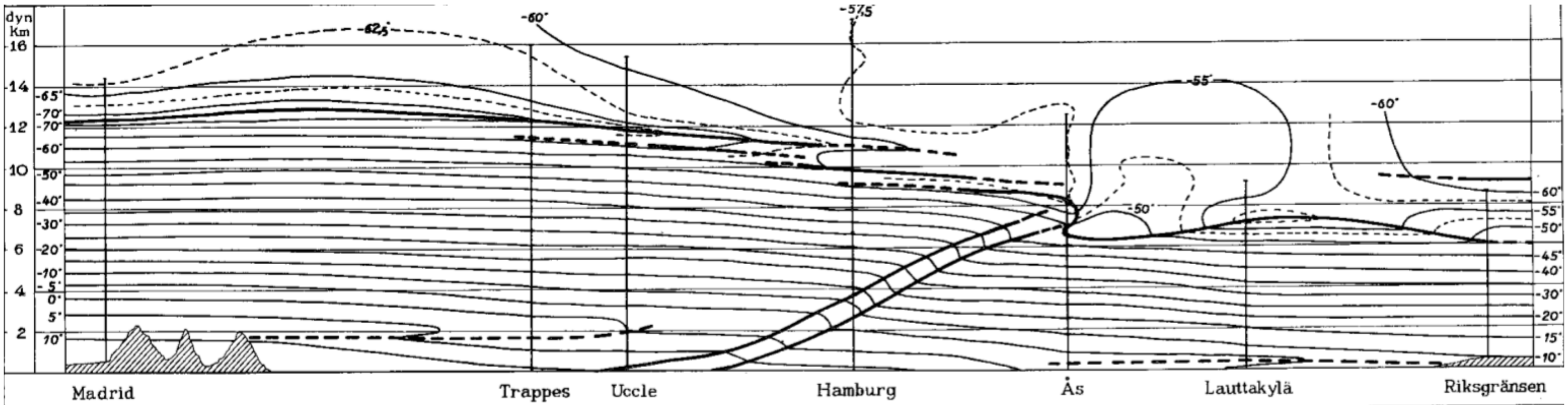
Bjerknes and Palmén (1937)



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

Building Blocks to Jet Stream "Discovery"

Bjerknes and Palmén (1937)



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

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

CCR

“Discovery” of the Jet Stream

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

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Cliff Mass

“Discovery” of the Jet Stream

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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

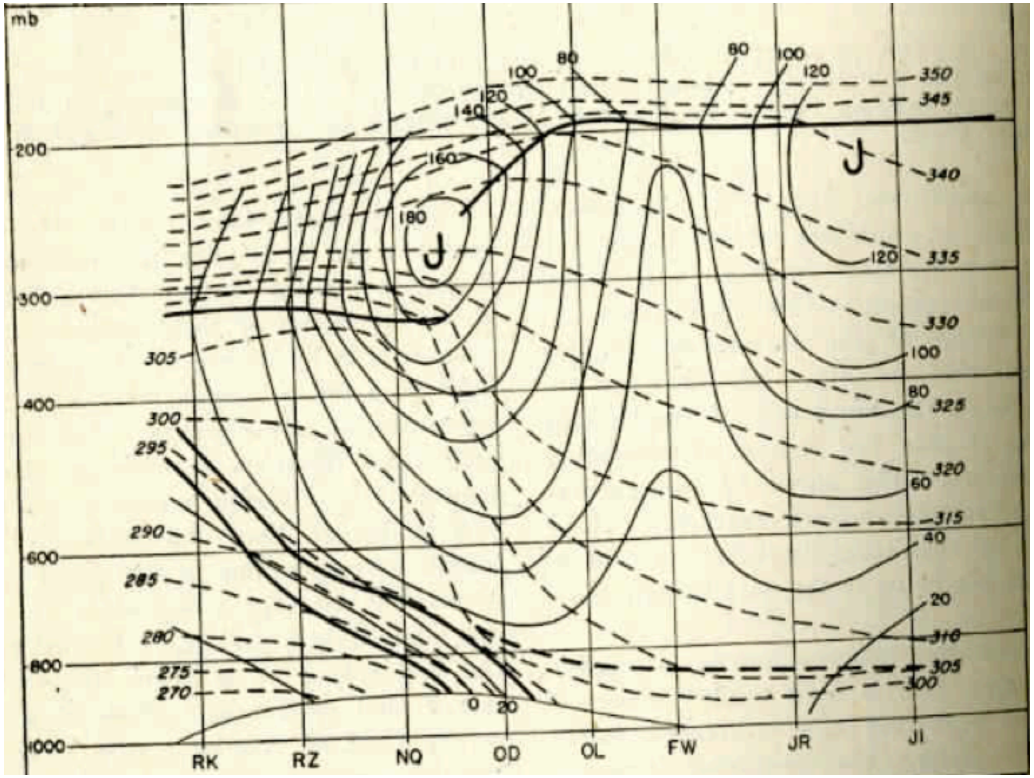
University of Chicago (1947)

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

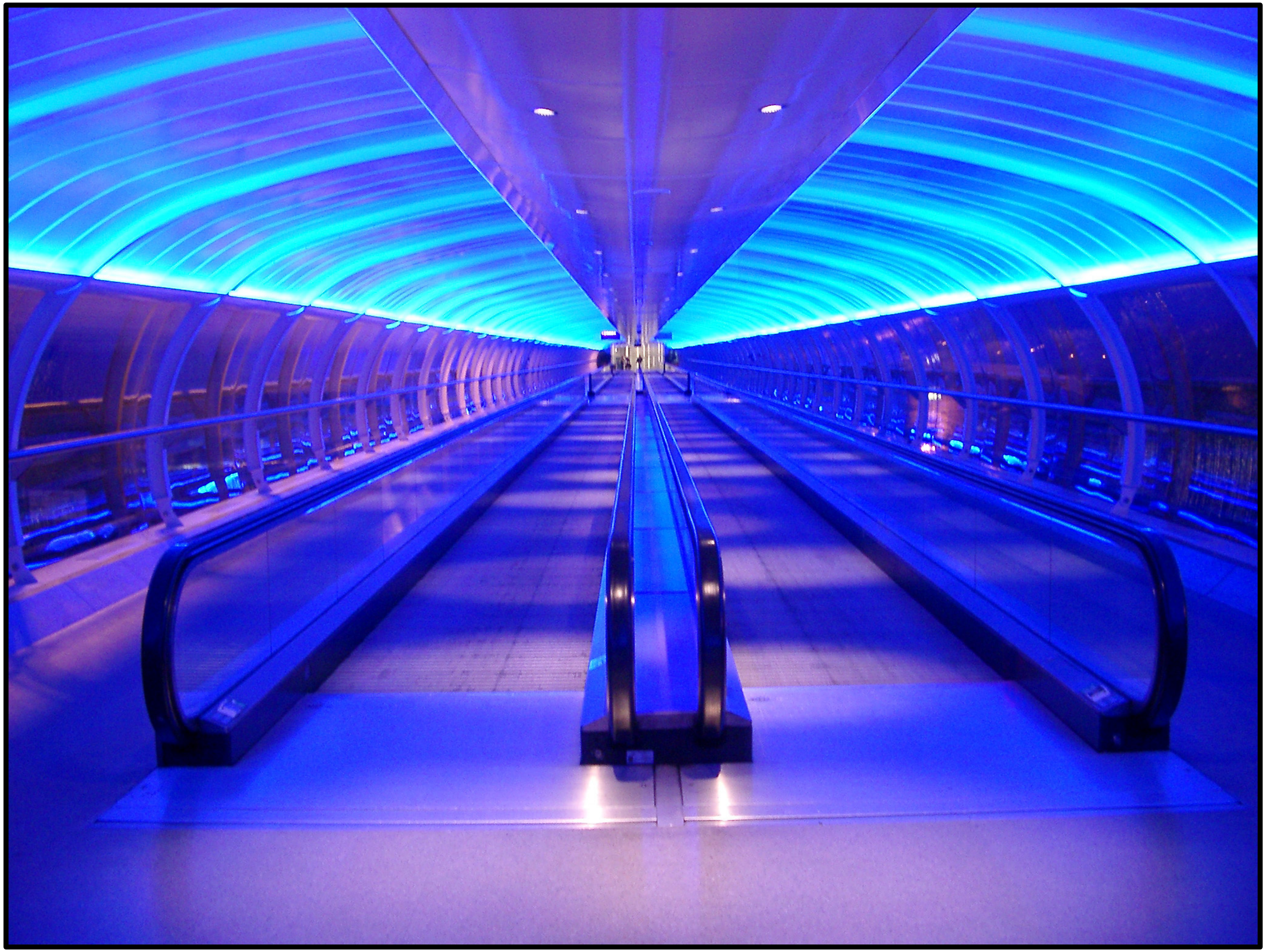
1) A nearly continuous band of strong zonal wind speeds.

2) Sat atop the strongly baroclinic polar front.

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

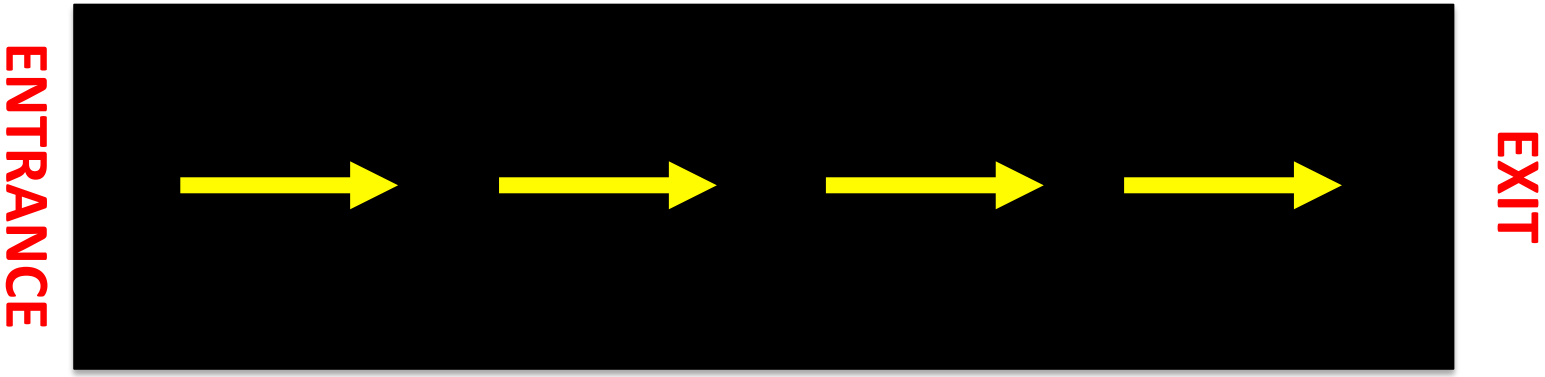


How do Jet Streams Impact the Weather?

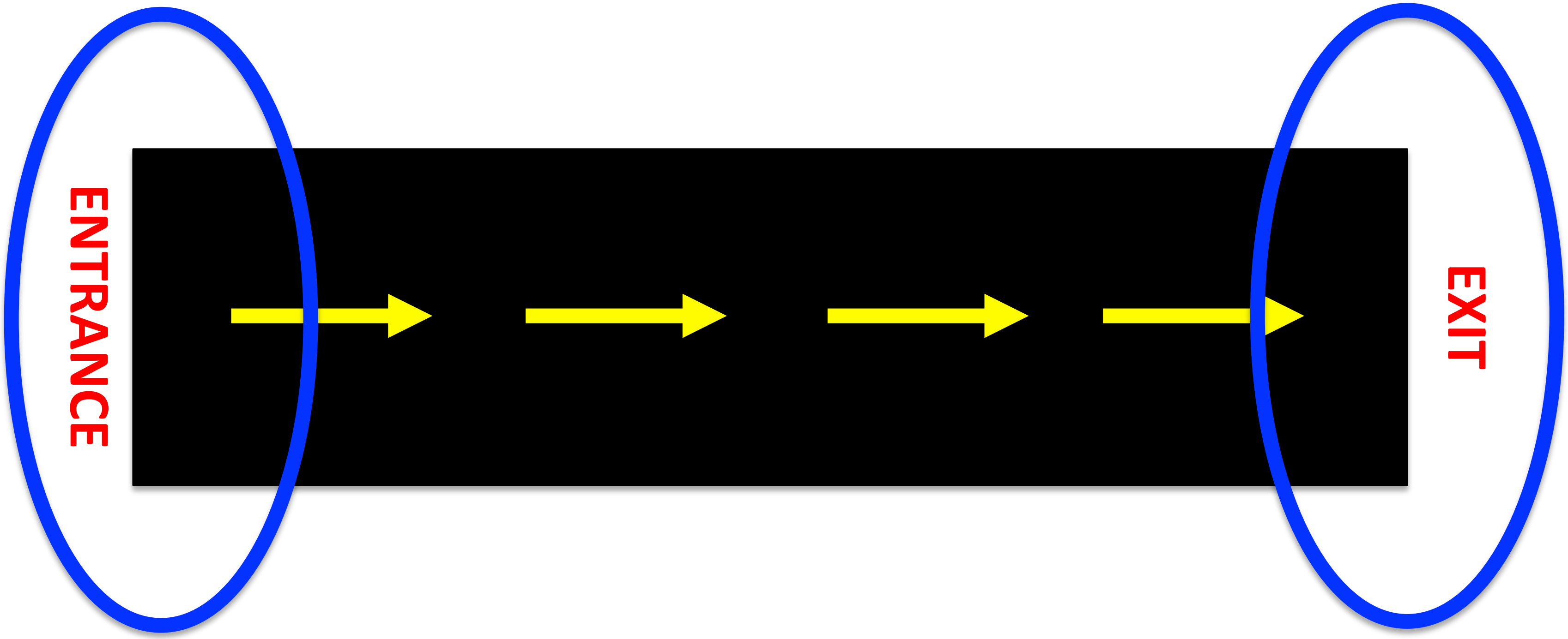


Photoeverywhere.co.uk

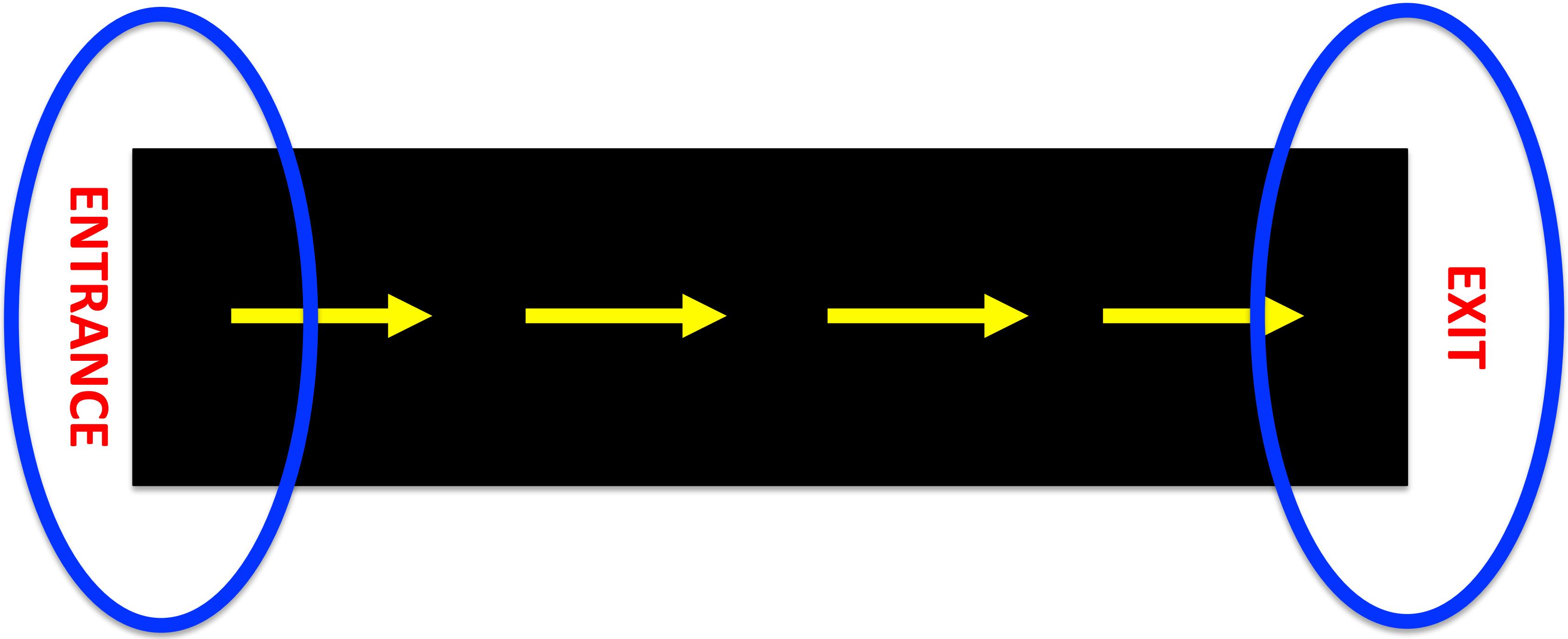
How do Jet Streams Impact the Weather?



How do Jet Streams Impact the Weather?

