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

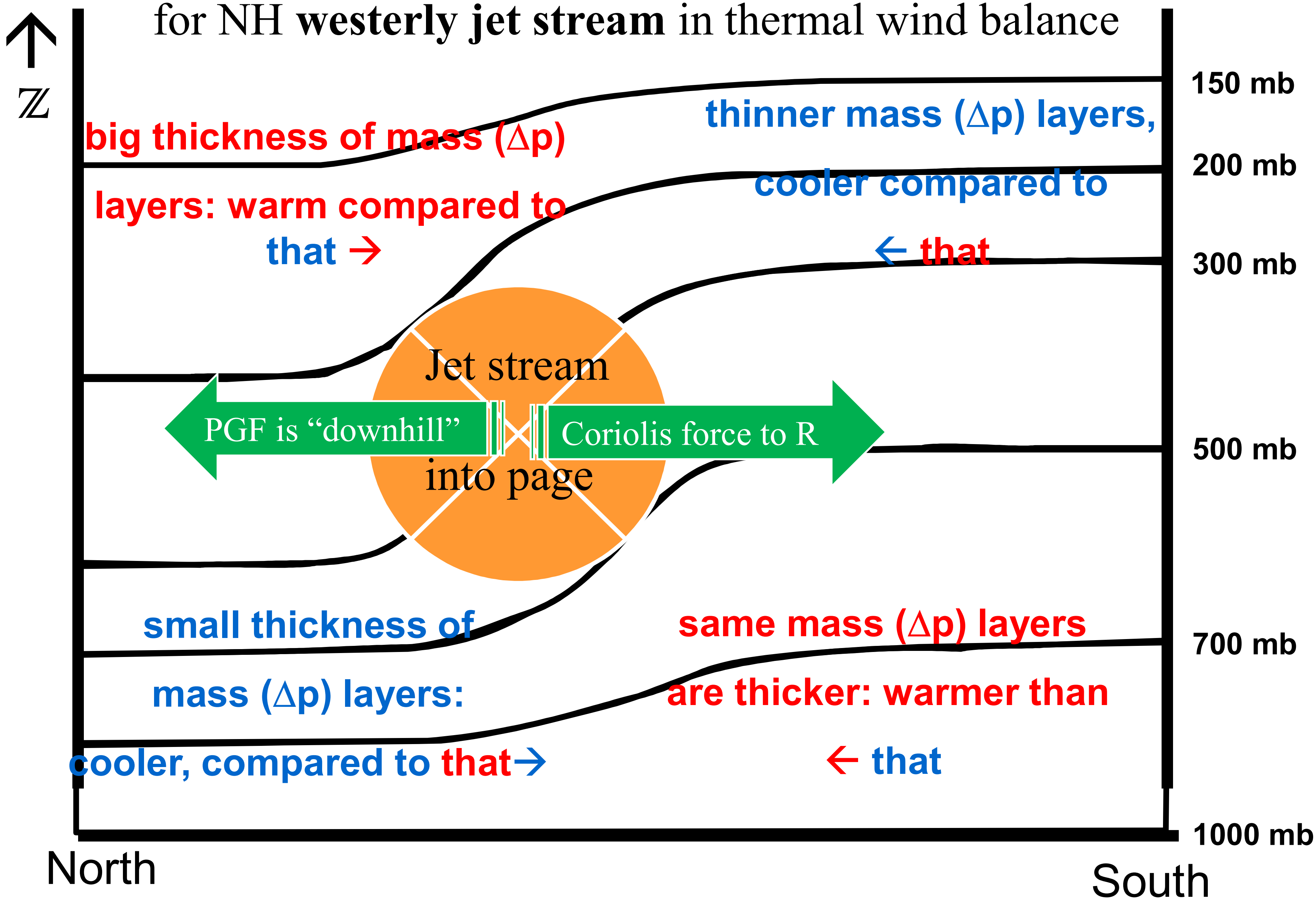
- In the thermal wind lab, you learned about how *the slope of pressure surfaces (indicating the PGF*) balances the Coriolis force in geostrophic flow
- You also learned how *thickness* (between pressure surfaces) is proportional to T

- 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.*

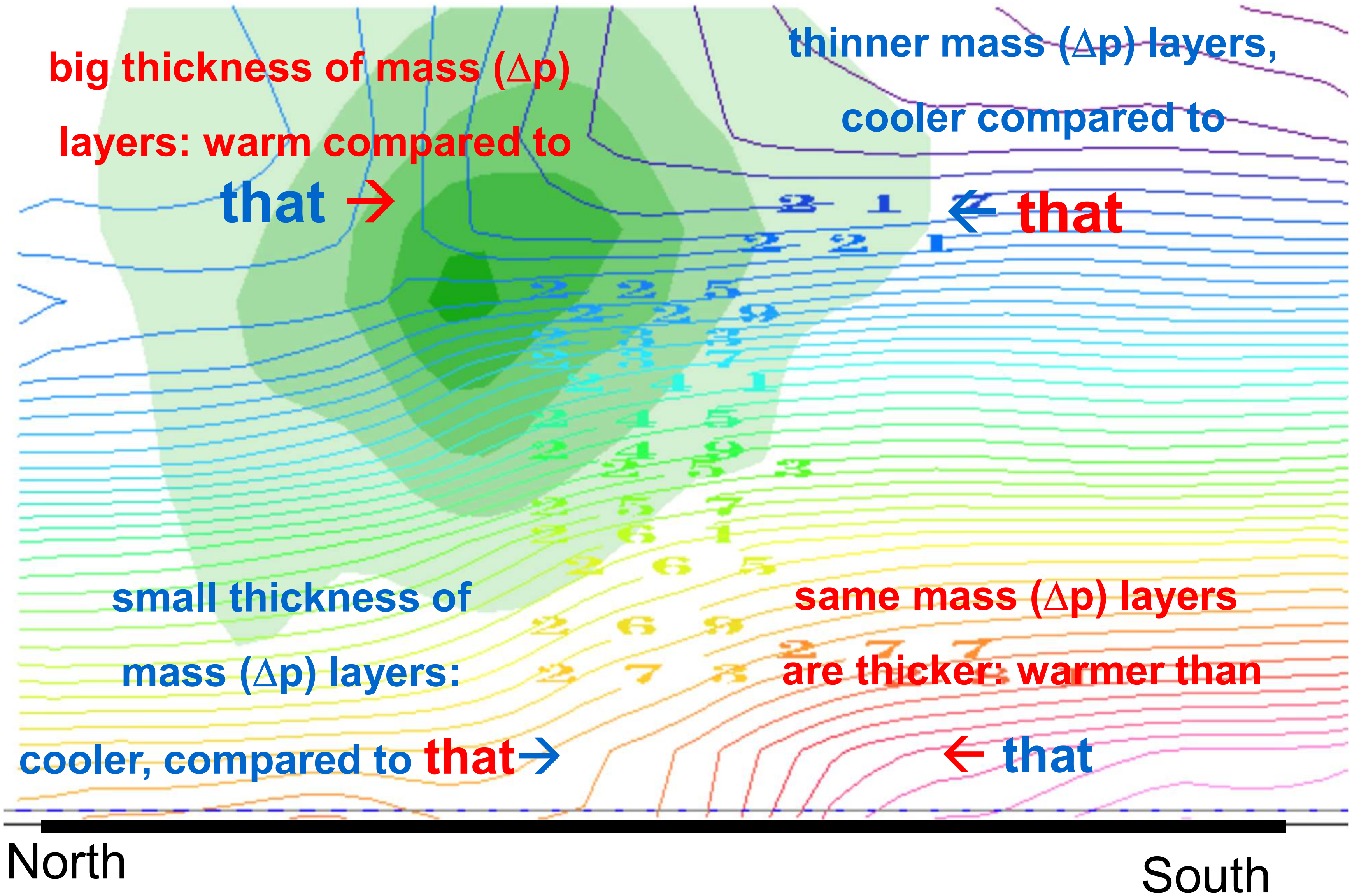
p surfaces on a z-coordinate diagram

for NH **westerly jet stream** in thermal wind balance



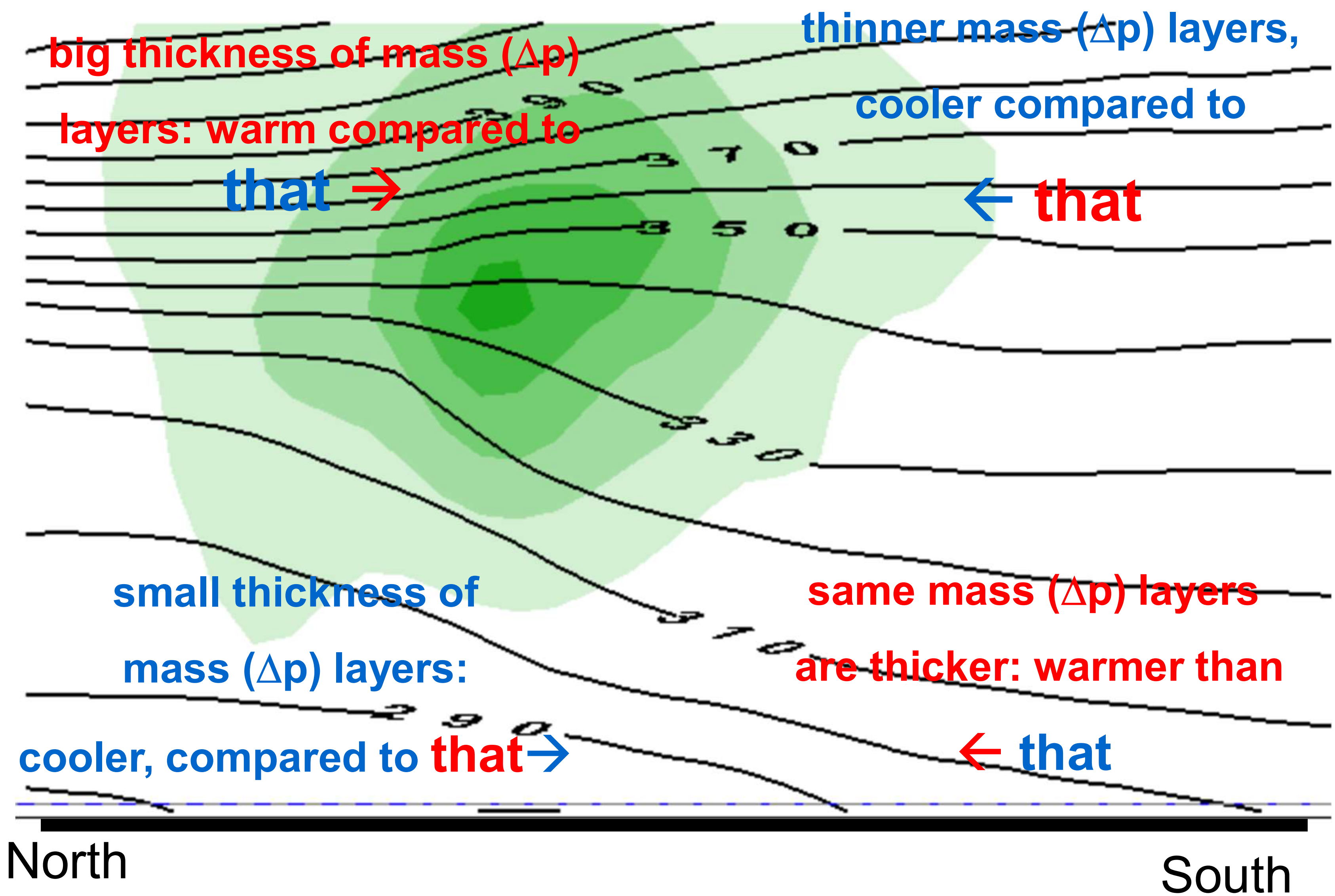
contours of T(K): it decreases with height

(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!**

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

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

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

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

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

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

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

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

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

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

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

vorticity equation

Wait a sec, what's this??

