Warm-core vs. cool-core vortices

Combining the prior concepts of:
thermal wind and vorticity

Background first, then

Assignment: slides 22-38

ATM 561, fall 2019

Brian Mapes, Univ of Miami

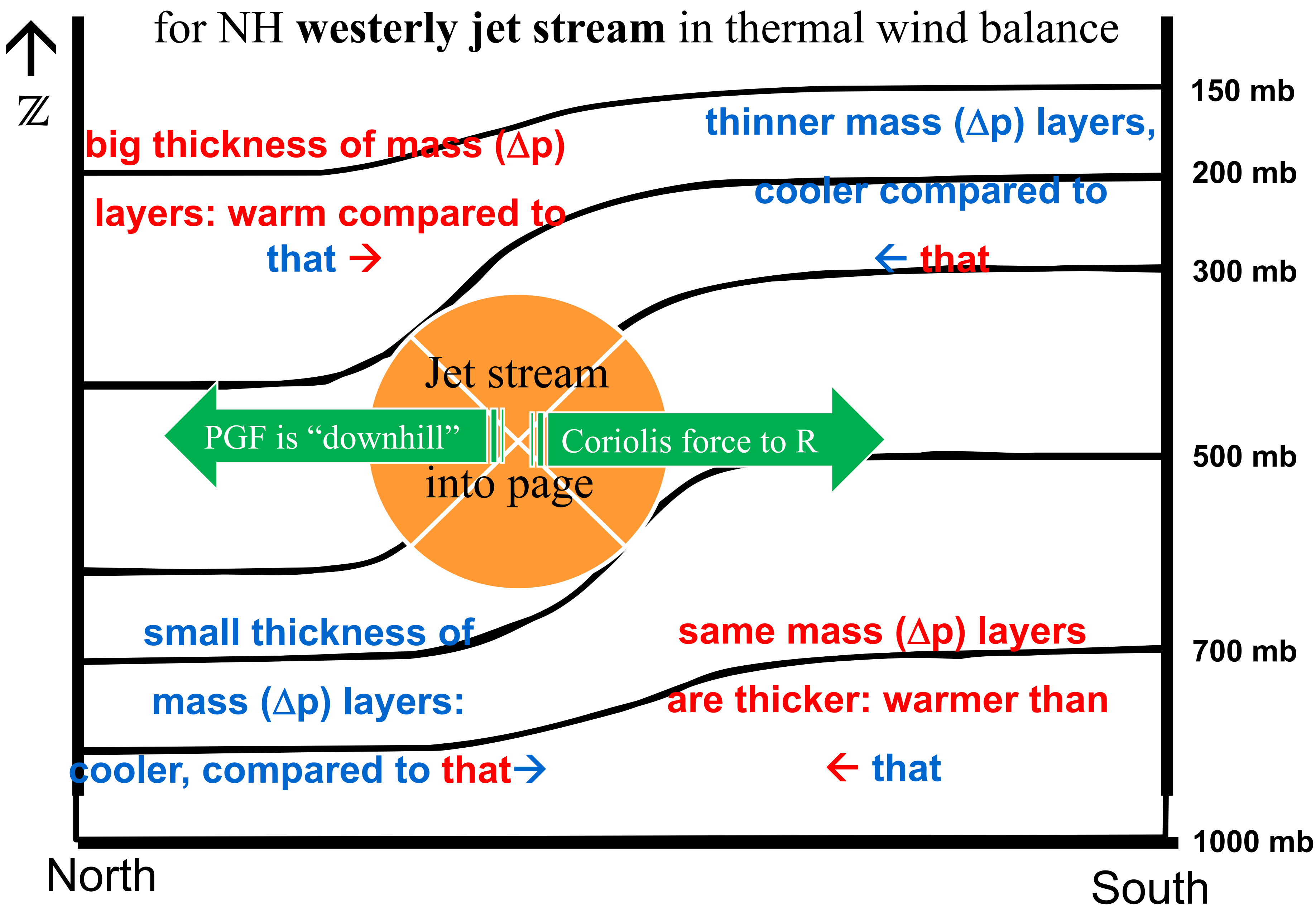
The big idea of it

- In the thermal wind lab, you learned about how *the slope of pressure surfaces (indicating the PGF*) balances the Coriolis force in geostrophic flow
- You also learned how *thickness* (between pressure surfaces) is proportional to T

- This gave you a 3D view of T around wind jets.

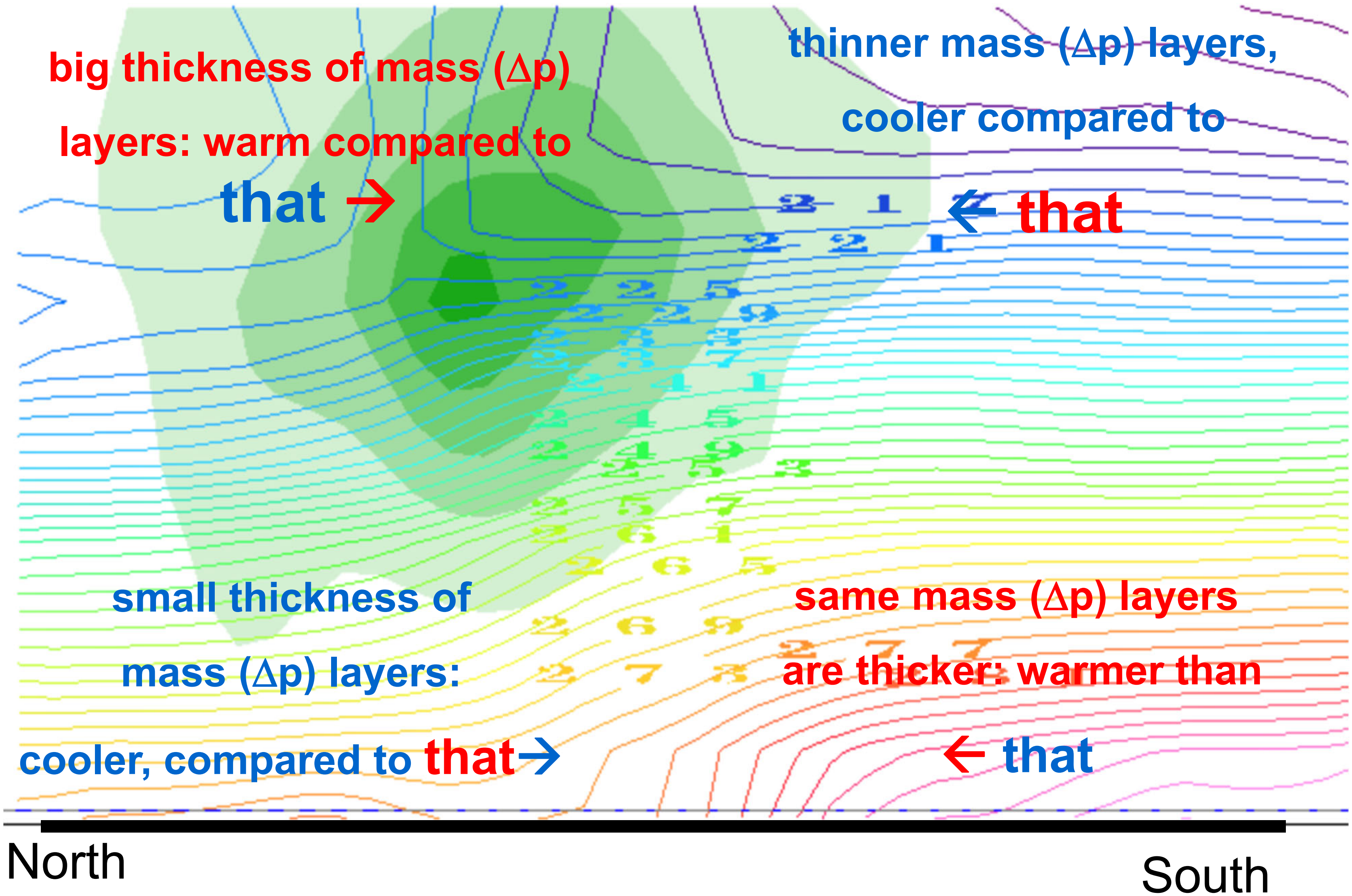
- But wind always blows in circuits (circulations), so it is often more useful to think of *vortices* (with vorticity as the budget equation) as the fundament of flow.
- Then T is understood in terms of warm and cool *cores.*

p surfaces on a z-coordinate diagram



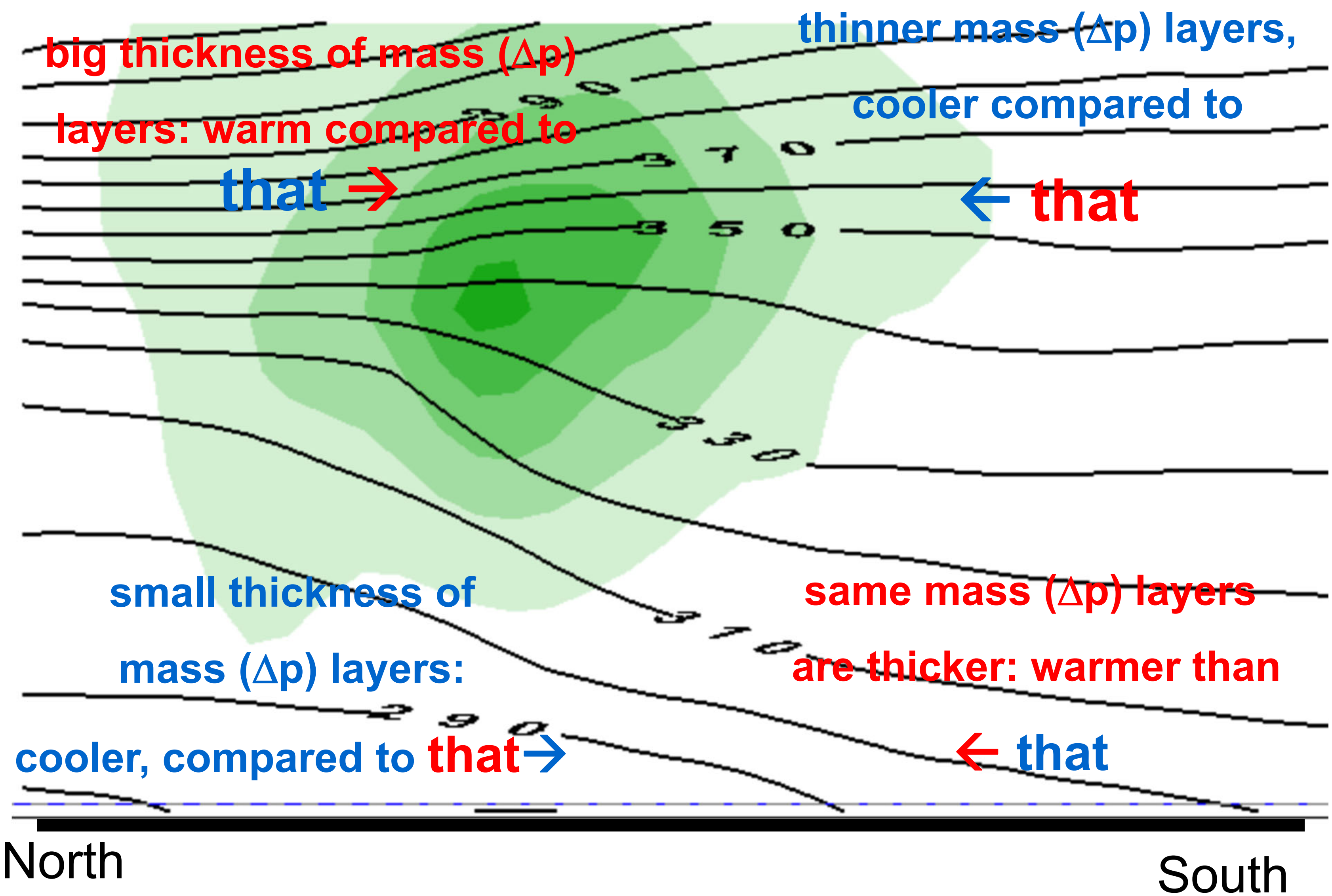
contours of T(K): it decreases with height

(plus the horizontal gradients due to TWB)



contours of θ(K): it increases with height

(plus the horizontal gradients due to TWB)



That view emphasized *jet streams* as the unit of flow

- OK, suppose we want to think in those terms.
- What is a jet made of?
  - *momentum, or ½ its square KE*
    - per unit mass
- What equation governs momentum?

$$\frac{D}{Dt}\vec{V}_h = -f\hat{k}\times\vec{V}_h - \vec{\nabla}_p\Phi$$

That view emphasized *jet streams* as the unit of flow

$$\frac{D}{Dt}\vec{V}_h = -f\hat{k}\times\vec{V}_h - \vec{\nabla}_p\Phi$$

- To predict vector momentum $\mathbf{V_h}$, need Φ
- But that drags thermo into our equation set
  - must *predict* T, not just guess its structure by TWB

- We work hard to avoid that with *vorticity*

Holy grail of dynamics: get div & ω

$$\frac{D}{Dt}\vec{V}_h = -f\hat{k} \times \vec{V}_h - \vec{\nabla}_p \Phi$$

Gotta avoid dragging thermo into this via Φ.