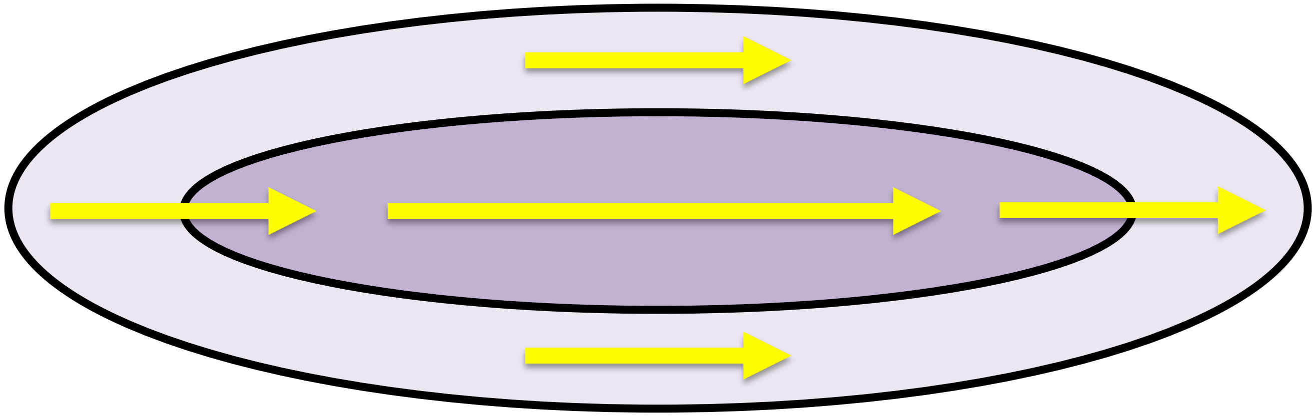


How do Jet Streams Impact the Weather?



Areas where there is an acceleration or deceleration are important for generating clumsiness

How do Jet Streams Impact the Weather?

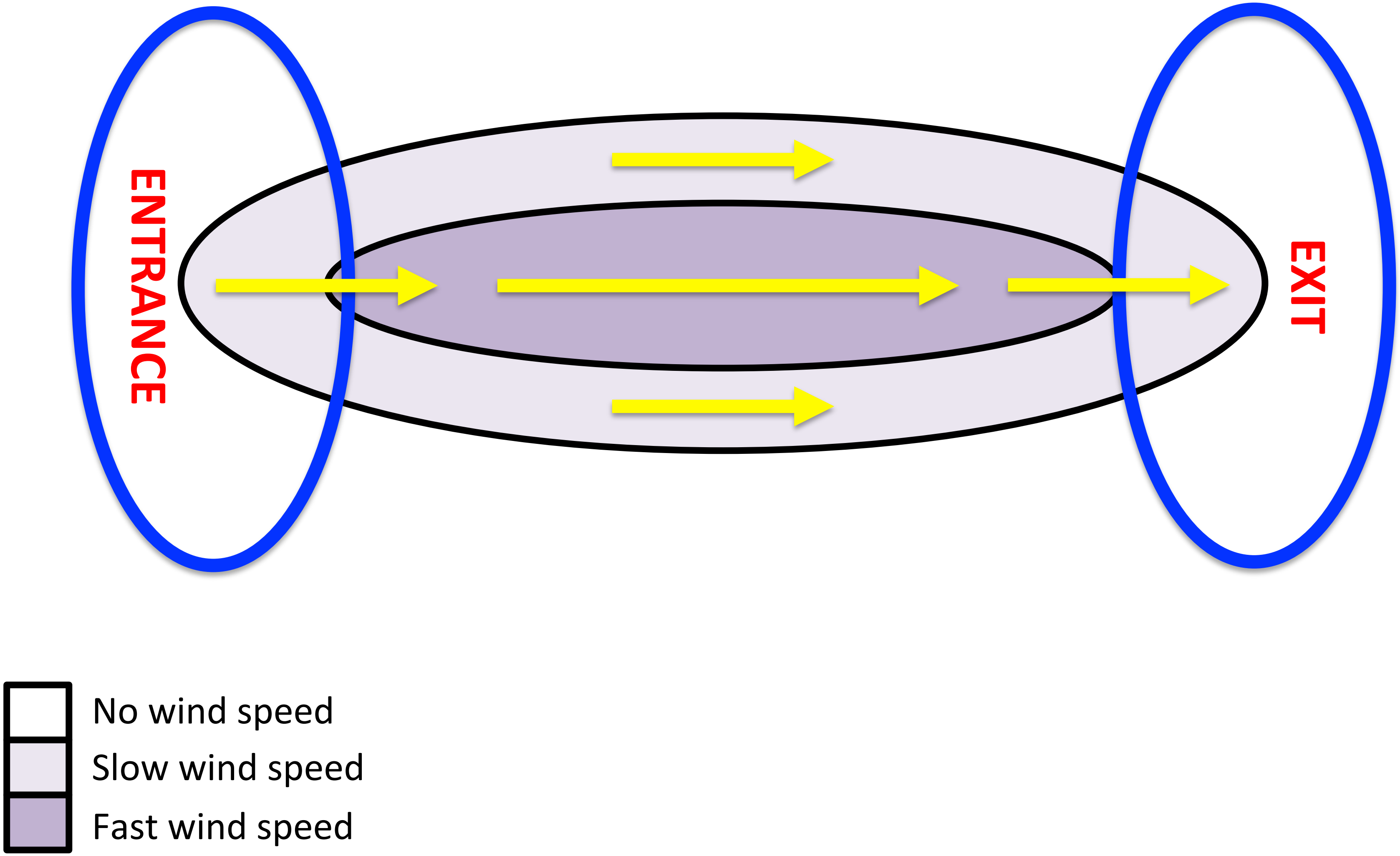


□ No wind speed

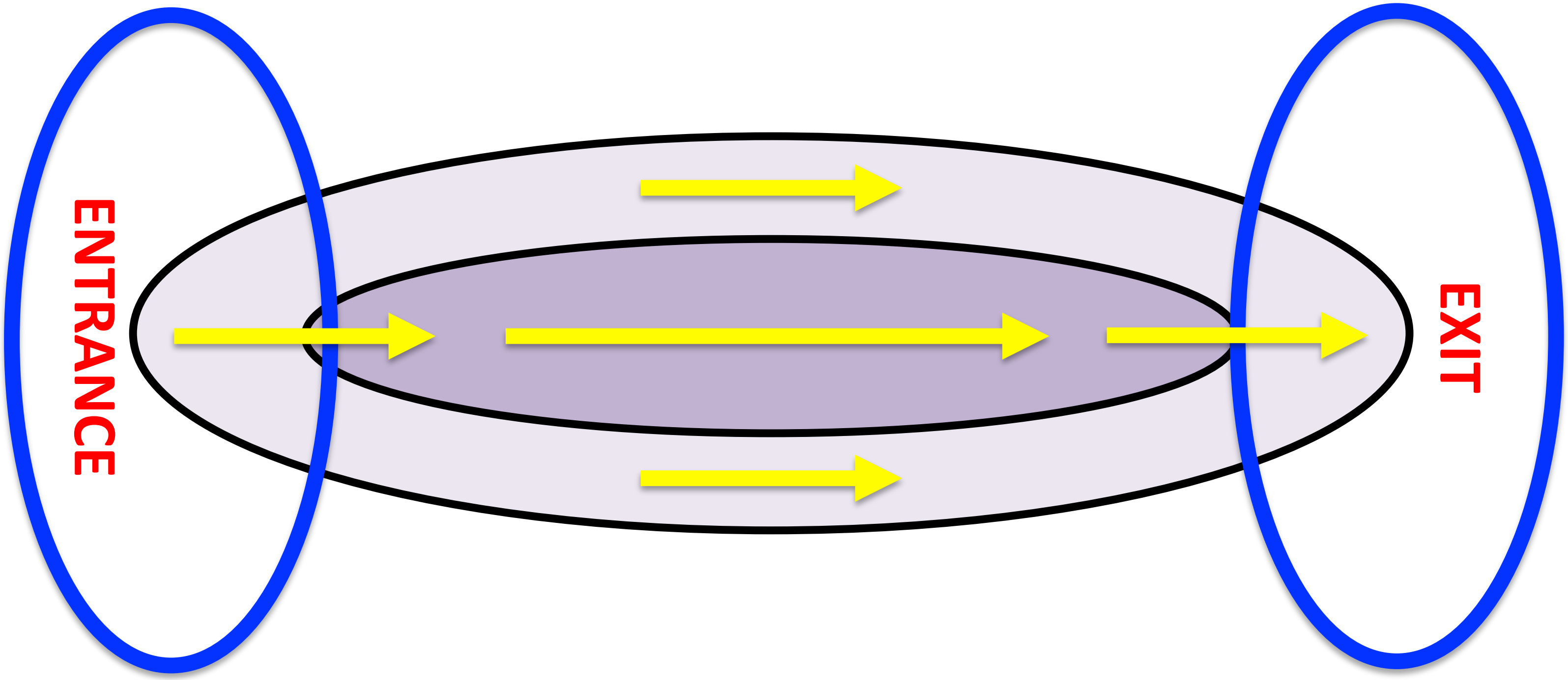
▨ Slow wind speed

■ Fast wind speed

How do Jet Streams Impact the Weather?



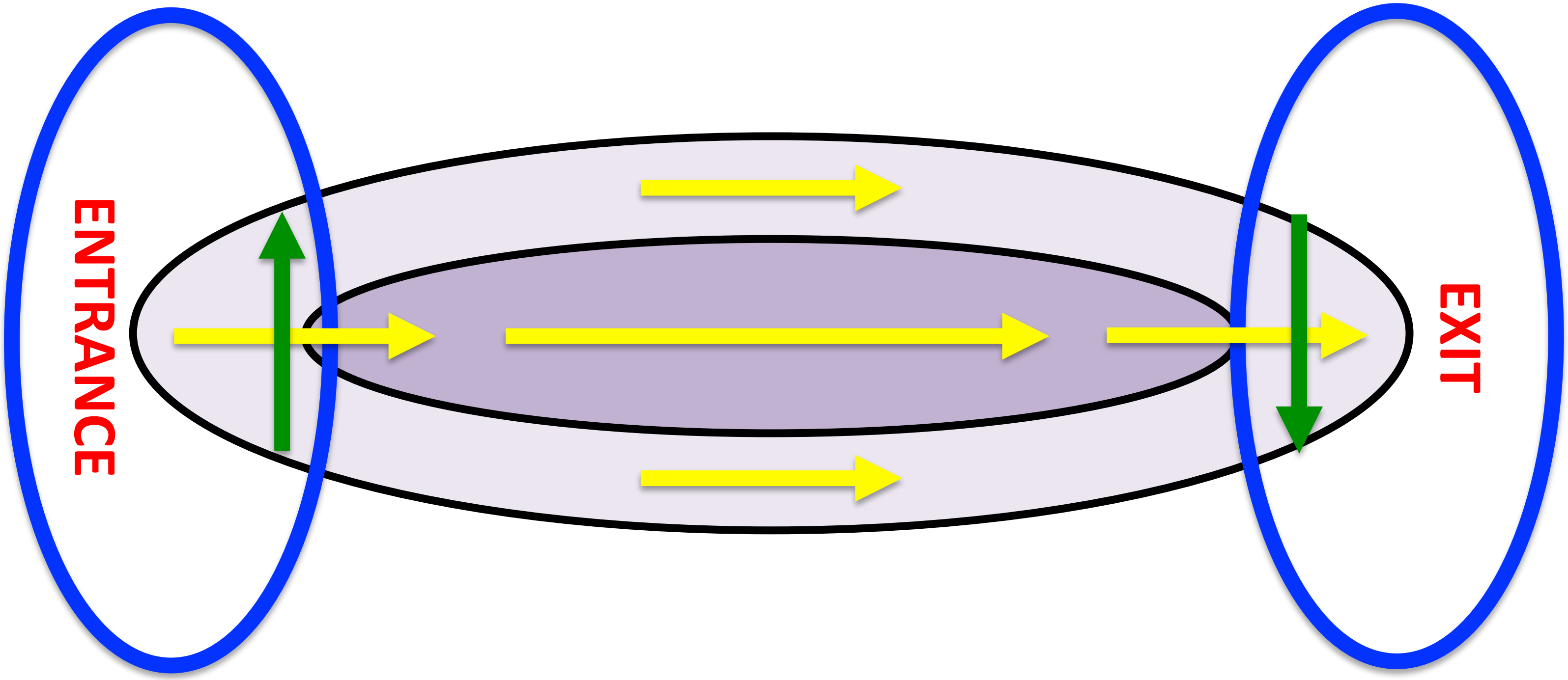
How do Jet Streams Impact the Weather?



- ☐ No wind speed
- ▨ Slow wind speed
- ■ Fast wind speed

Areas where the wind is accelerating or decelerating are important for generating weather

How do Jet Streams Impact the Weather?



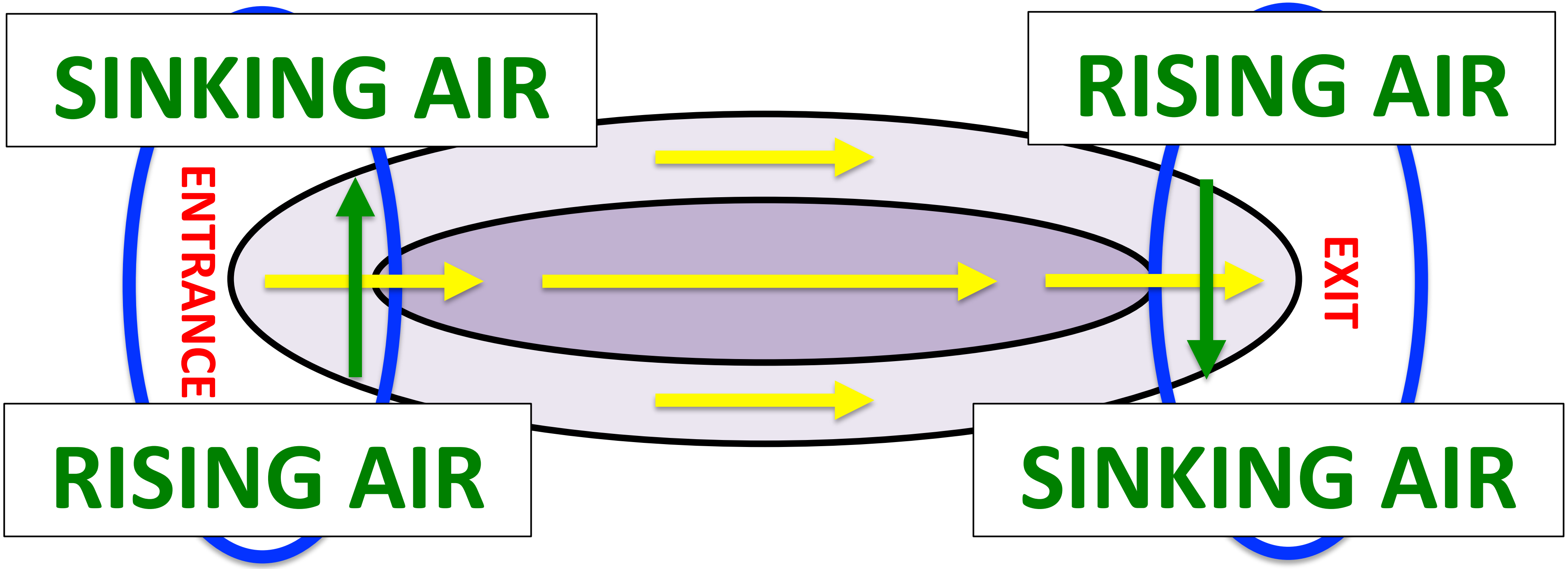
☐ No wind speed

▨ Slow wind speed

▩ Fast wind speed

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

How do Jet Streams Impact the Weather?



SINKING AIR

RISING AIR

RISING AIR

SINKING AIR

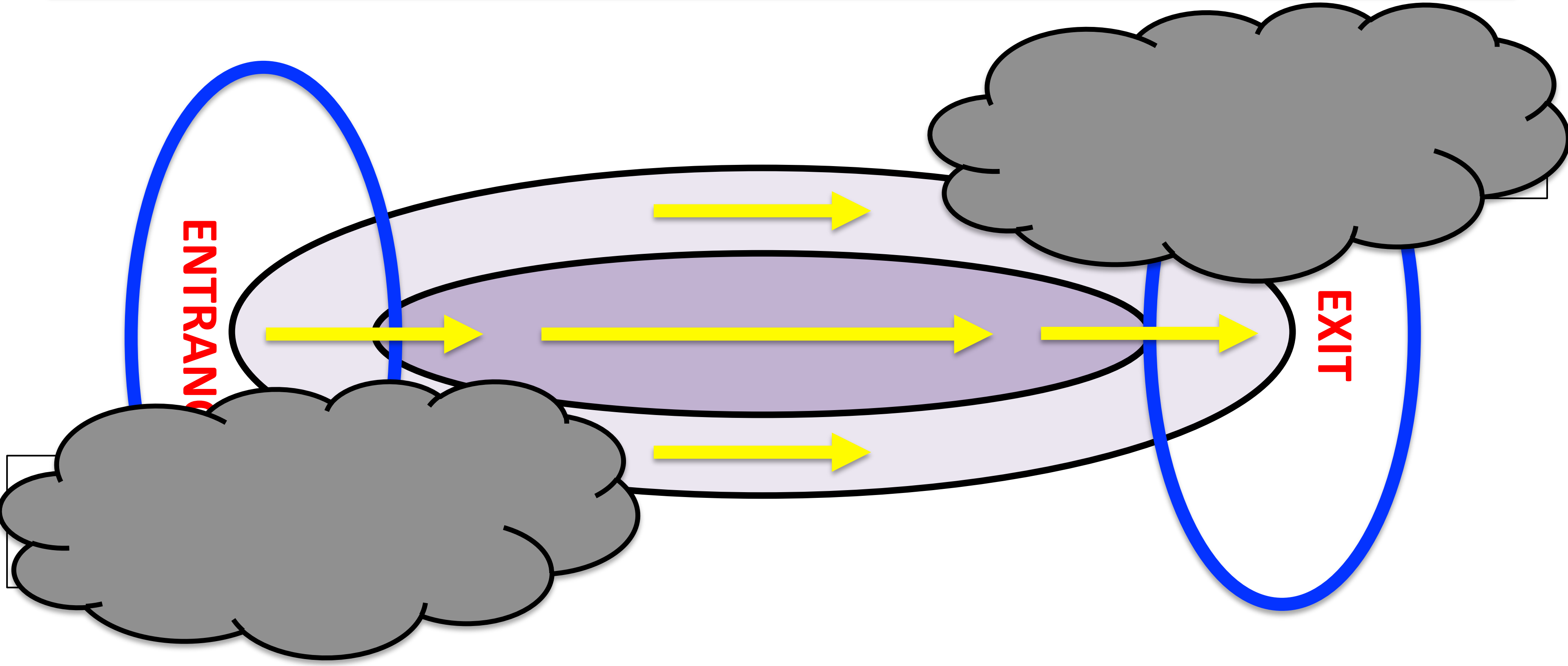
☐ No wind speed

▨ Slow wind speed

▨ Fast wind speed

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

How do Jet Streams Impact the Weather?