Can we scrape back some of these cobwebs?

This view emphasizes *vortices* as the unit of flow

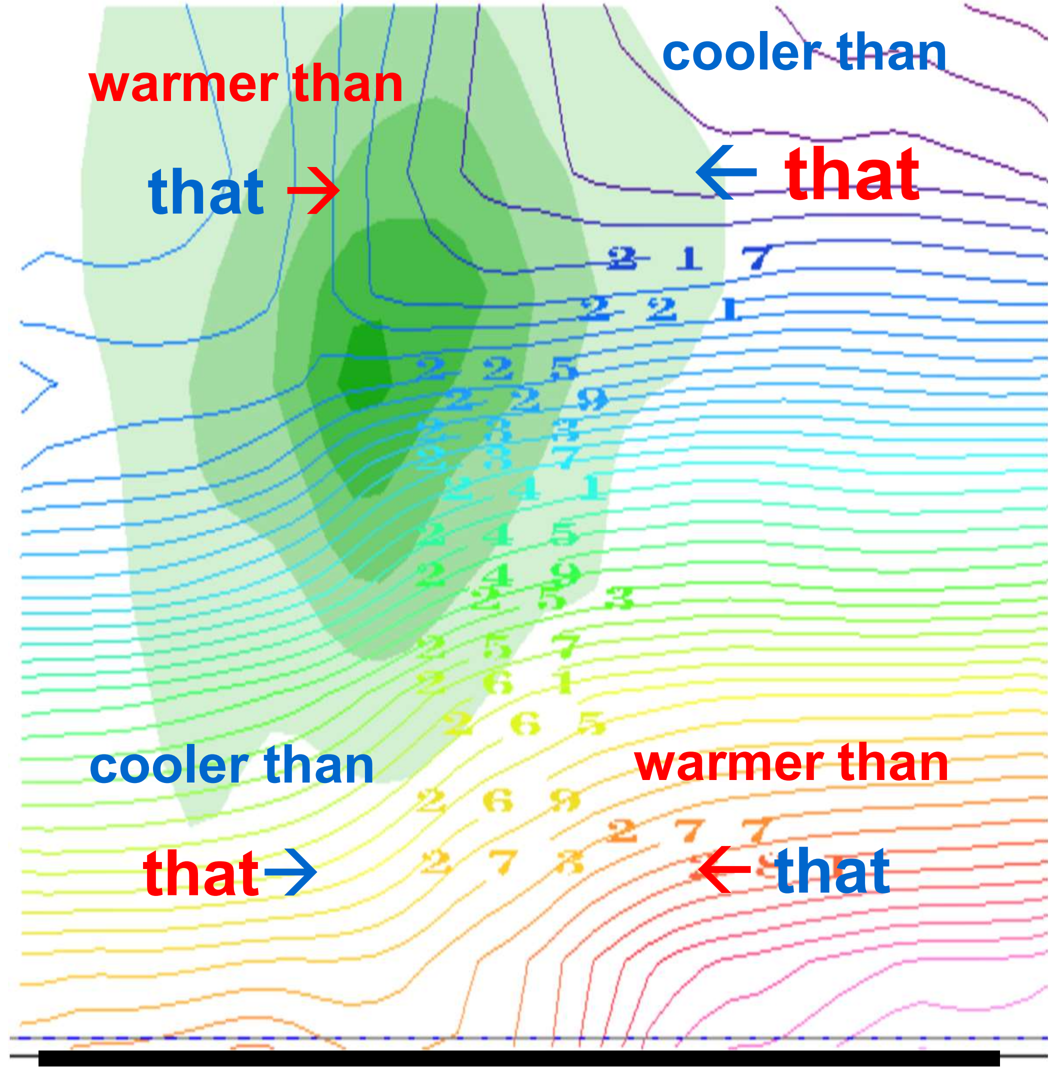
$$D\zeta/Dt = 0 + complications$$

- 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?

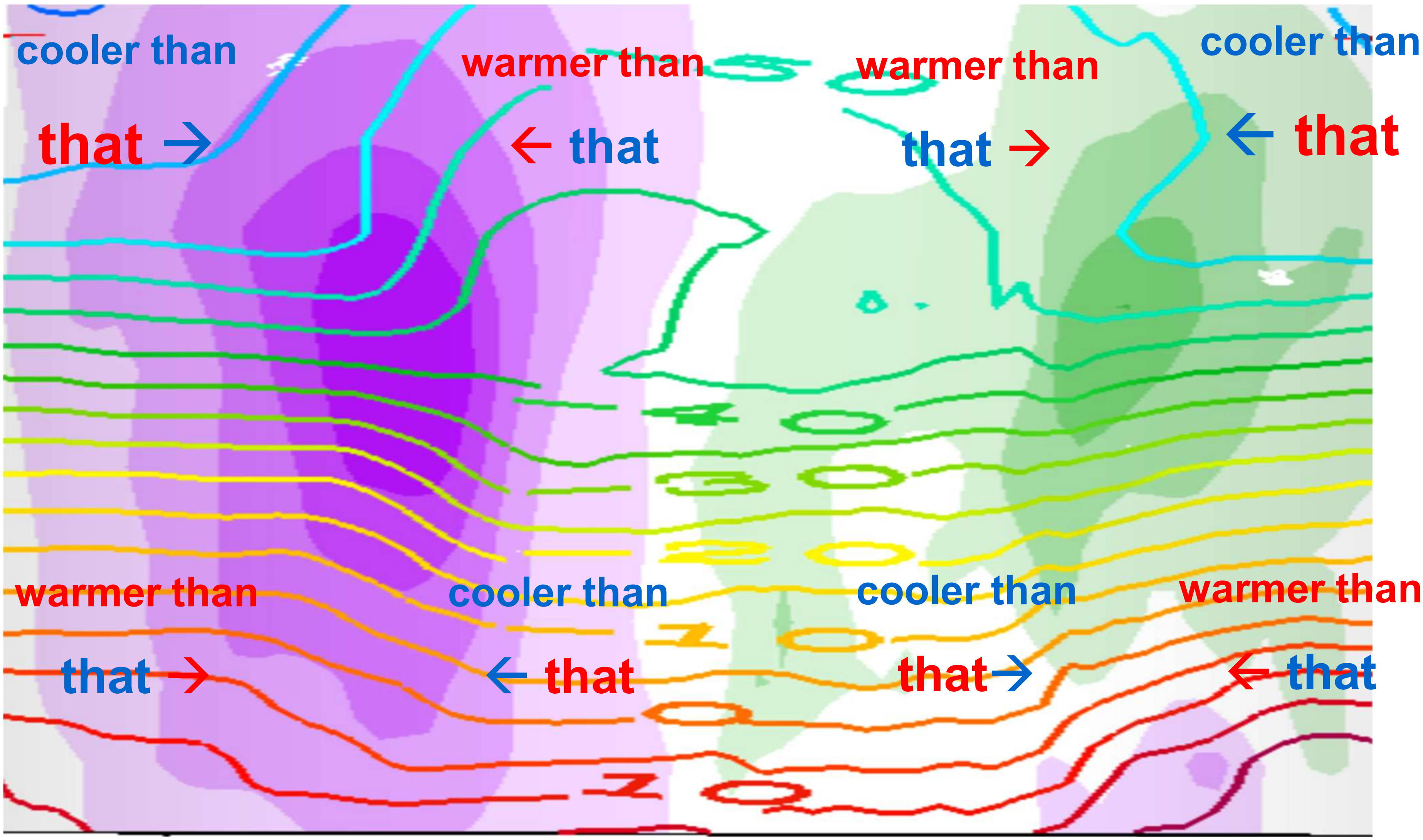
- In this case, one near the tropopause (like the jet stream)

This is only half the story of a vortex



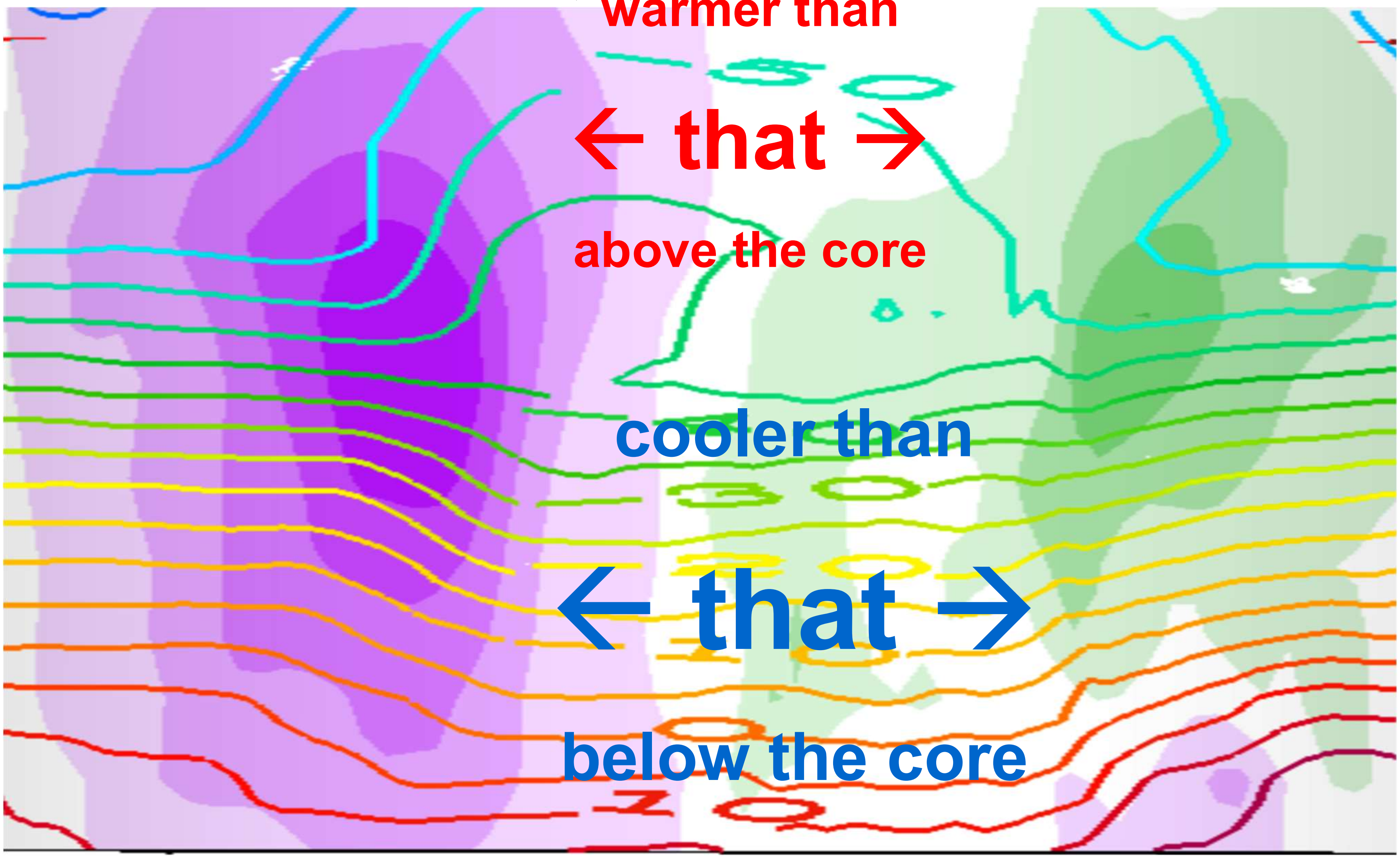
This is a whole vortex (two jets)