Get rid of Φ at any cost. **Curl to the rescue!**

$$\nabla \times (\frac{D}{Dt}\vec{V}_h) = \nabla \times (-f\hat{k} \times \vec{V}_h) - \cancel{\nabla \times (\vec{\nabla}_p \Phi)}$$

Ker-CHING!

We are Masters of the Universe with our sexy vector identities!

The grail is in the bag!

Heh heh ... did I say "any cost"... ? gulp

$$\frac{\partial}{\partial x}\text{[y-component momentum equation]} - \frac{\partial}{\partial y}\text{[x-component momentum equation]} =$$

$$\frac{\partial}{\partial x}\left[\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} + w\frac{\partial v}{\partial z} + fu = -\frac{1}{\rho}\frac{\partial p}{\partial y}\right] - \frac{\partial}{\partial y}\left[\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + w\frac{\partial u}{\partial z} - fv = -\frac{1}{\rho}\frac{\partial p}{\partial x}\right]$$

$$\frac{\partial}{\partial x}\frac{\partial v}{\partial t} + u\frac{\partial^2 v}{\partial x^2} + \frac{\partial v}{\partial x}\frac{\partial u}{\partial x} + v\frac{\partial^2 v}{\partial x\partial y} + \frac{\partial v}{\partial y}\frac{\partial v}{\partial x} + w\frac{\partial^2 v}{\partial x\partial z} + \frac{\partial v}{\partial z}\frac{\partial w}{\partial x} + f\frac{\partial u}{\partial x} + \cancel{u\frac{\partial f}{\partial x}} = \cancel{-\frac{1}{\rho}\frac{\partial^2 p}{\partial x\partial y}} + \frac{1}{\rho^2}\left(\frac{\partial p}{\partial y}\frac{\partial \rho}{\partial x}\right)$$

$$-\quad \frac{\partial}{\partial y}\frac{\partial u}{\partial t} + u\frac{\partial^2 u}{\partial x\partial y} + \frac{\partial u}{\partial x}\frac{\partial u}{\partial y} + v\frac{\partial^2 u}{\partial y^2} + \frac{\partial u}{\partial y}\frac{\partial v}{\partial y} + w\frac{\partial^2 u}{\partial y\partial z} + \frac{\partial u}{\partial z}\frac{\partial w}{\partial y} - f\frac{\partial v}{\partial y} - v\frac{\partial f}{\partial y} = \cancel{-\frac{1}{\rho}\frac{\partial^2 p}{\partial x\partial y}} + \frac{1}{\rho^2}\left(\frac{\partial p}{\partial x}\frac{\partial \rho}{\partial y}\right)$$

$$\boxed{\frac{\partial}{\partial t}\left(\frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}\right)} + \boxed{u\frac{\partial}{\partial x}\left(\frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}\right)} + \boxed{v\frac{\partial}{\partial y}\left(\frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}\right)} + \boxed{w\frac{\partial}{\partial z}\left(\frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}\right)} + \boxed{\left(\frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}\right)\left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y}\right)} + \boxed{f\left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y}\right)}$$

$$+\boxed{\left(\frac{\partial w}{\partial x}\frac{\partial v}{\partial z} - \frac{\partial w}{\partial y}\frac{\partial u}{\partial z}\right)} + \boxed{v\frac{\partial f}{\partial y}} = \boxed{\frac{1}{\rho^2}\left(\frac{\partial p}{\partial y}\frac{\partial \rho}{\partial x} - \frac{\partial p}{\partial x}\frac{\partial \rho}{\partial y}\right)}$$

$$\boxed{\frac{df}{dt} = \cancel{\frac{\partial f}{\partial t}} + \cancel{u\frac{\partial f}{\partial x}} + v\frac{\partial f}{\partial y} + \cancel{w\frac{\partial f}{\partial z}}}$$

$$\frac{\partial \zeta}{\partial t} + u\frac{\partial \zeta}{\partial x} + v\frac{\partial \zeta}{\partial y} + w\frac{\partial \zeta}{\partial z} + \zeta\left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y}\right) + f\left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y}\right) + \left(\frac{\partial w}{\partial x}\frac{\partial v}{\partial z} - \frac{\partial w}{\partial y}\frac{\partial u}{\partial z}\right) + v\frac{\partial f}{\partial y} = \frac{1}{\rho^2}\left(\frac{\partial p}{\partial y}\frac{\partial \rho}{\partial x} - \frac{\partial p}{\partial x}\frac{\partial \rho}{\partial y}\right)$$

$$\boxed{\frac{d}{dt}(\zeta + f) = -(\zeta + f)\boxed{\left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y}\right)} - \left(\frac{\partial w}{\partial x}\frac{\partial v}{\partial z} - \frac{\partial w}{\partial y}\frac{\partial u}{\partial z}\right) + \frac{1}{\rho^2}\left(\frac{\partial p}{\partial y}\frac{\partial \rho}{\partial x} - \frac{\partial p}{\partial x}\frac{\partial \rho}{\partial y}\right)}$$

vorticity equation

Can we scrape back some of these cobwebs?

Wait a sec, what's this??

This view emphasizes *vortices* as the unit of flow

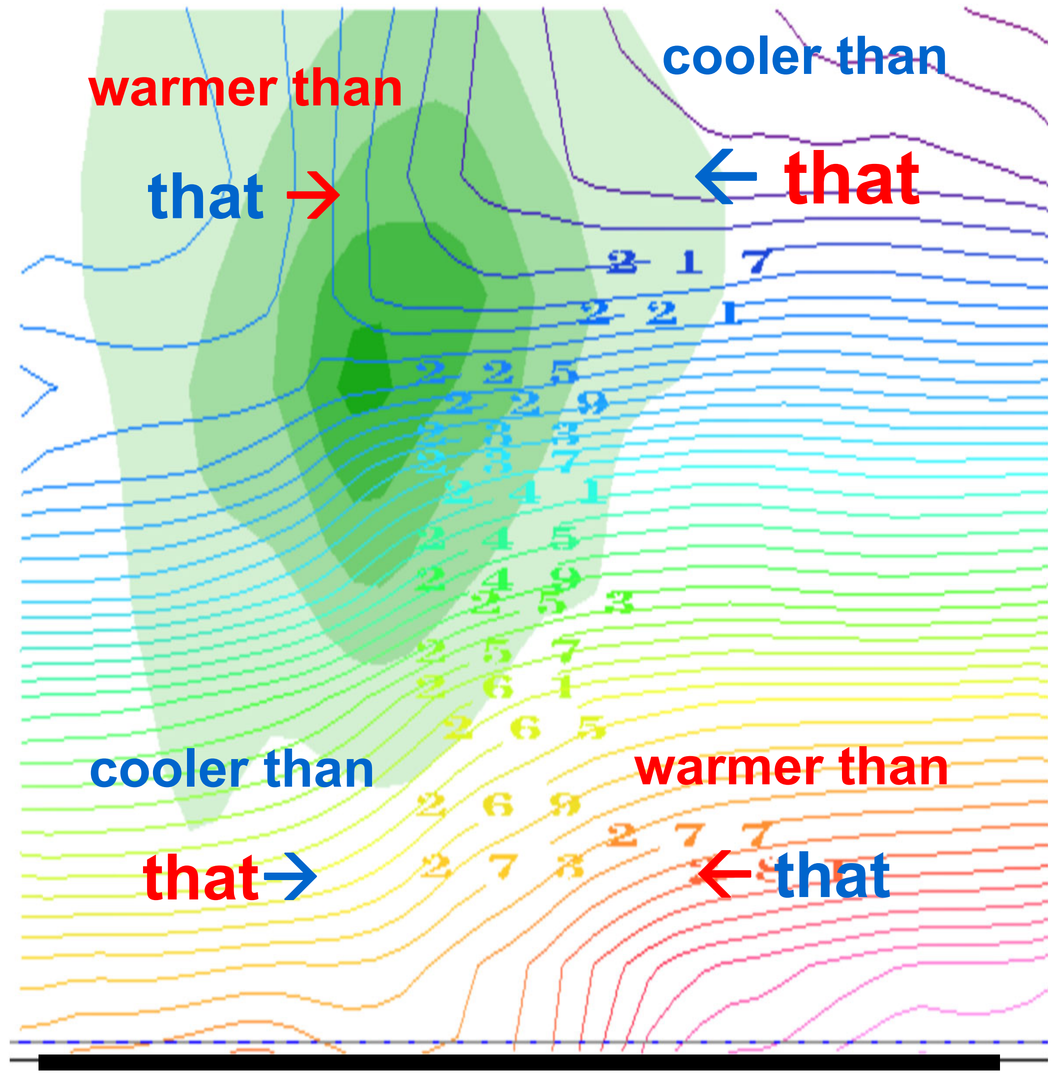
$$D\zeta/Dt = 0 + complications$$

- To predict vorticity, we just need vorticity
  - induced wind drops like 1/distance
  - vorticity itself is advected by wind like a tracer
    - plus complications
    - advection of *planetary vorticity f* →Rossby waves
    - divergence term can be rolled up into *potential* vorticity

So what's the TWB structure of a vortex?

