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

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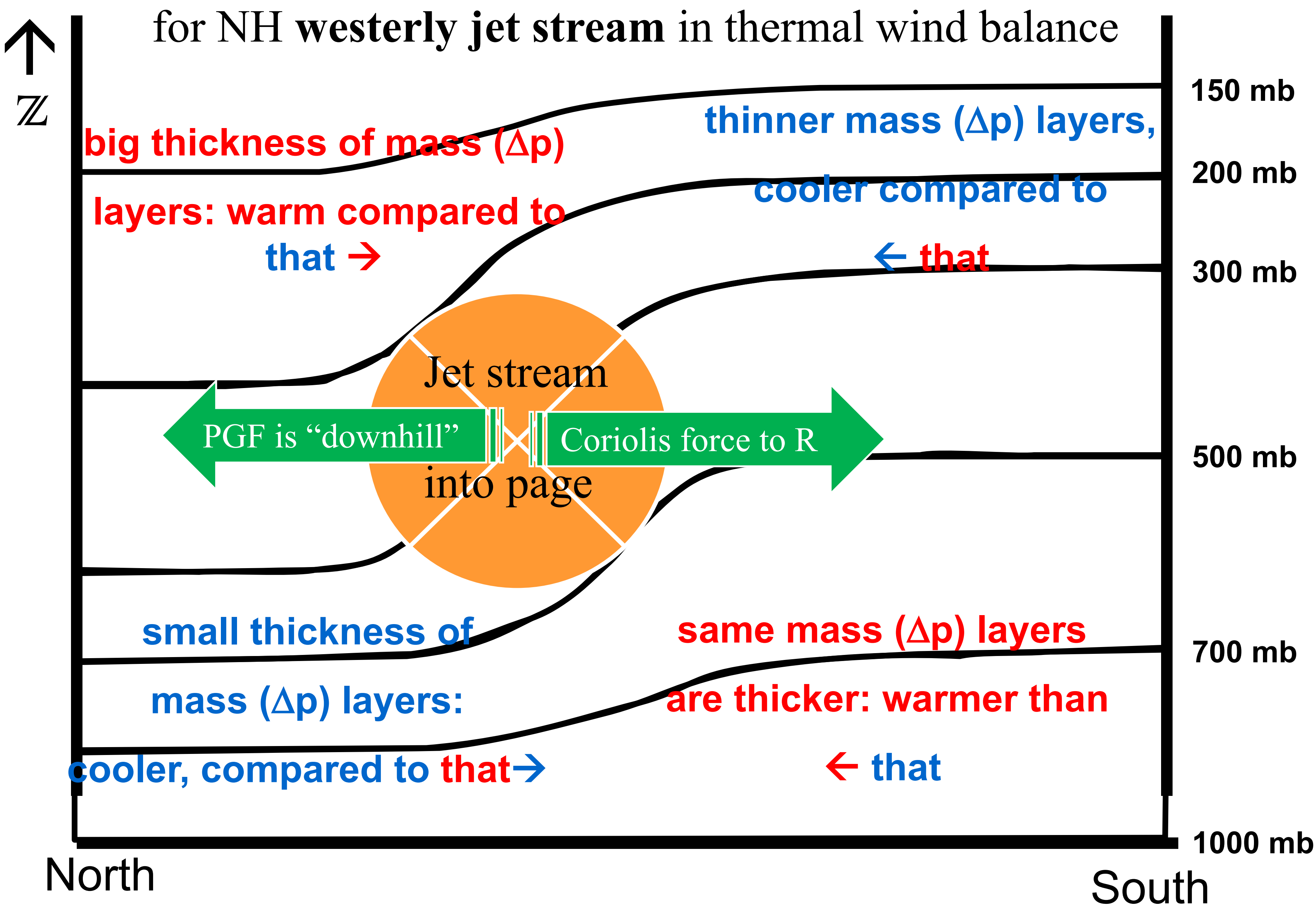
The big idea of it

- 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.

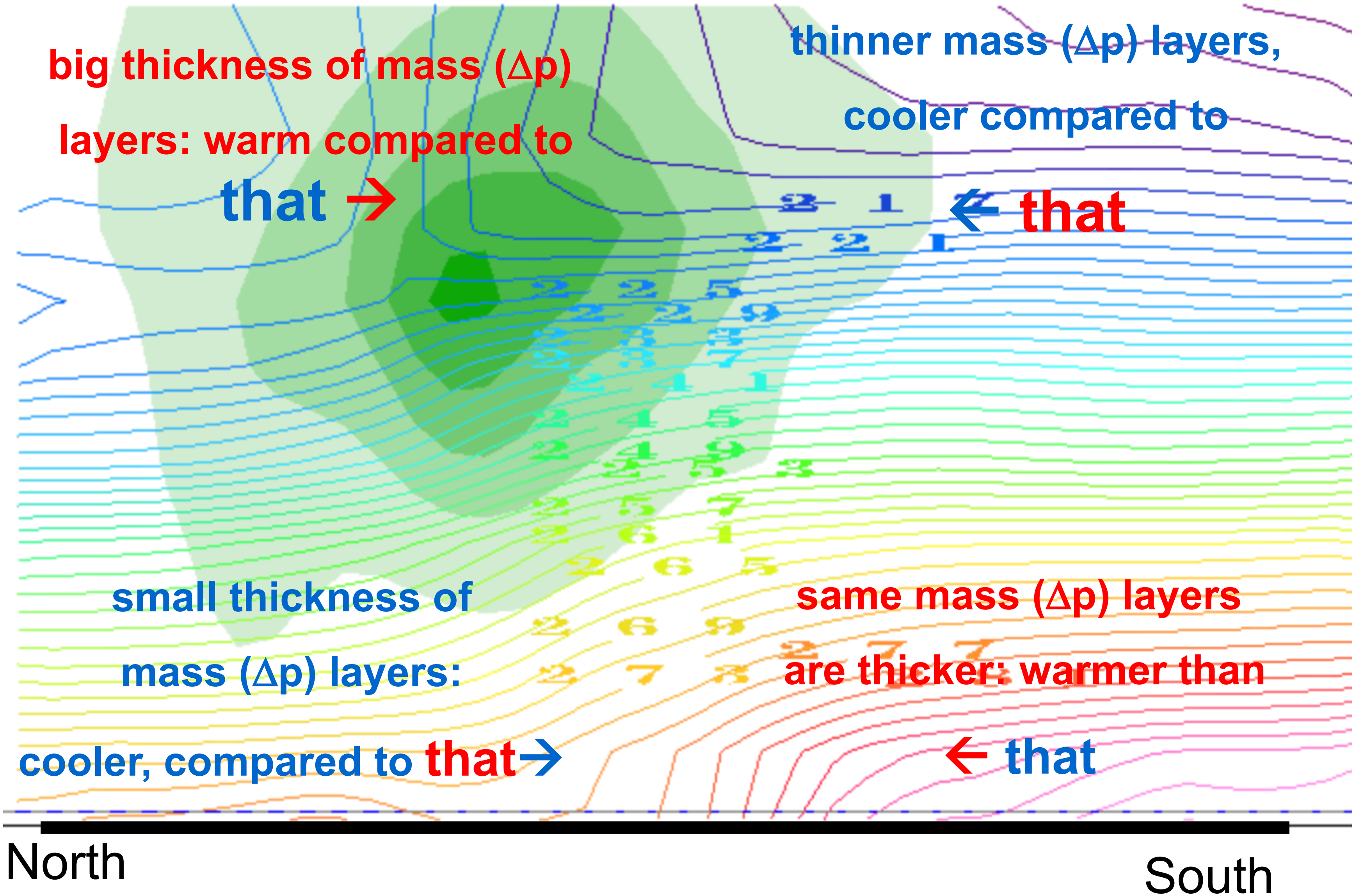
- But wind always blows in circuits (circulations), so it is often more useful to think of *vortices* (with vorticity as the budget equation) as the fundament of flow.
- Then T is understood in terms of warm and cool *cores.*

p surfaces on a z-coordinate diagram



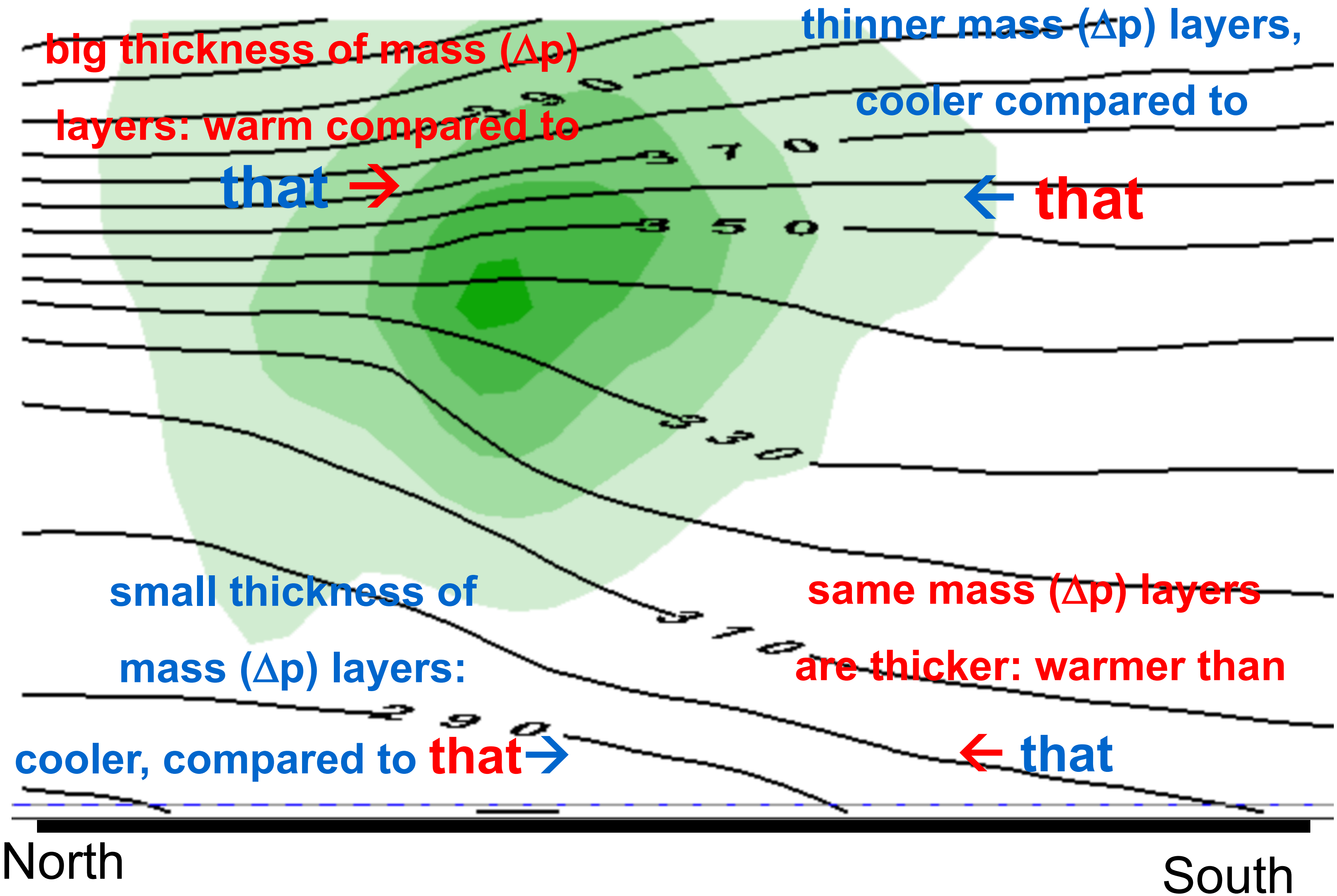
contours of T(K): it decreases with height