T(K) contours



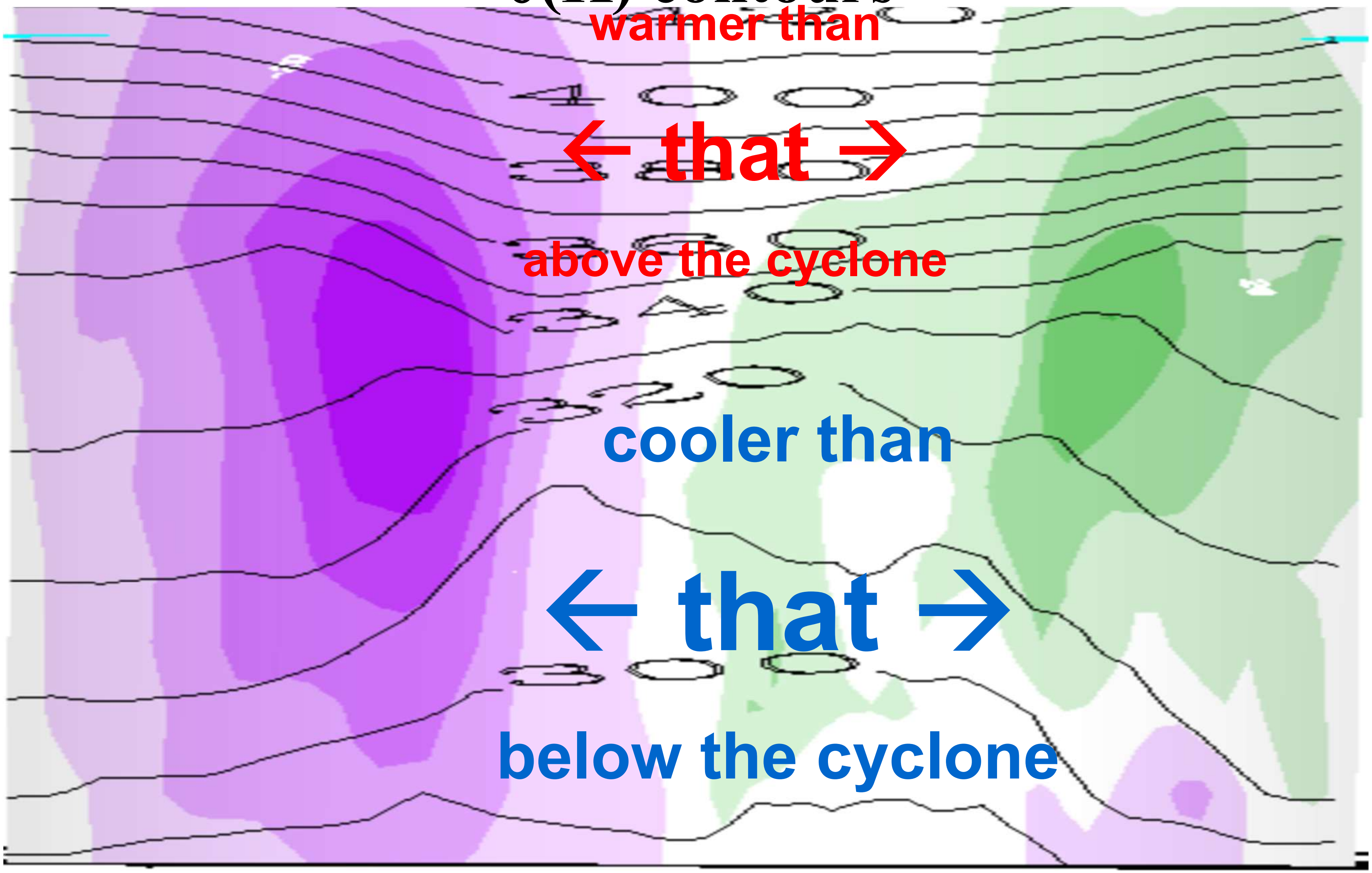
This is a whole vortex (two jets)

T(K) contours

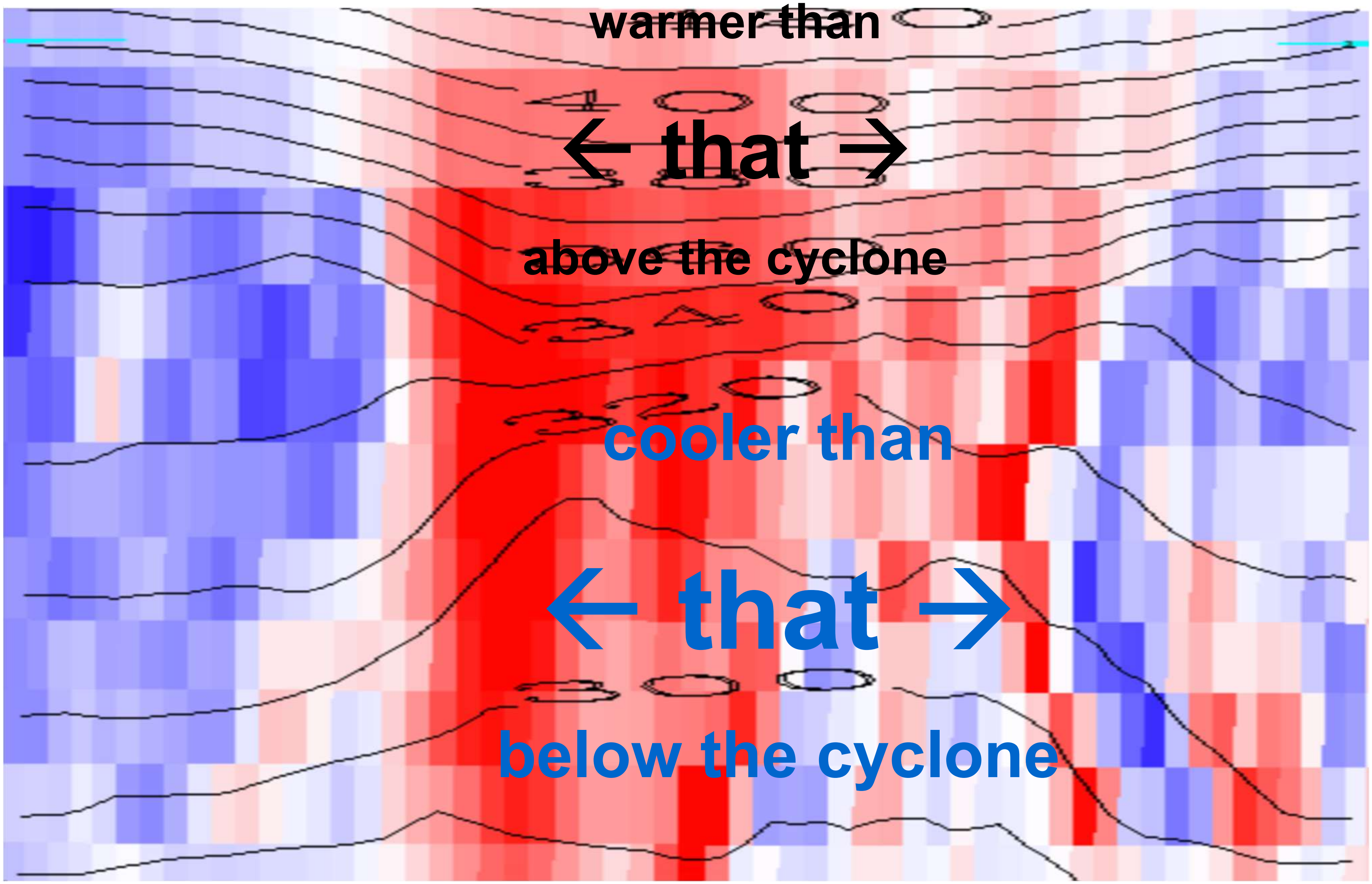


This is a whole vortex (two jets)