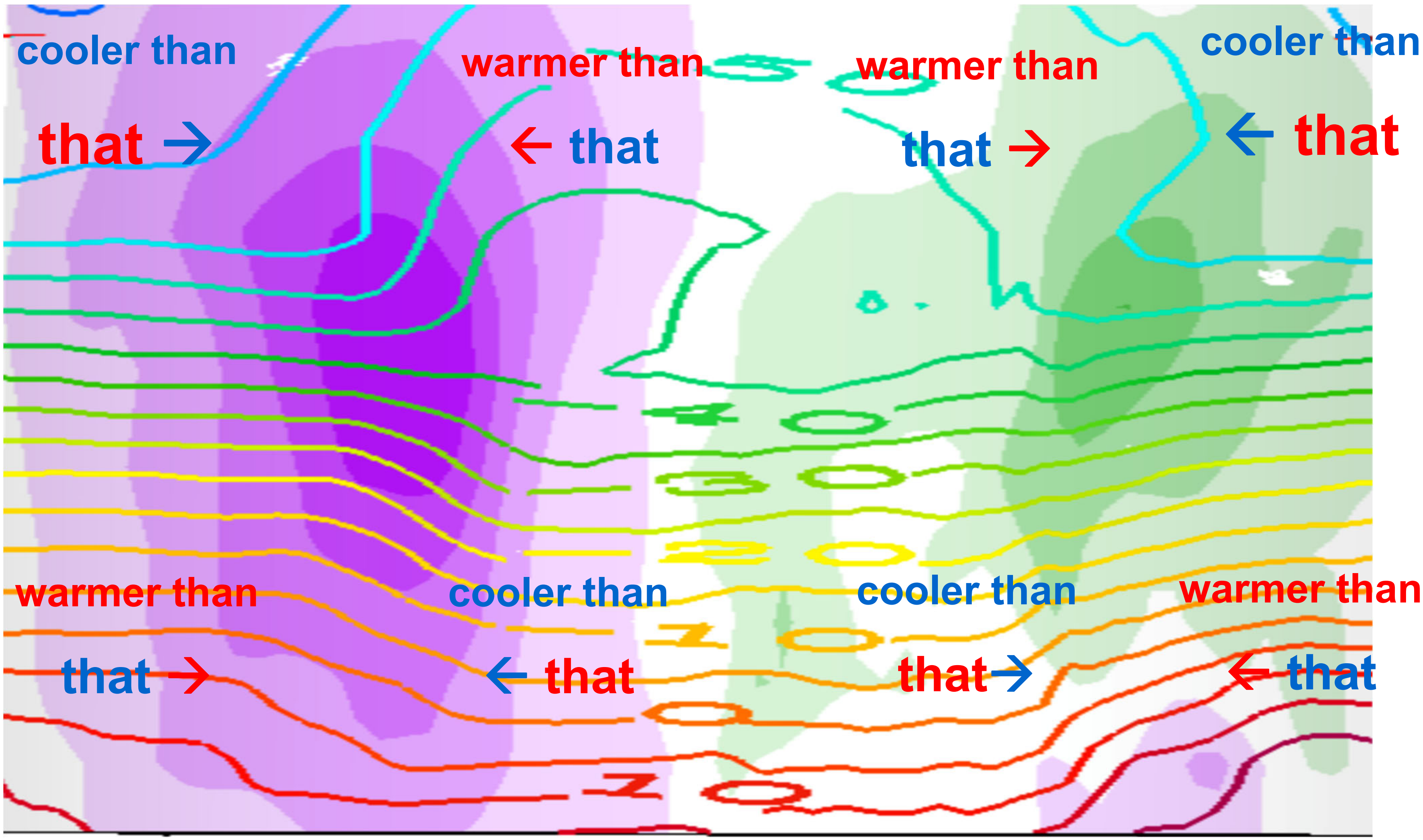
- In this case, one near the tropopause (like the jet stream)

This is only half the story of a vortex



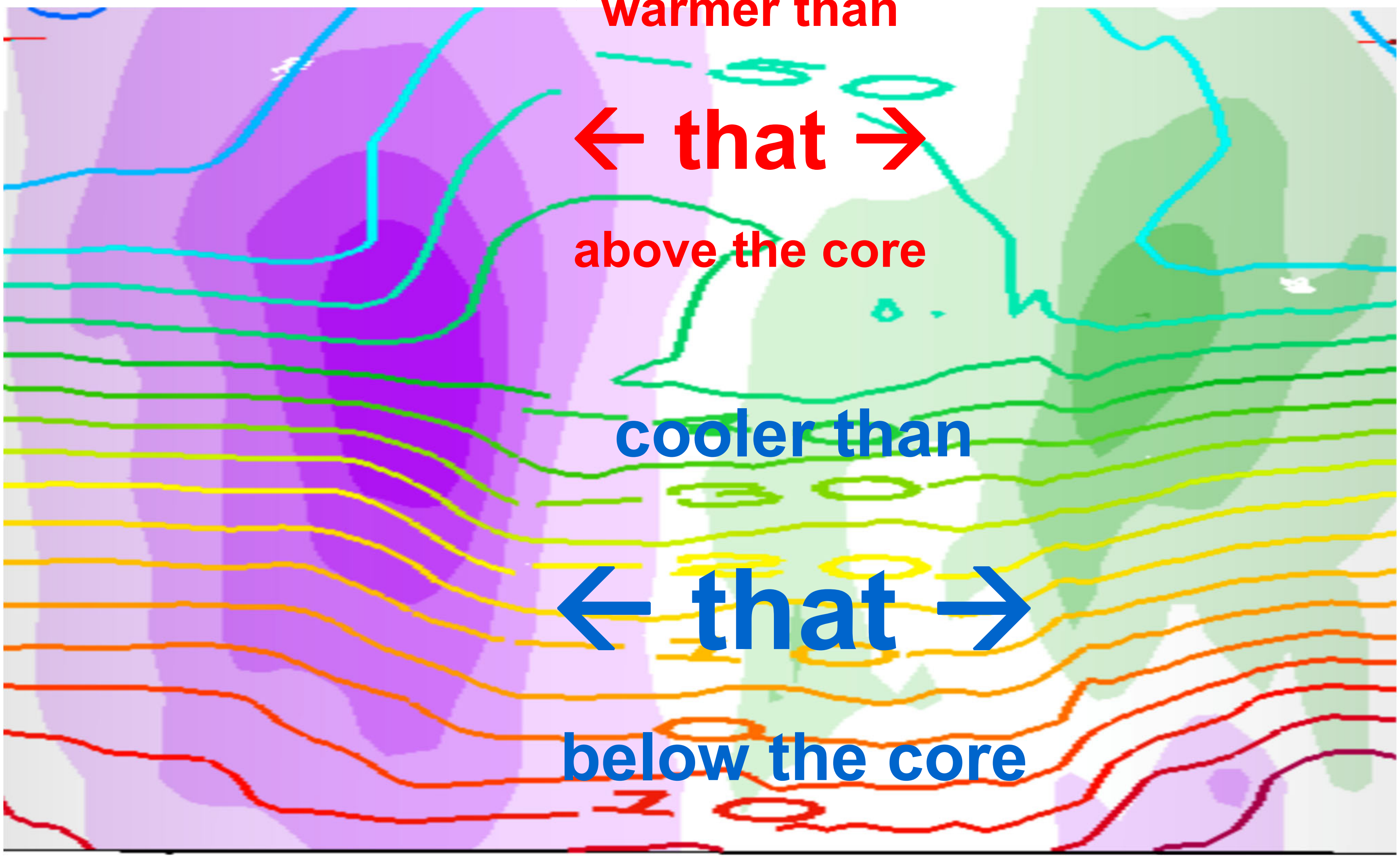
This is a whole vortex (two jets)

T(K) contours



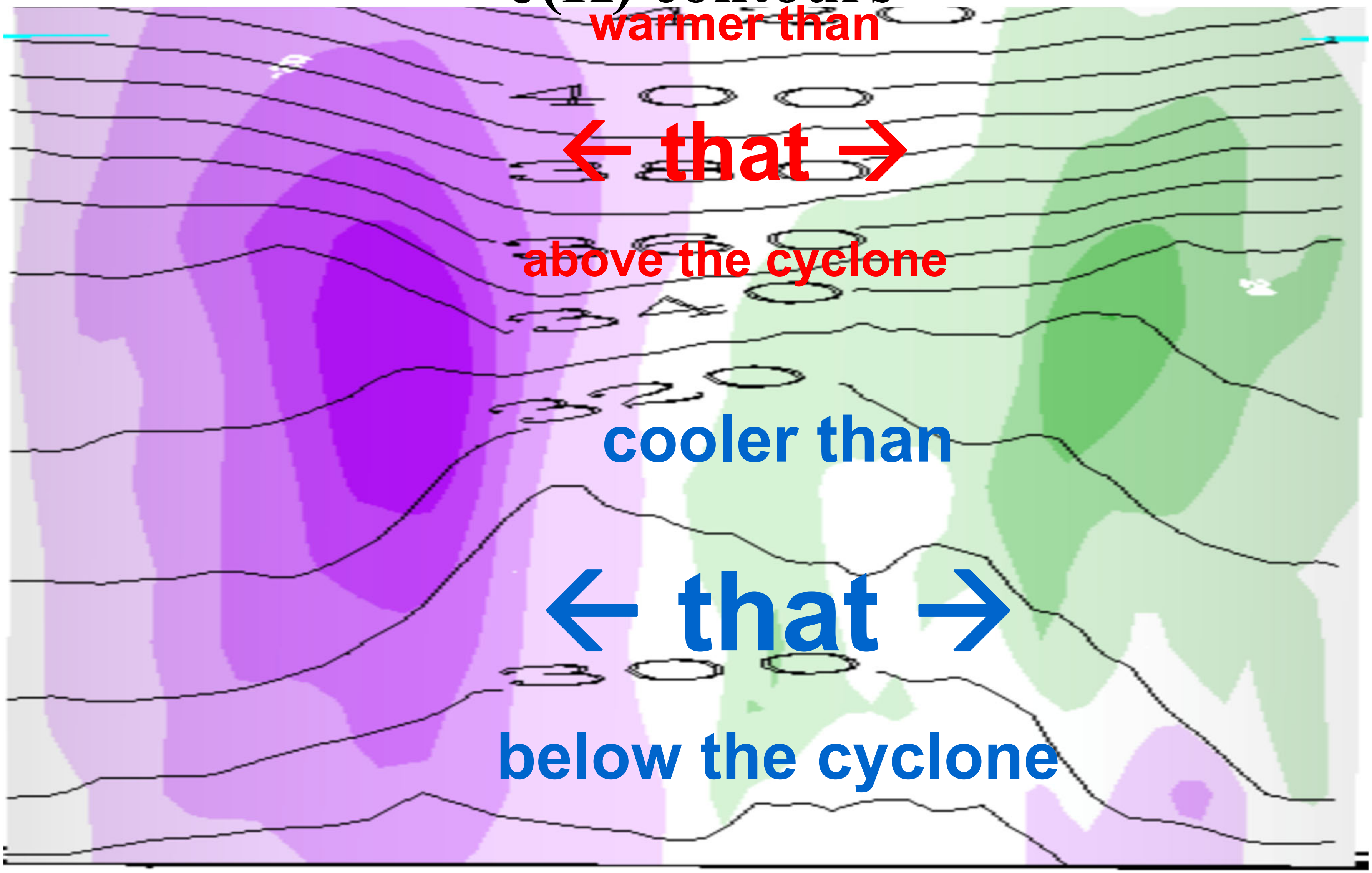
This is a whole vortex (two jets)