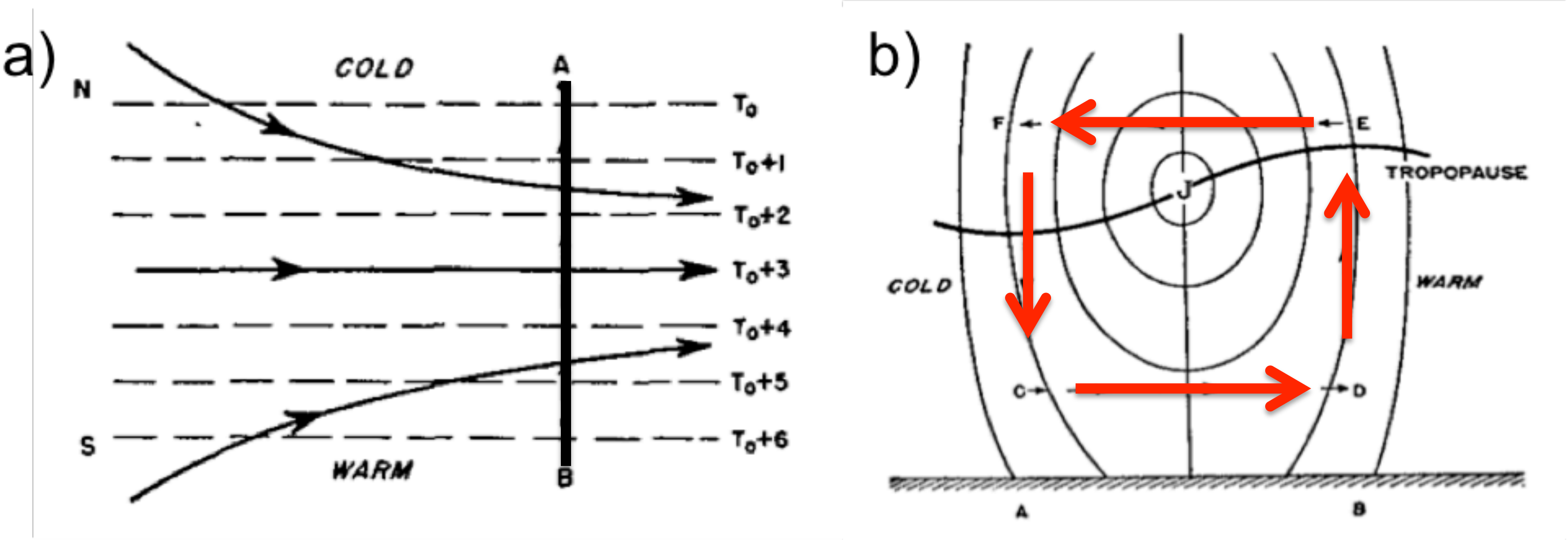
- No wind speed
- Slow wind speed
- Fast wind speed

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

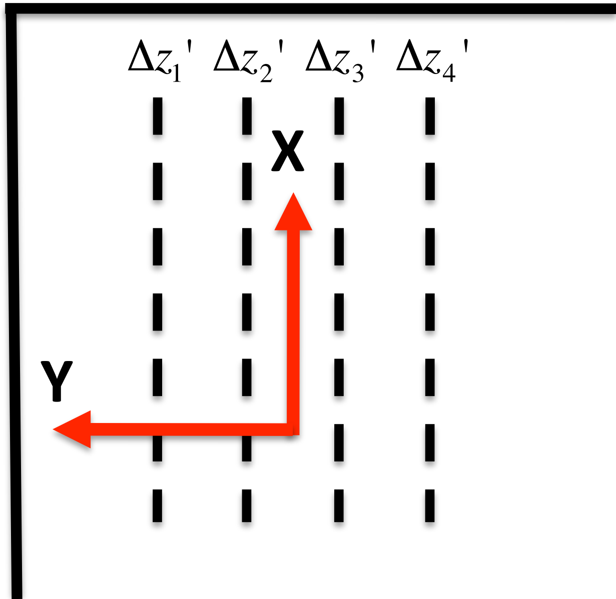
$$(-\gamma\frac{\partial\theta}{\partial p})\frac{\partial^2\psi}{\partial y^2}+(2\frac{\partial M}{\partial p})\frac{\partial^2\psi}{\partial p\,\partial y}+(-\frac{\partial M}{\partial y})\frac{\partial^2\psi}{\partial p^2}=Q_g-\gamma\frac{\partial}{\partial y}(\frac{d\theta}{dt})$$

Where:

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

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

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



Sawyer–Eliassen Circulation Equation

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

Static Stability
Across-Front Baroclinicity
Horizontal Relative Vorticity

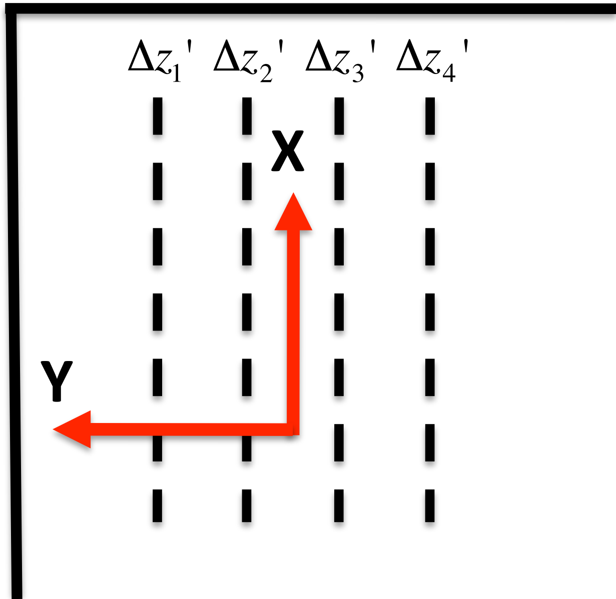
Frontal Characteristics

Where:

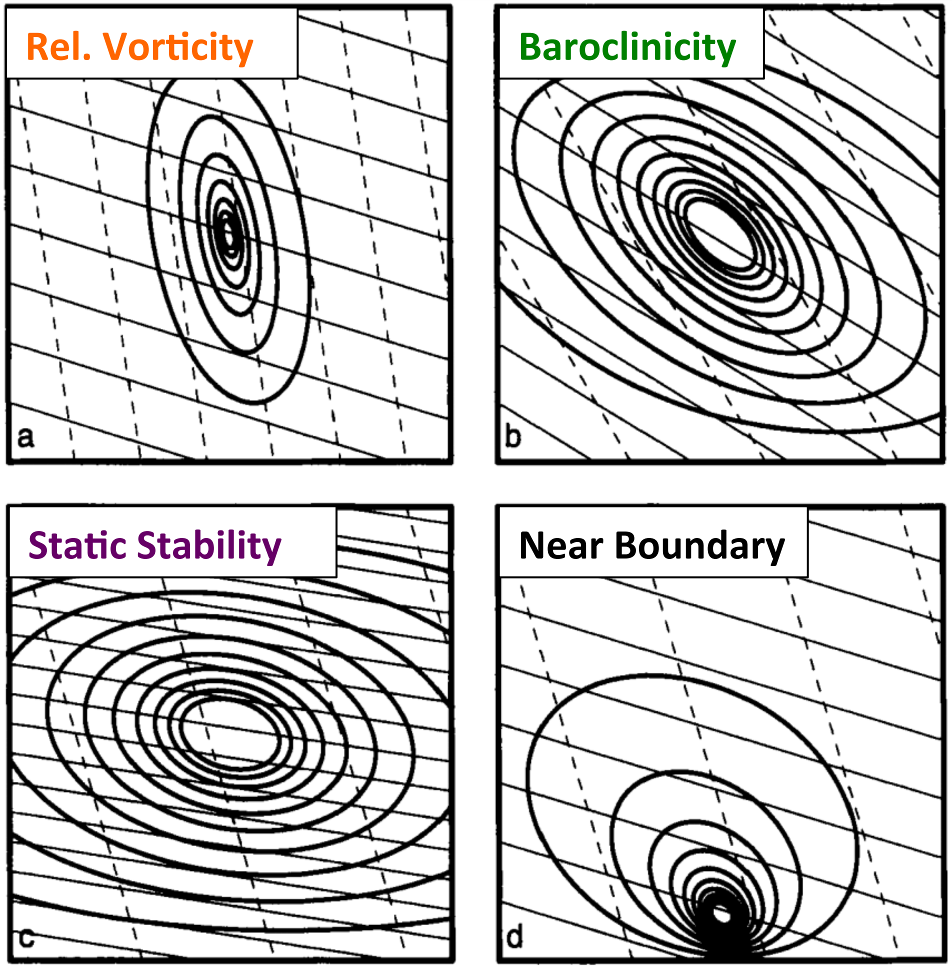
$$\omega = \frac{\partial\psi}{\partial y}$$

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

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



Sawyer–Eliassen Circulation Equation



Hakim and Keyser (2001)

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

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

Sawyer–Eliassen Circulation Equation

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

Static Stability
Across-Front Baroclinicity
Horizontal Relative Vorticity

Frontal Characteristics

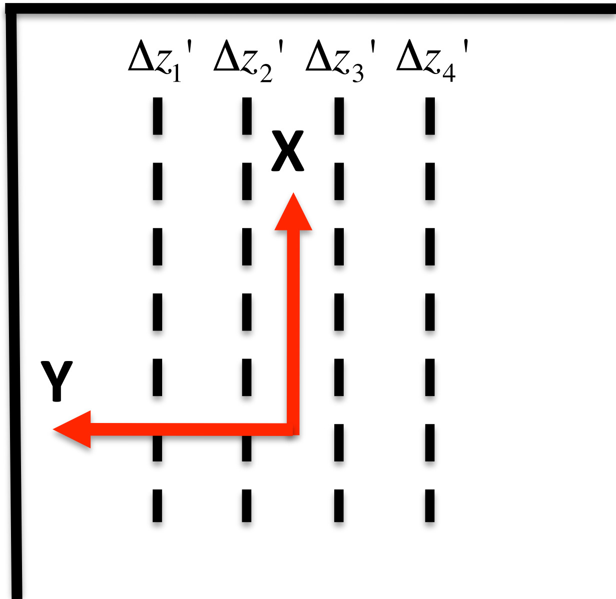
Geostrophic and Diabatic Forcing

Where:

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

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

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



Sawyer–Eliassen Circulation Equation

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

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

Sawyer–Eliassen Circulation Equation

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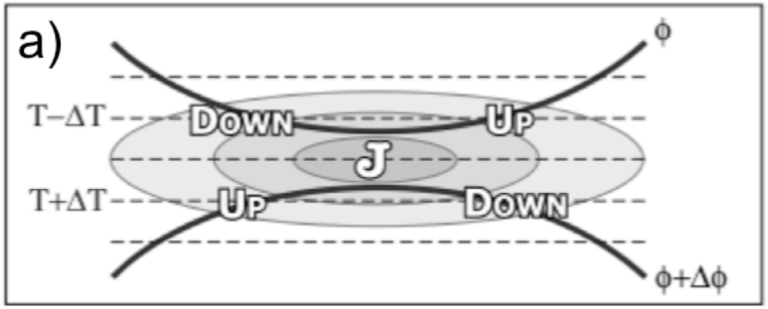
No Temp. Advection



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

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

Lang and Martin (2012)

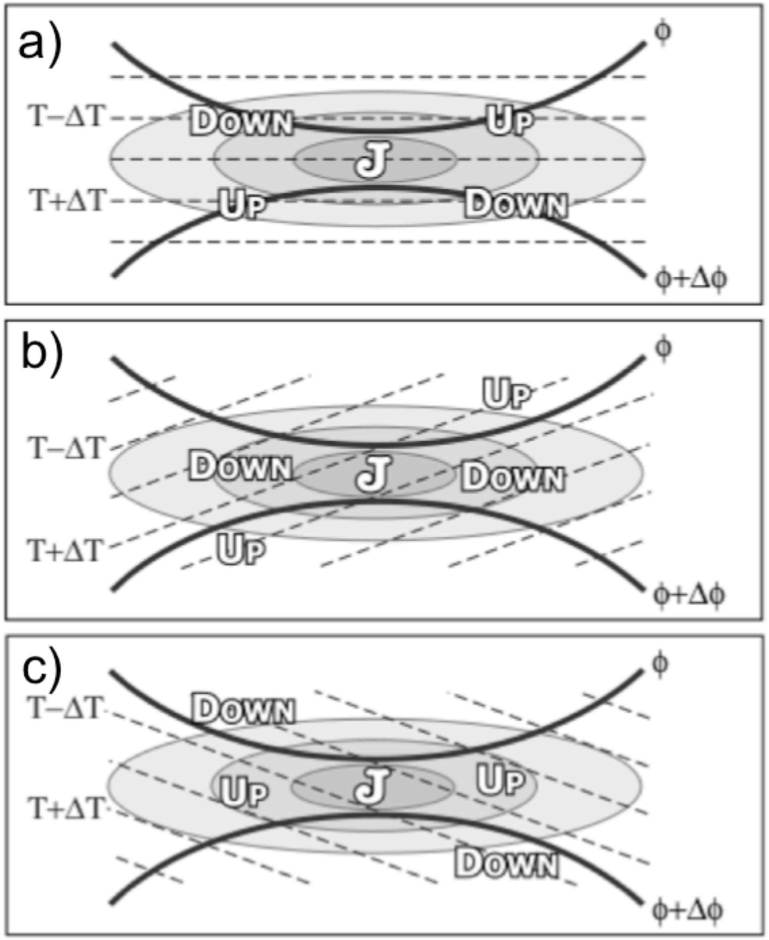
Sawyer–Eliassen Circulation Equation

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

No Temp. Advection

Geo. CAA

Geo. WAA

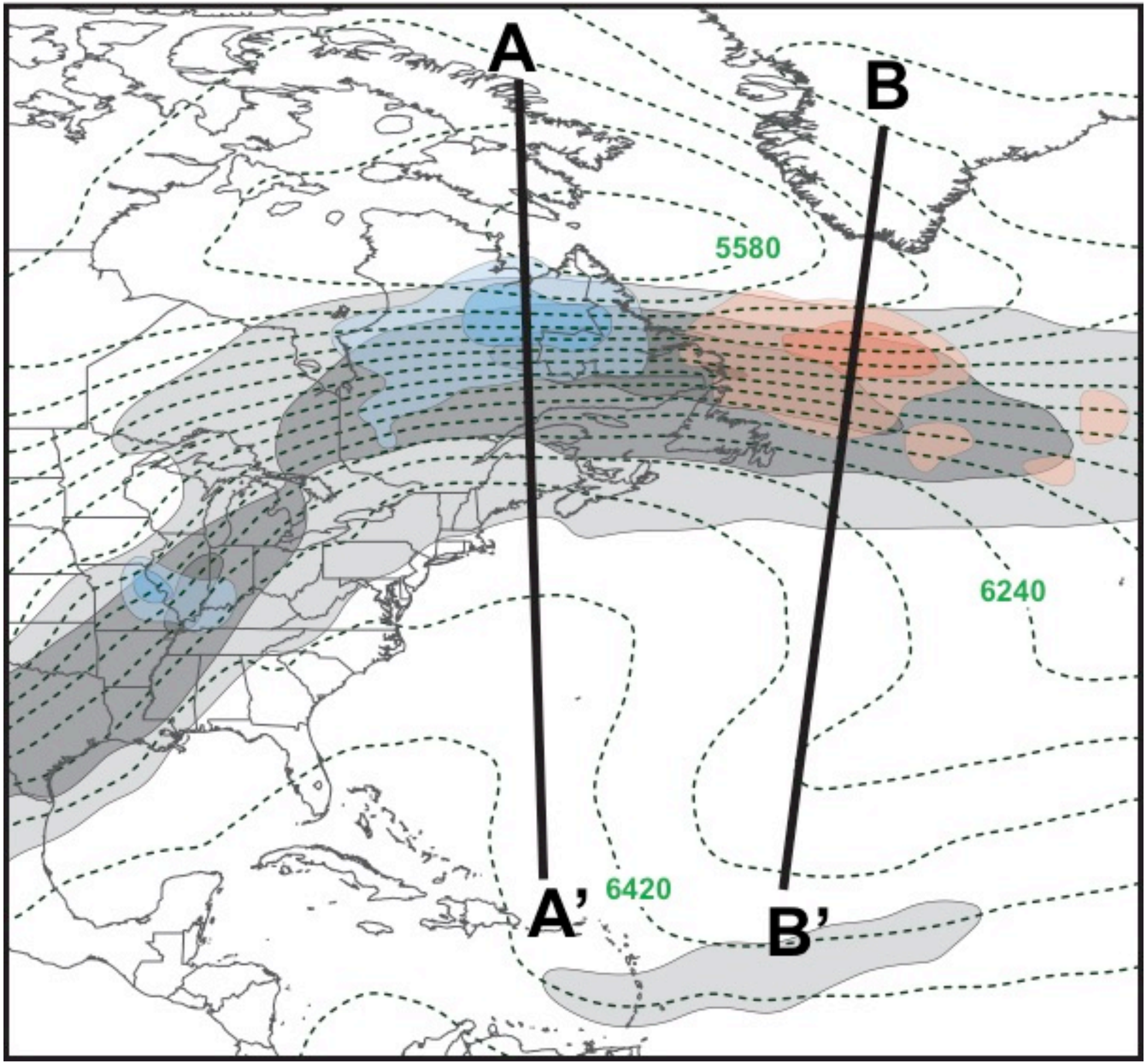


$$Q_g=2\gamma(\underbrace{\frac{\partial U_g}{\partial y}\frac{\partial\theta}{\partial x}}_{\text{Shearing}}+\underbrace{\frac{\partial V_g}{\partial y}\frac{\partial\theta}{\partial y}}_{\text{Confluence}})$$