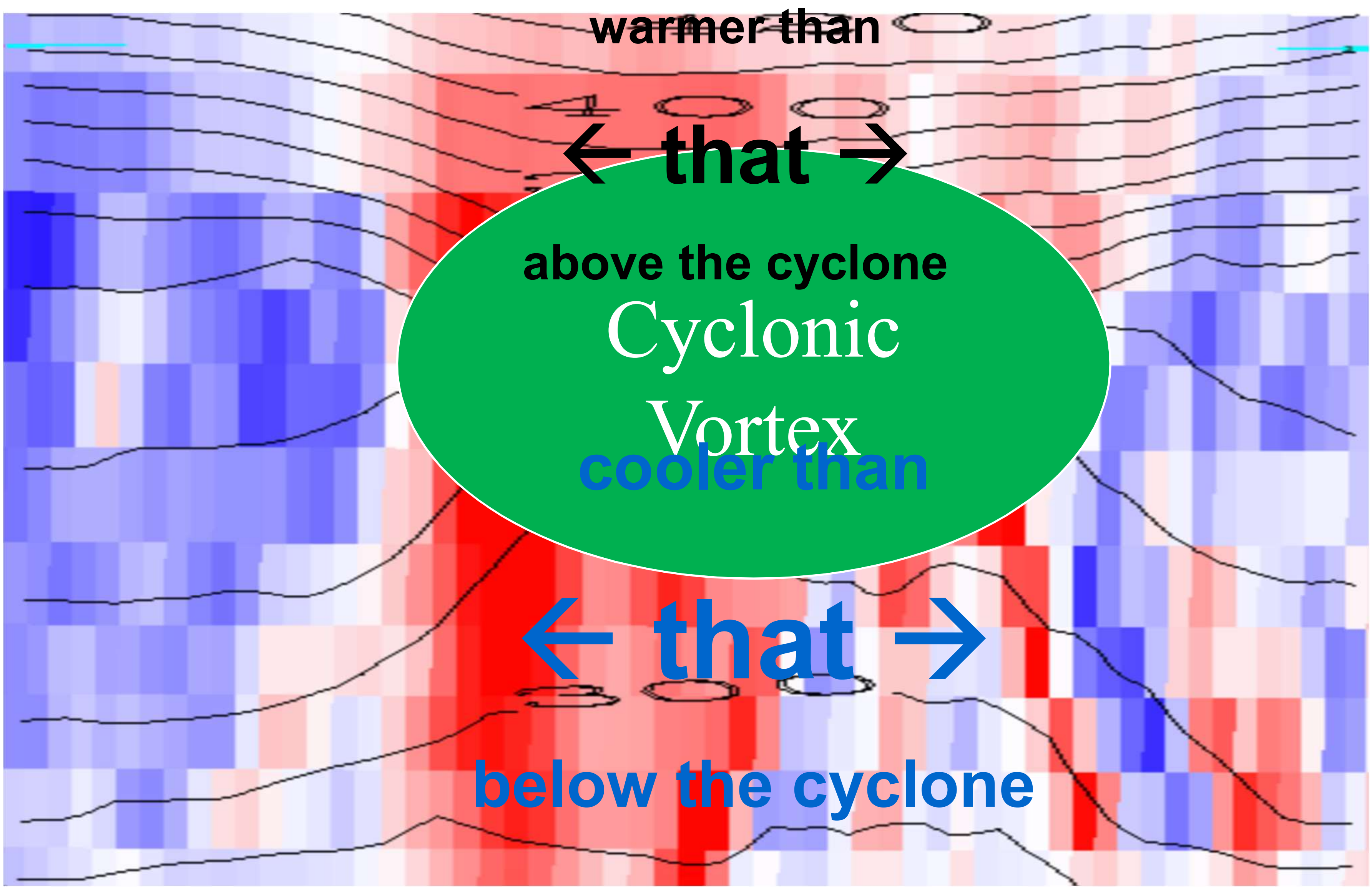
θ(K) contours



Red is positive vorticity , θ(K) contours

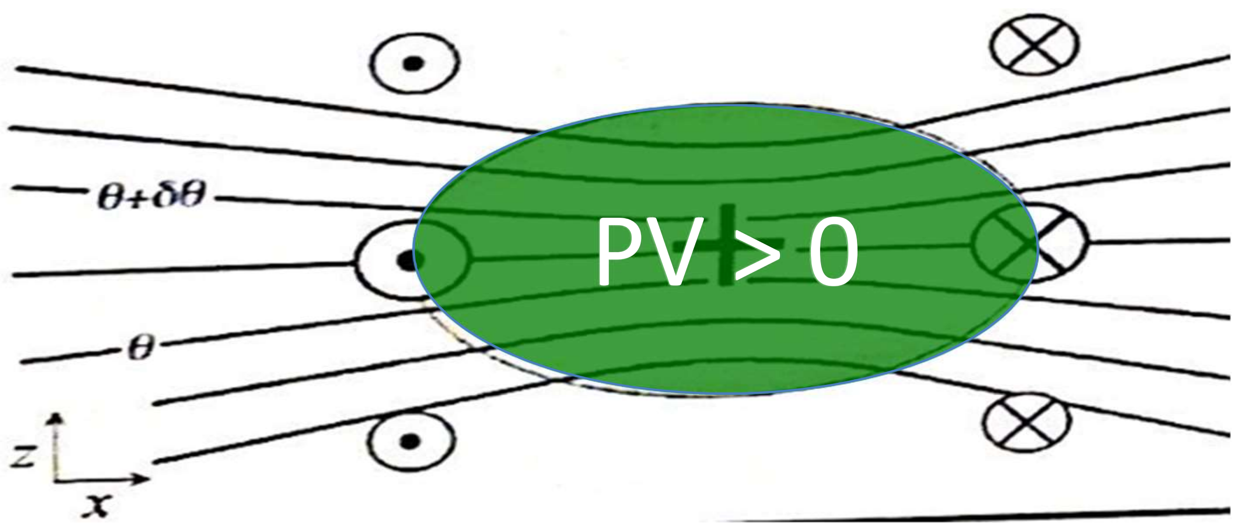


Red is positive vorticity , θ(K) contours



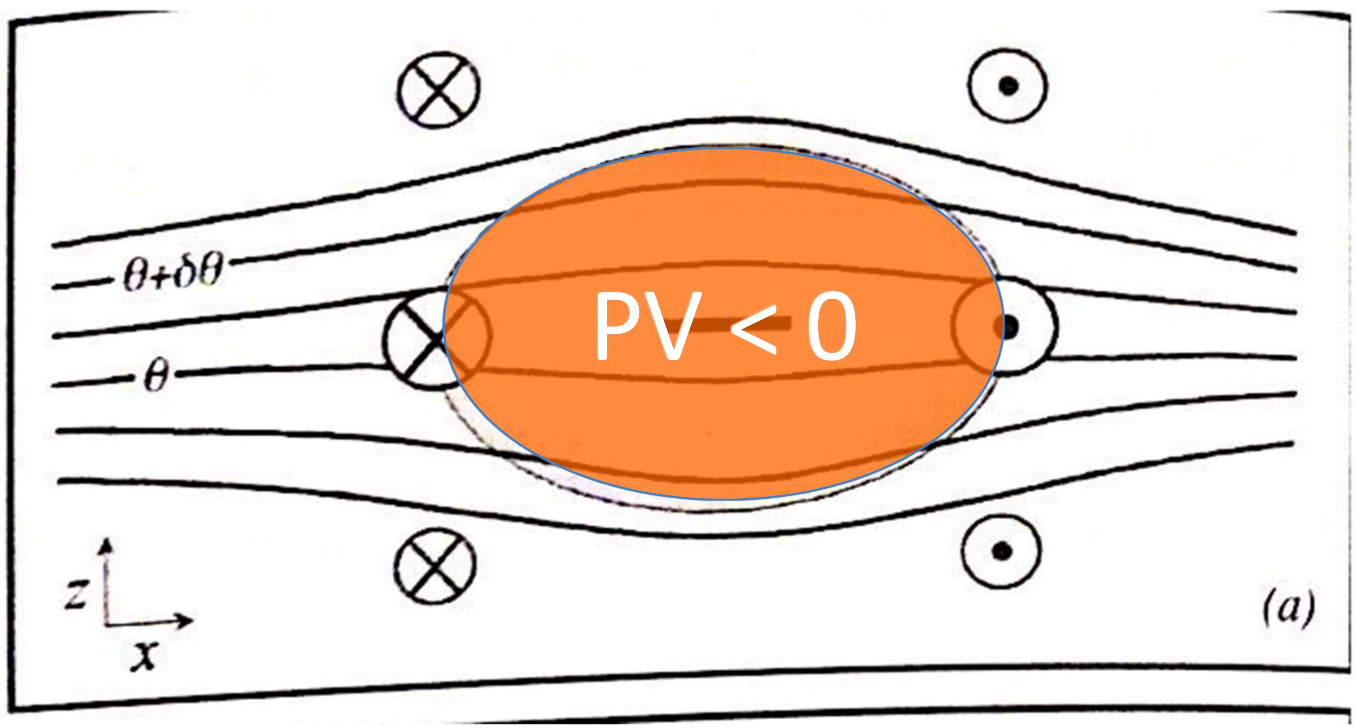
Generalization: *PV*

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):

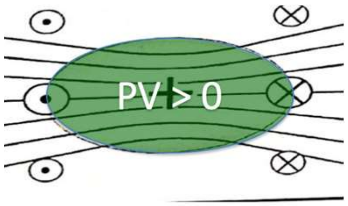


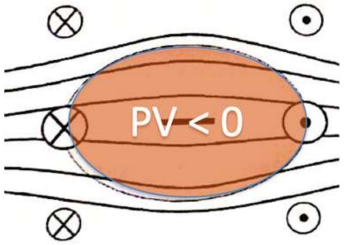
Balanced anticyclones exist too...

- Just the opposite of a cyclone...



Vorticity (or PV) blobs





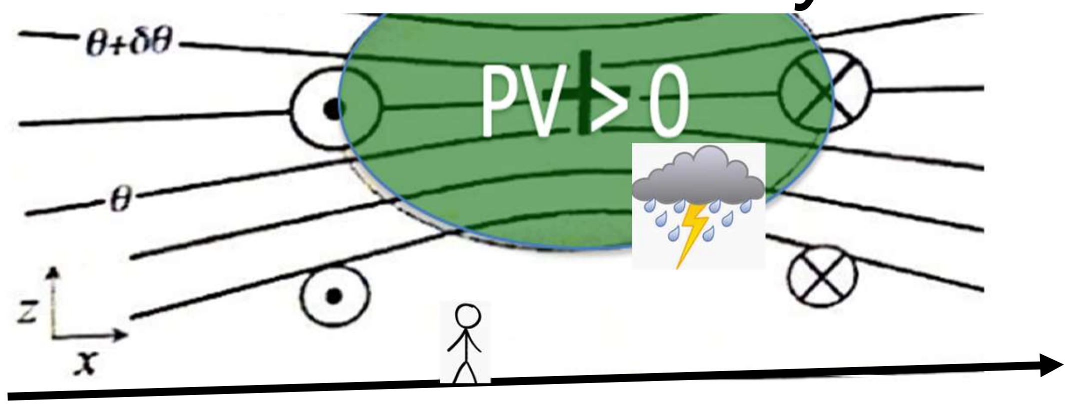
- Where do they come from?
- How do they interact?
  - (this we studied, in the horizontal plane)
- Do they get destroyed?

- (Soon: tackling the complications)

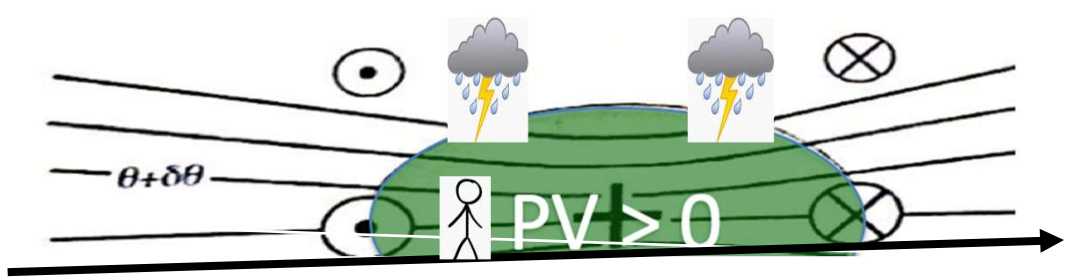
$$D\zeta/Dt = 0 + complications$$

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

- This is called a *cool core cyclone:*

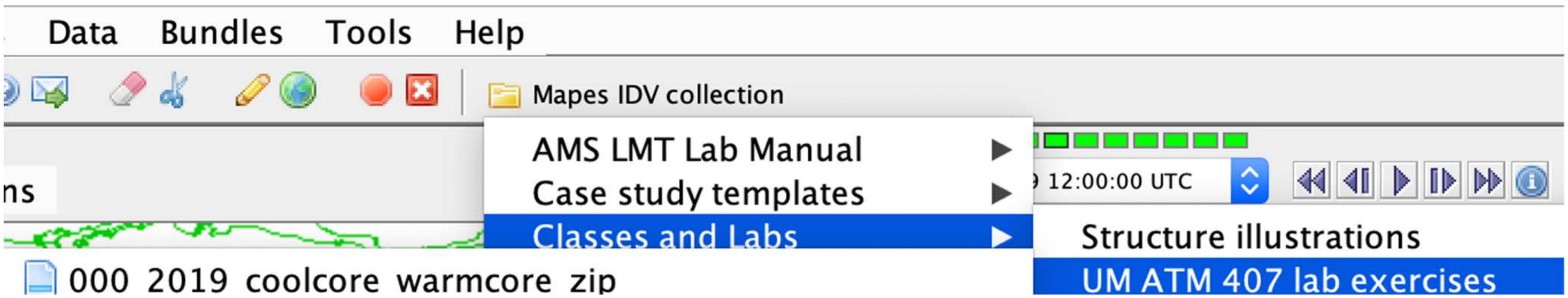


- This is called a *warm core cyclone:*



IDV lab assignment -- part 1

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



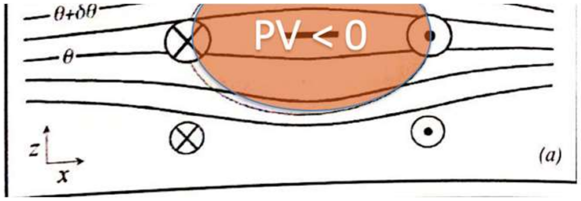
Explore ALL of its displays, at ALL of its times (loop the animation). Learn to use the IDV. The Help menu has pan-zoom help on top. A mouse is a HUGE help for 3D views.