T(K) contours

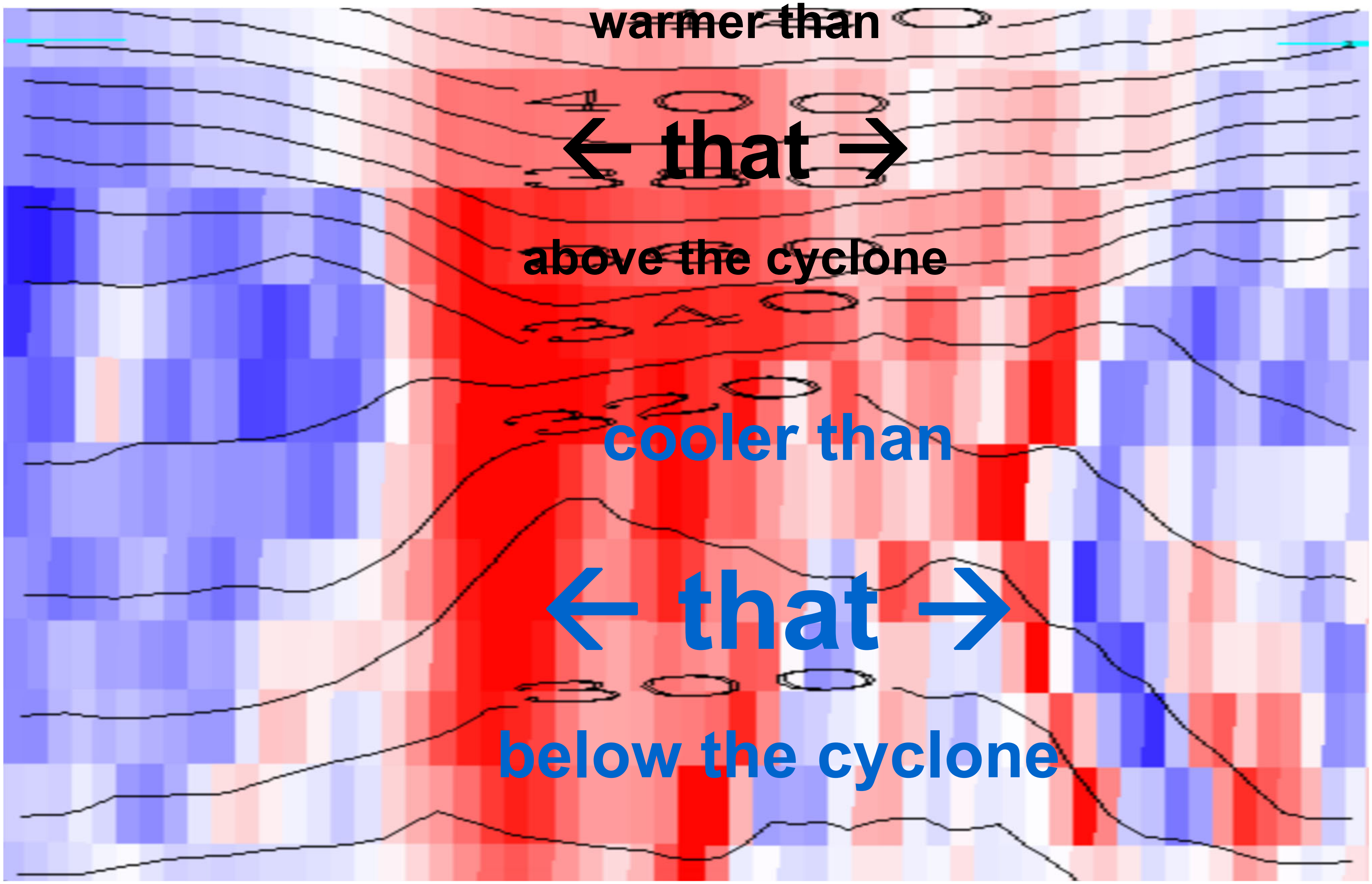


This is a whole vortex (two jets)

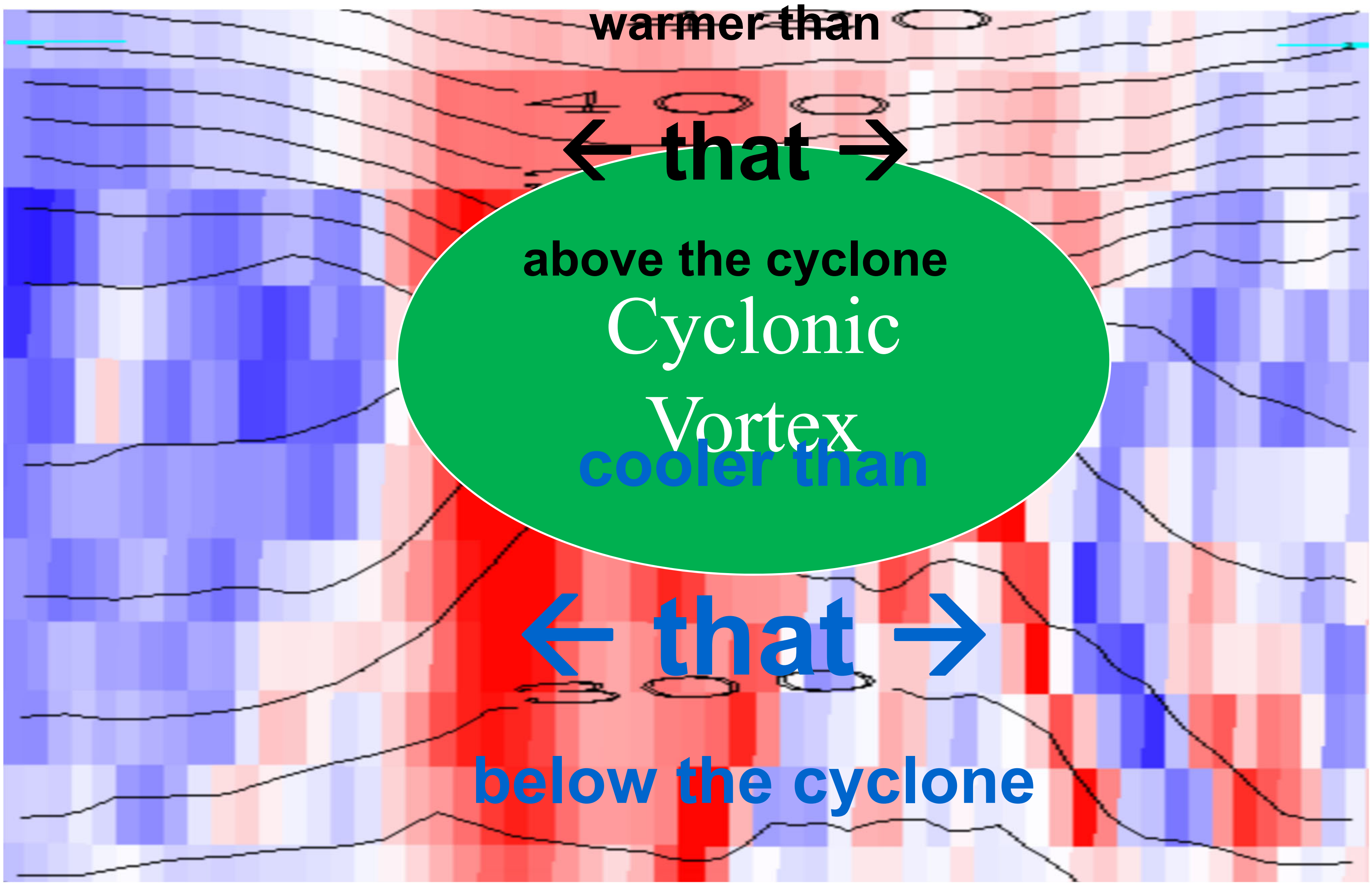
θ(K) contours



Red is positive vorticity , θ(K) contours

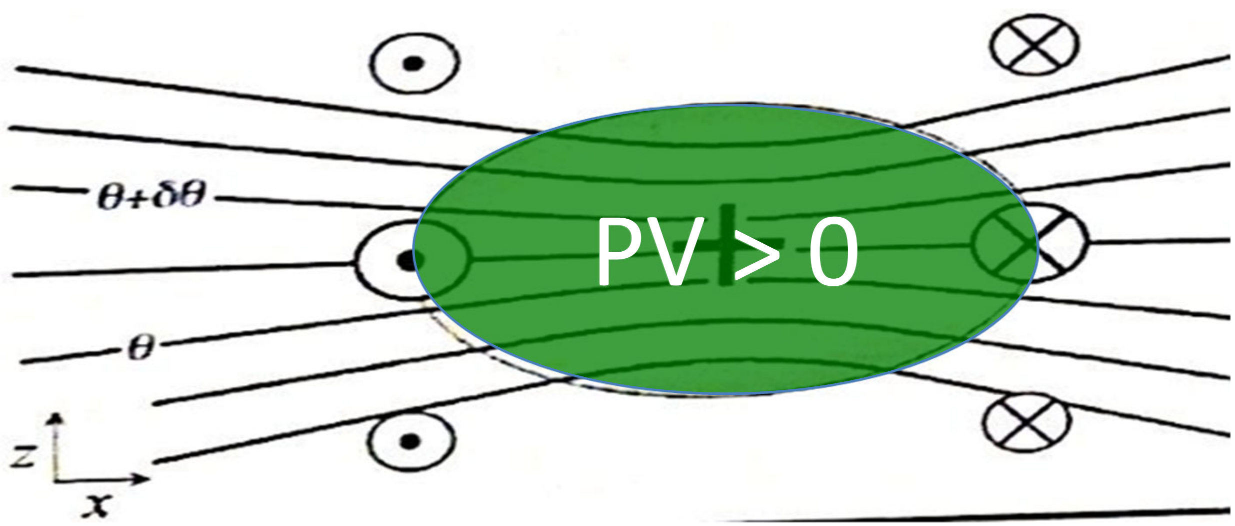


Red is positive vorticity , θ(K) contours



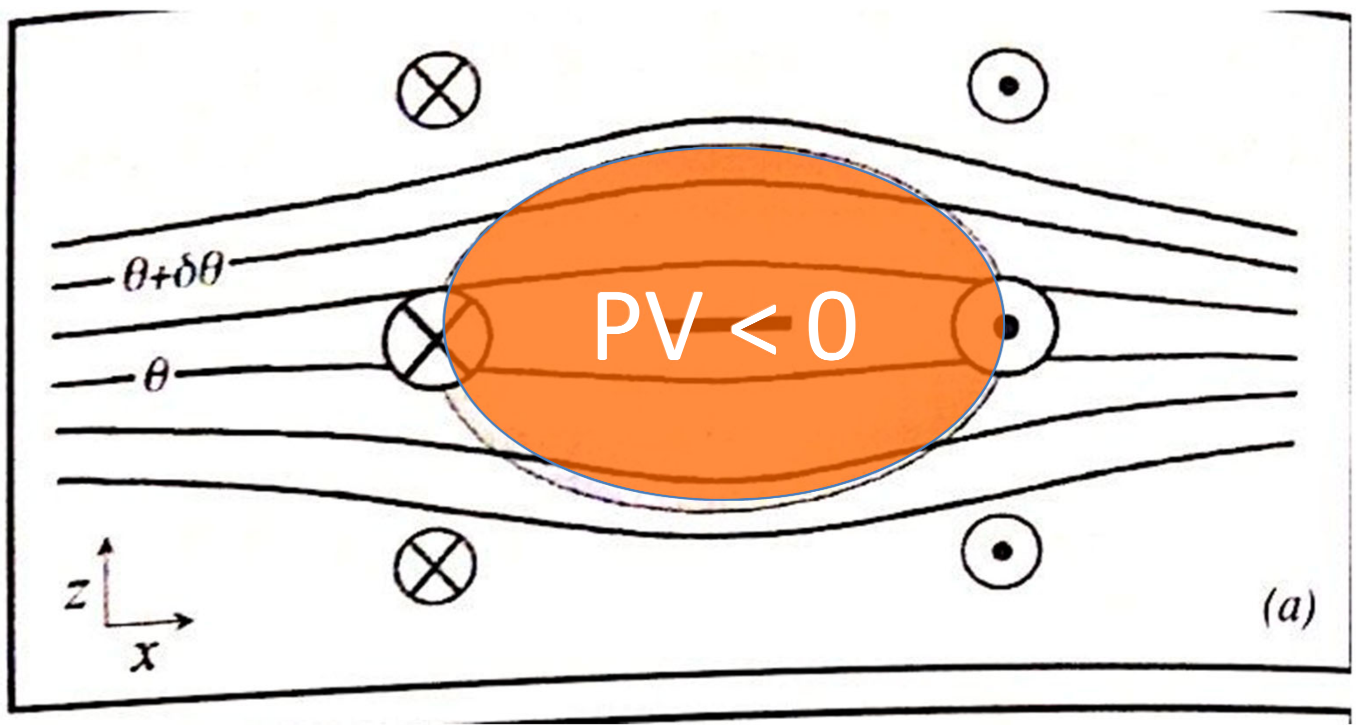
Generalization: *PV*

1. We will see that every **cyclonic** vortex obeying vertical (hydrostatic) and horizontal (geostrophic or other) balance looks similar to this (maybe stretched or shrunk):

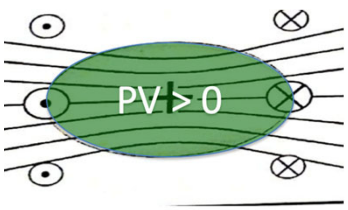


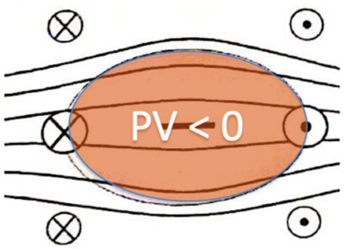
Balanced anticyclones exist too...