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

Lang and Martin (2012)

Sawyer–Eliassen Circulation Equation

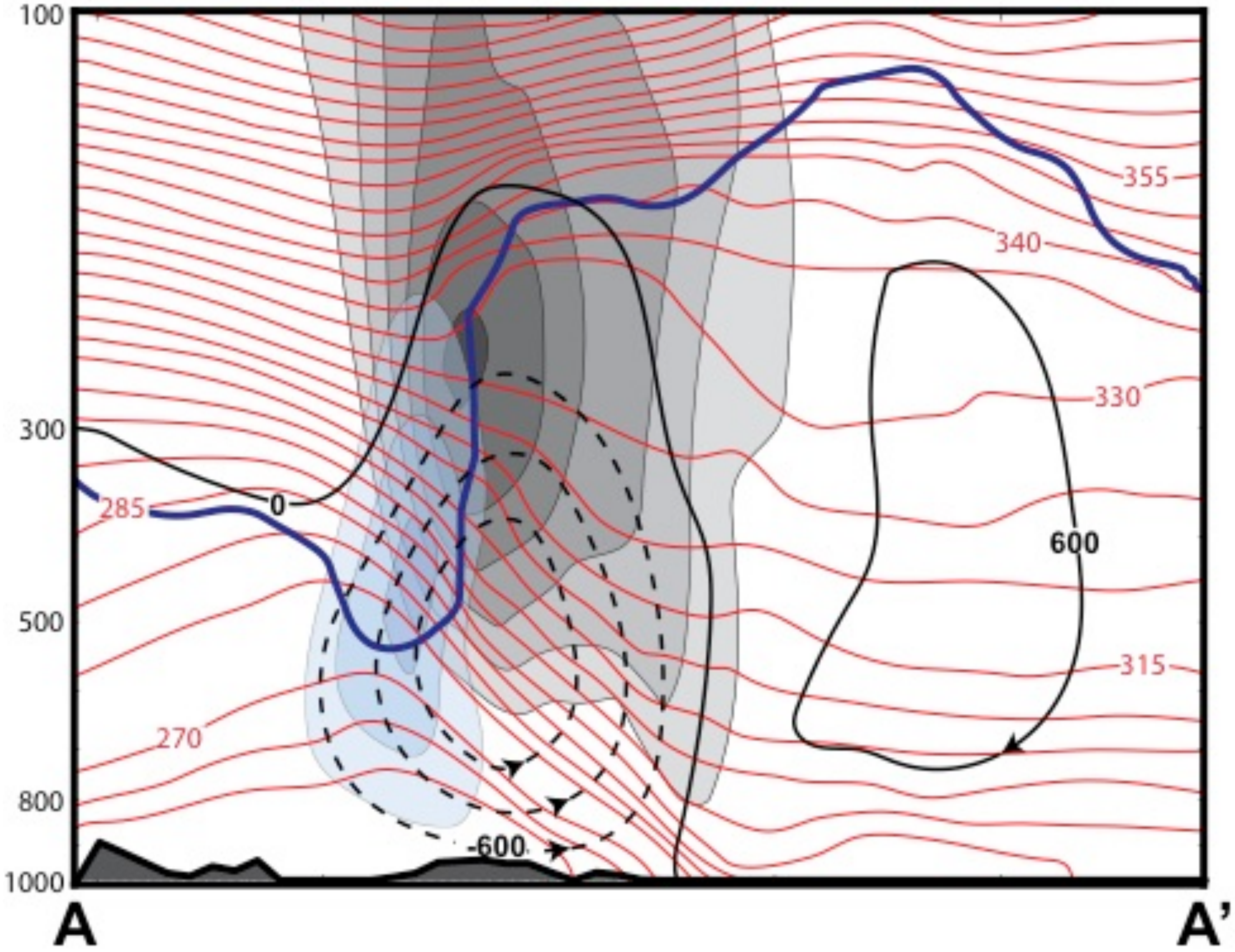


1200 UTC
22 Dec 2013

Geo. CAA in the jet entrance region

Geo. WAA in the jet exit region

Sawyer–Eliassen Circulation Equation

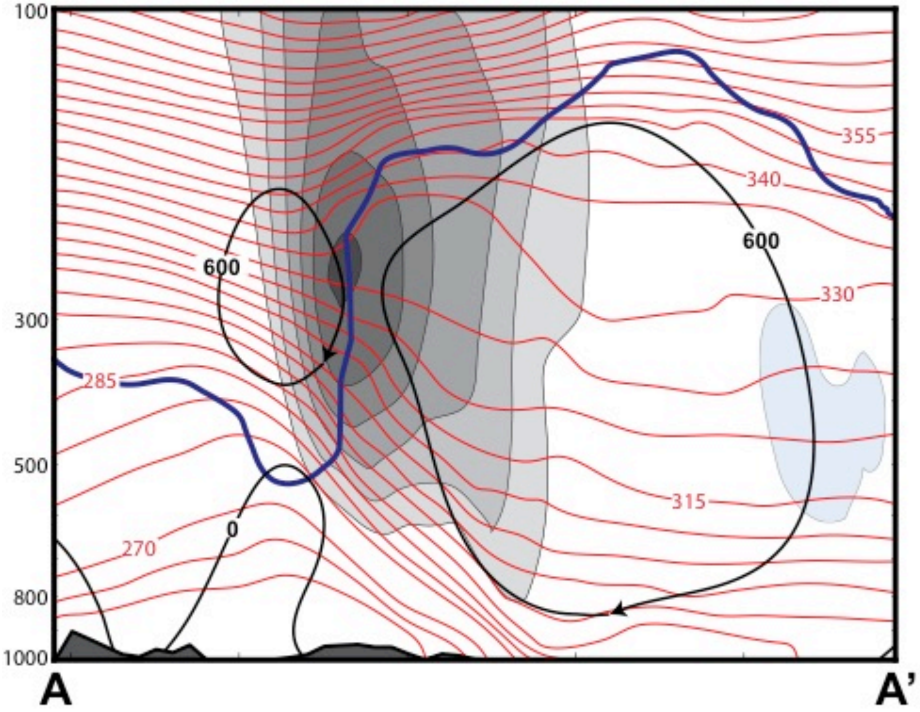


1200 UTC
22 Dec 2013

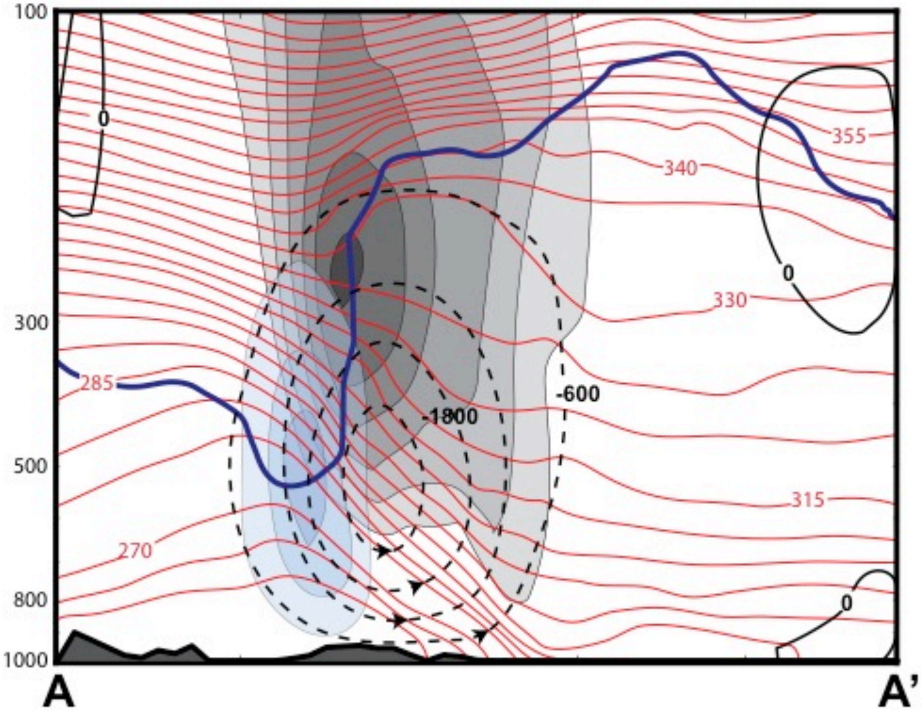
Subsidence is present slightly poleward of the jet core in association with a thermally direct circulation

Sawyer–Eliassen Circulation Equation

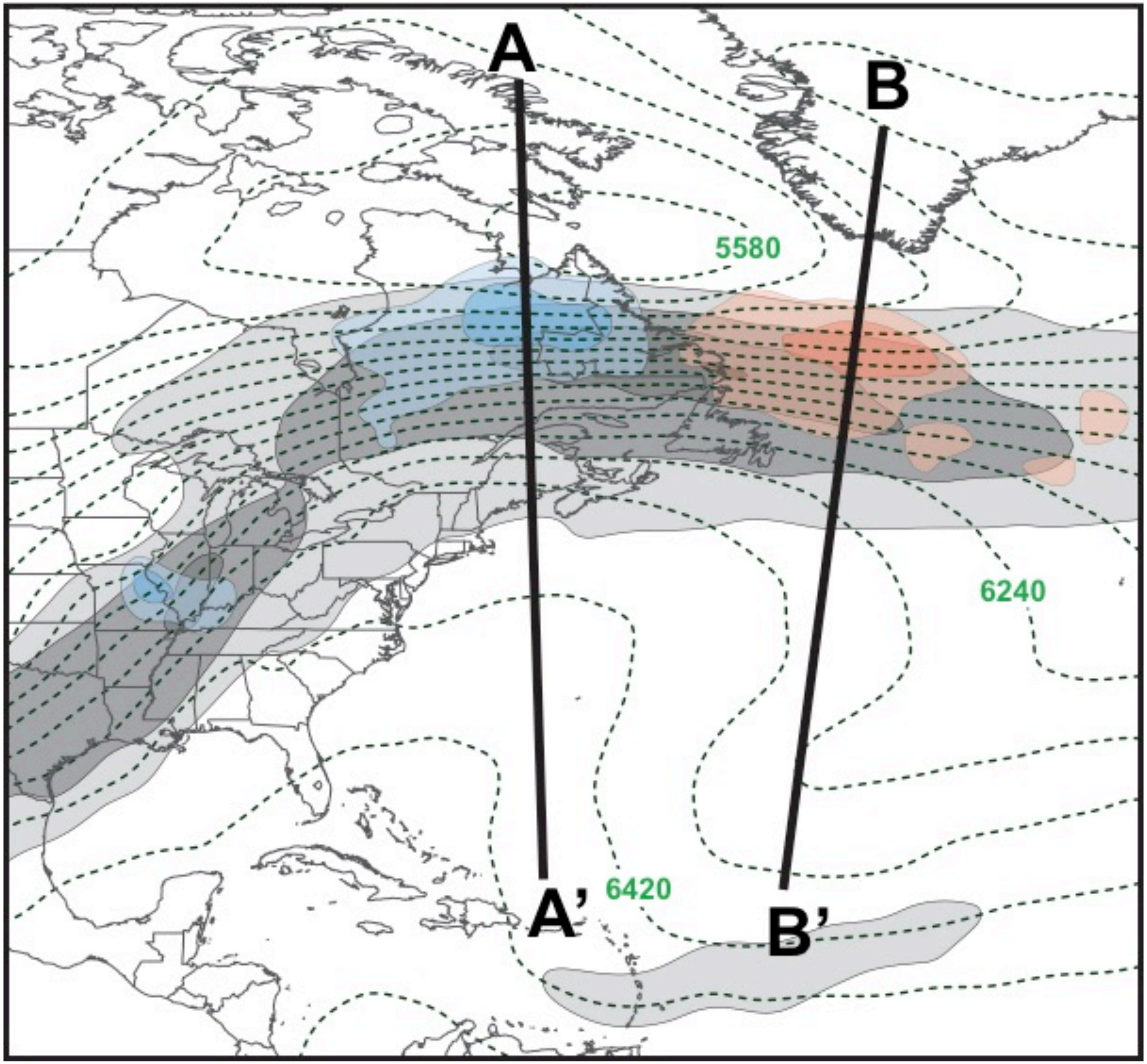
Shearing Term



Confluence Term



Sawyer–Eliassen Circulation Equation

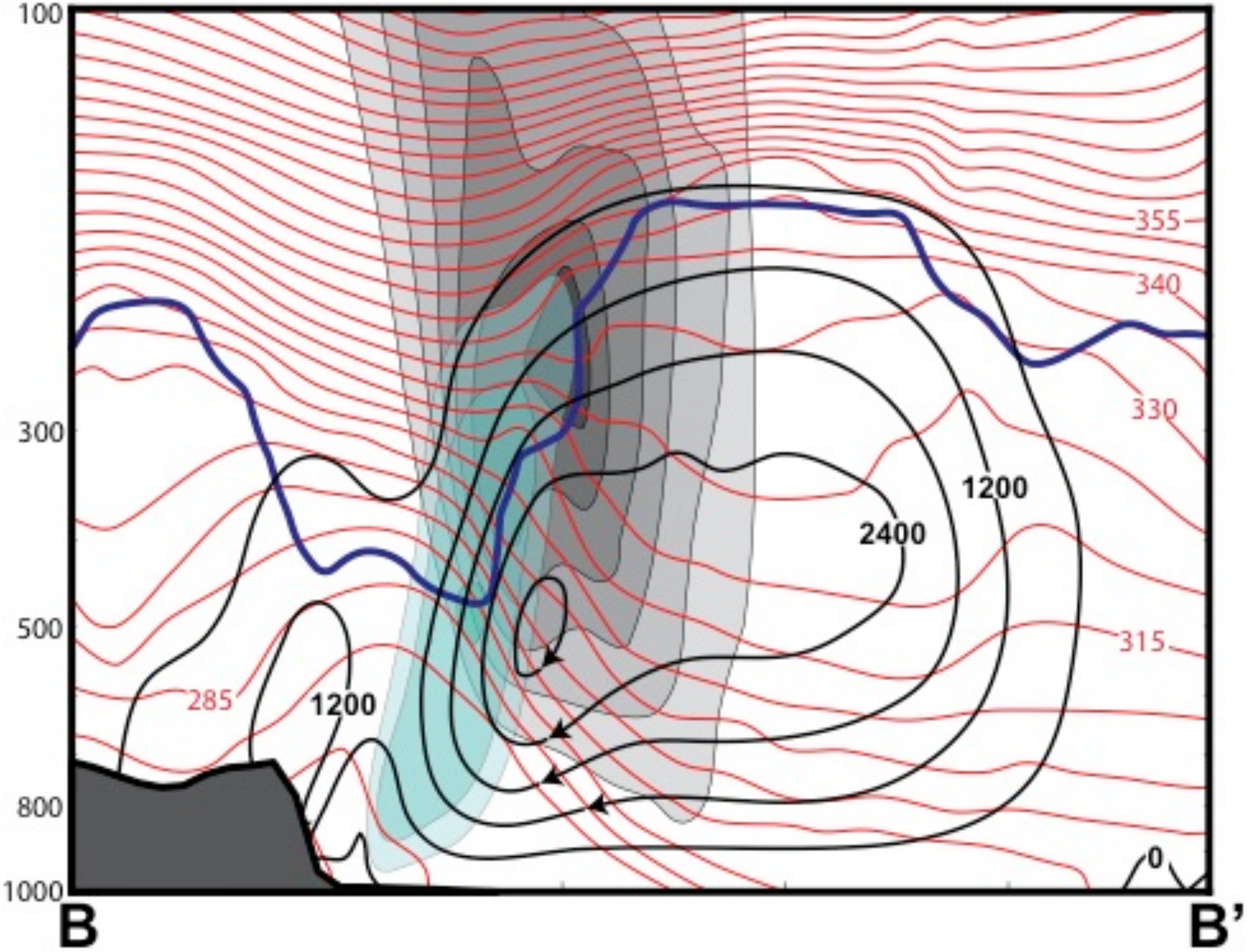


1200 UTC
22 Dec 2013

Geo. CAA in the jet entrance region

Geo. WAA in the jet exit region

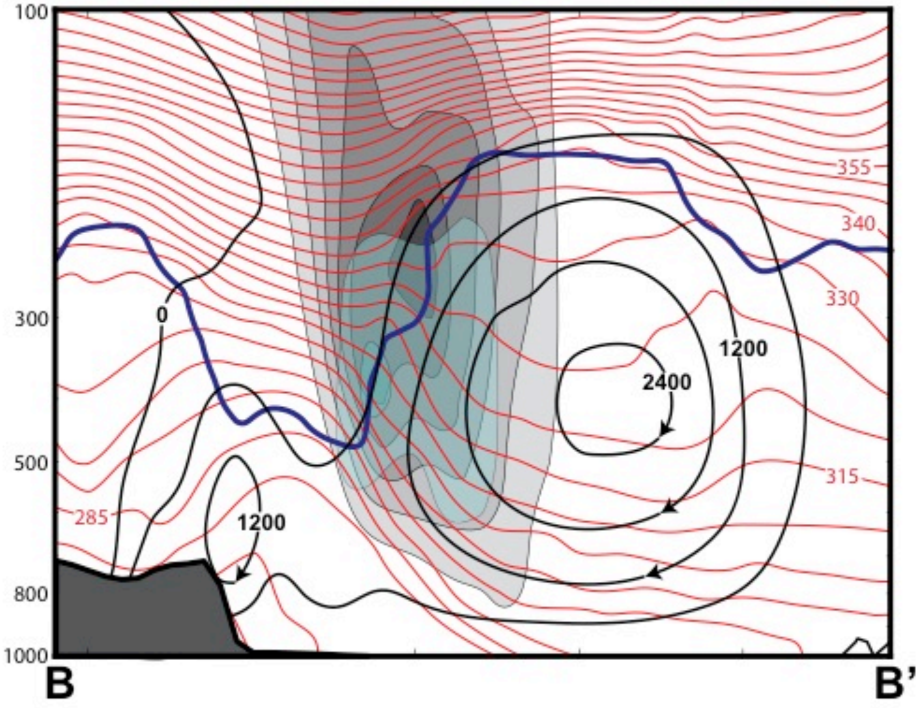
Sawyer–Eliassen Circulation Equation



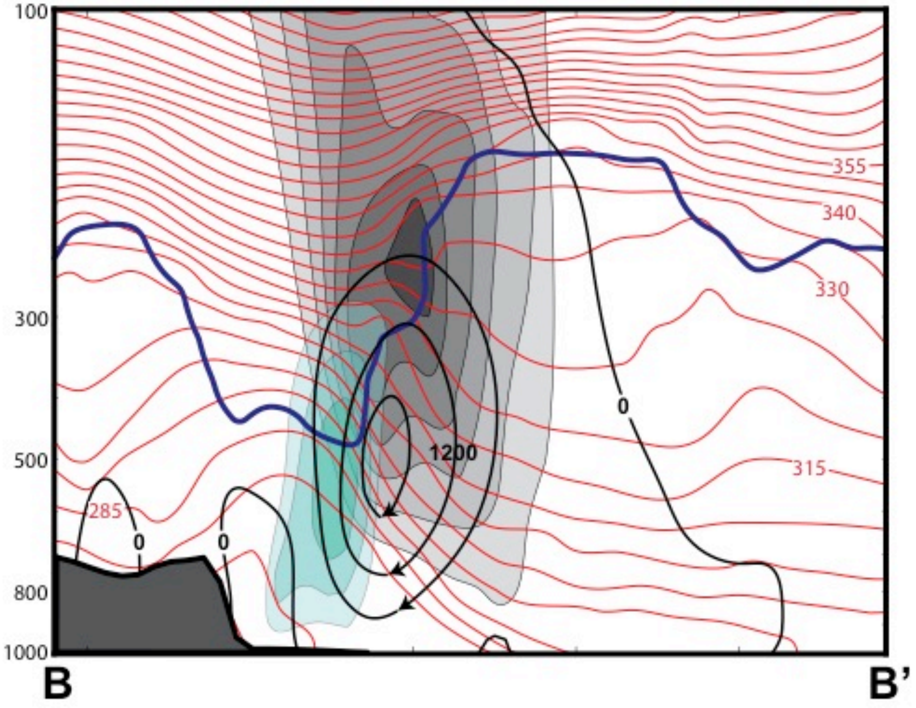
1200 UTC
22 Dec 2013

Ascent is present slightly poleward of the jet core in association with a thermally indirect circulation