(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!**

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

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

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

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

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

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

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

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

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

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

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

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

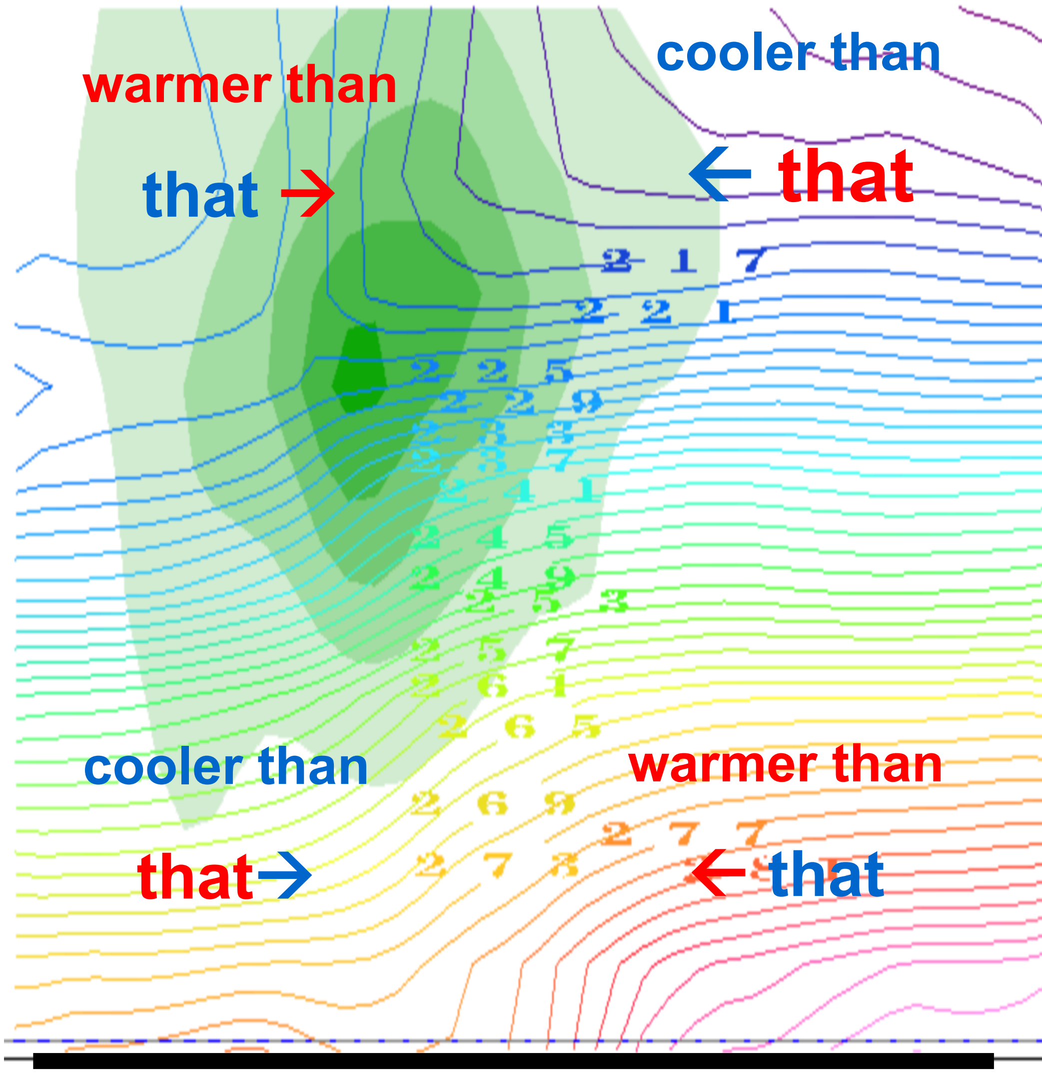
$$D\zeta/Dt = 0 + complications$$

- 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?

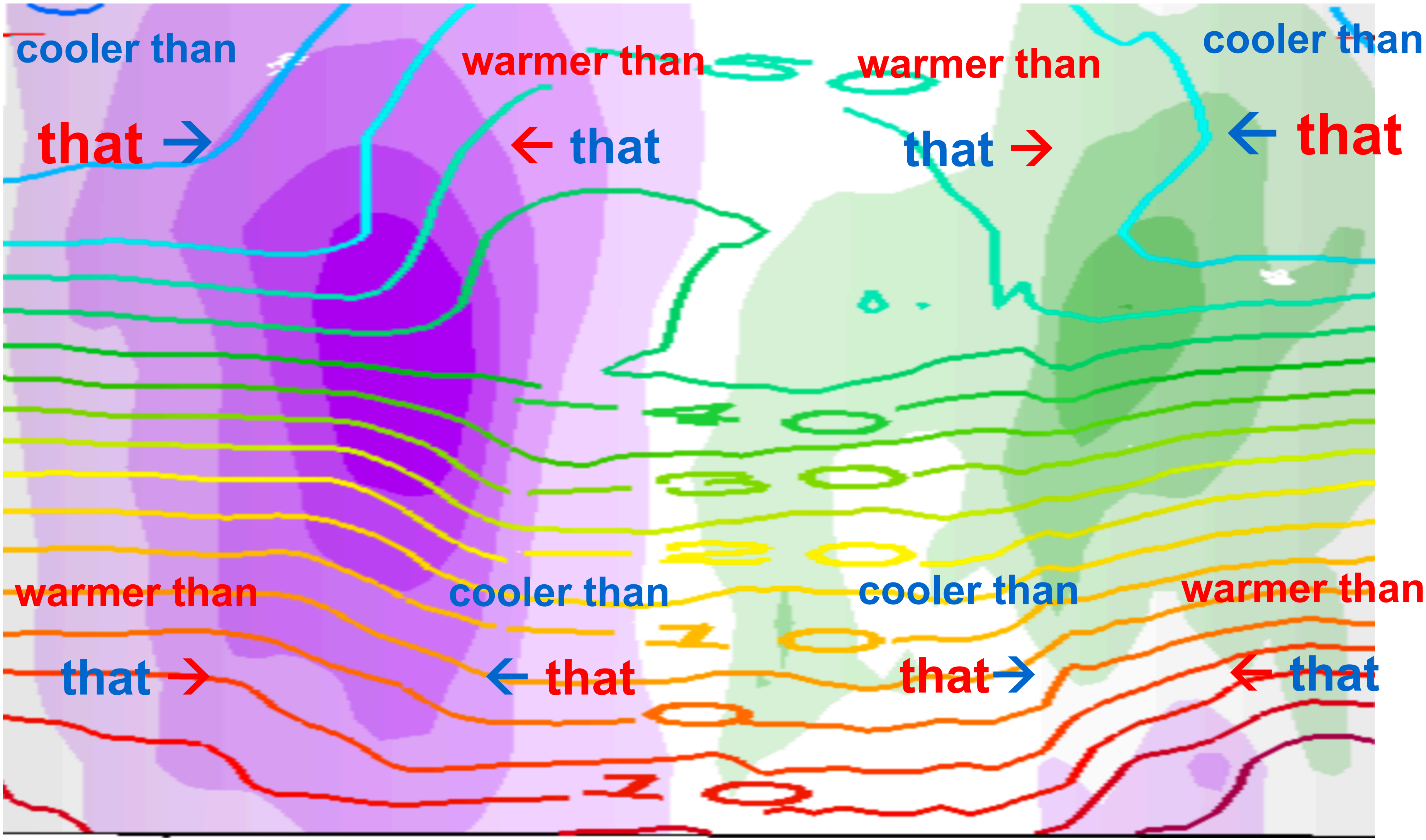
- In this case, one near the tropopause (like the jet stream)

This is only half the story of a vortex



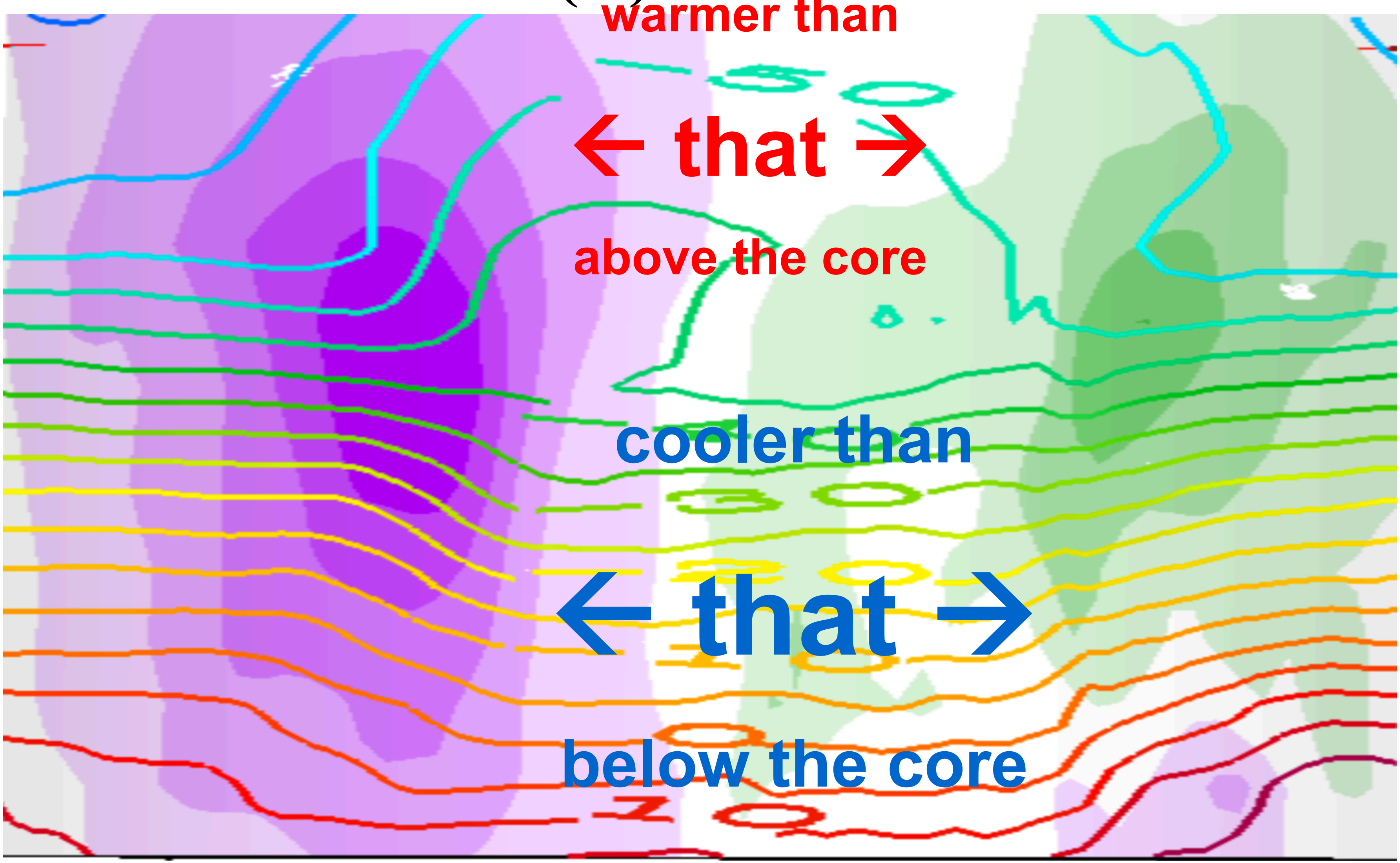
This is a whole vortex (two jets)