- Just the opposite of a cyclone...



Vorticity (or PV) blobs





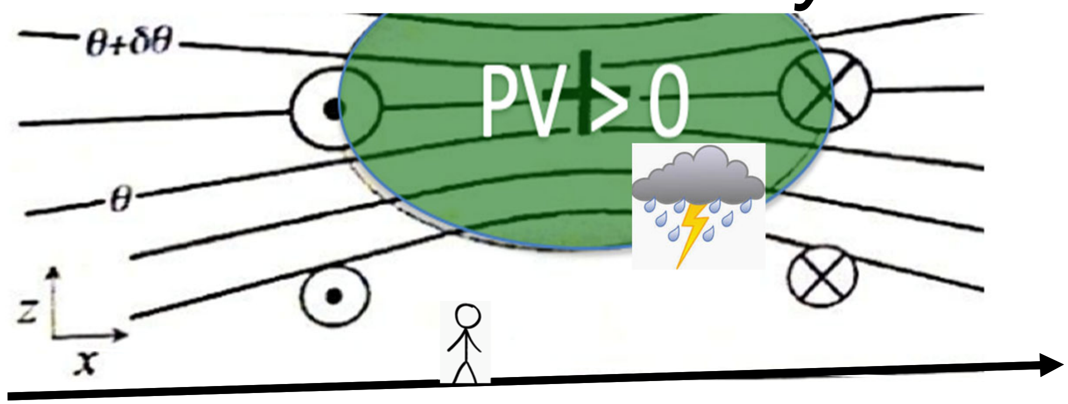
- Where do they come from?
- How do they interact?
  - (this we studied, in the horizontal plane)
- Do they get destroyed?

- (Soon: tackling the complications)

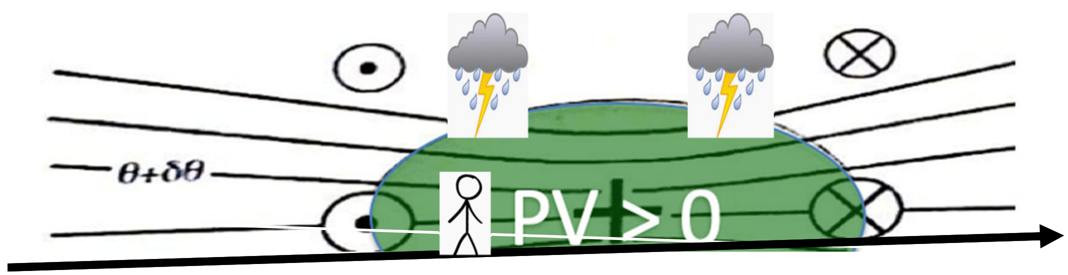
$$D\zeta/Dt = 0 + complications$$

Since our main weather concern is in the *lower troposphere* (where water is),

- This is called a *cool core cyclone:*

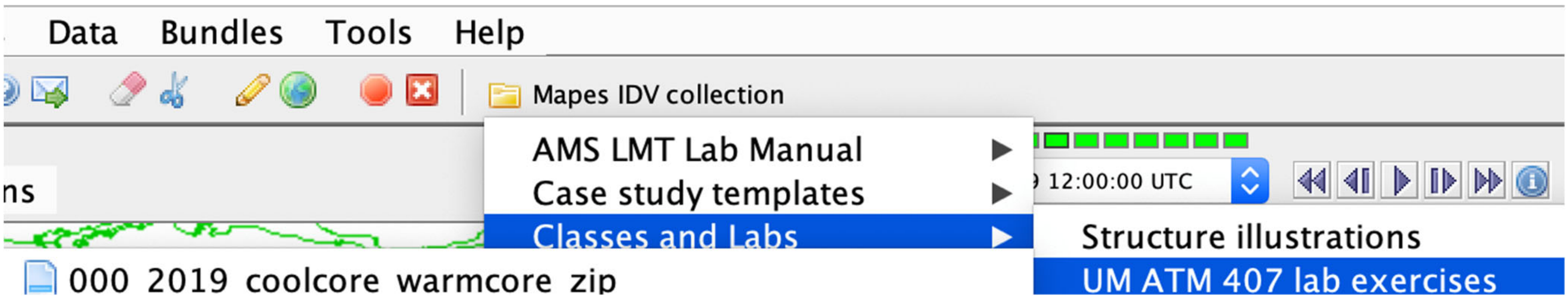


- This is called a *warm core cyclone:*



IDV lab assignment -- part 1

- Open Mapes IDV → UM ATM407…
  - 0000_coolcore_warmcore…



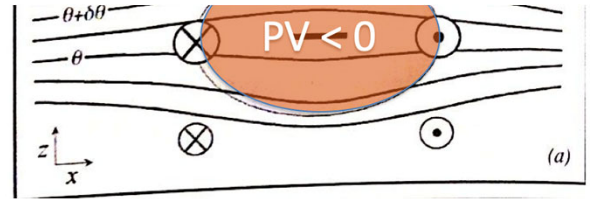
Explore ALL of its displays, at ALL of its times (loop the animation). Learn to use the IDV. The Help menu has pan-zoom help on top. A mouse is a HUGE help for 3D views.

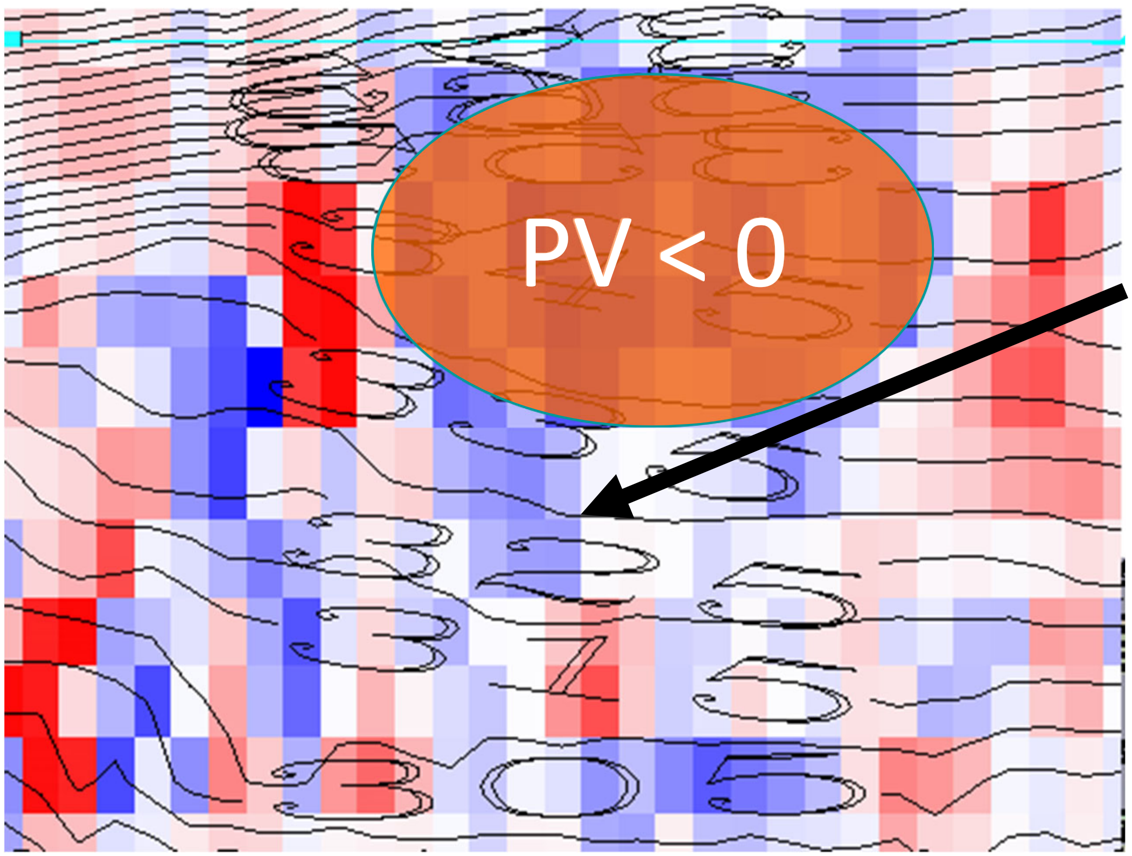
IDV lab assignment -- part 1

- In the following slides, make and label and explain nice clear illustrations like slides 13-17, but for
  - a warm core anticyclone
  - a warm core cyclone
  - a cool core anticyclone

A warm core anticyclone

- Over the central/midwestern United States, at 12z on 9-24-19, an upper-level center of negative vorticity was visible. This was associated with elevated heights on the 250hPa and 500hPa surfaces.

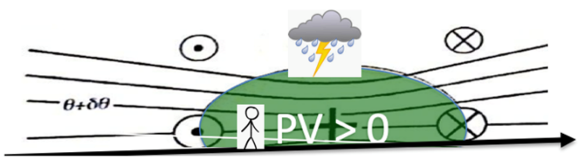




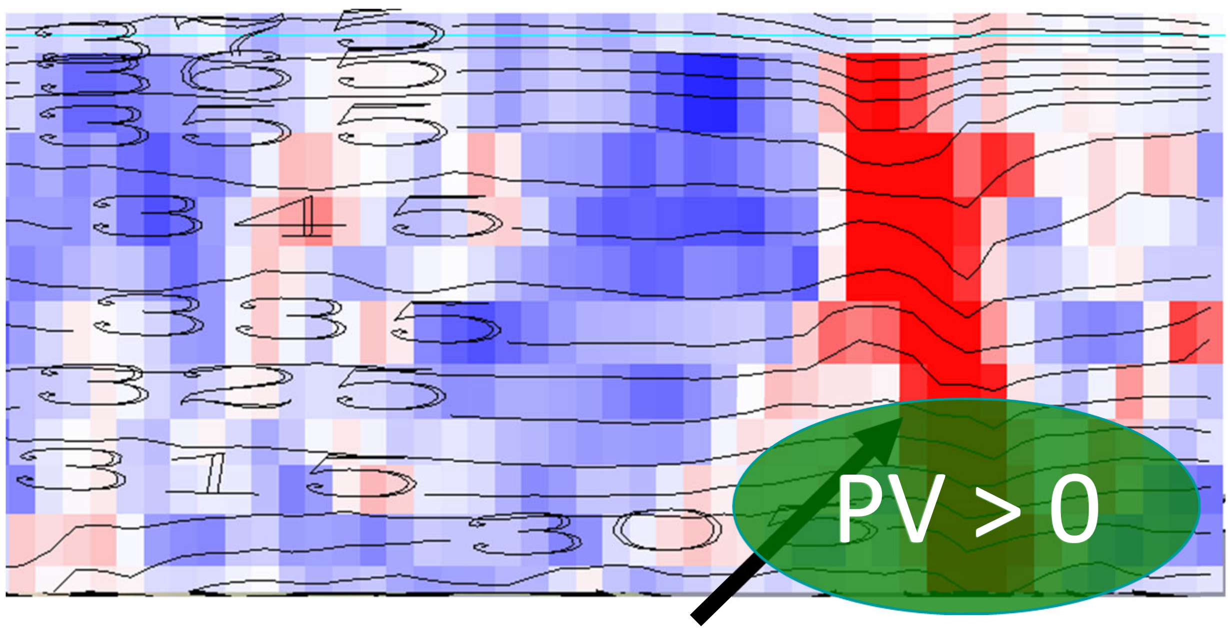
<u>depressed</u> theta surface below cyclonic core, hence <u>warmer</u> than surroundings

A warm core cyclone

This is called a *warm core cyclone:*

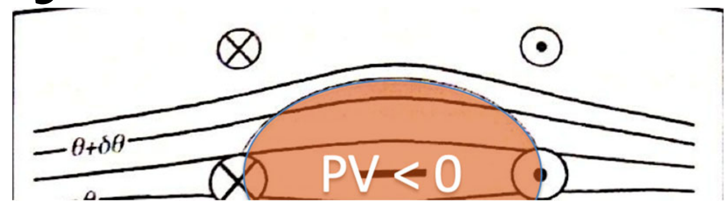


- At 18Z on 9-24-19, I took a zonal slice of vorticity and potential temperature (with height) over the Atlantic ocean. Here a prominent warm-core cyclone is visible – at the time, this was Tropical Storm Jerry.