Sawyer–Eliassen Circulation Equation



Shearing Term



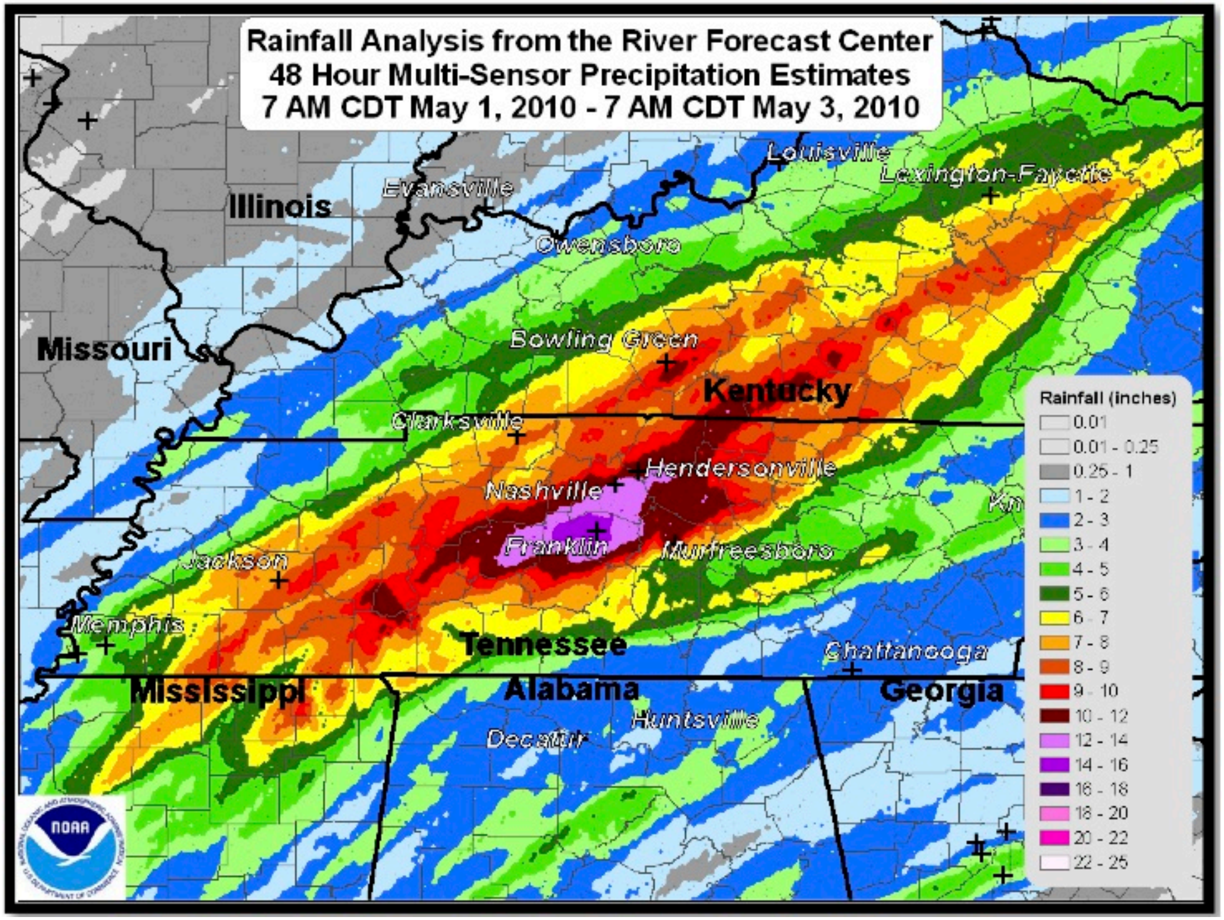
Confluence Term

Case Study:
1–3 May 2010 Nashville Flood

Winters and Martin 2014

1–3 May 2010 Nashville Flood

Record Setting Rainfall: 1–3 May 2010



Several repeated rounds of rainfall beginning during the early morning hours of 1 May

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

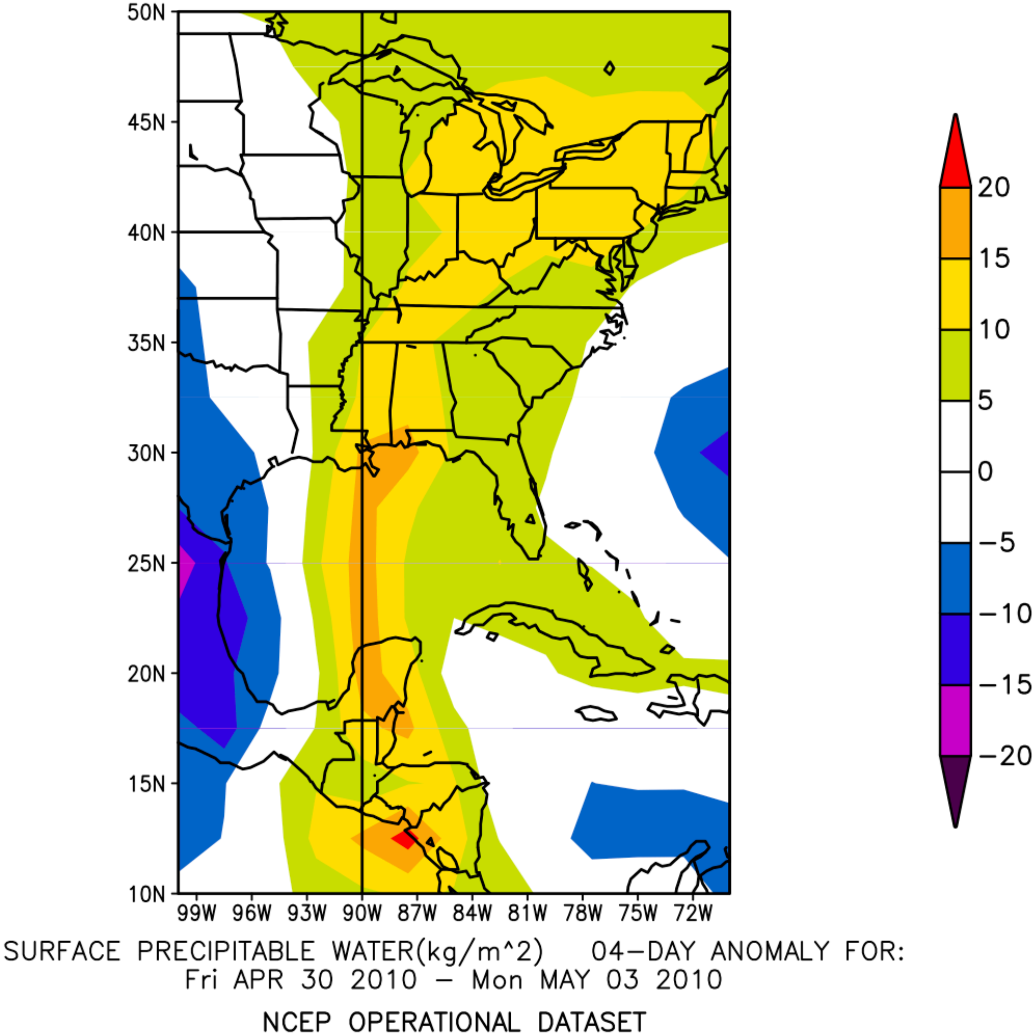
USGS

1–3 May 2010 Nashville Flood

Anomalous Moisture Flux

Atmospheric river helped to transport anomalously high Precipitable Water values into the eastern US (Moore et al. 2012)

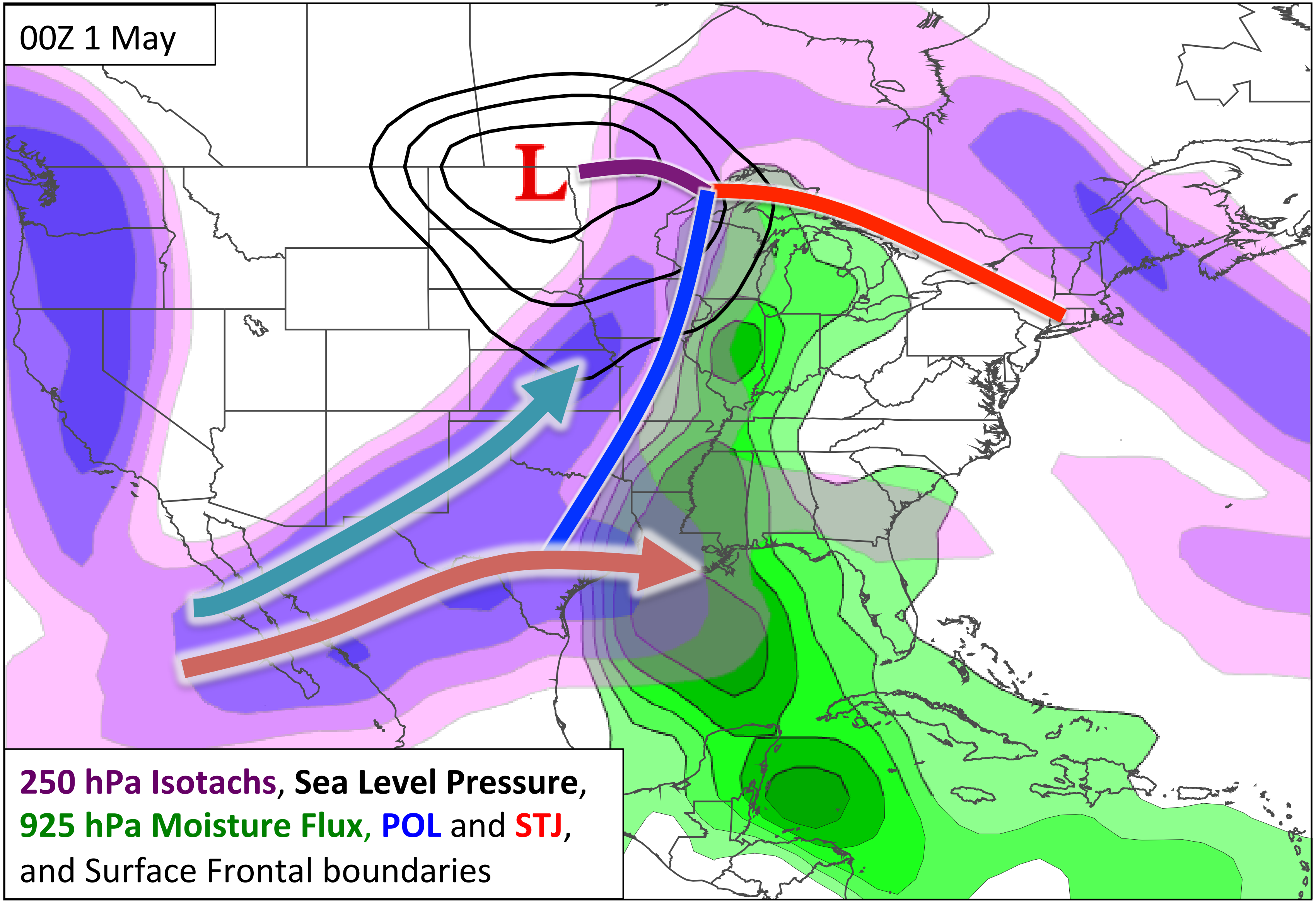
PWAT: 2.02 in. (00Z 5/2/10) Registers well above the 99th percentile for this time of year in Nashville (NOAA)