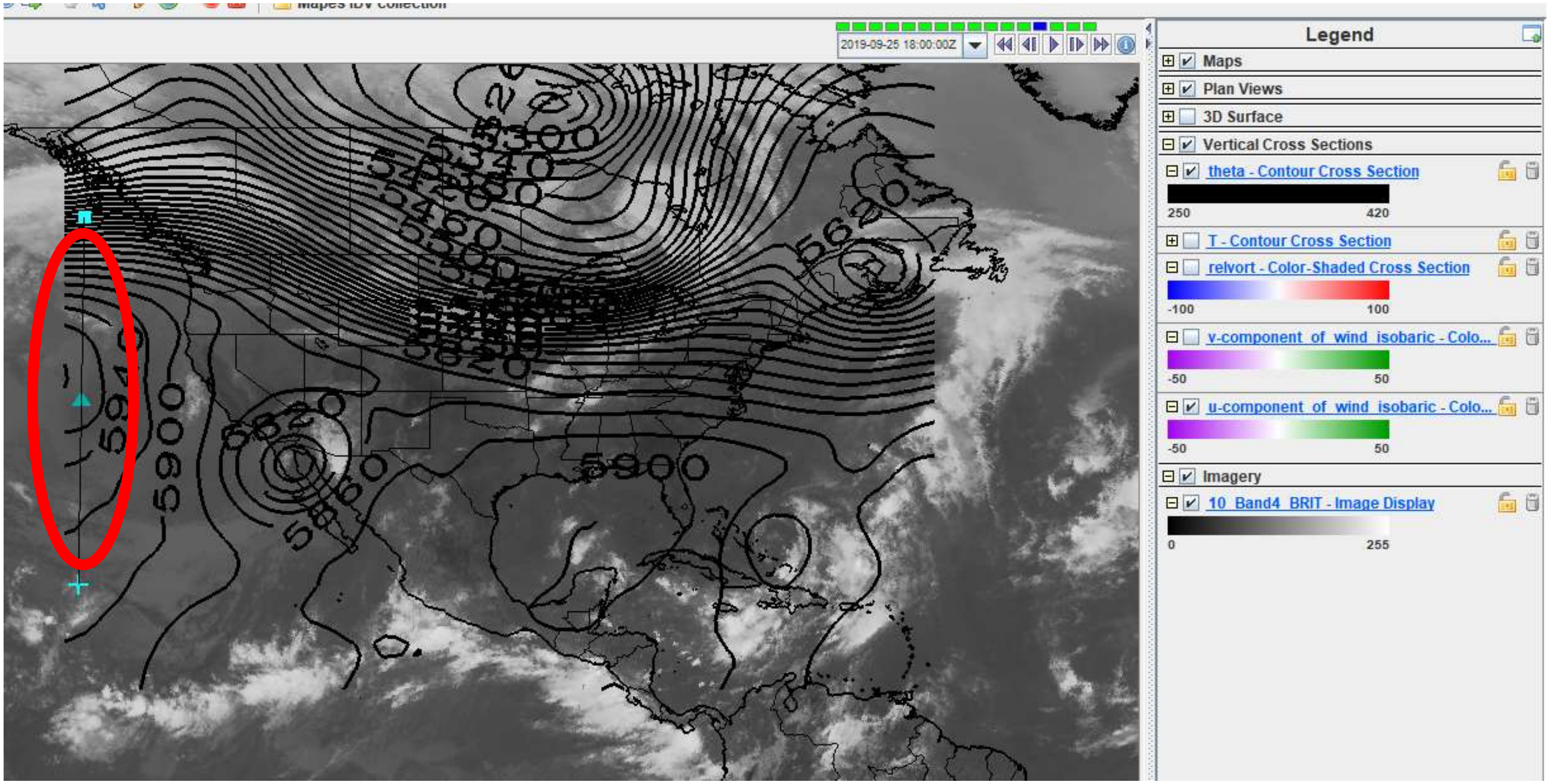
IDV lab assignment -- part 1

- 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

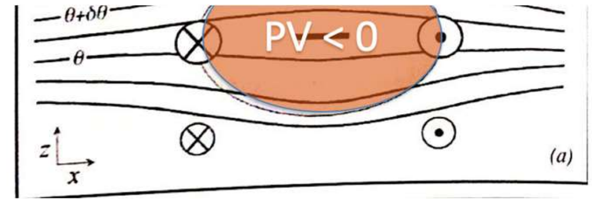
- Western coast of United States (09/25/2019 1800Z). A warm core anticyclone (high pressure system) is better observed in middle/upper levels.

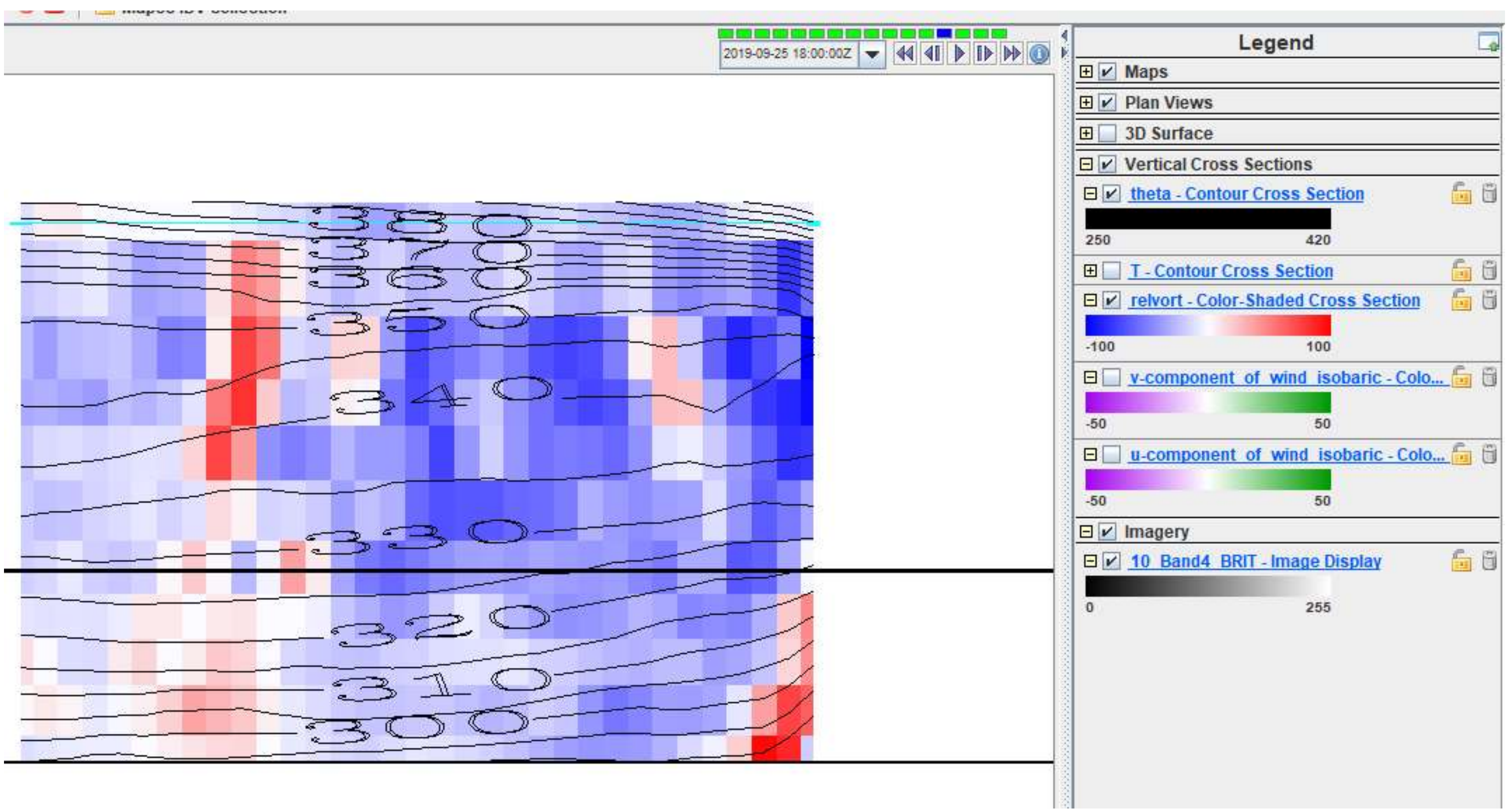




A warm core anticyclone

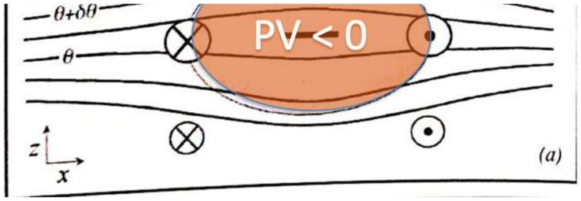
- Negative relative vorticity patch located abode mid level troposphere. In addition, isolines of same potential temperature present a slightly trend to reach lower altitudes when close to negative relative vorticity zone.

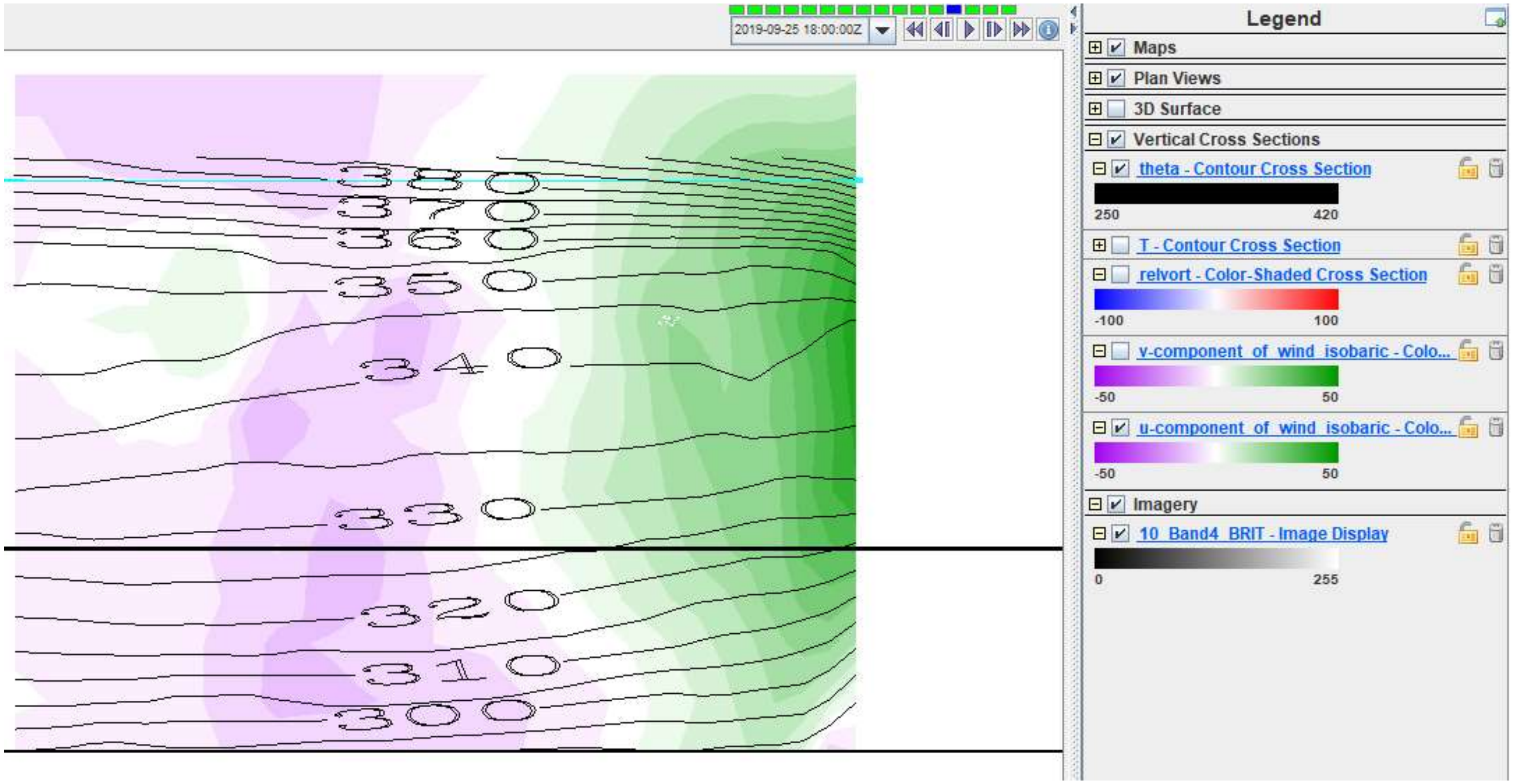




A warm core anticyclone

- Inward velocities on the left of the anticyclone and outward velocities on the right. In addition, surface velocities are lower than mid level ones.