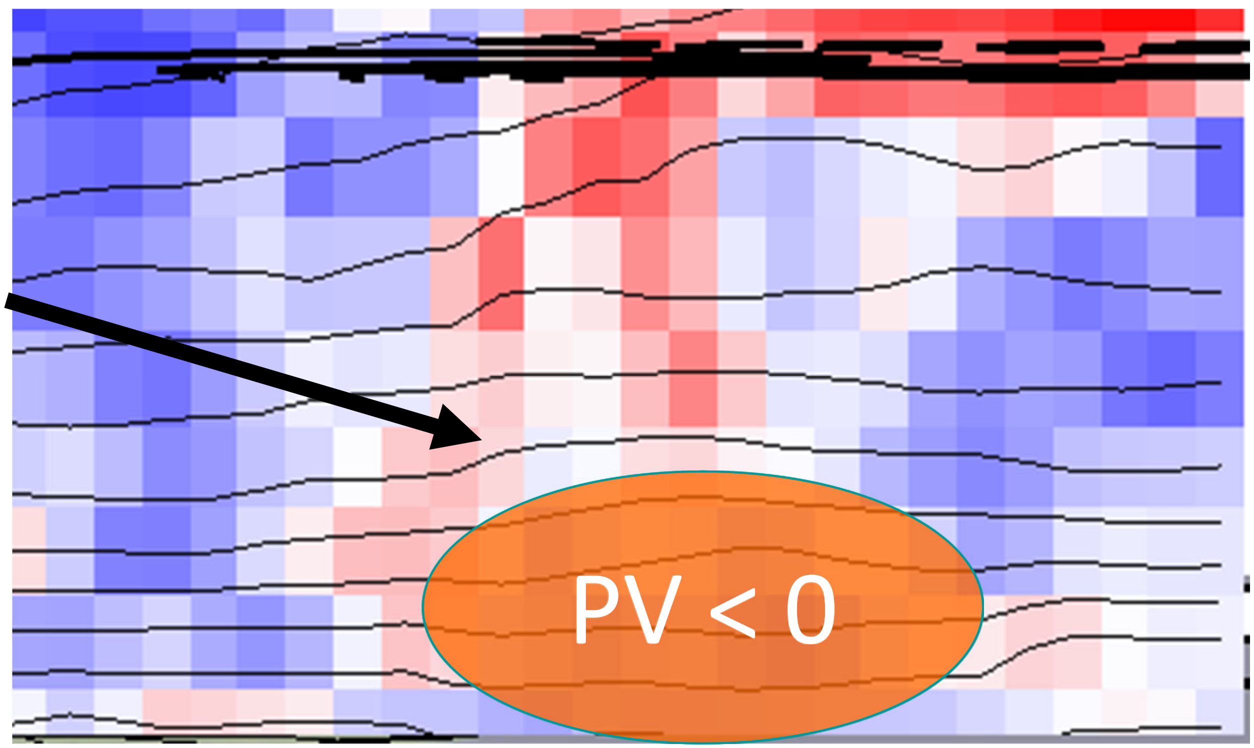
<u>depressed</u> theta surface in and around cyclonic core at surface, hence <u>warmer</u> than surroundings

A cool core anticyclone



- Zonal slice of potential temperature and relative vorticity over the Atlantic ocean on 9-22-19 18Z. Here, an area of negative vorticity near the surface – associated with a surface high-pressure system over the Atlantic – is evident.

raised theta surfaces in and around cyclonic core at surface, hence colder than surroundings

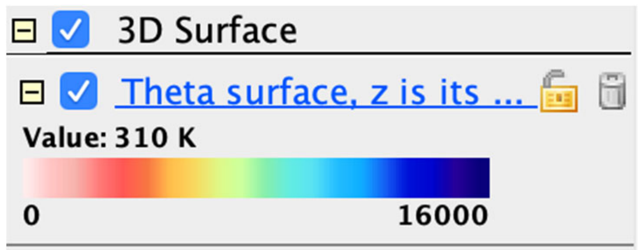


Isentropic surfaces

- Isentrope contours on the cross sections above are *slices of isentropic surfaces*
  - surfaces of constant entropy
    - or potential temperature, or dry static energy $C_pT + gz$
- Let's learn to see isentropic surfaces
- They are almost like *material surfaces*
  - because $D\theta/Dt = 0$ for adiabatic flow
    - *(plus nonadiabatic or "diabatic" complications)*
- Their vertical motion is air vertical motion!
  - the holy grail, for clouds+rain (weather)

IDV Lab assignment part 2

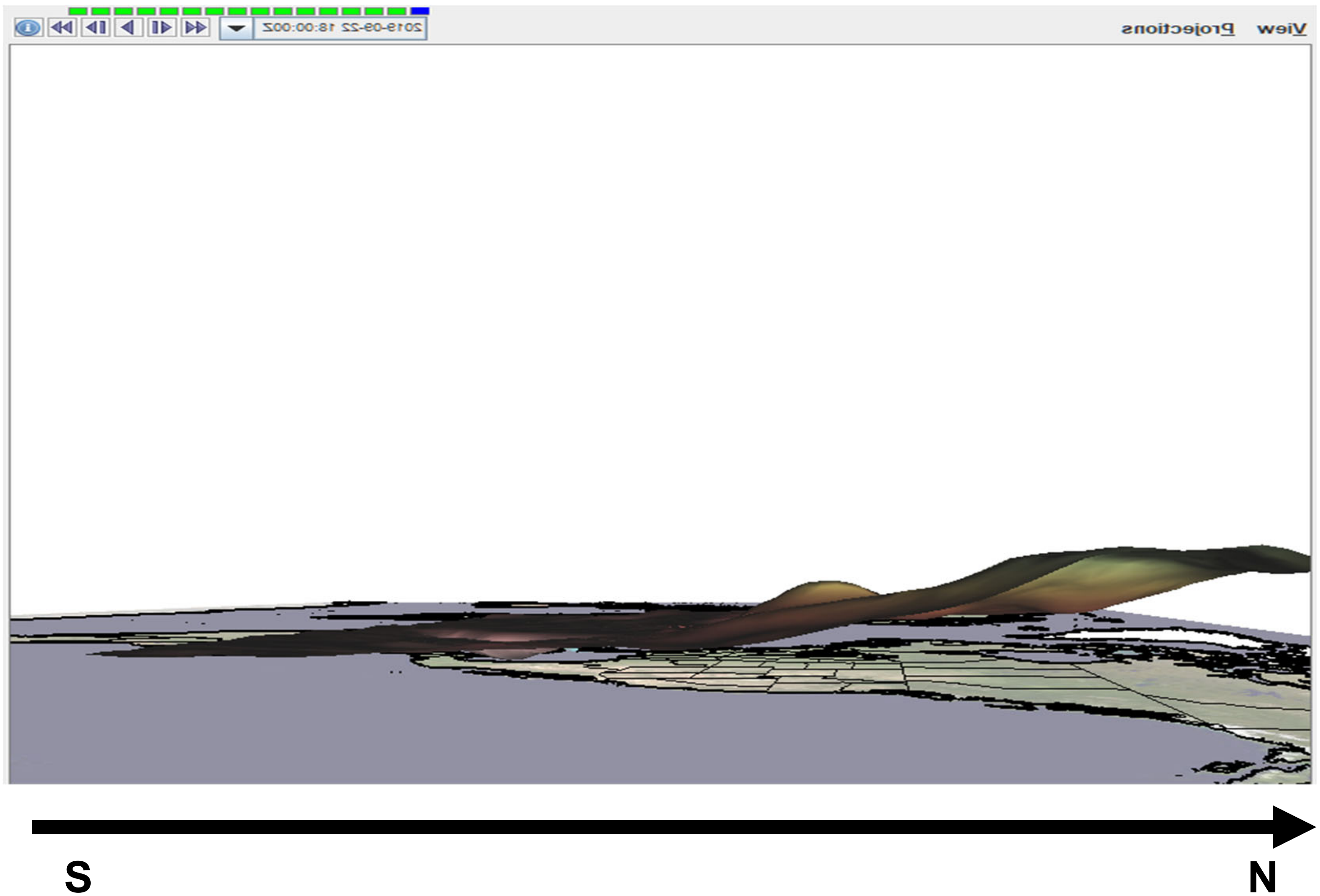
- In the same bundle, activate (check) the display called “Theta surface, z is its color”



- Adjust the value (310K, 330K, 360K)
- Use vorticity isosurfaces and cross sections in an illustrated description of its topography.
  – Is there a mean north-south slope? hint: 
  – What vorticity features (Part I) explain dimples?
  – What vorticity features (Part I) explain peaks?

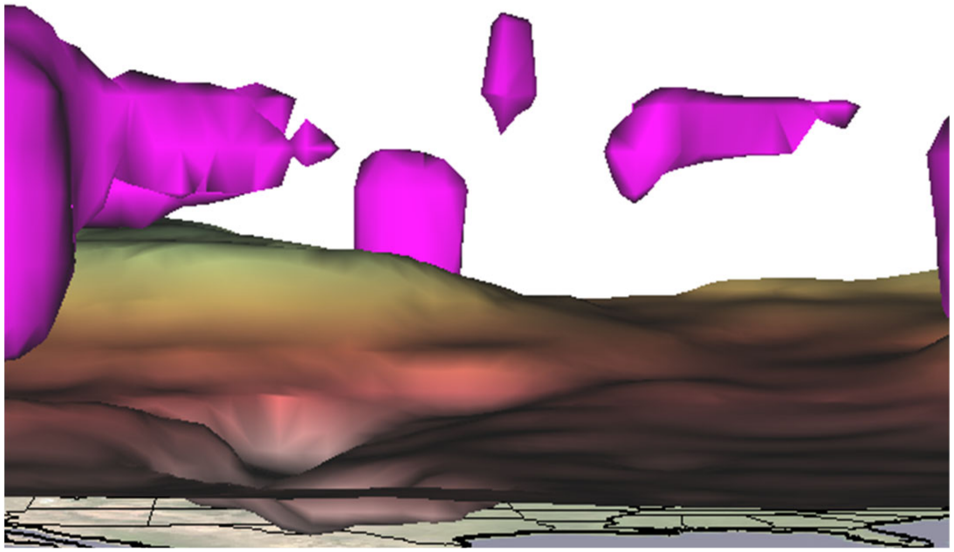
Mean slope of the 310K isosurface

The mean slope appears to increase with latitude, probably related to the decrease in mean temperature with latitude.