SURFACE PRECIPITABLE WATER(kg/m^2) 04-DAY ANOMALY FOR:
Fri APR 30 2010 – Mon MAY 03 2010

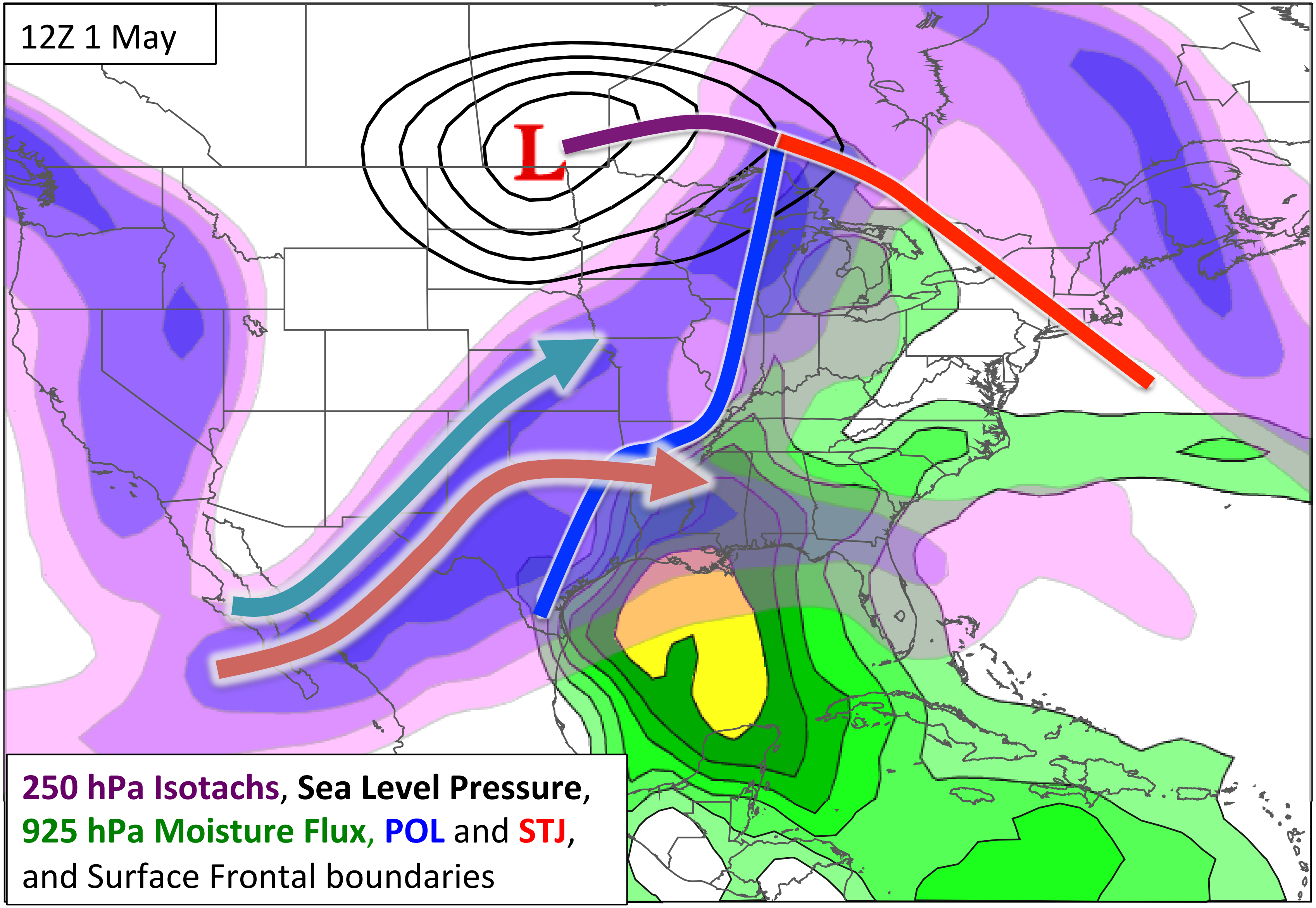
NCEP OPERATIONAL DATASET

1–3 May 2010 Nashville Flood



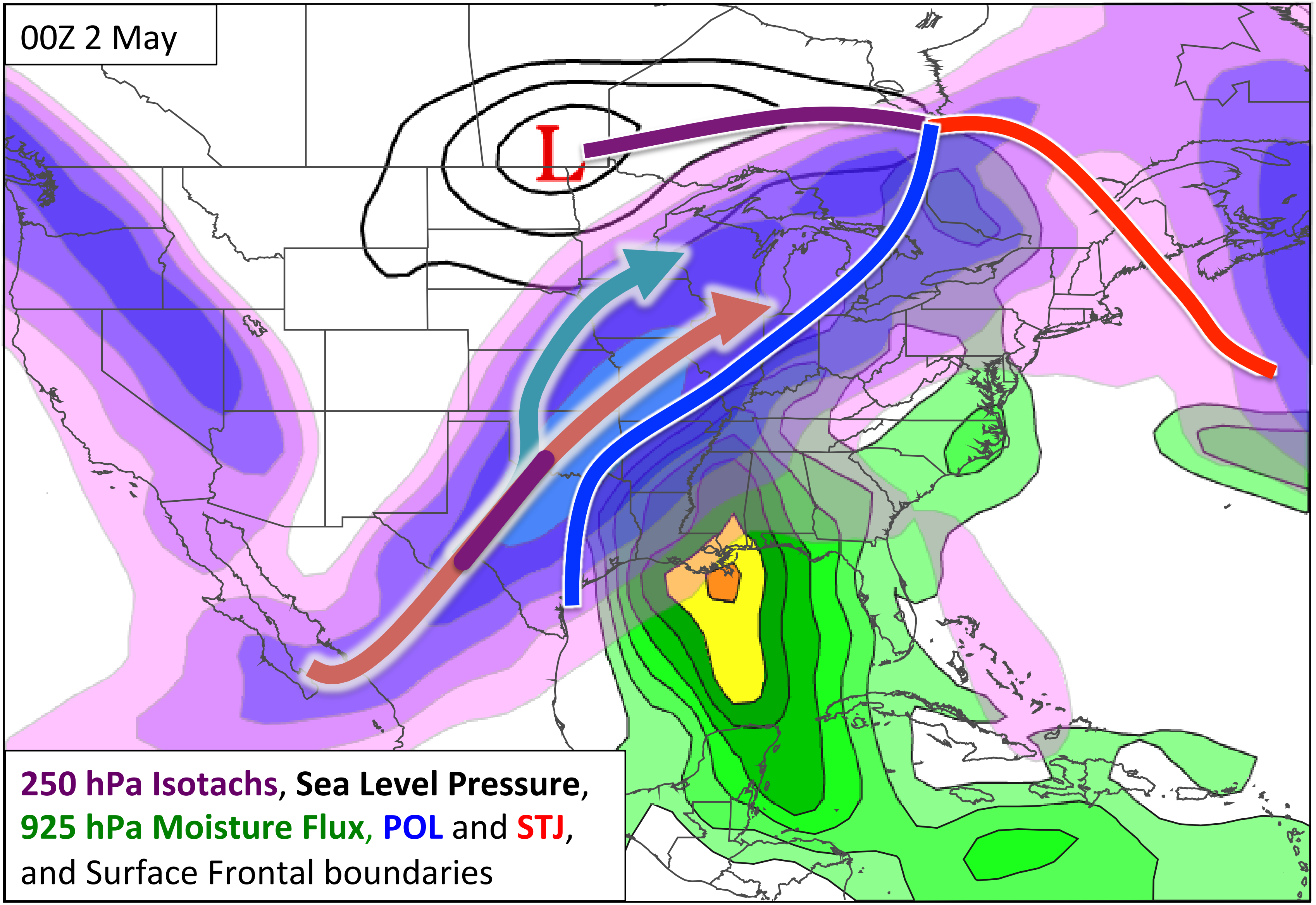
250 hPa Isotachs, **Sea Level Pressure**,
925 hPa Moisture Flux, **POL** and **STJ**,
and Surface Frontal boundaries

1–3 May 2010 Nashville Flood



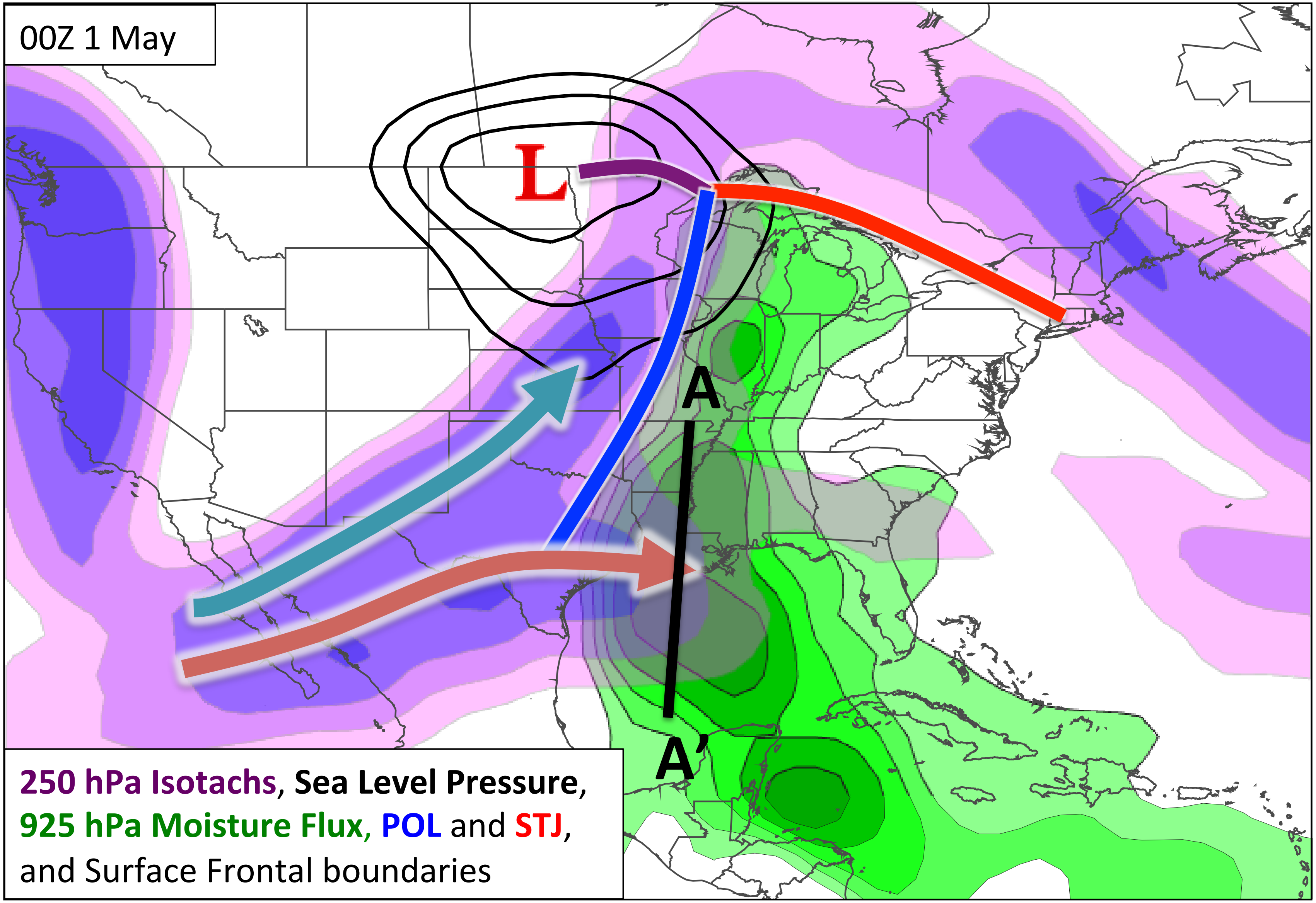
250 hPa Isotachs, **Sea Level Pressure**, **925 hPa Moisture Flux**, **POL** and **STJ**, and Surface Frontal boundaries

1–3 May 2010 Nashville Flood



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

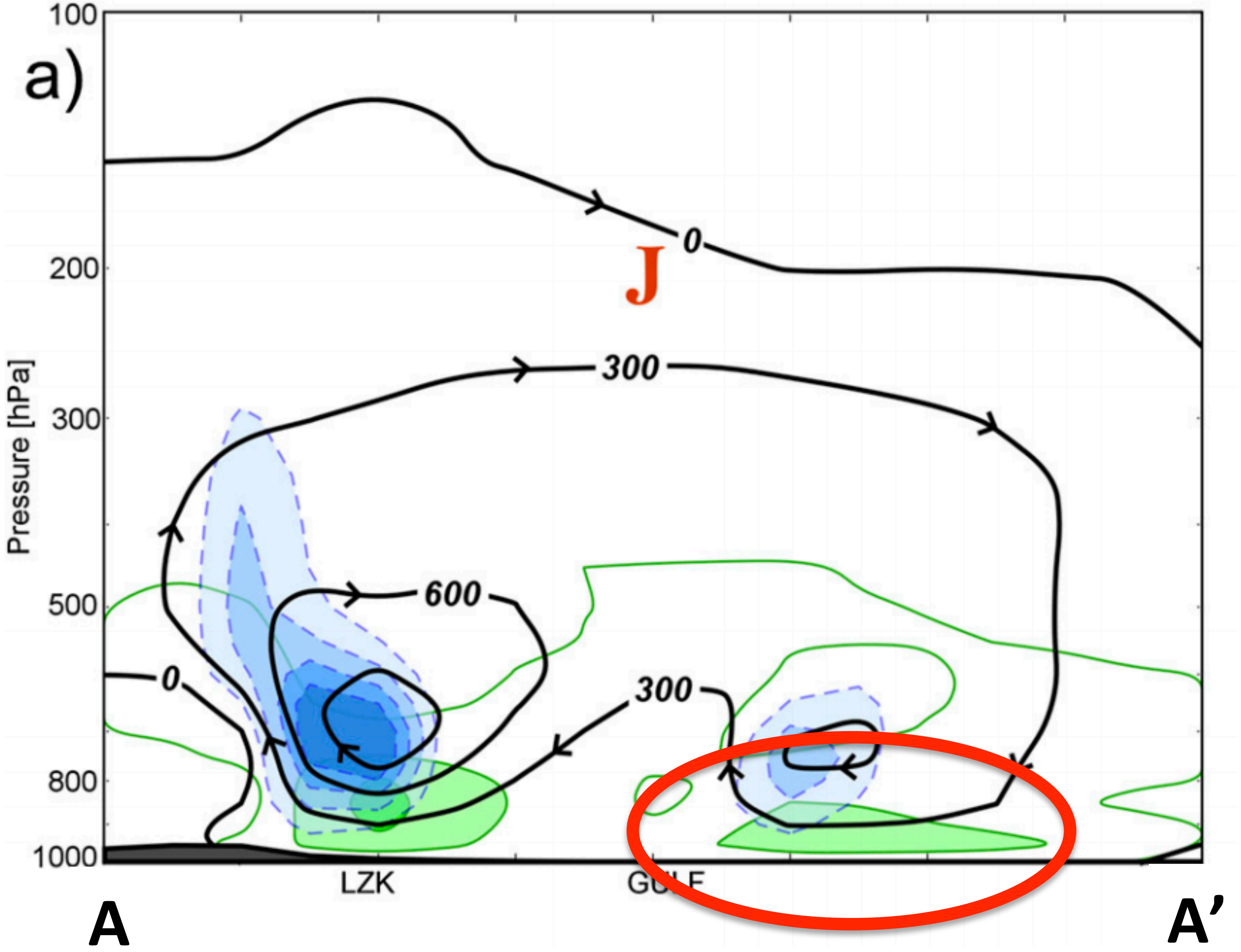
1–3 May 2010 Nashville Flood



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

1–3 May 2010 Nashville Flood

1 May 2010 – Subtropical Jet Circulation



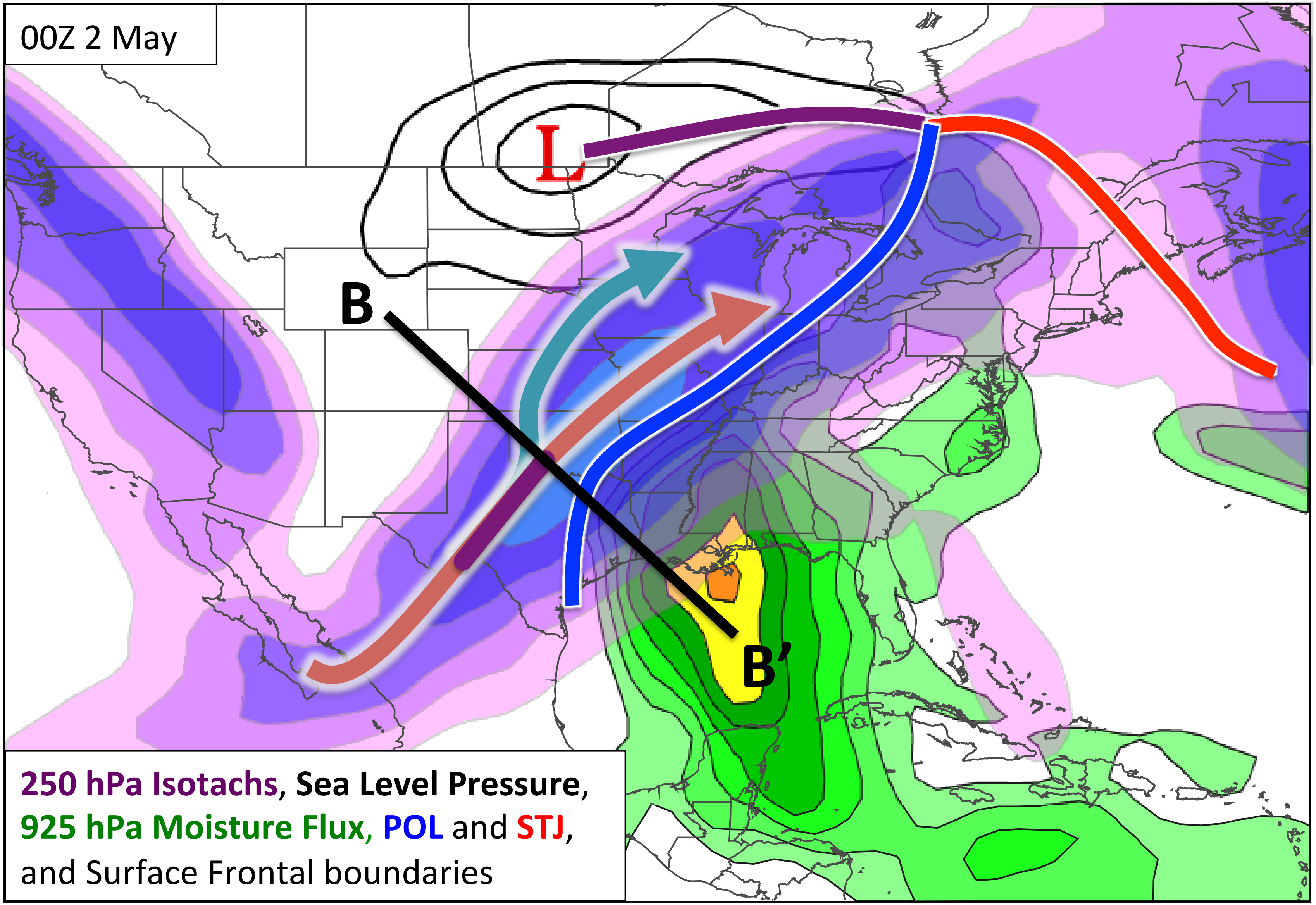
Streamlines (m hPa s^{-1})

negative omega (dPa)