T(K) contours



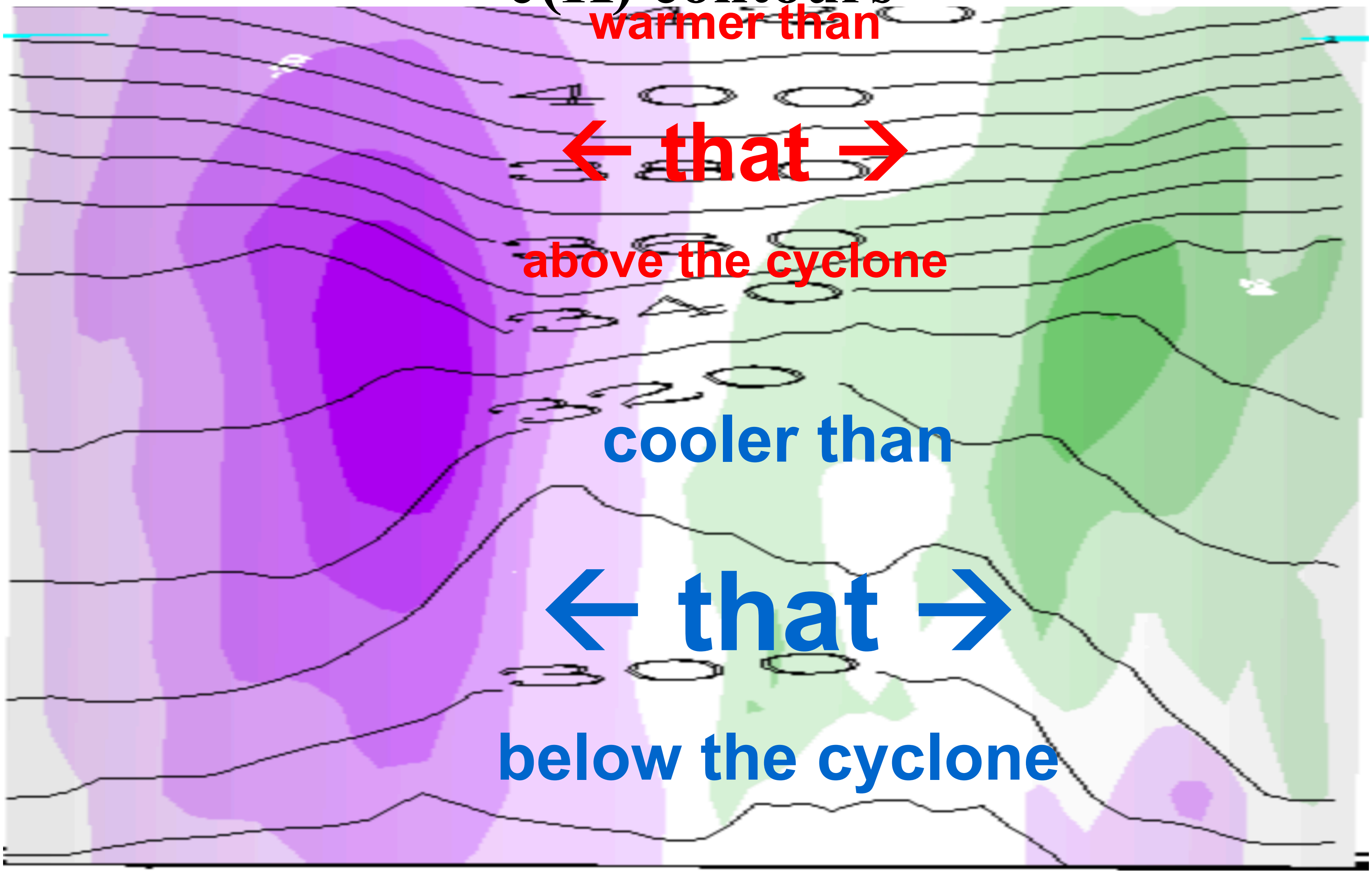
This is a whole vortex (two jets)

T(K) contours

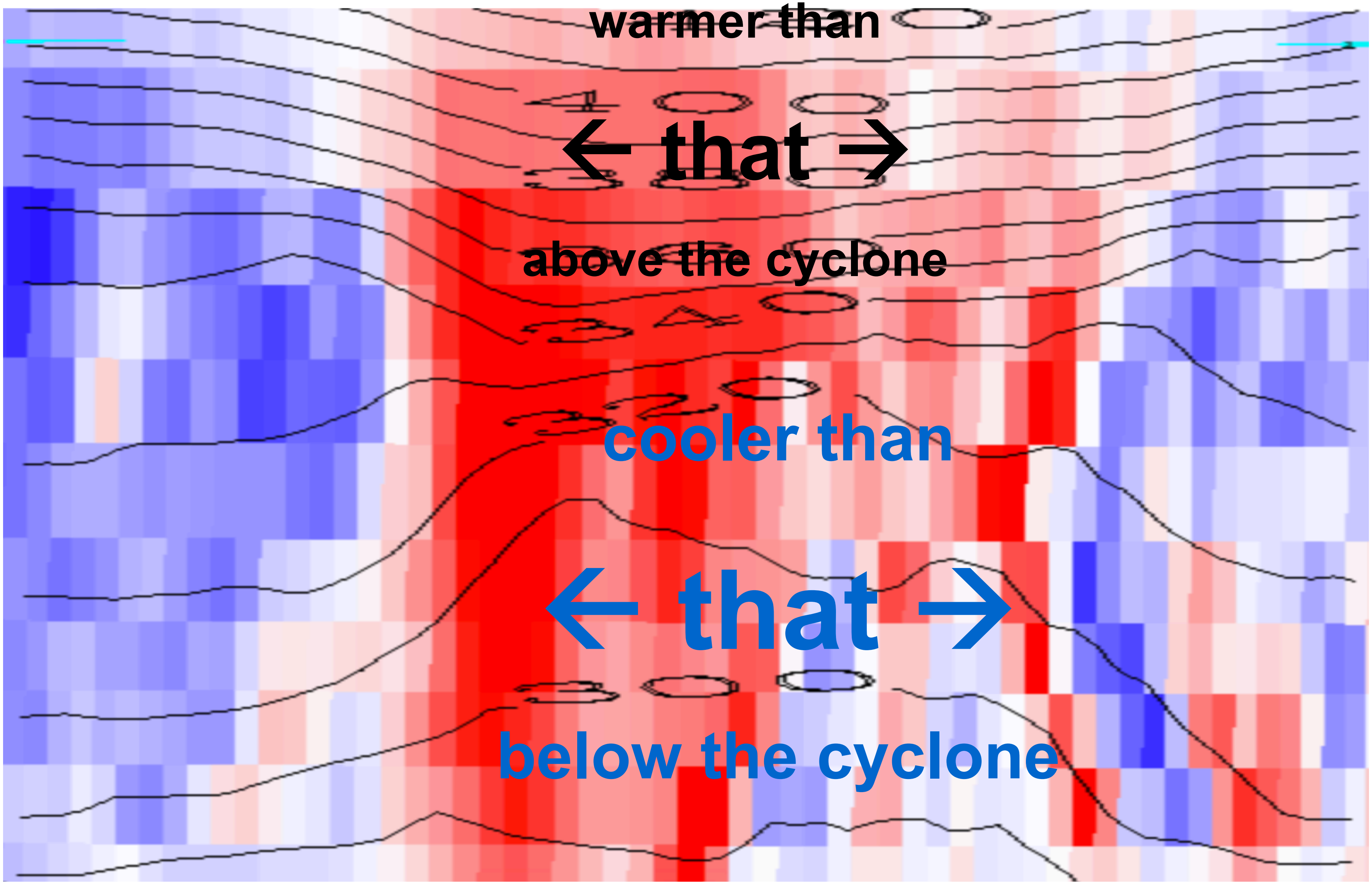


This is a whole vortex (two jets)