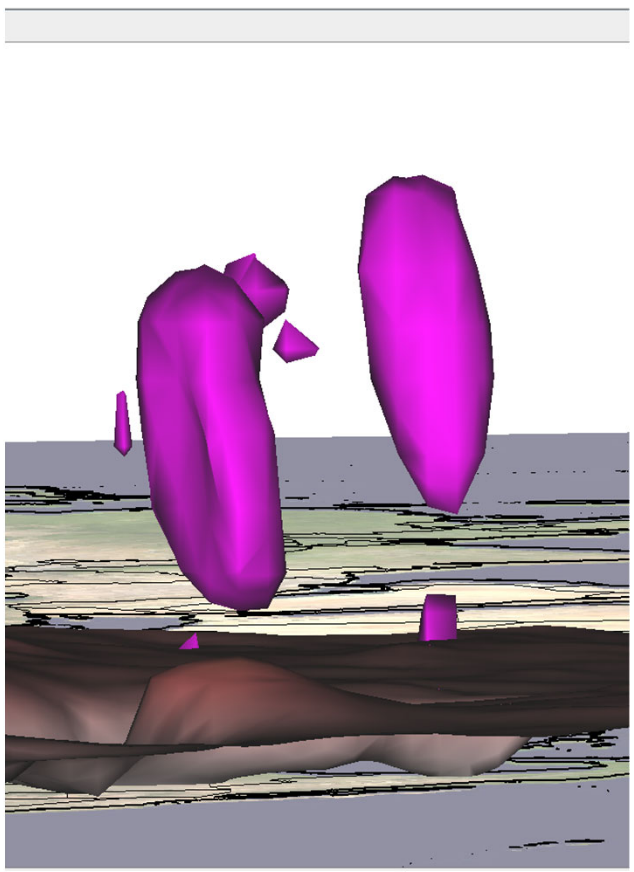
A depression in the 310K surface

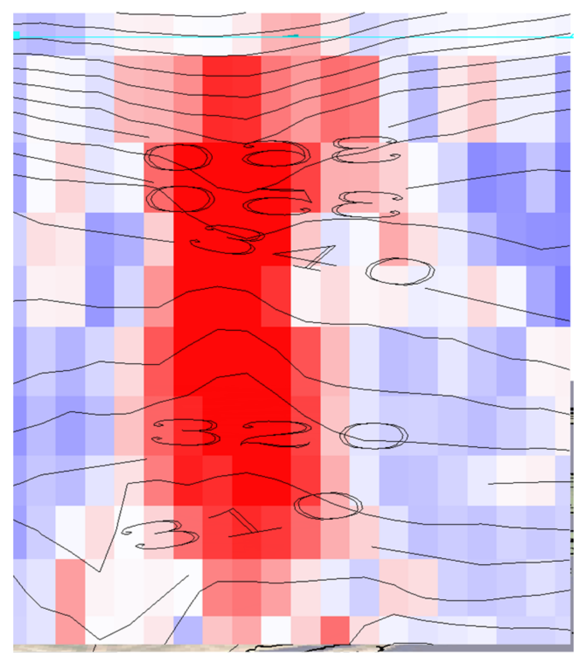
There is a very prominent depression evident over the desert southwest of the United States during the daytime. This is likely the result of diabatic daytime heating, with the surface likely approaching 310K in temperature.



A peak on the 310K isosurface

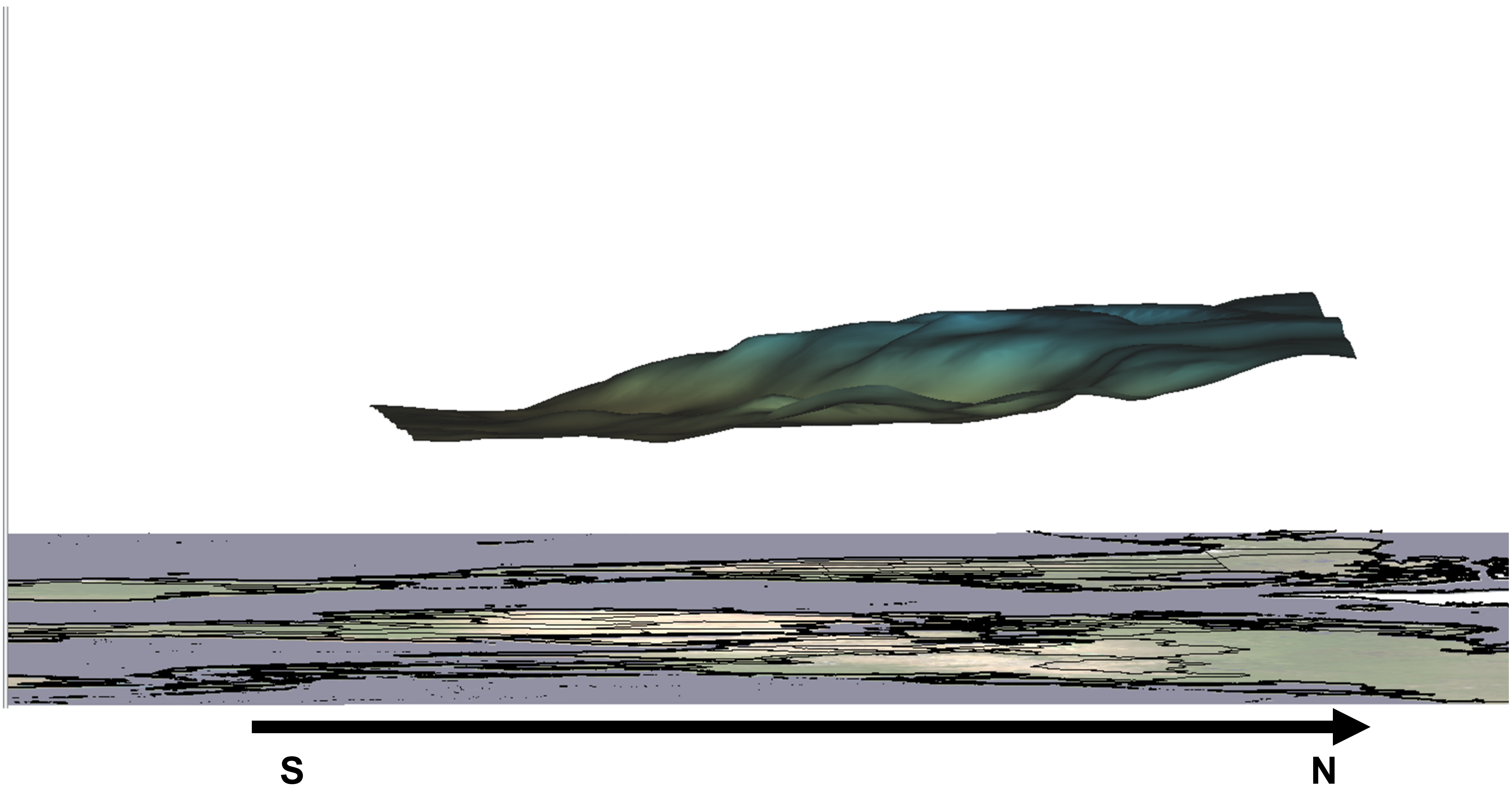
This peak is located below a cold-core cyclone over the northern United States. This is evident by the co-location of the raised surface below a positive vorticity blob (shown on left), and in the raised 310K isentropes in the cross-section through said cyclone (shown to right).





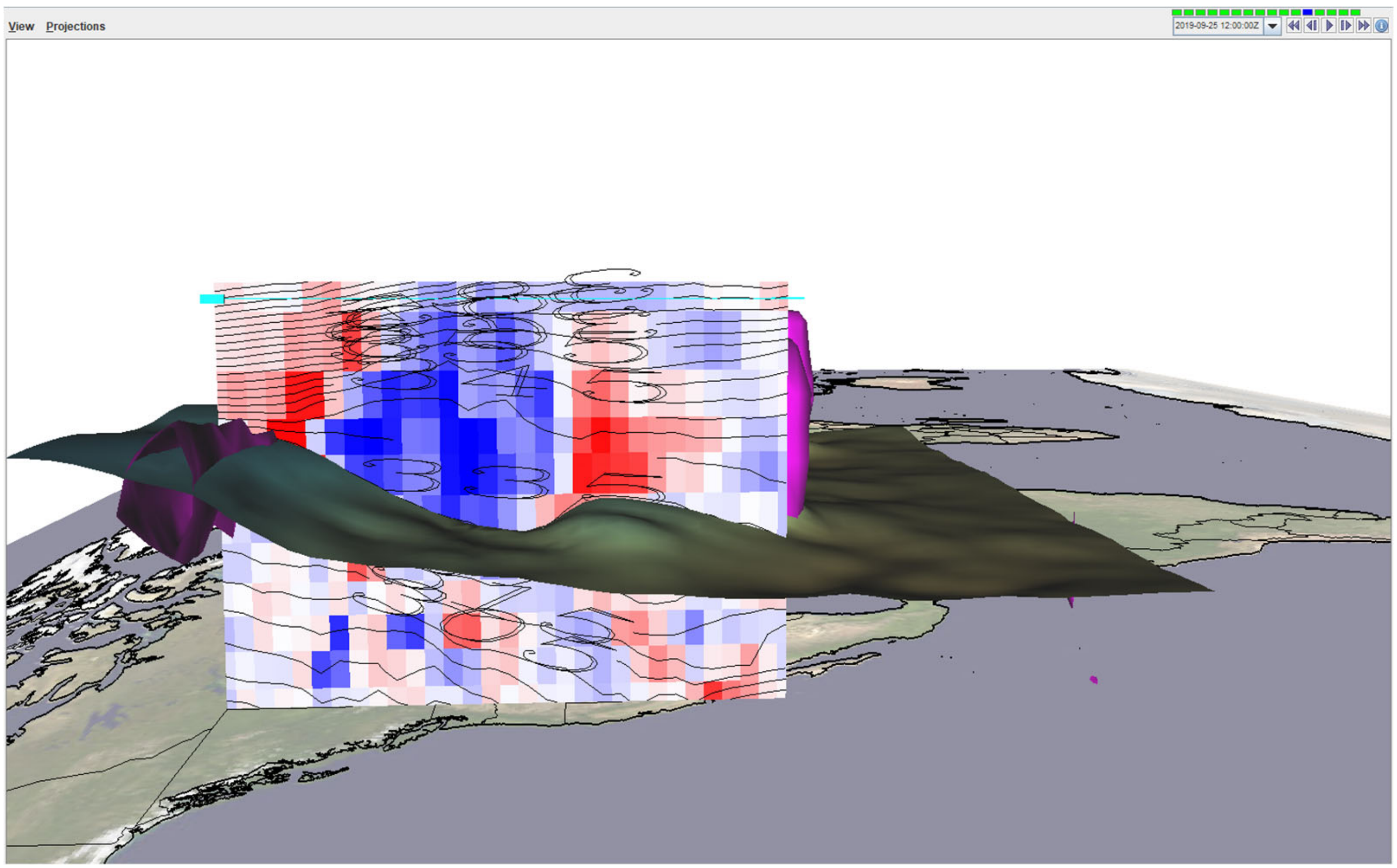
Mean slope of the 330K isosurface

Like 310K surface, increases with increasing latitude. This is again likely related to average temperature decrease with latitude present in the mid-troposphere.