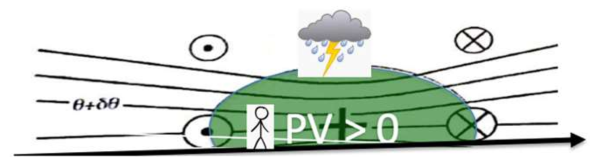


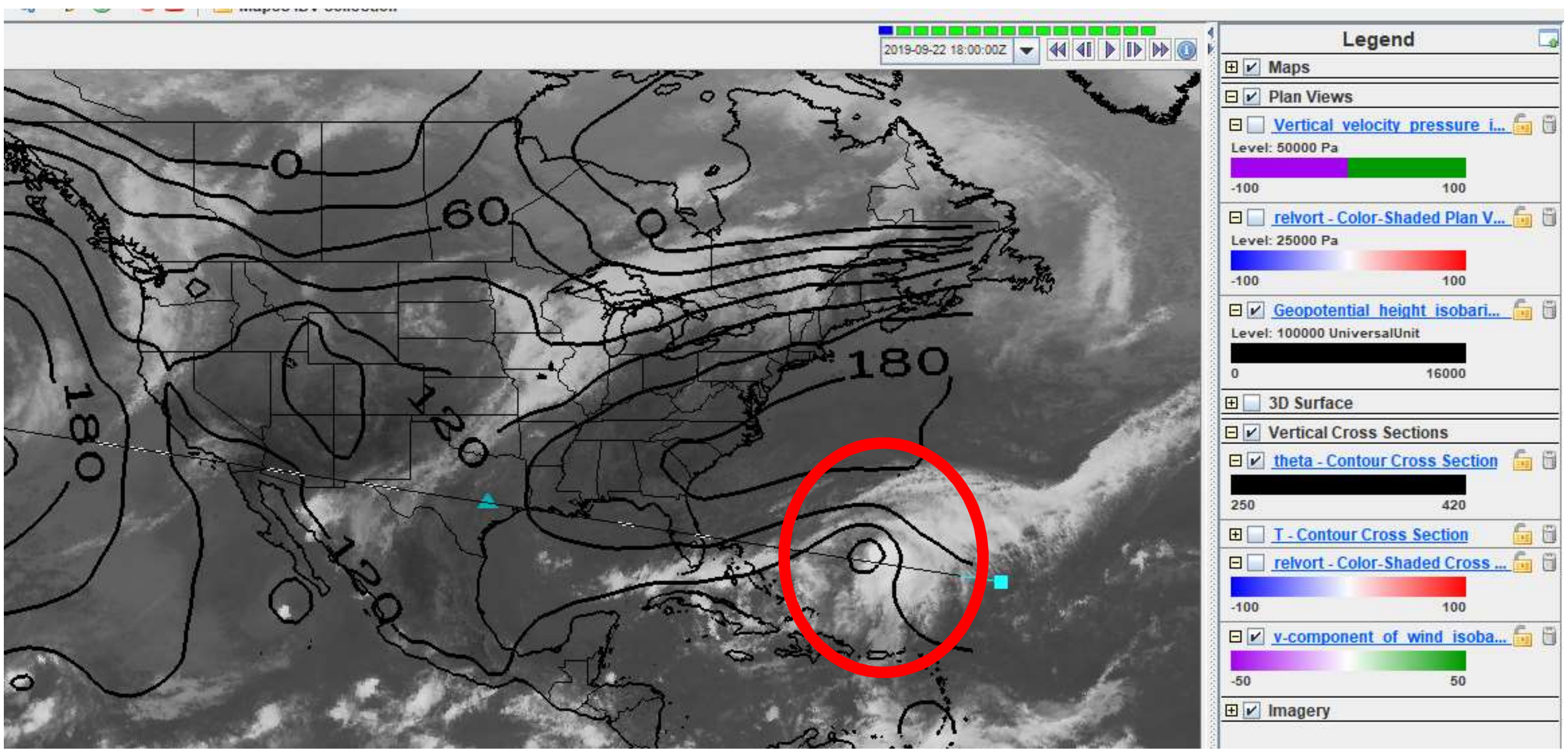


A warm core cyclone

- Located northern of Puerto Rico (09/22/2019 – 1800Z), on the Atlantic Ocean, this feature could be called warm core cyclone, because of this well visible low in the lower troposphere, with PV>0 in the middle of the cyclone, Higher wind intensity close to surface and lower intensity winds above.

This is called a *warm core cyclone:*

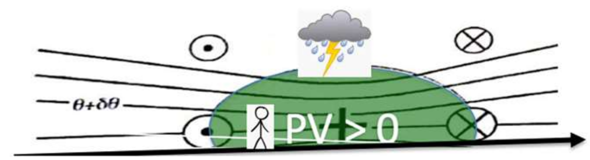


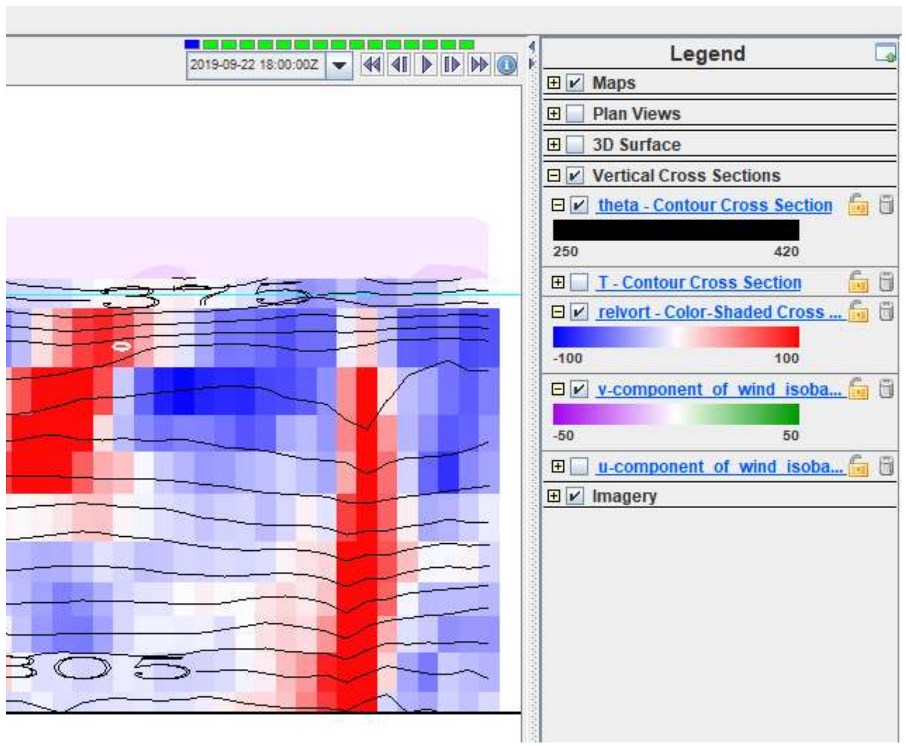


A warm core cyclone

- On the cross-section view, it is possible to observe greater PV close to surface. In addition, the lines with same potential temperature reach the lowest height where relative Vorticity >0

This is called a *warm core cyclone:*

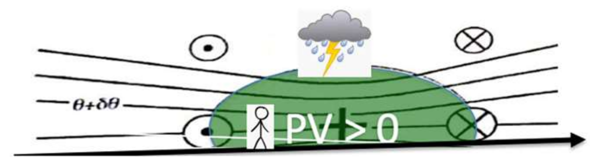


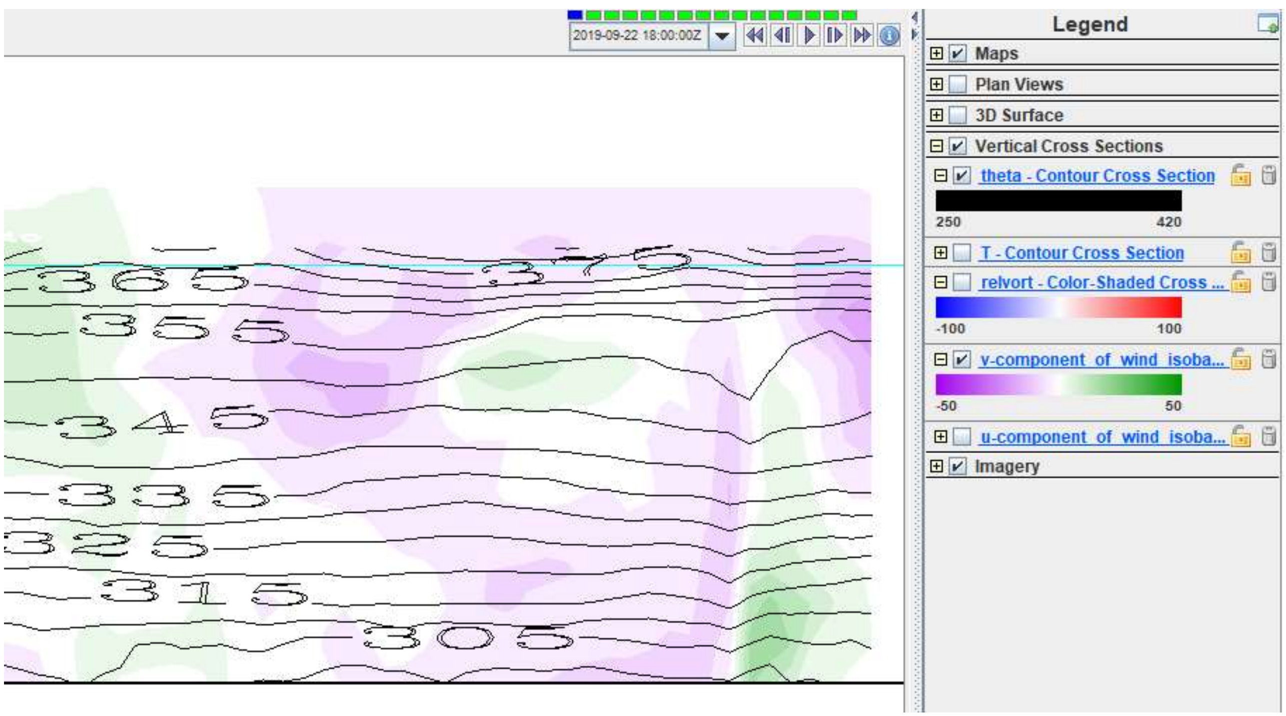


A warm core cyclone

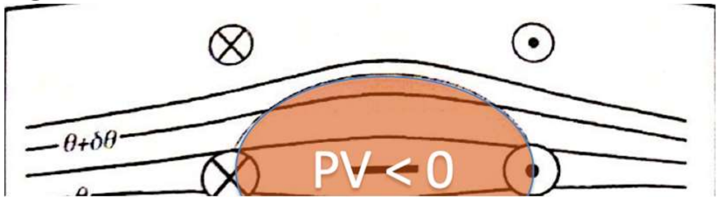
- Positive meridional velocities eastern of the cyclone and negative meridional velocities on the west side can be noticed. It is also possible to observe the decrease of wind intensity with height.