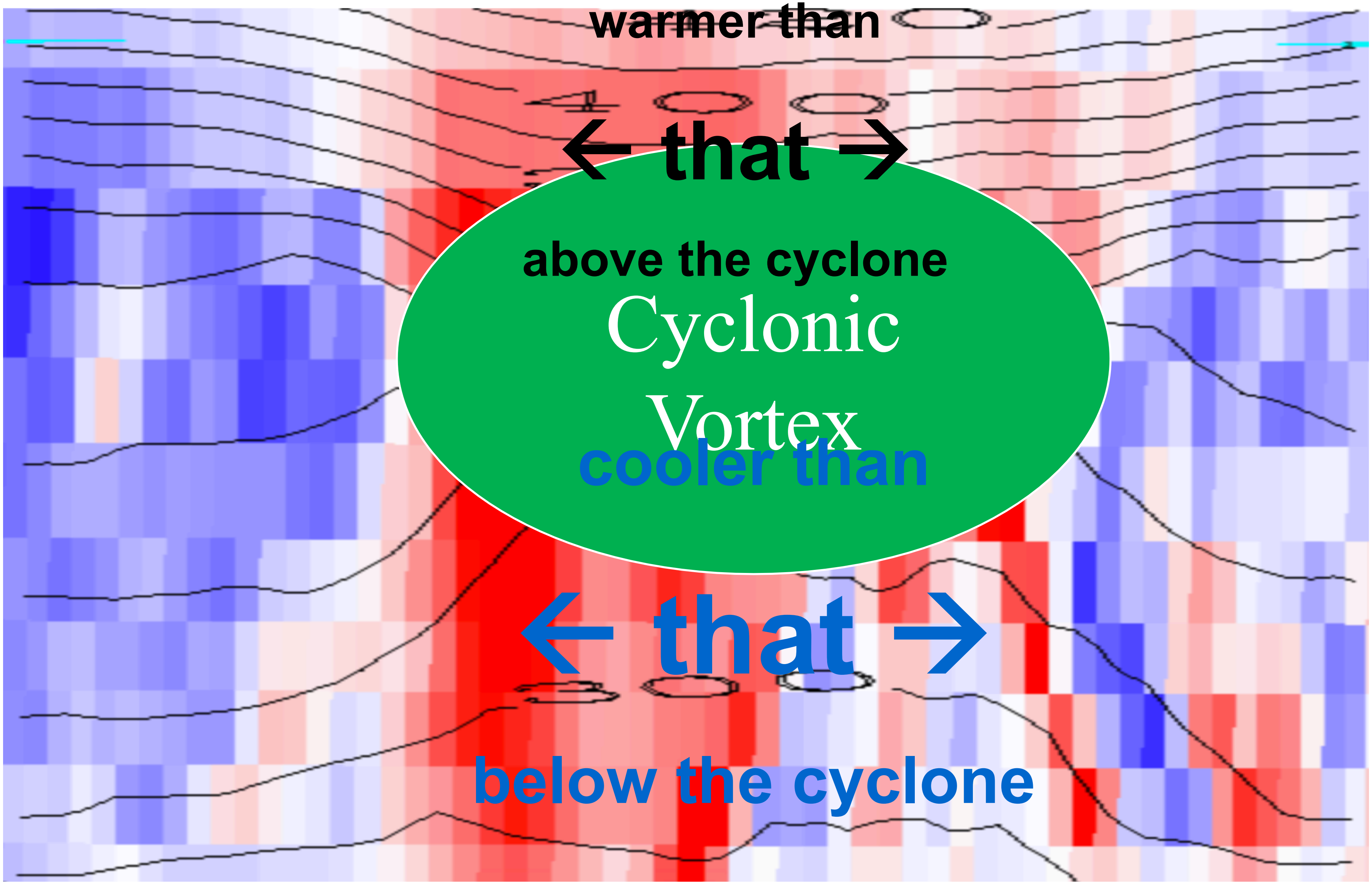
θ(K) contours



Red is positive vorticity , θ(K) contours

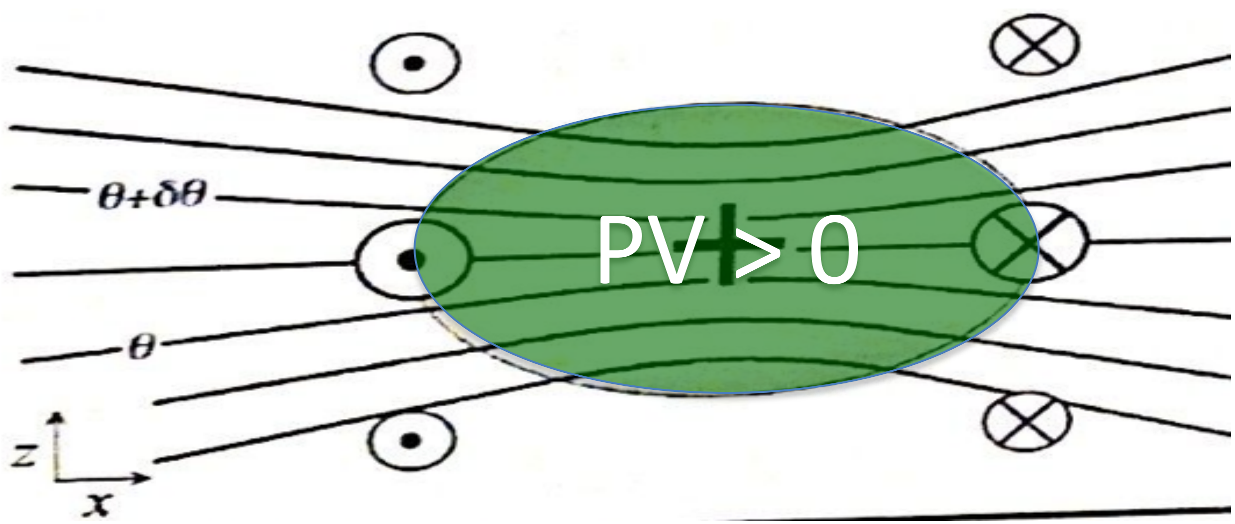


Red is positive vorticity , θ(K) contours



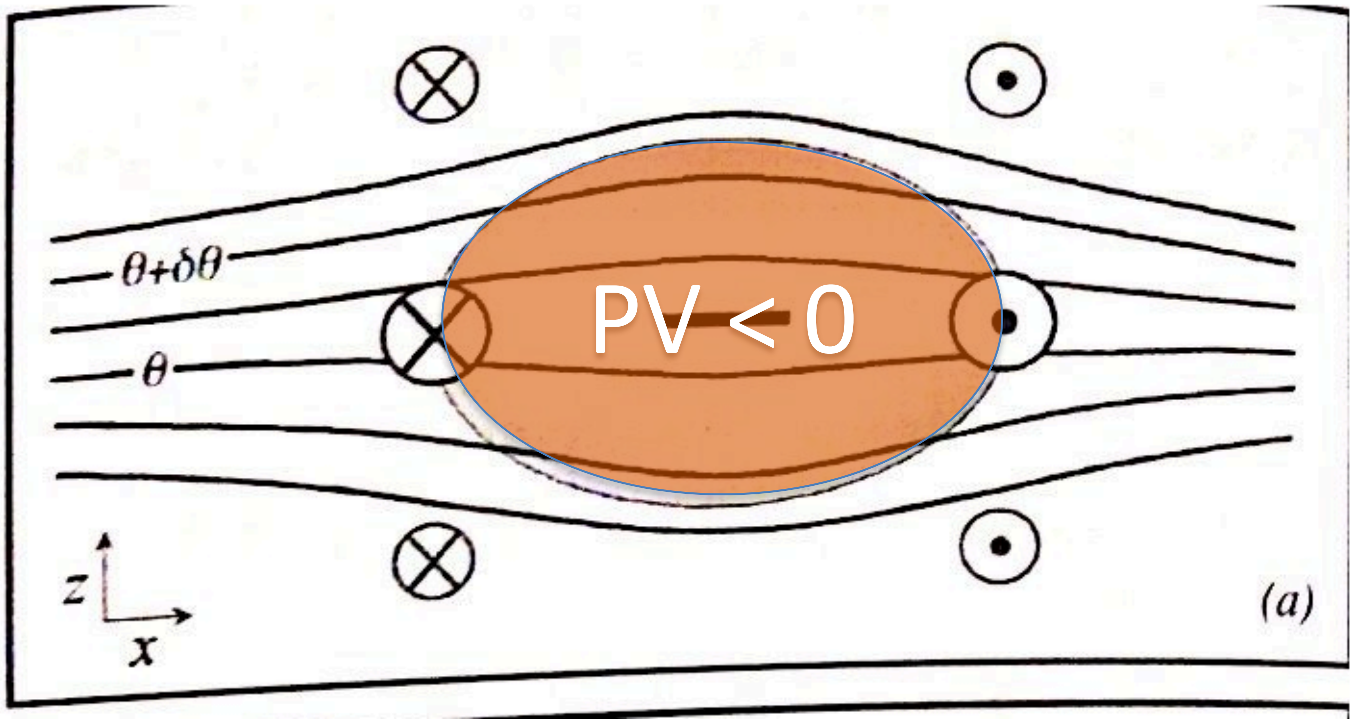
Generalization: *PV*

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):

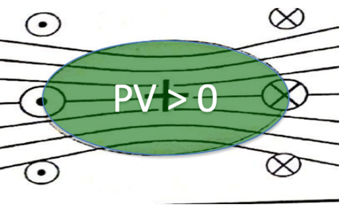


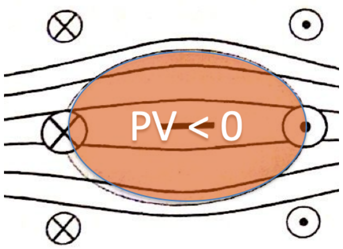
Balanced anticyclones exist too...

- Just the opposite of a cyclone...



Vorticity (or PV) blobs





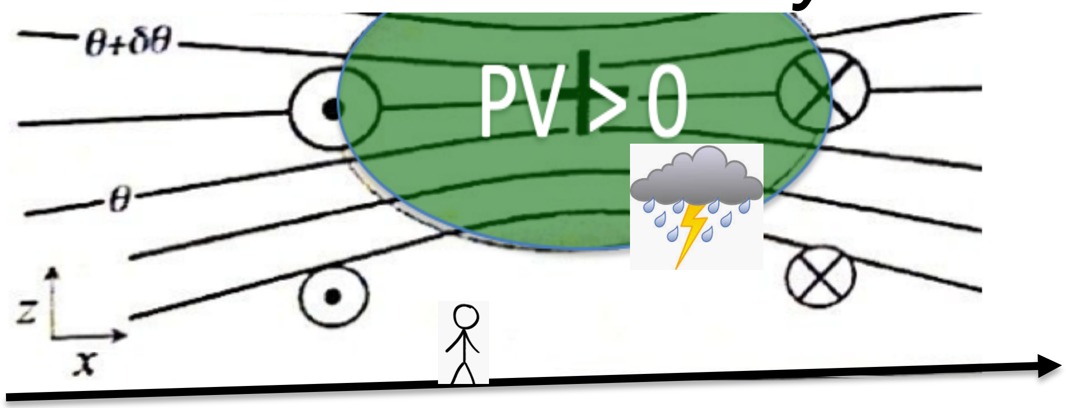
- Where do they come from?
- How do they interact?
  - (this we studied, in the horizontal plane)
- Do they get destroyed?

- (Soon: tackling the complications)

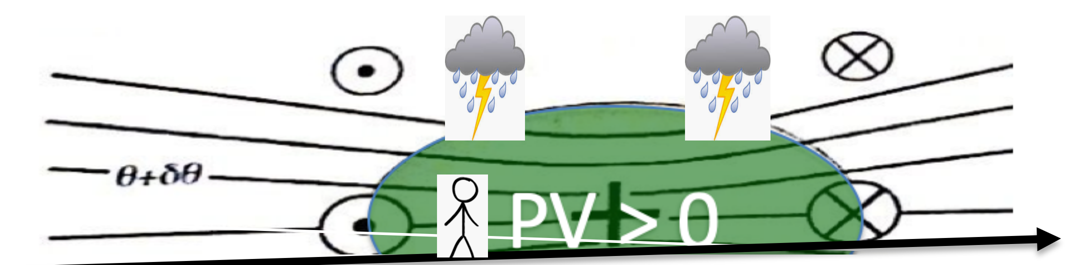
$$D\zeta/Dt = 0 + complications$$

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

- This is called a *cool core cyclone:*

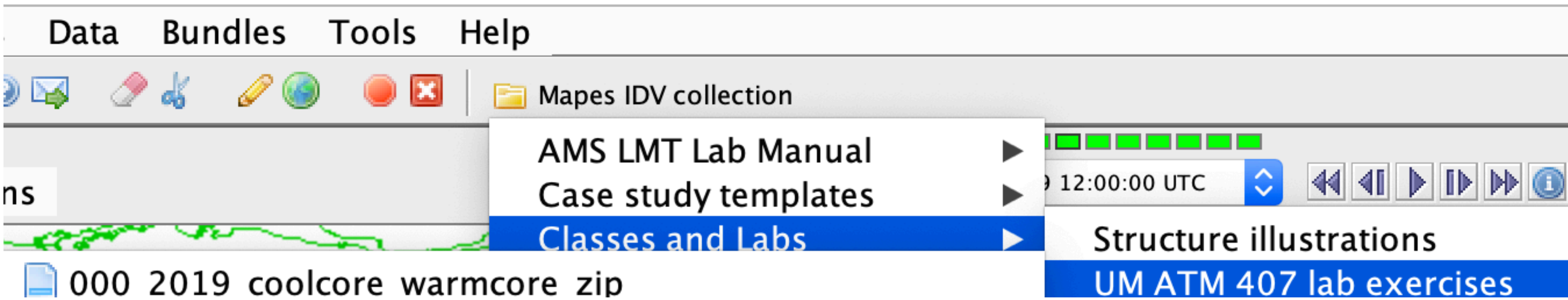


- This is called a *warm core cyclone:*



IDV lab assignment -- part 1

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

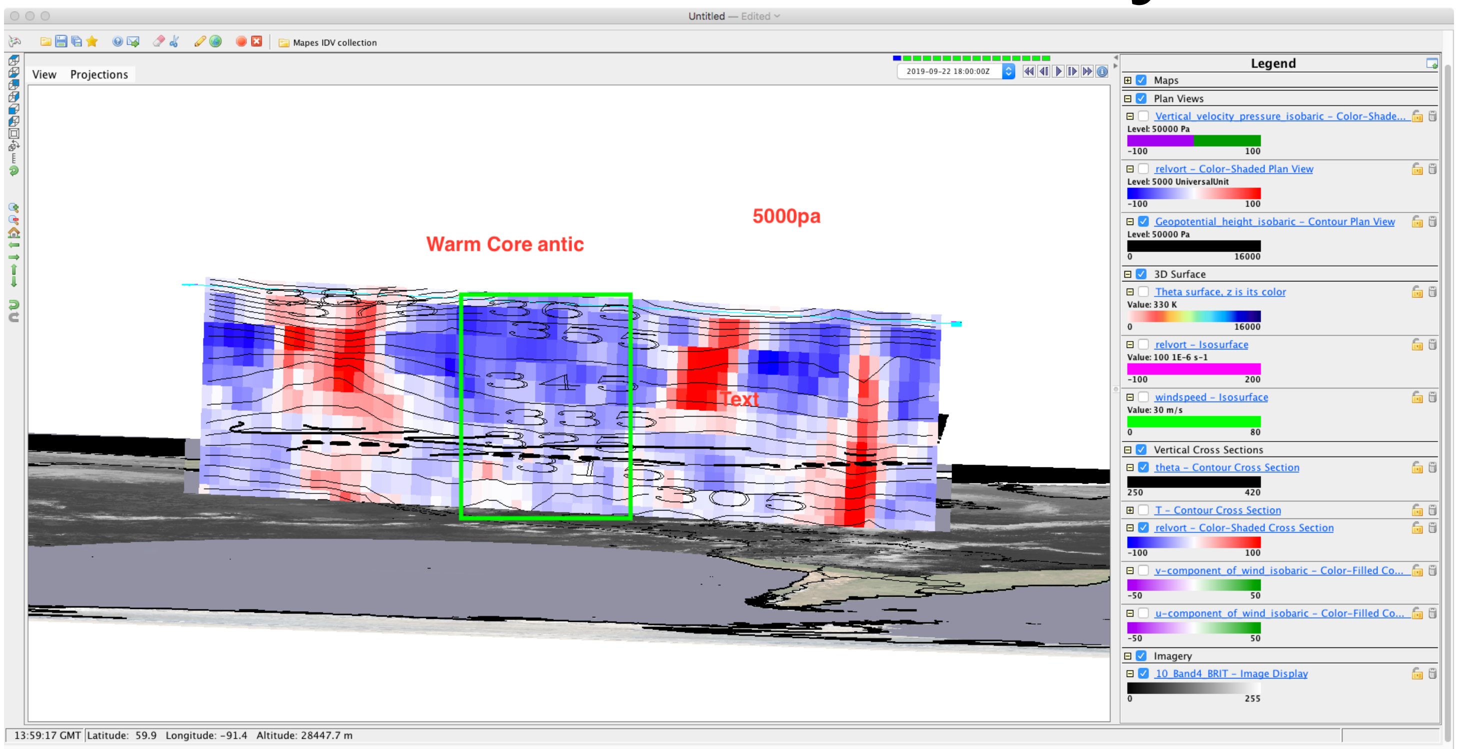


Explore ALL of its displays, at ALL of its times (loop the animation). Learn to use the IDV. The Help menu has pan-zoom help on top. A mouse is a HUGE help for 3D views.