moisture flux every 3 cm s^{-1}

Max moisture flux ~ 5 cm s^{-1}

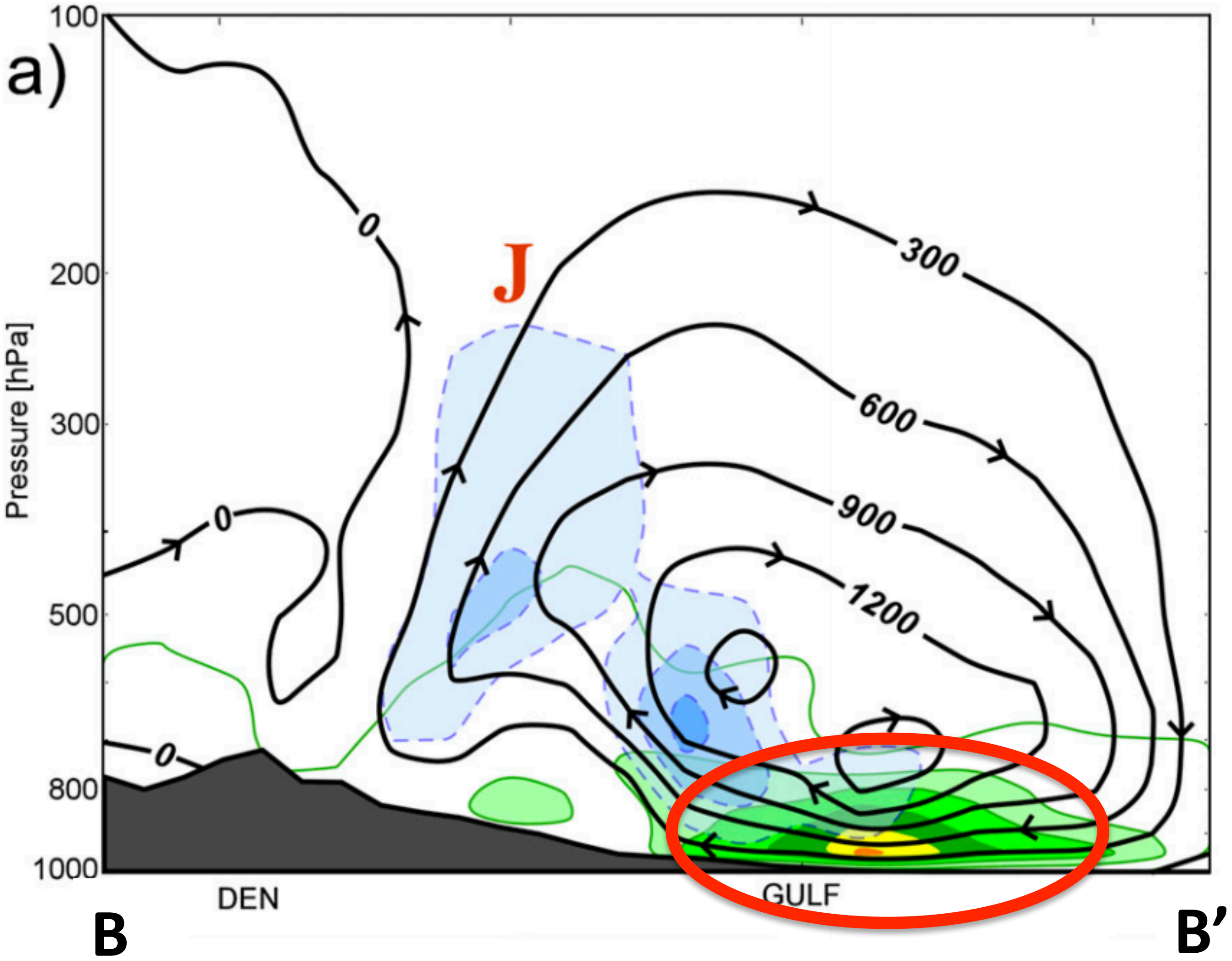
1–3 May 2010 Nashville Flood



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



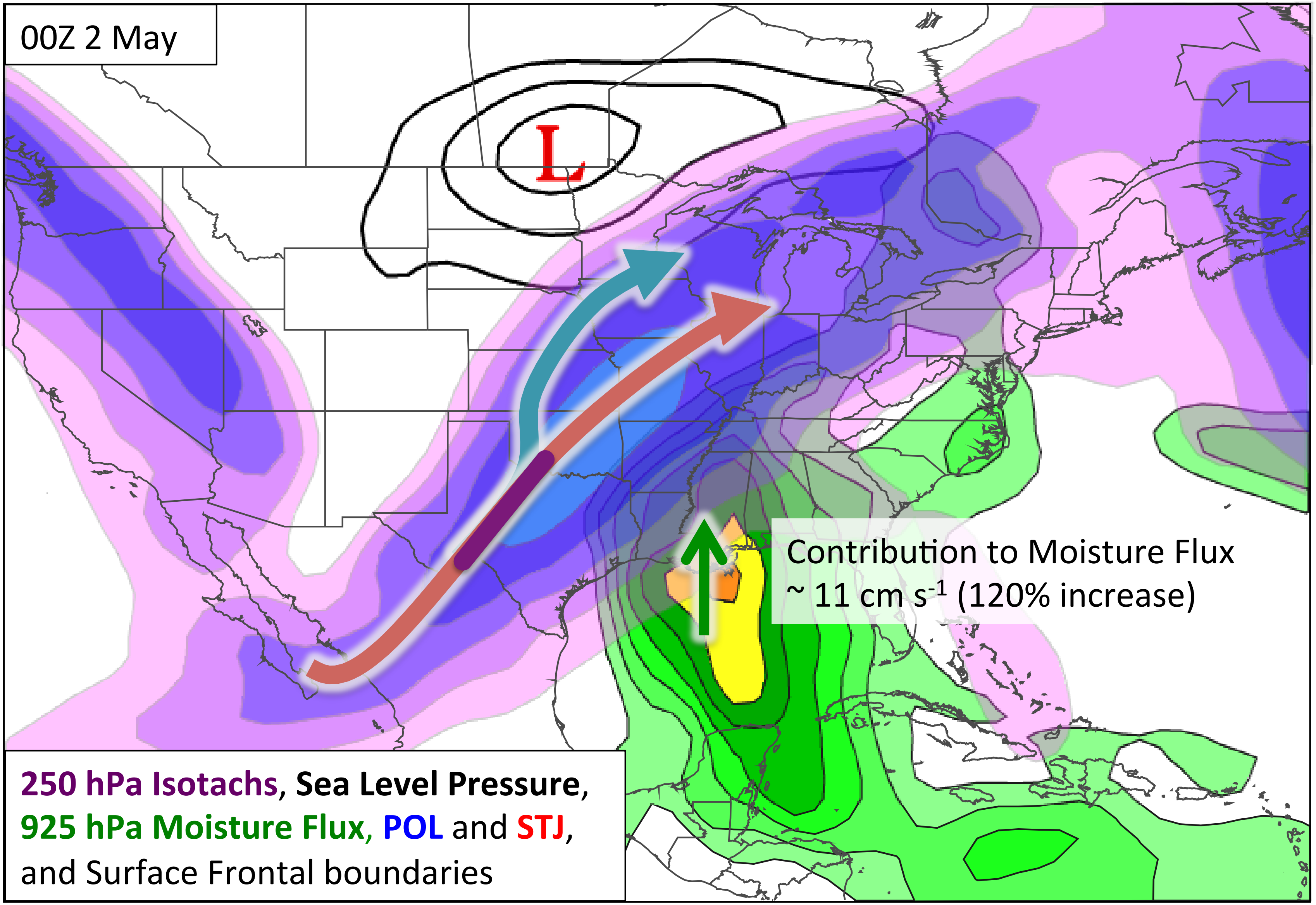
Streamlines (m hPa s^{-1})

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

Contribution to Moisture Flux
~ 11 cm s^{-1} (120% increase)

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

1–3 May 2010 Nashville Flood

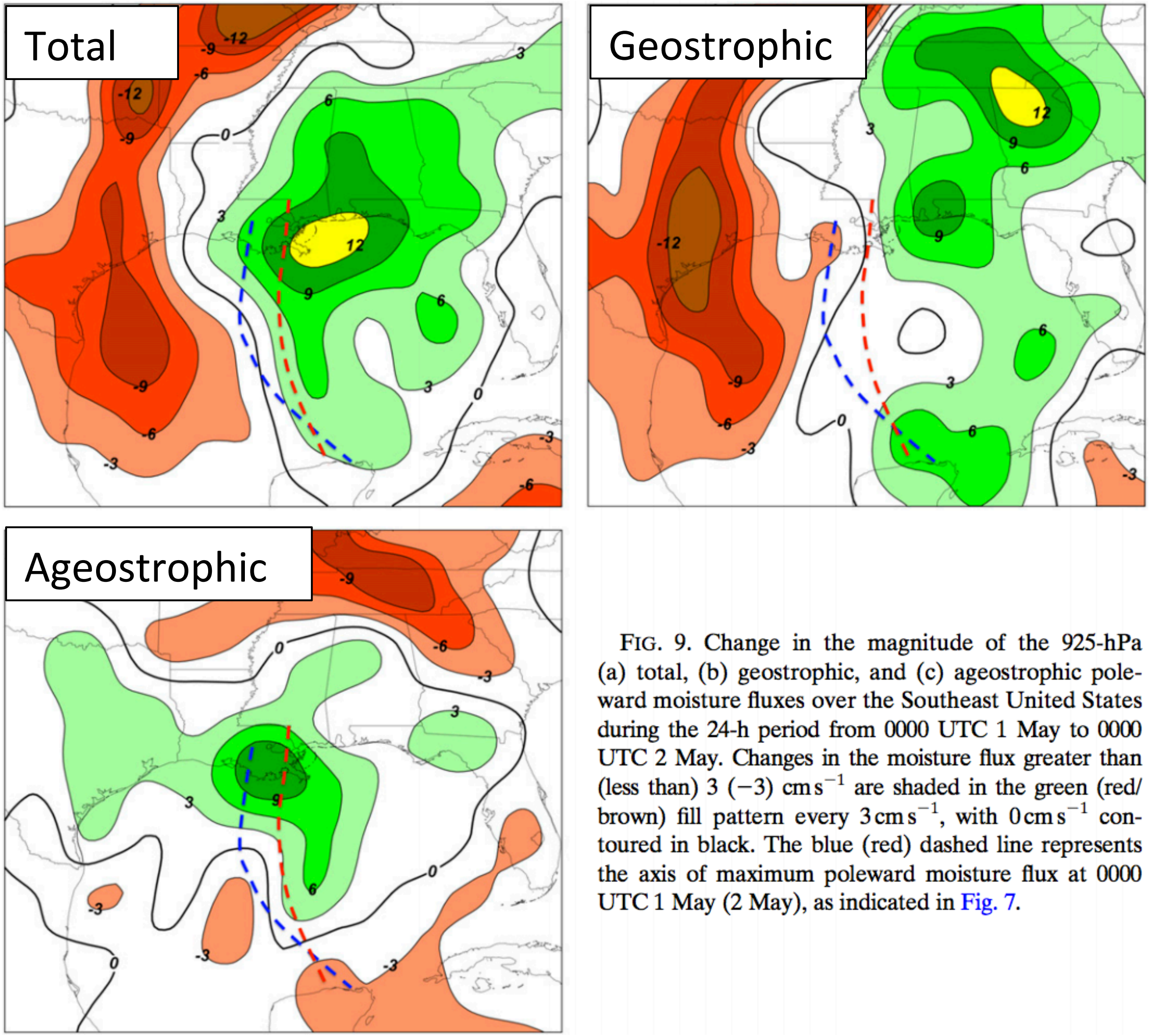


FIG. 9. Change in the magnitude of the 925-hPa (a) total, (b) geostrophic, and (c) ageostrophic poleward moisture fluxes over the Southeast United States during the 24-h period from 0000 UTC 1 May to 0000 UTC 2 May. Changes in the moisture flux greater than (less than) 3 (−3) $\mathrm{cm\,s^{-1}}$ are shaded in the green (red/brown) fill pattern every 3 $\mathrm{cm\,s^{-1}}$, with 0 $\mathrm{cm\,s^{-1}}$ 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.

24-h change in poleward moisture flux between 0000 UTC 2 May and 0000 UTC 1 May

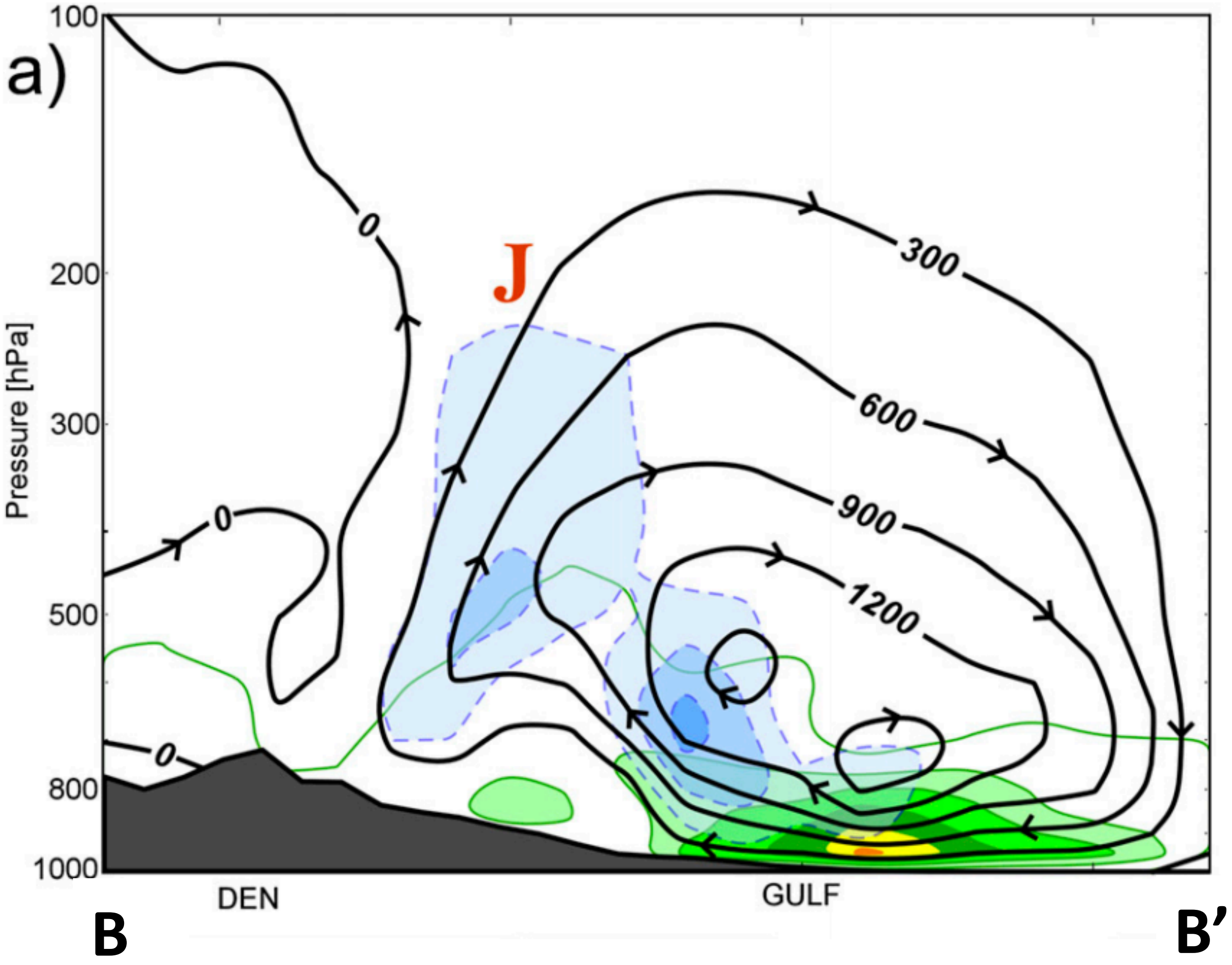
Axis of maximum moisture flux at:

00Z 1 May

00Z 2 May

1–3 May 2010 Nashville Flood

2 May 2010 – Superposed Jet Circulation



Streamlines (m hPa s^{-1})

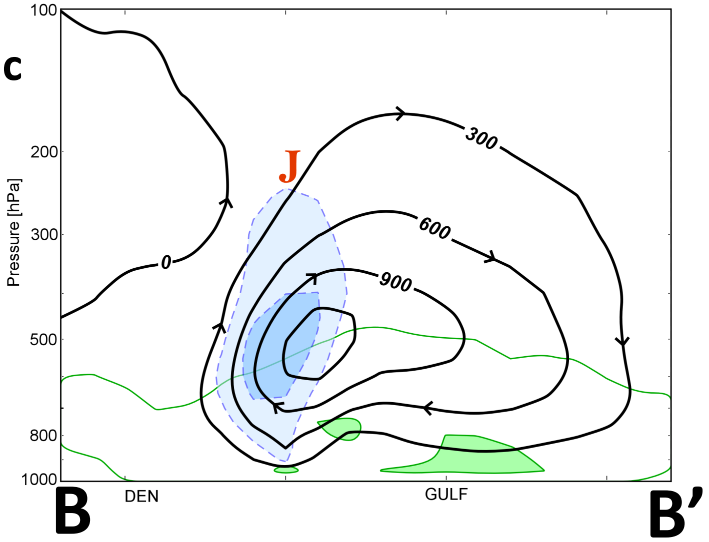
negative omega (dPa)

moisture flux every 3 cm s^{-1}

Max Moisture Flux ~ 15 cm s^{-1}

1–3 May 2010 Nashville Flood

Geostrophic

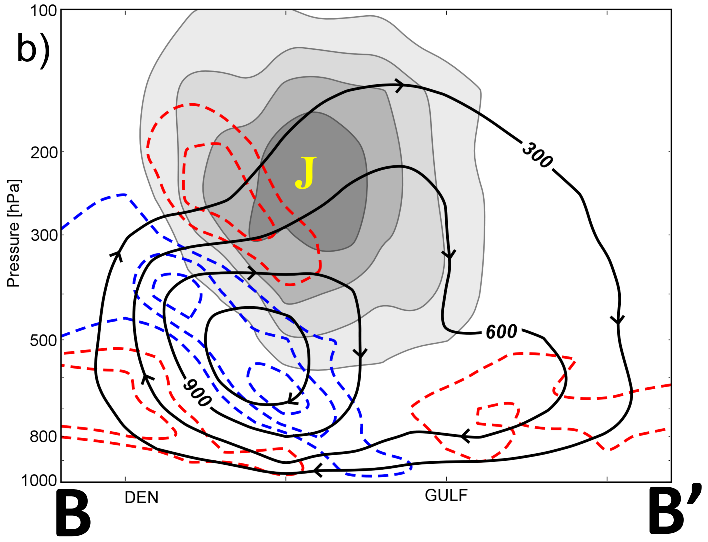


Streamlines (m hPa s^{-1})