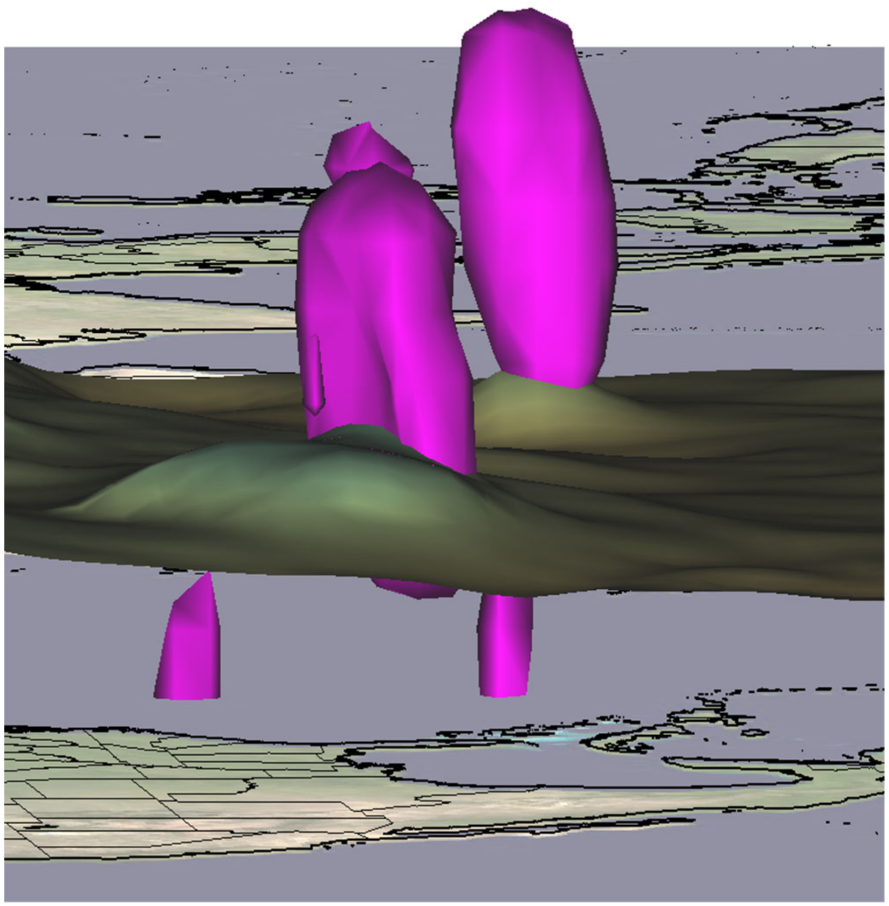
A depression in the 330K surface

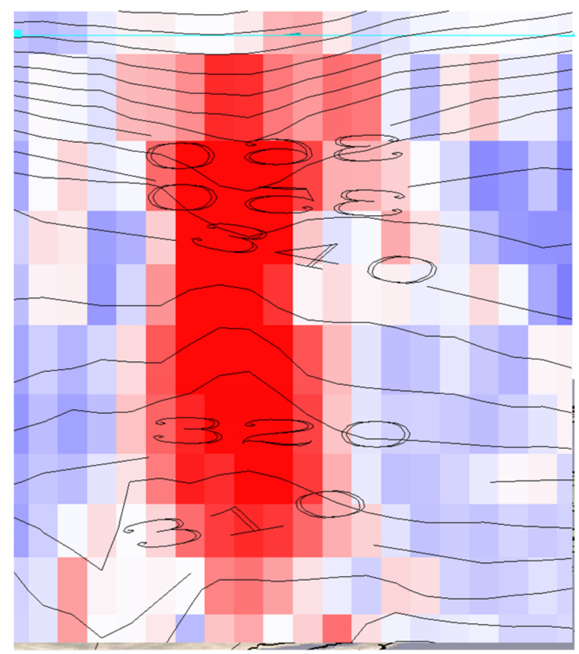
In this case, the depression in the 330K isosurface appears associated with an upper-level anti-cyclone, known as a warm-core anticyclone. This is also evidence in cross sections, where the 330K isosurface is pushed downward below said anticyclone.



A peak on the 330K isosurface

This peak, captured over the southern United States, appears co-located with an area of cyclonic vorticity above it. This feature is also clled a cold-core cyclone. Notice the raised 330K surface in cross-sections, similar to what was seen before with the 310K surface.



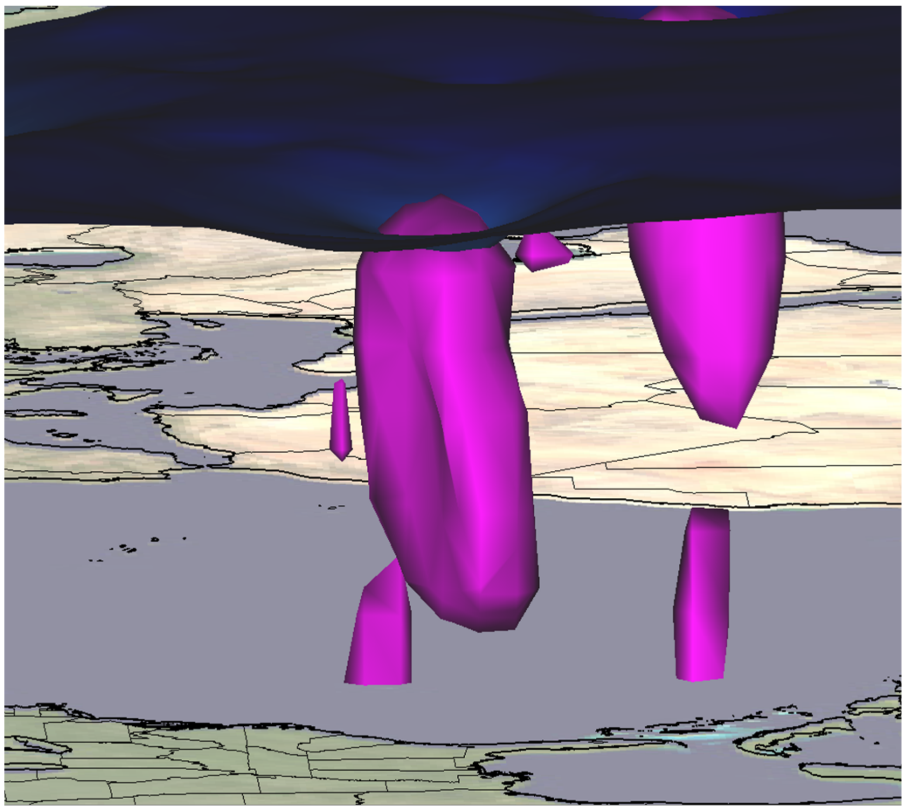


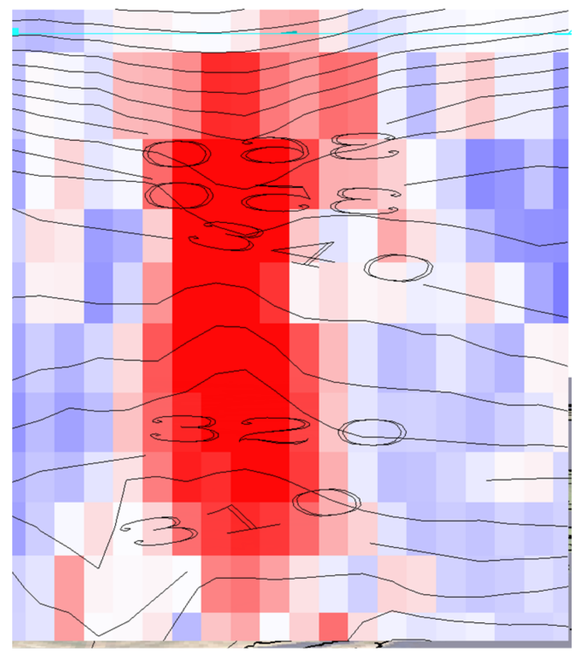
Mean slope of the 360K isosurface

Unlike the 310K and 330K surfaces, this actually decrease with increasing latitude. This is likely because this surface is found somewhere near the tropopause/start of the stratosphere. As the tropopause tends to decrease in height at high latitudes, so will the 360K surface.

A depression in the 360K surface

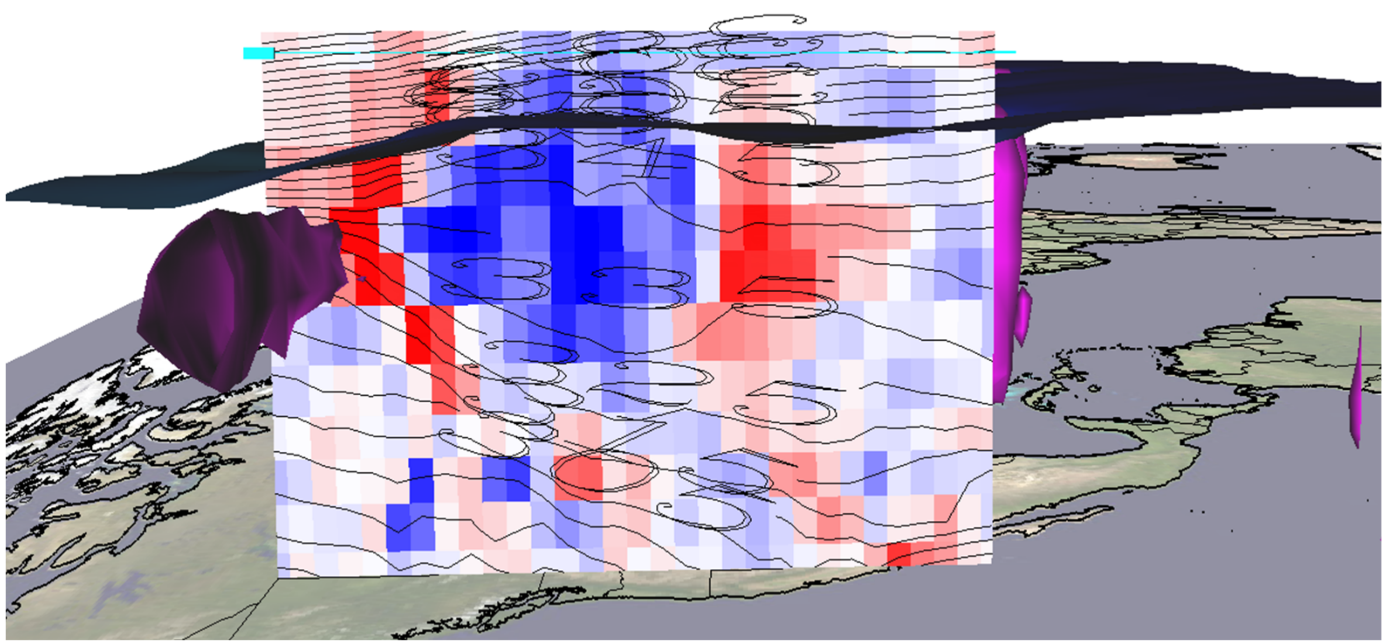
This depression occurs over an area of cyclonic vorticity in the upper atmosphere. The depression in this surface is thus associated with the area of relatively warmer air found above cyclonic vortices in the atmosphere. This is further visualized with a cross-section of RV and theta through said feature. This phenomenon is often referred to as a “stratospheric intrusion”.





A peak on the 360K isosurface

In contrast to the depression, a peak in the 360K surface is instead associated with an upper-tropospheric anticyclone. This is related to the relatively cold air that must be in place direction above said anticyclone – and is easily pictured using the included



Use the Print facility of Powerpoint

- to put a PDF of this into your class Github repository
- so we can look them over in class