IDV lab assignment -- part 1

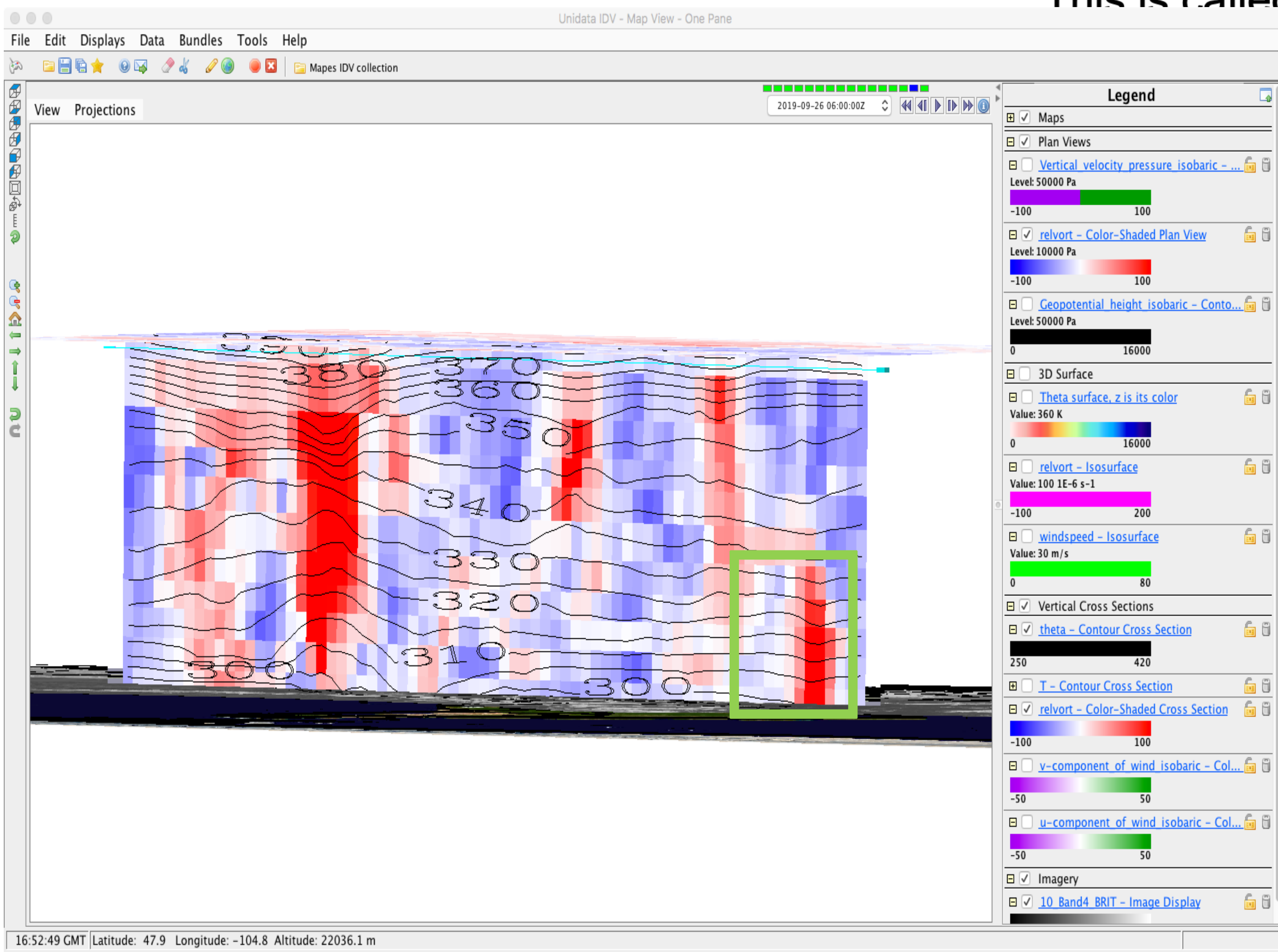
- In the following slides, make and label and explain nice clear illustrations like slides 13-17, but for
  - a warm core anticyclone
  - a warm core cyclone
  - a cool core anticyclone

A warm core anticyclone

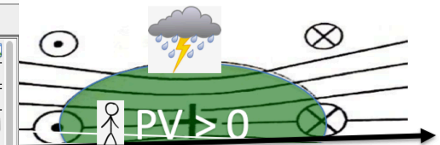


- Warm core because of the bulging between 365 and 335. Blue = anticyclonic PV
- Found between two cold core cyclones
- Warm core because of the bulging structure – warm in center = expanding and cool on outer edges – contracting ?

A warm core cyclone

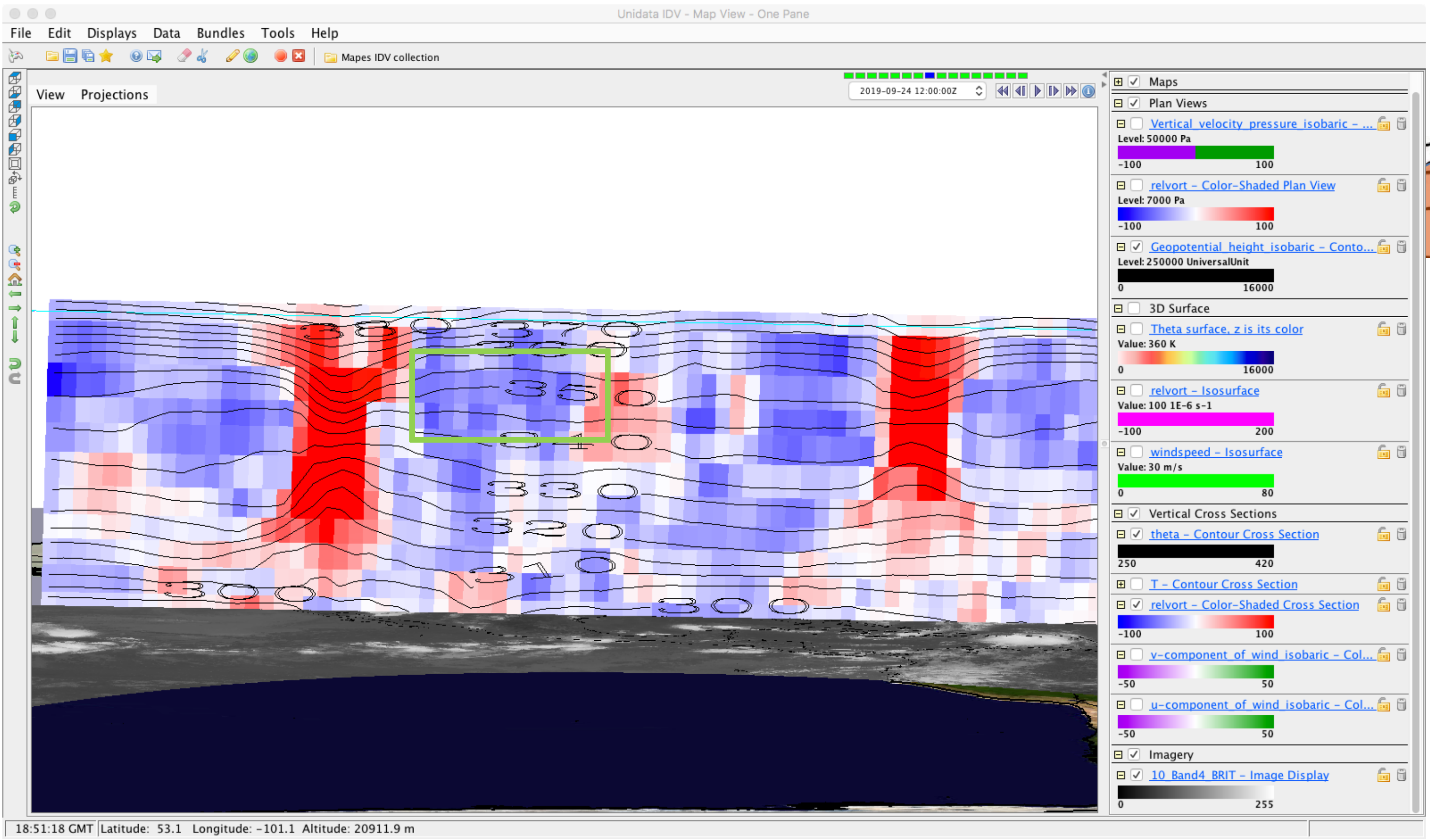


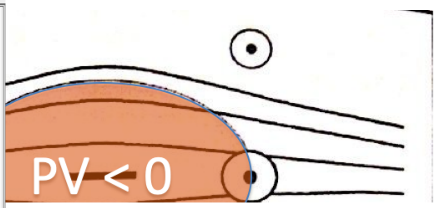
This is called a *warm core cyclone:*



Cyclone bc of positive vorticity. Warm core because of the depressed isentropes

A cool core anticyclone





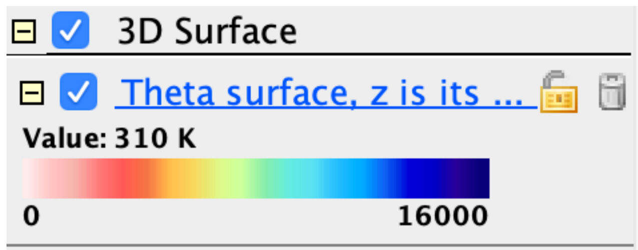
I originally had a different section selected, but in class I realized this was wrong and I think this more so what I was looking for? We want the isentropes to be lifting and bulging

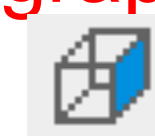
Isentropic surfaces

- 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)