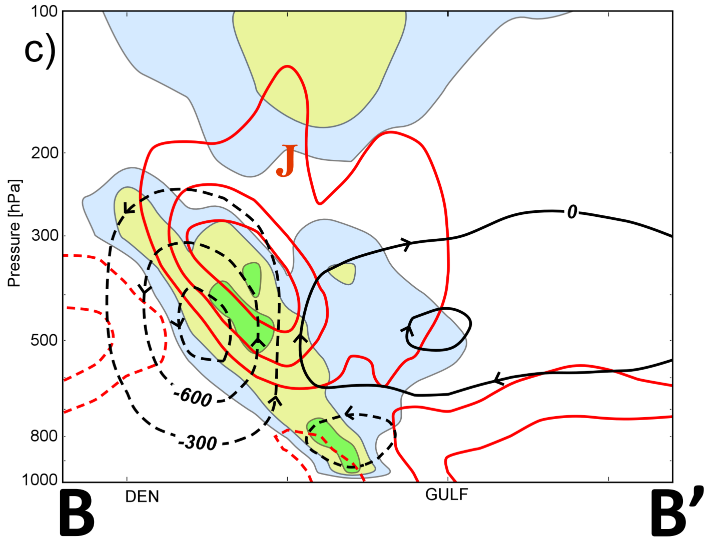
negative omega (dPa)

moisture flux every 3 cm s^{-1}

Shearing

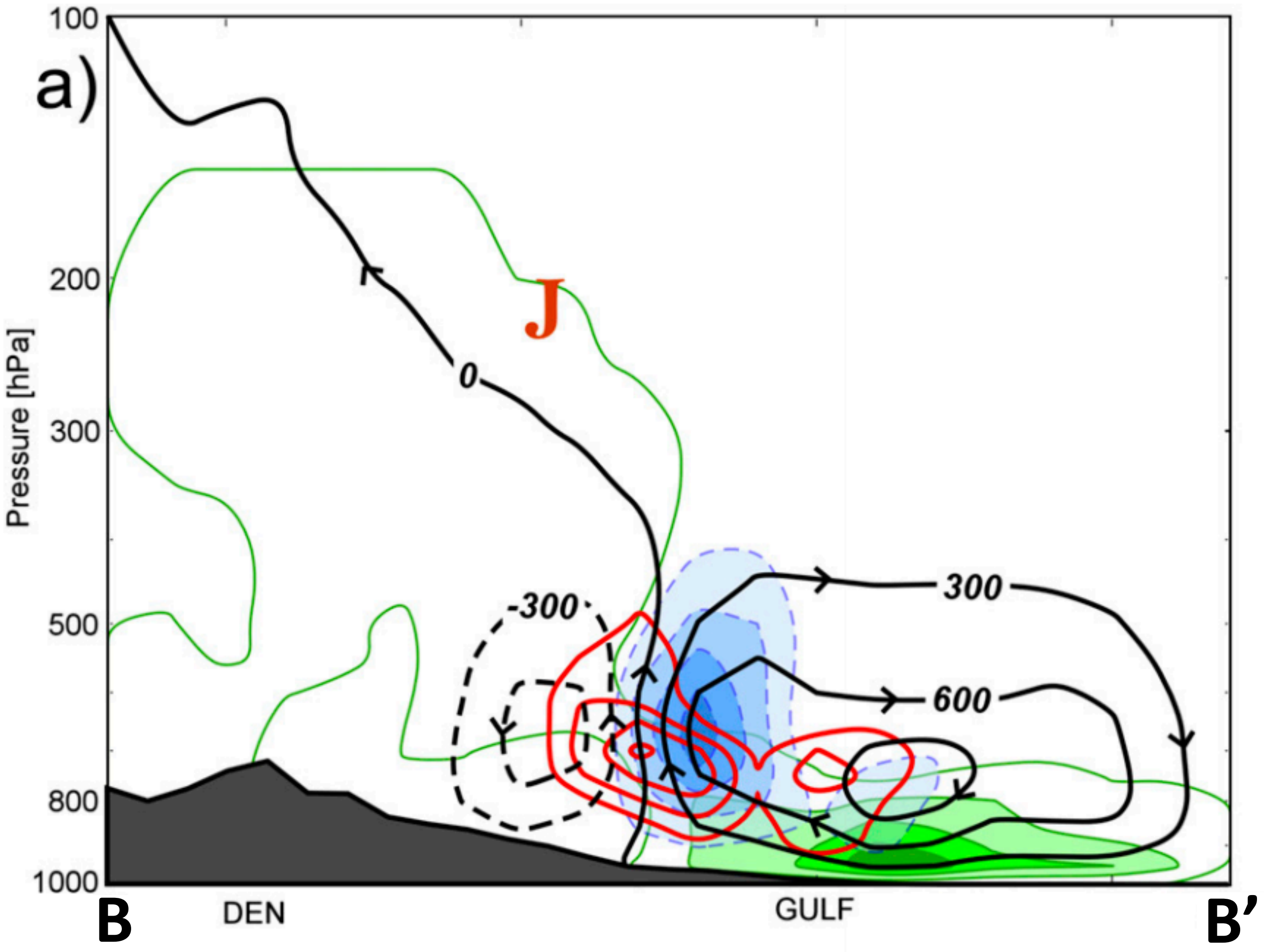


Confluence



1–3 May 2010 Nashville Flood

Diabatically Forced Circulation



Streamlines (m hPa s^{-1})

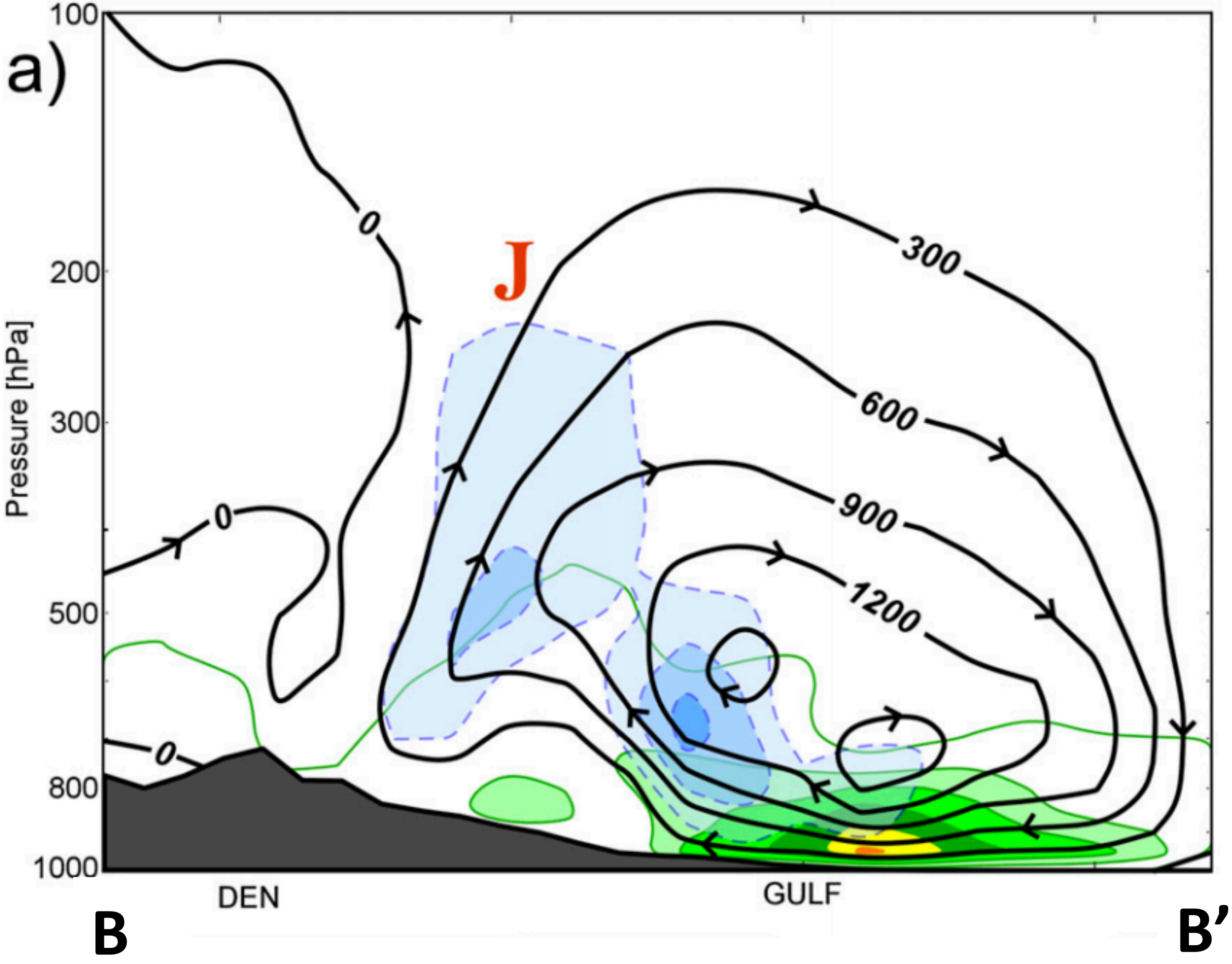
negative omega (dPa)

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



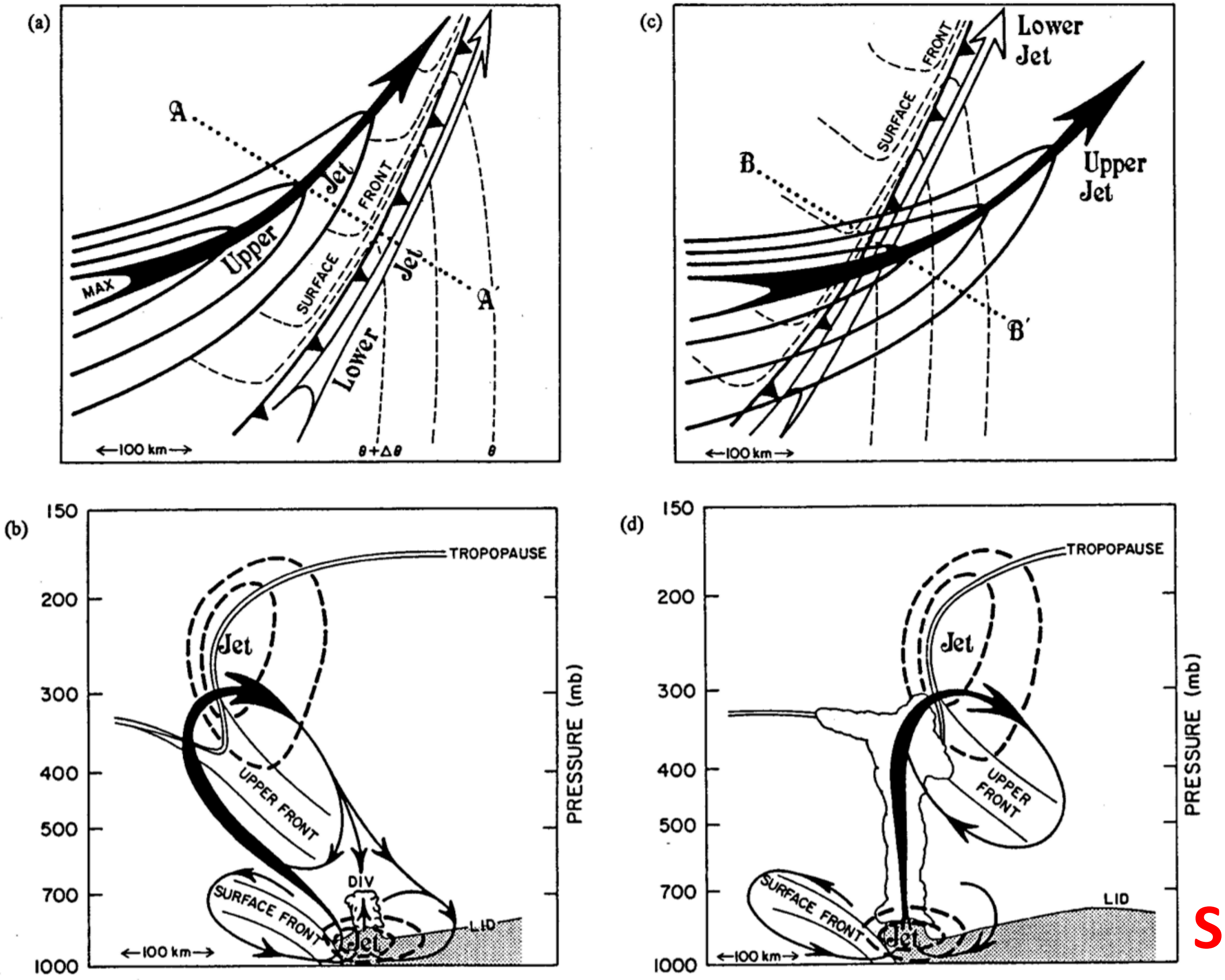
Streamlines (m hPa s^{-1})

negative omega (dPa)

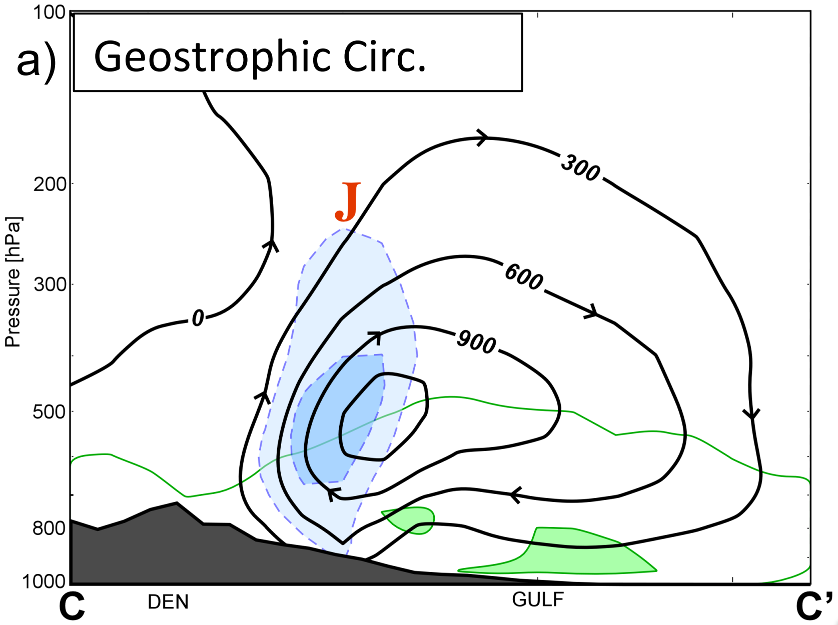
moisture flux every 3 cm s^{-1}

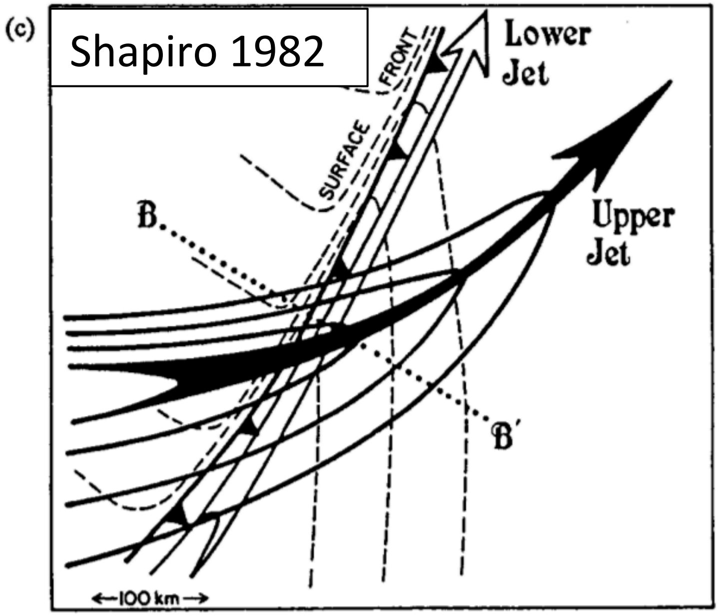
Max Moisture Flux ~ 15 cm s^{-1}

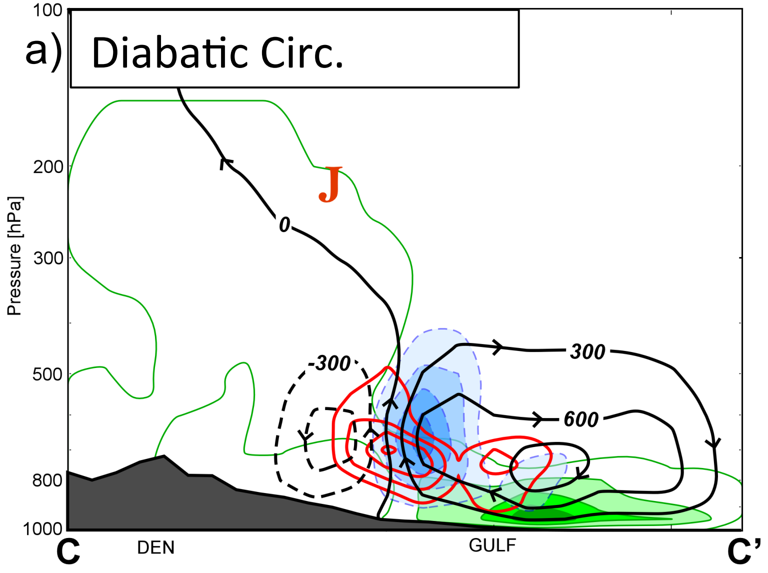
1–3 May 2010 Nashville Flood

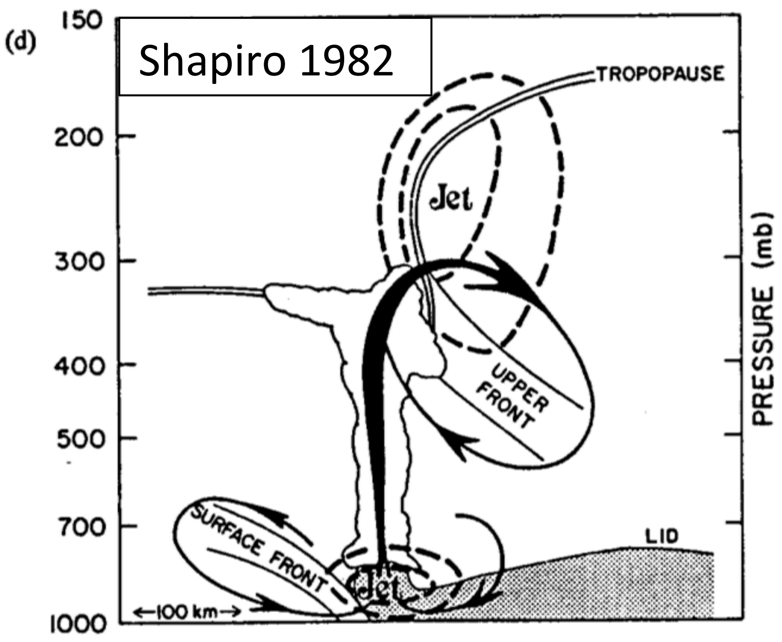


Shapiro 1982


a) Geostrophic Circ.


(c) Shapiro 1982


a) Diabatic Circ.


(d) 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)

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