This is called a *warm core cyclone:*

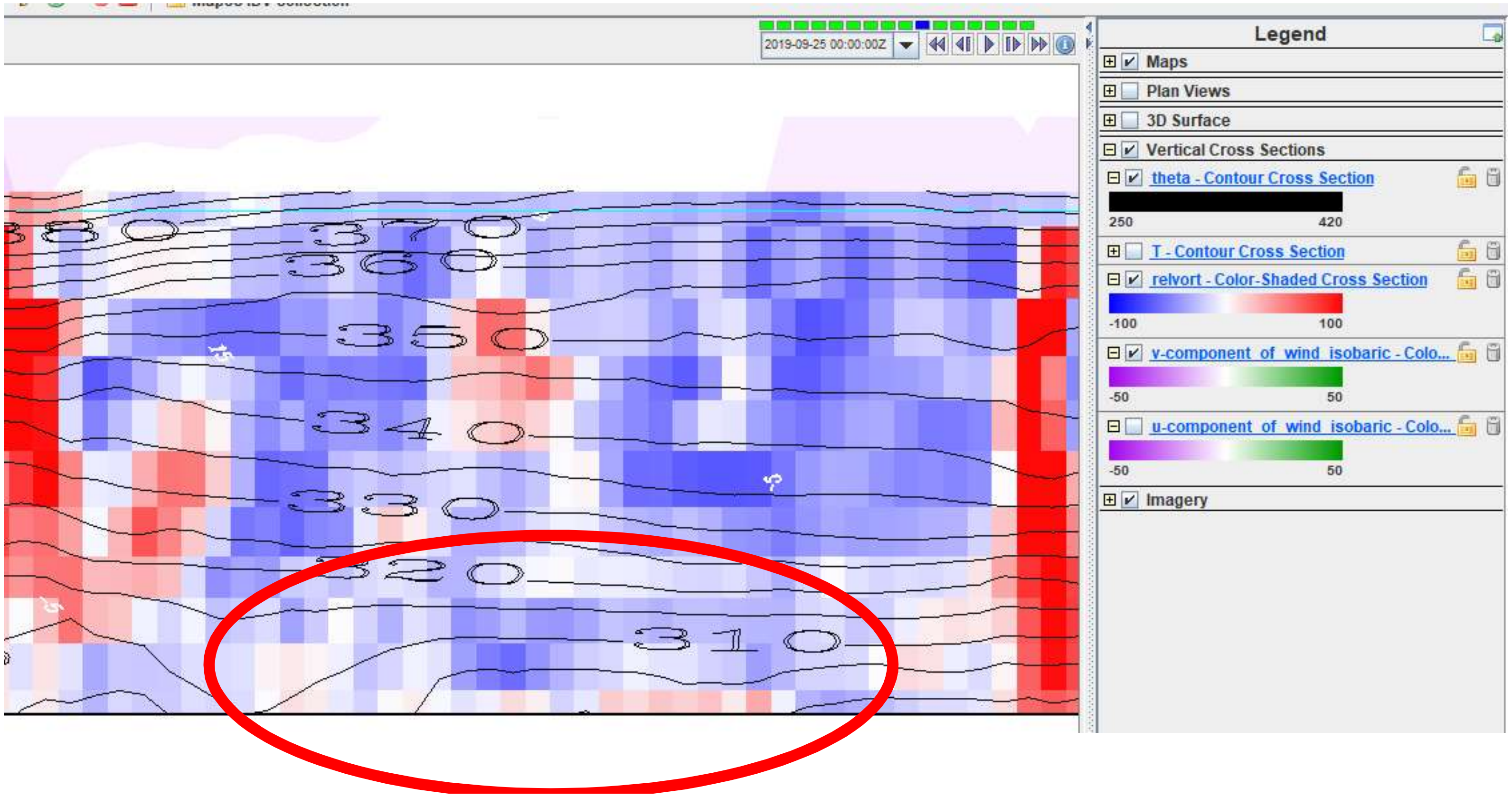




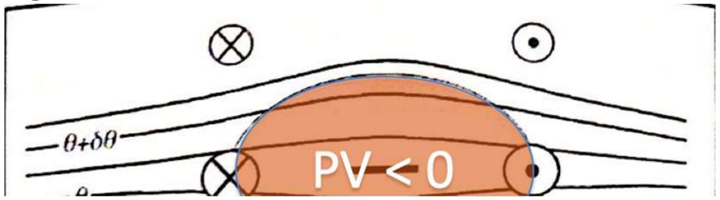
A cool core anticyclone



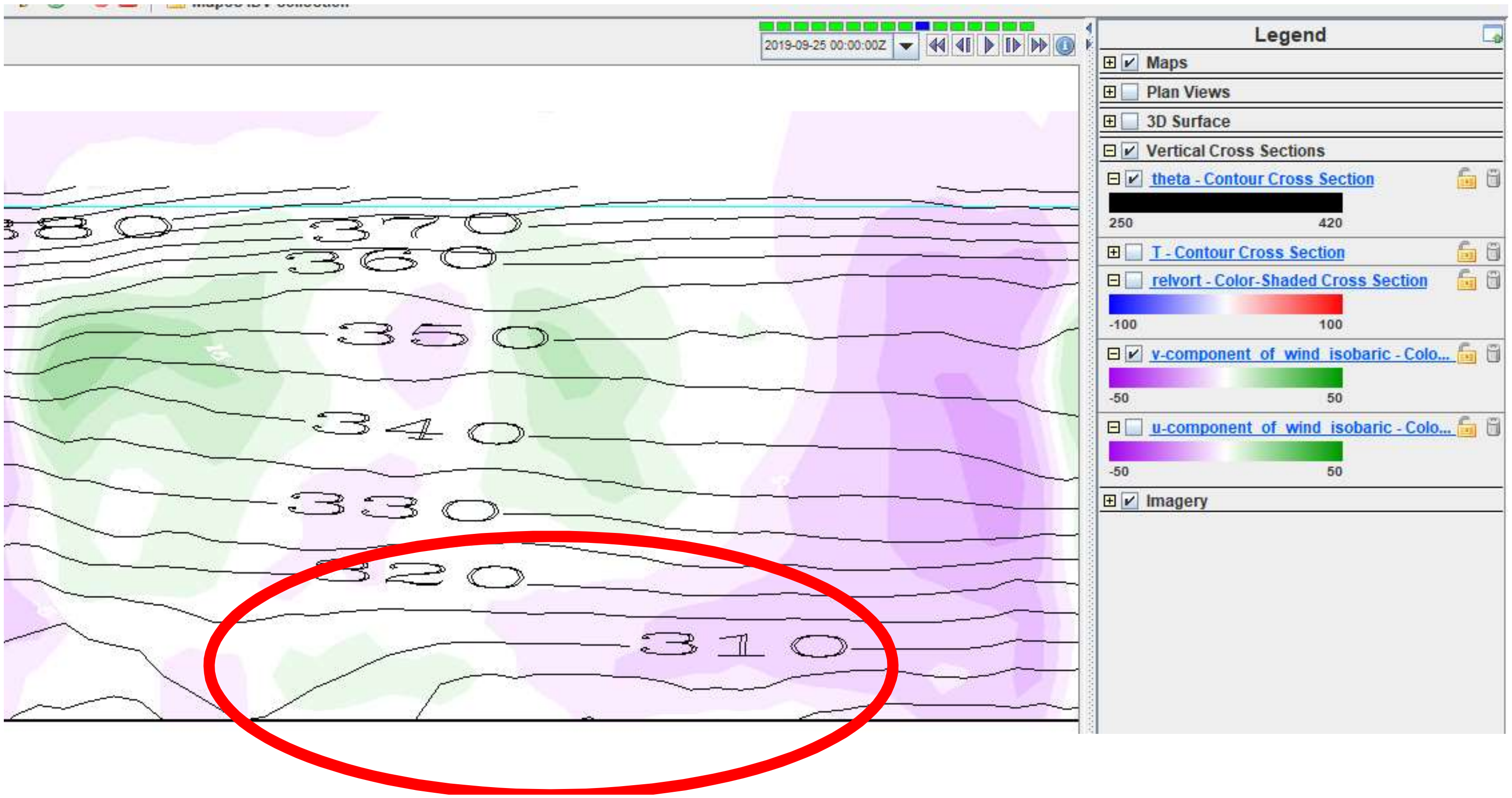
- A cool core anticyclone was located on the coast of Mississippi and Louisiana on 09/25/2019 0000Z. Negative vorticity patch in lower troposphere, with isentrope lines going upward in the center of the anticyclone.



A cool core anticyclone



- Equatorward velocities on the east side of the vortex and poleward velocities on the west. Note that the velocity decreases with height, and the vortex is restrained to height where potential temperature >320 K .

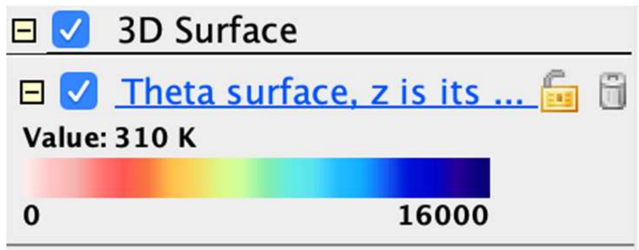


Isentropic surfaces

- 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)