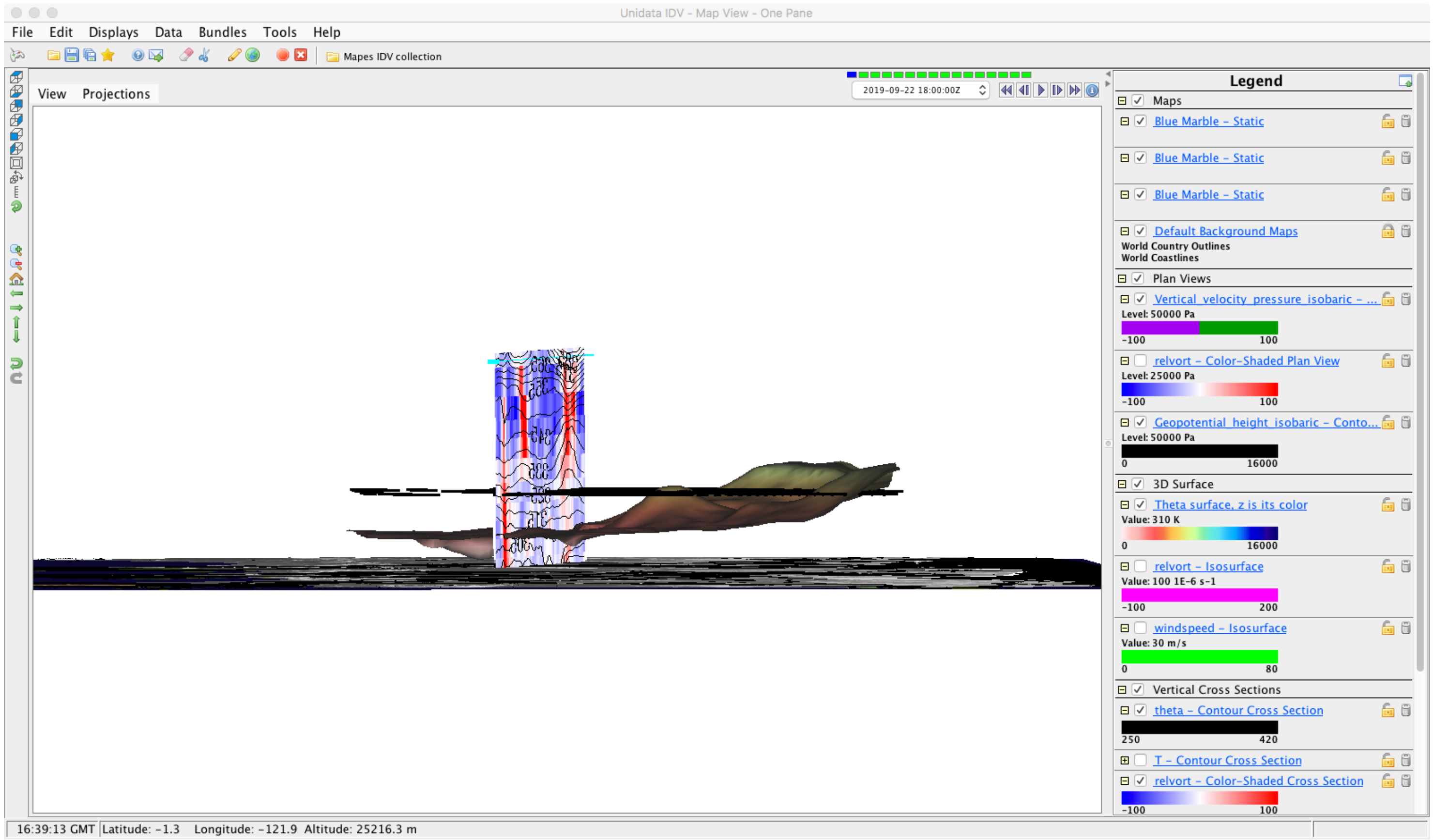
IDV Lab assignment part 2

- 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?

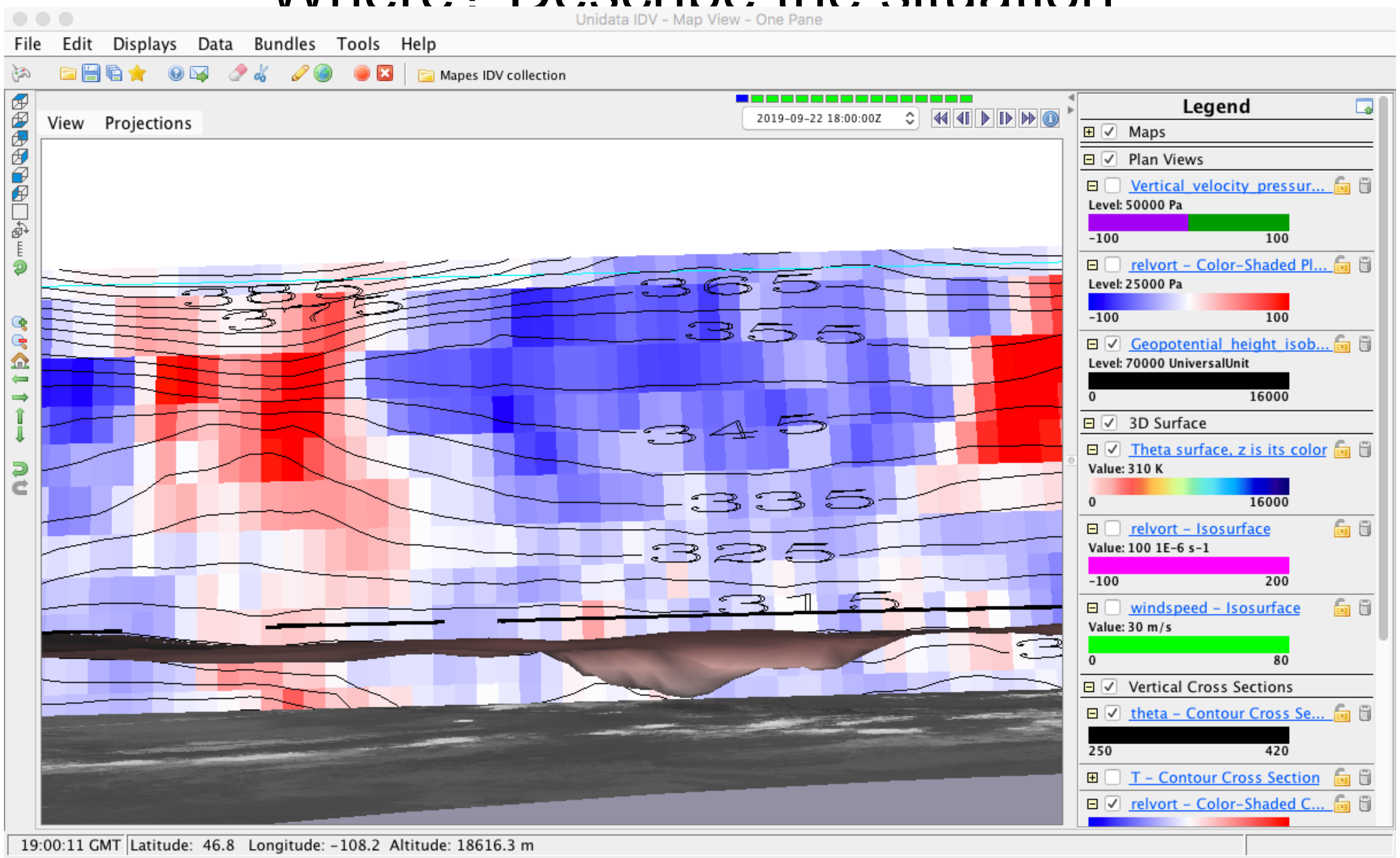
Mean slope of the 310K isosurface



Mean slope is higher in the N to lower in the S

A depression in the 310K surface

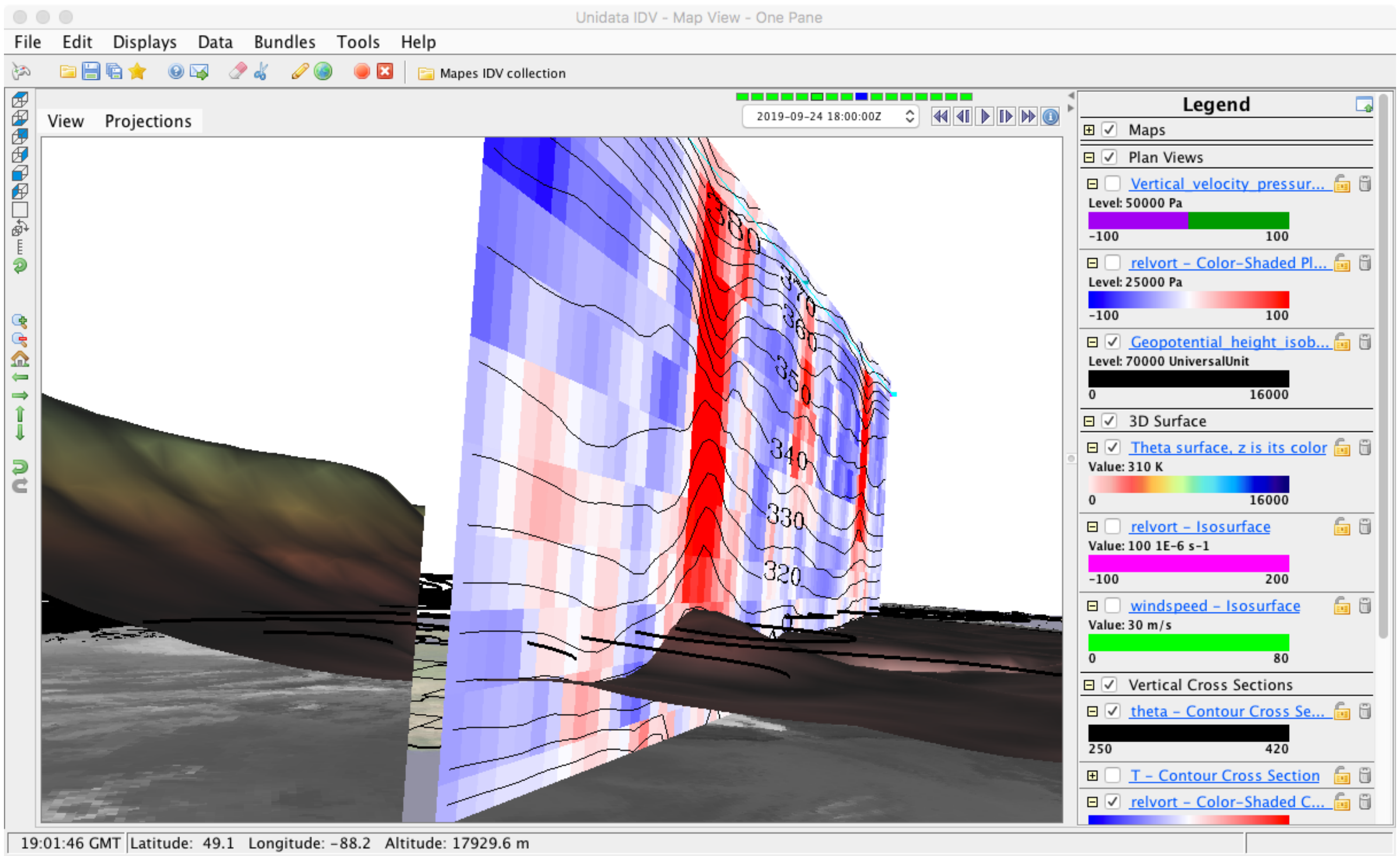
Where? Describe the situation



The depression appears to be below a warm core anti cyclone. At this 310 isentrope it looks like it's pretty anticyclonic, but not so strong – still negative vorticity but less negative than the vorticity at 345-365. – follows pattern of depressed isentropes above it

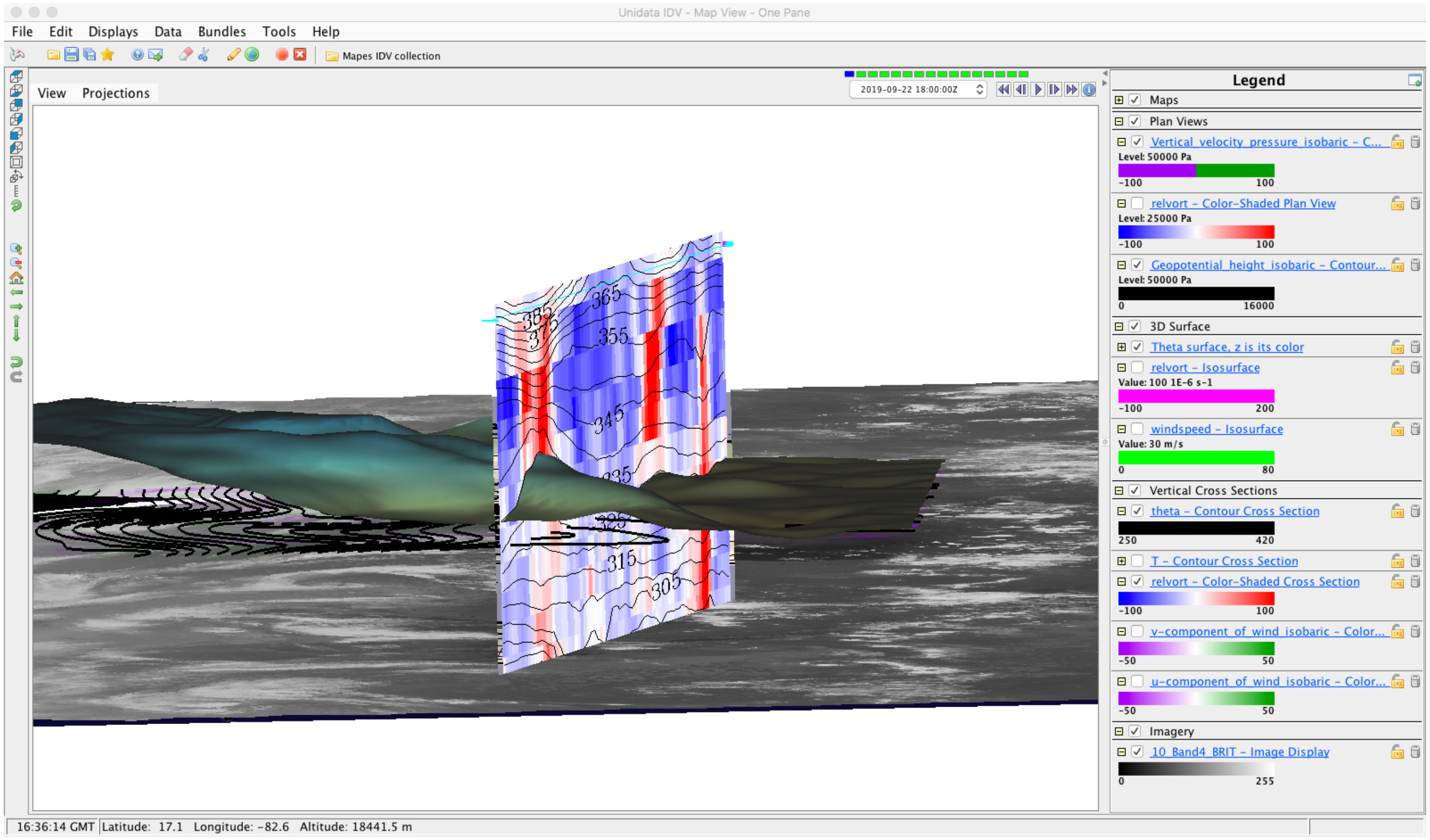
A peak on the 310K isosurface

Where? Describe the situation



The peak appears to be below a strong cold core cyclone, which makes sense I think because It follows the lifted isentropes of that cyclone.

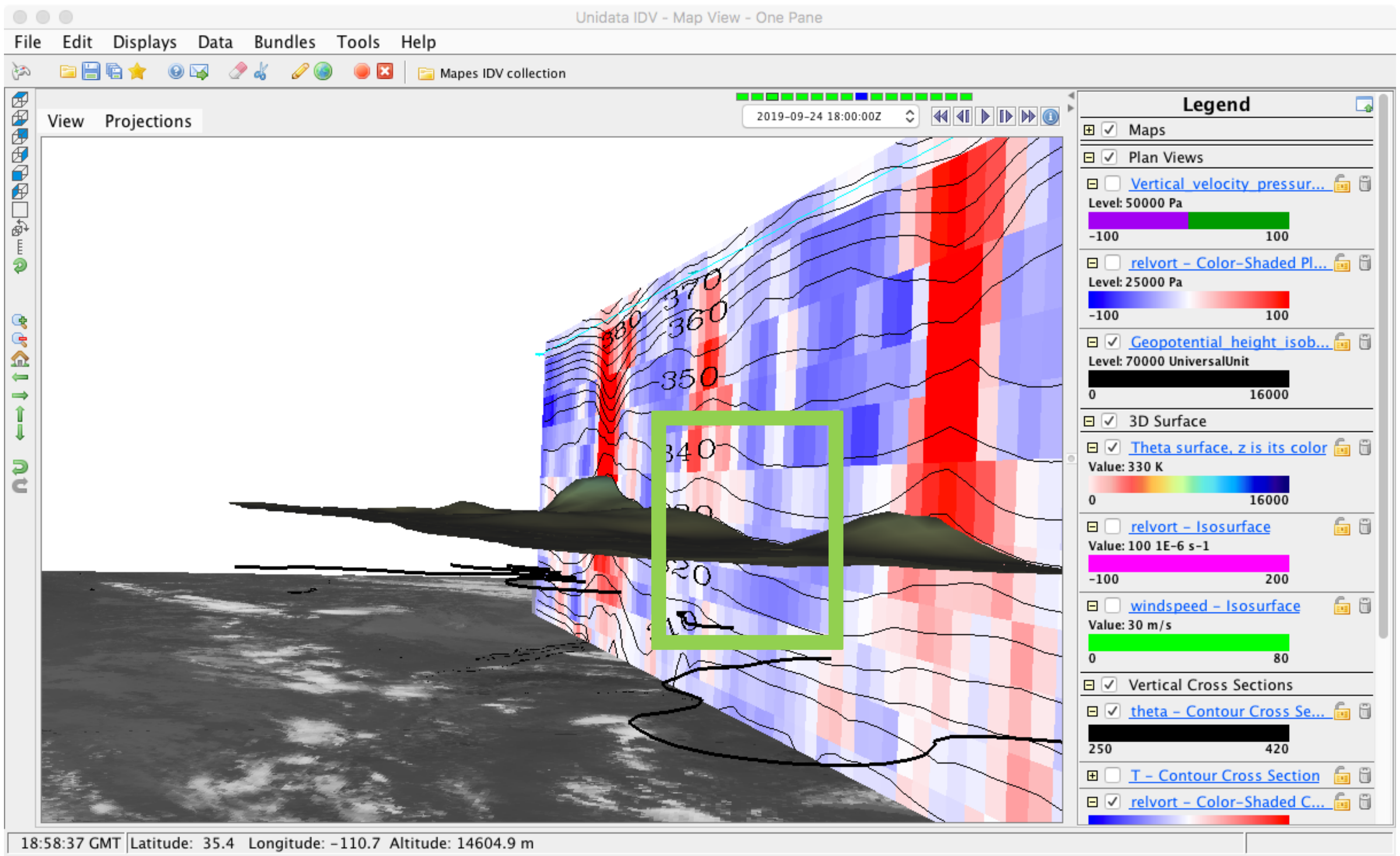
Mean slope of the 330K isosurface



Mean slope is higher in the N to lower in the S

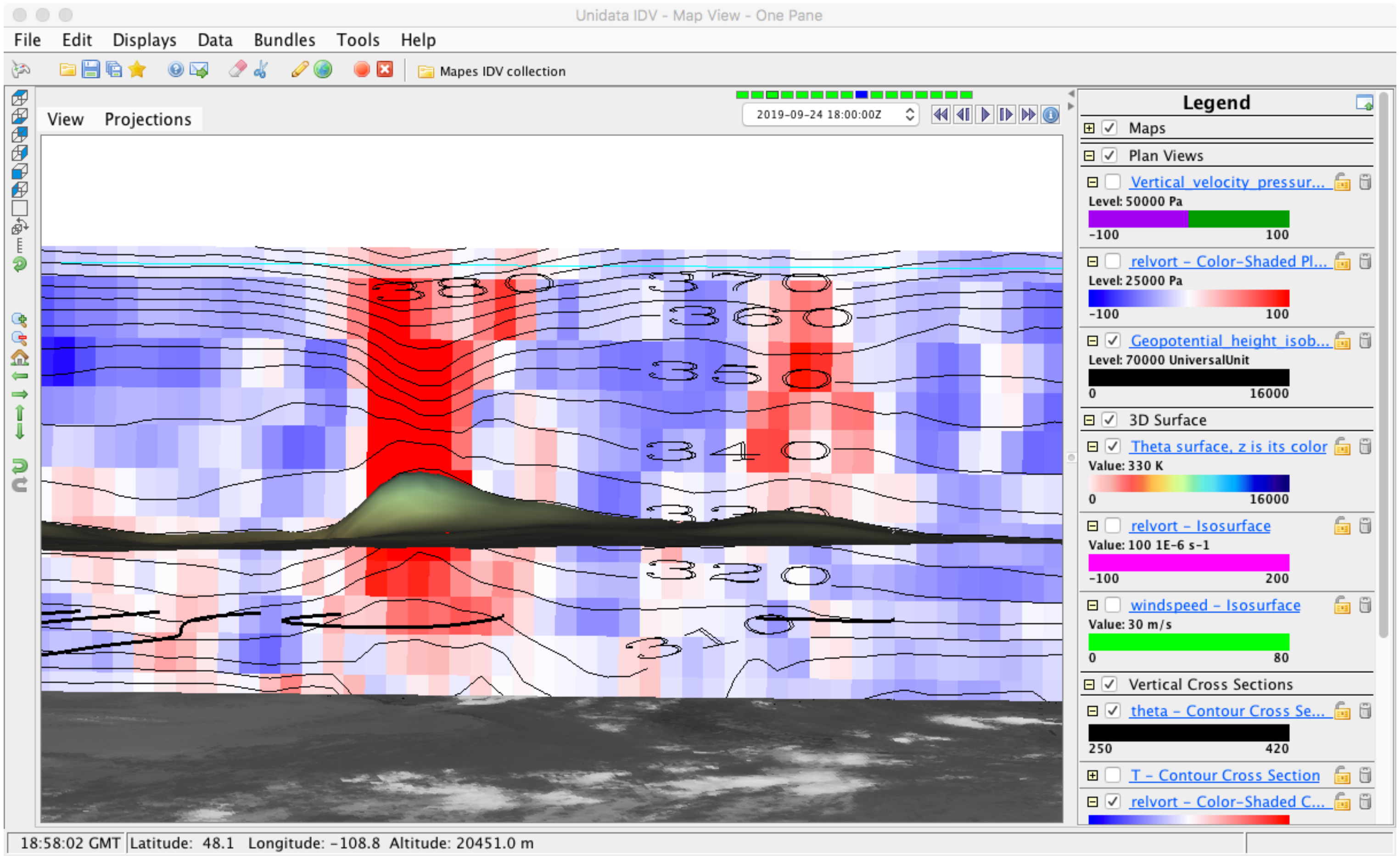
I have the view angle switched from the 310 image but both have higher pt in the north

A depression in the 330K surface



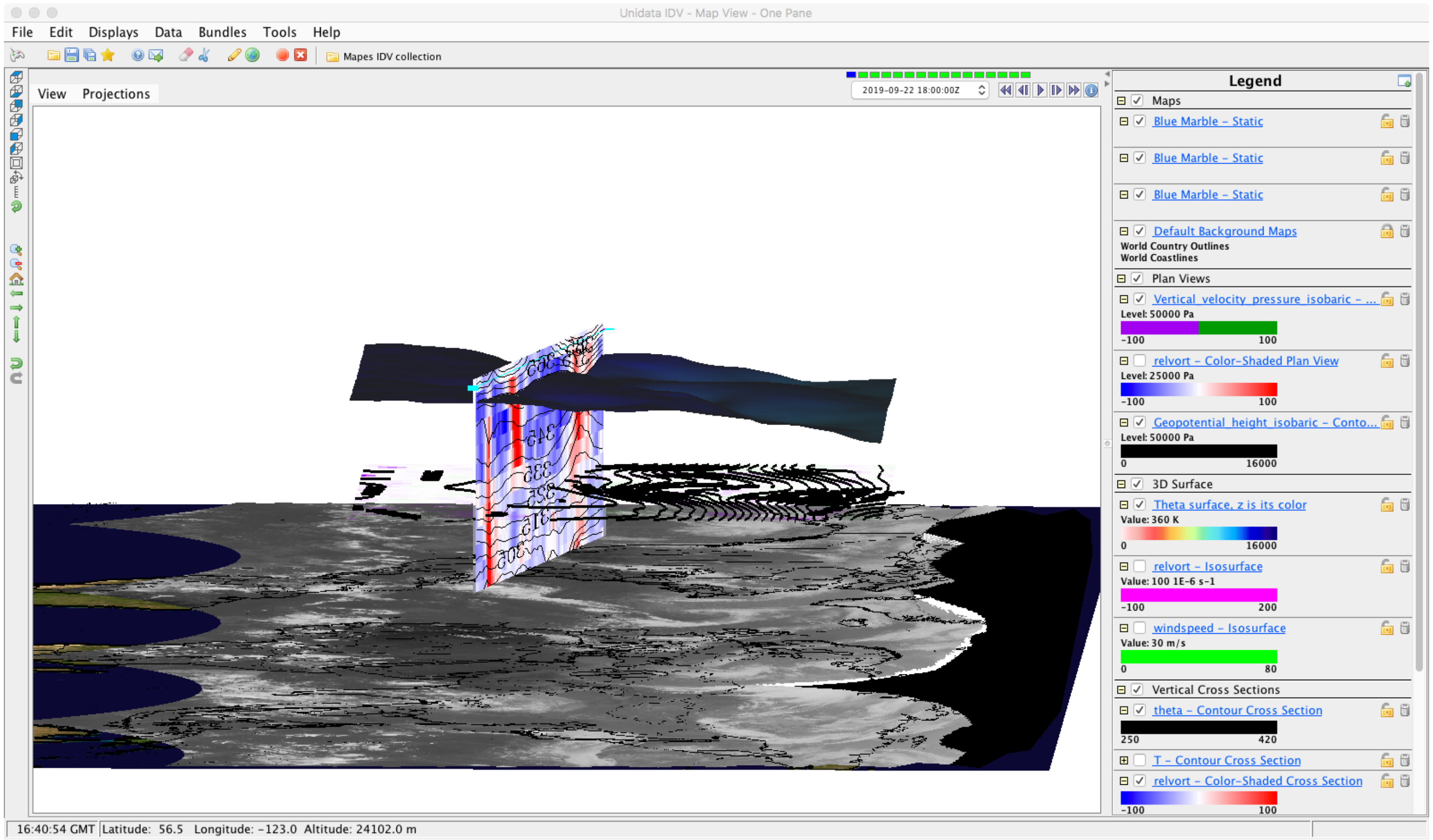
Follows same pattern as 310. depressed PT where there is negative vortictity. Follows isentropes of warm core anticyclone. In between 2 cold core cyclones

A peak on the 330K isosurface



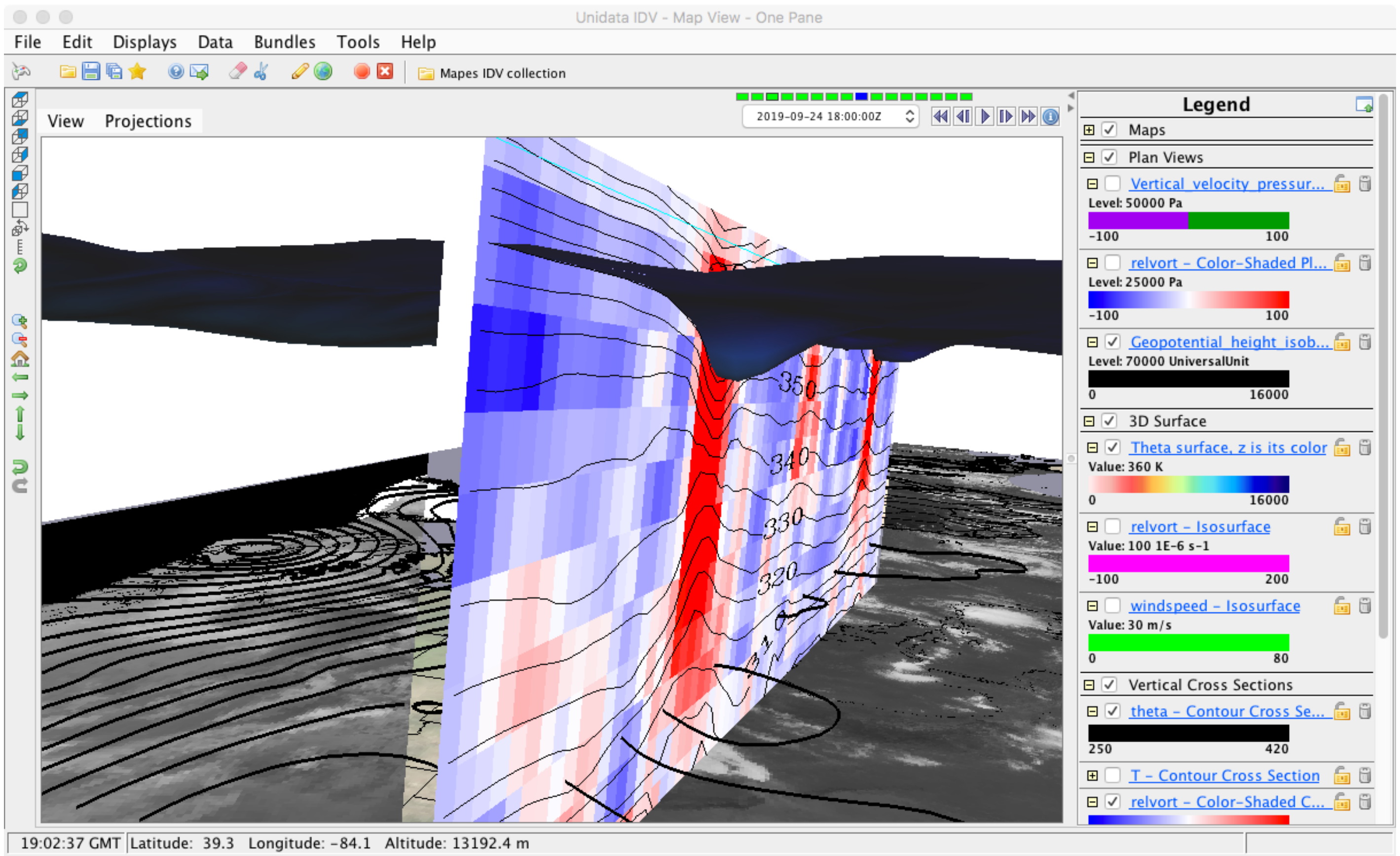
Follows same pattern as 310. Peaking PT where there is positive vorticity. Follows isentropes of cold core cyclone

Mean slope of the 360K isosurface



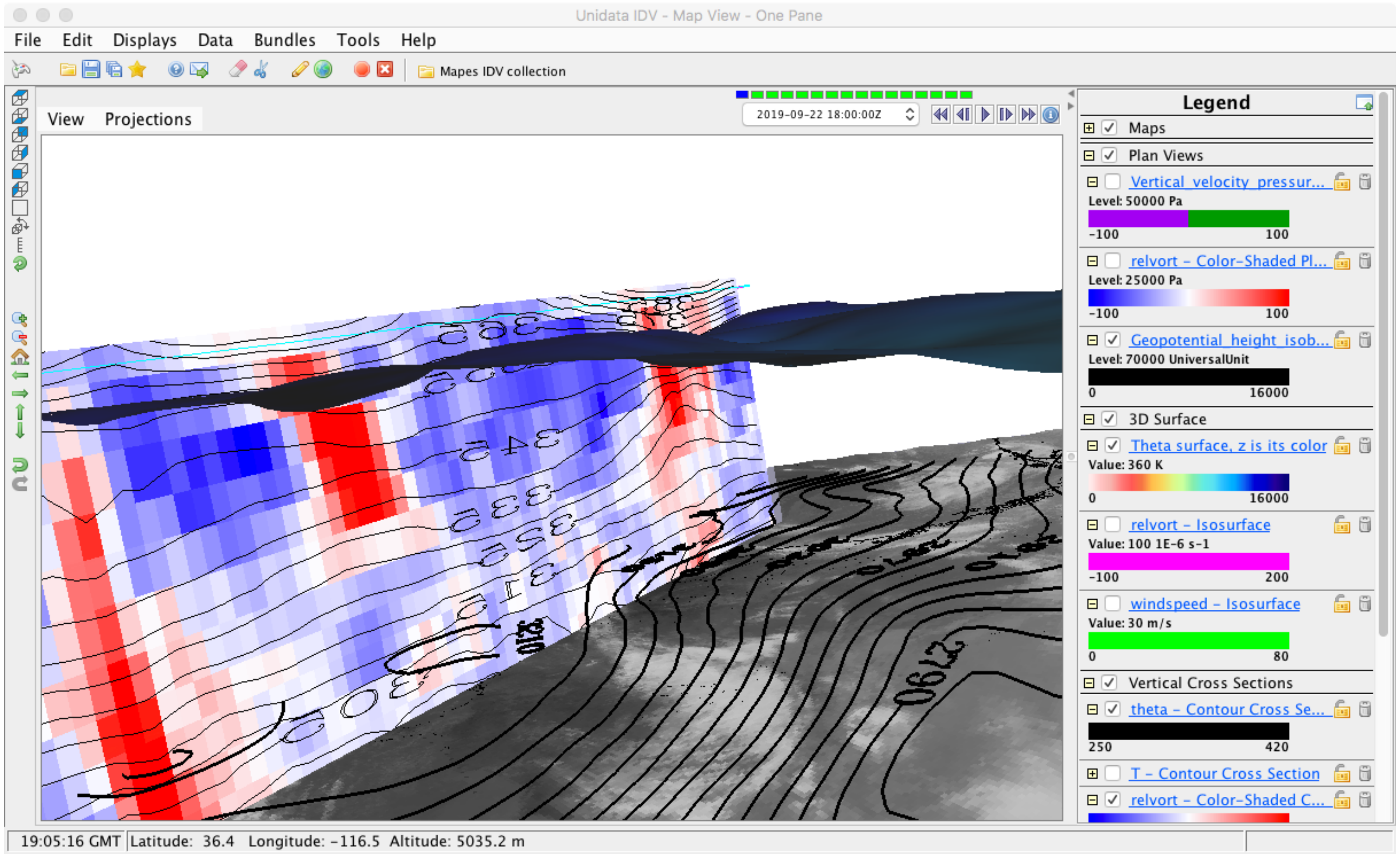
This slope is opposite of 310 and 330. It slopes from higher pt in the south to lower pt in the north

A depression in the 360K surface



Again opposite of 310 and 330. depressed isotherms in cold core cyclone. Makes sense bc upper level isentropes are depressed but lower levels are lifted.

A peak on the 360K isosurface



Slight peaks where we have negative vorticity warm core anti cyclone. Again makes sense because at upper levels in this anticyclone the isentropes are lifted while at lower levels they're depressed.

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