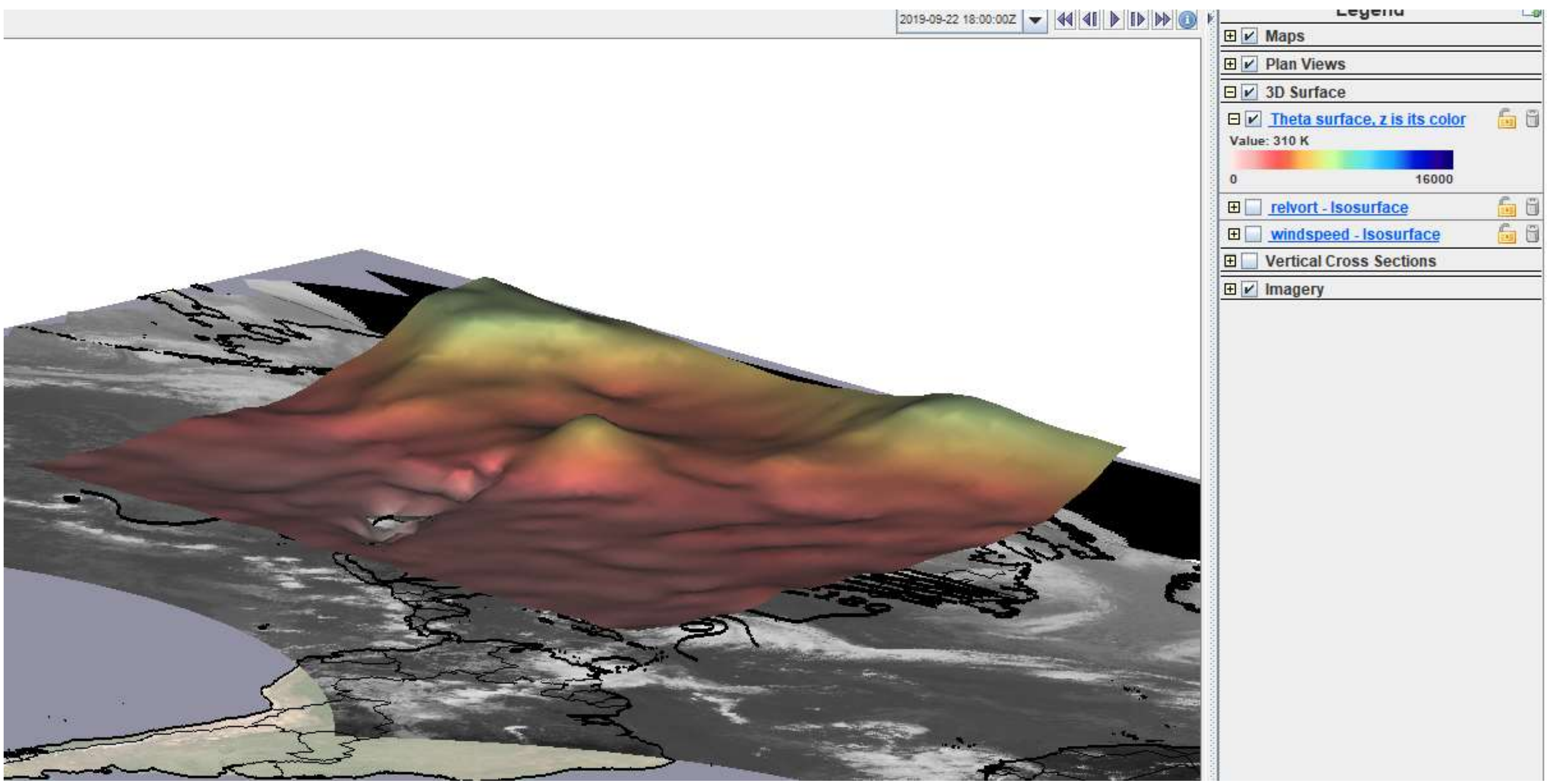
IDV Lab assignment part 2

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



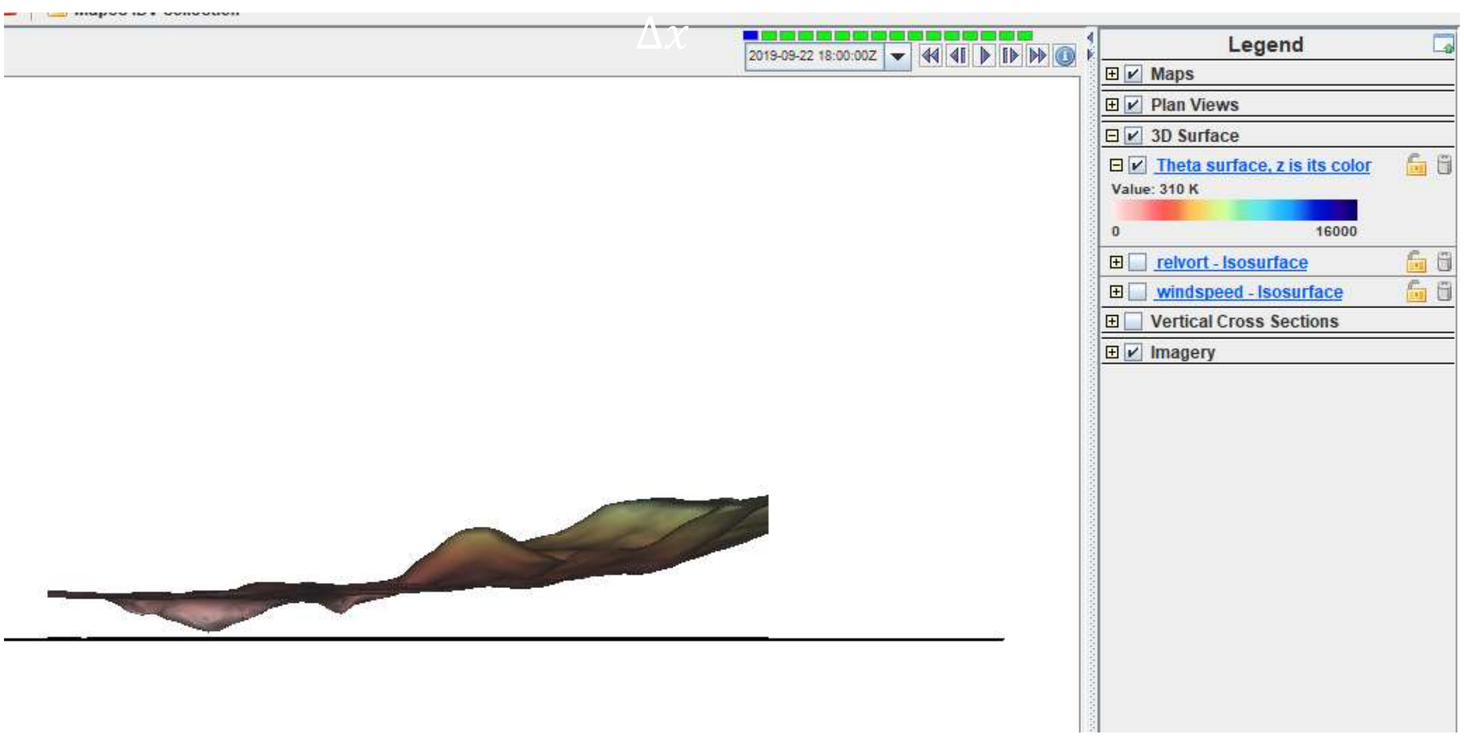
- Adjust the value (310K, 330K, 360K)
- Use vorticity isosurfaces and cross sections in an illustrated description of its topography.
  - Is there a mean north-south slope? hint: 
  - What vorticity features (Part I) explain dimples?
  - What vorticity features (Part I) explain peaks?

Mean slope of the 310K isosurface



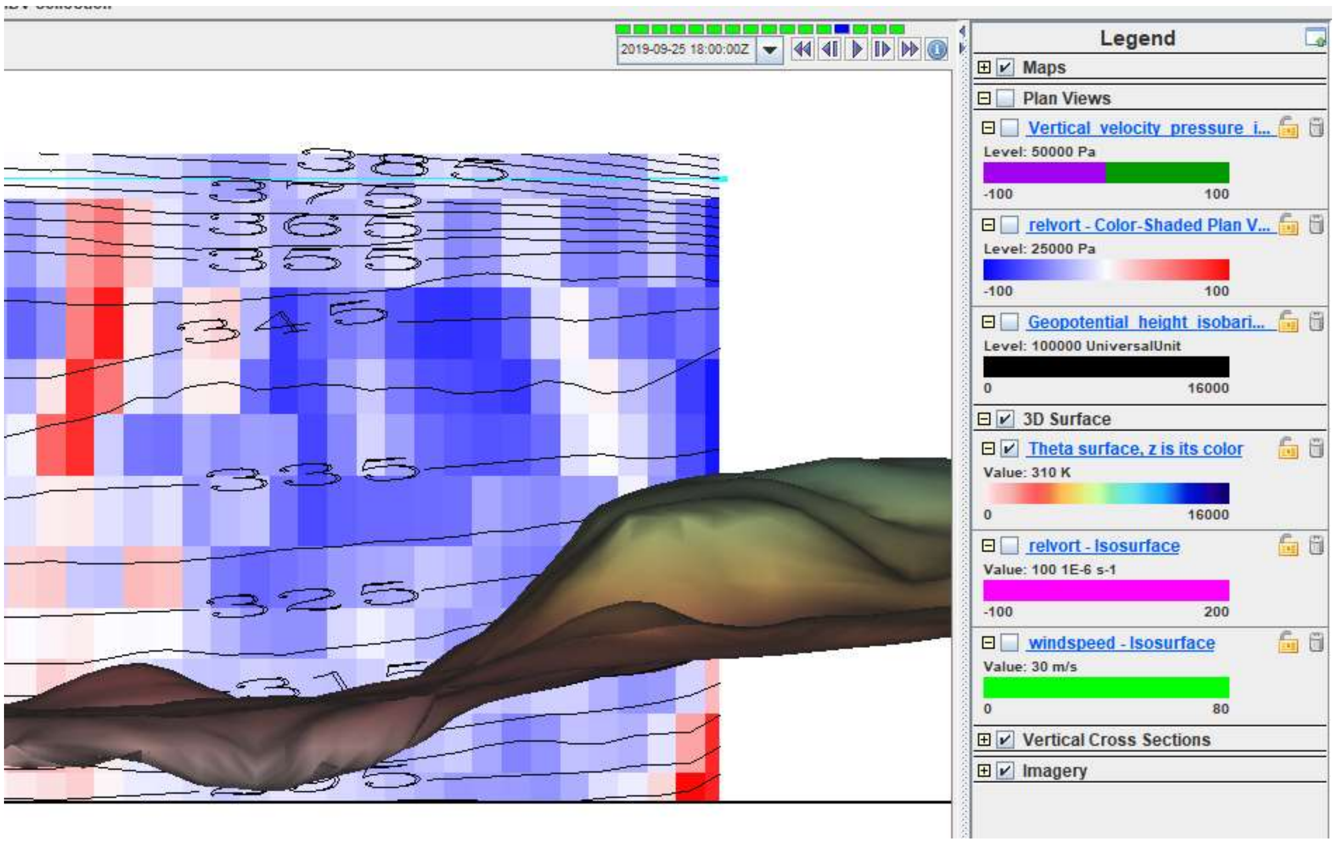
Mean slope of the 310K isosurface

$$\frac{\Delta z}{\Delta y} = \frac{Z2 - Z1}{y2 - y1} = \frac{7000m - 2200m}{65° - 12°} = \frac{4800m}{43°} = 111.62\ m/°$$



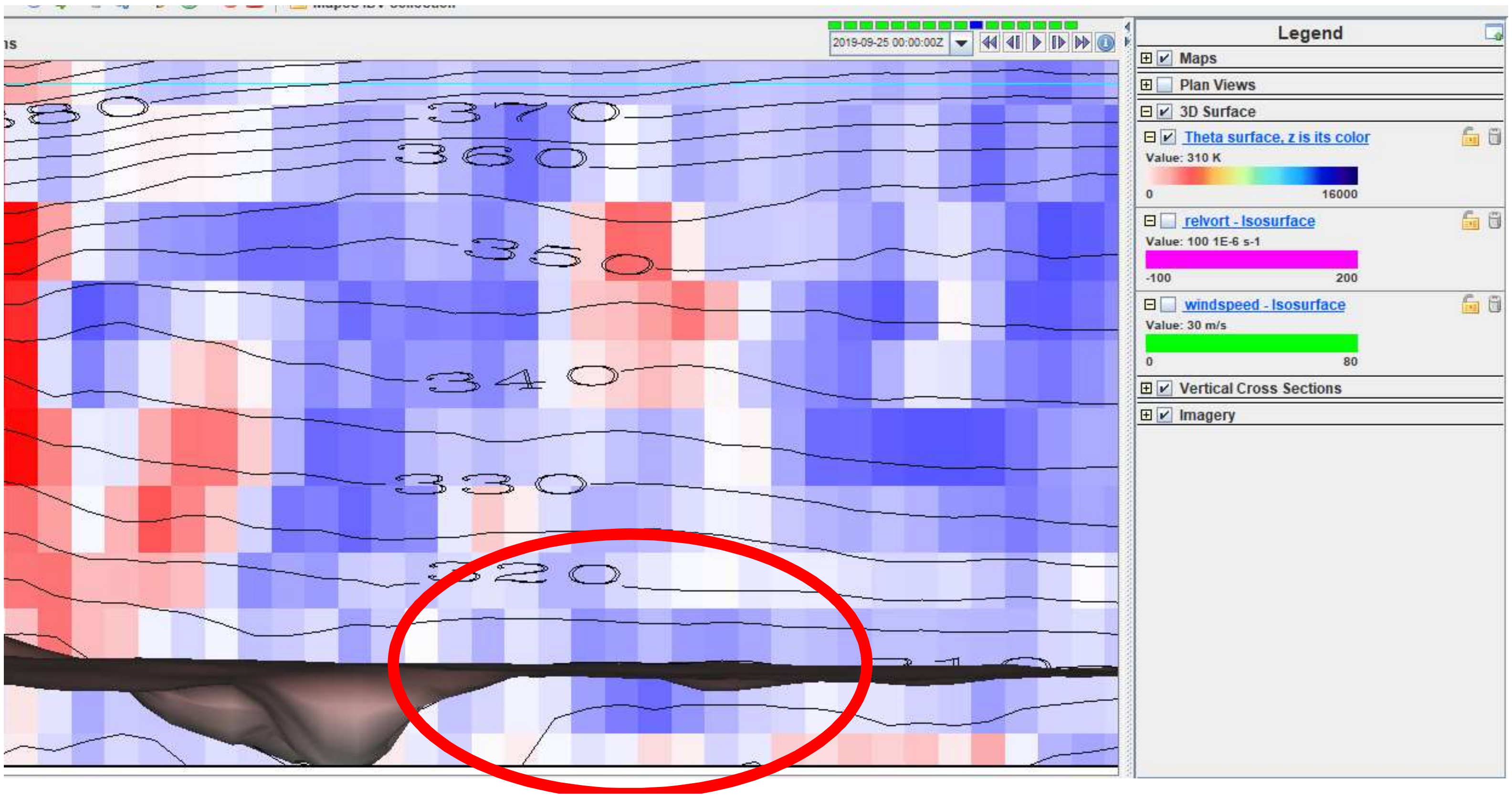
A depression in the 310K surface

- In a warm core anticyclone, the 310K isosurface is pushed away from the vortex, because the vortex is located on mid levels.

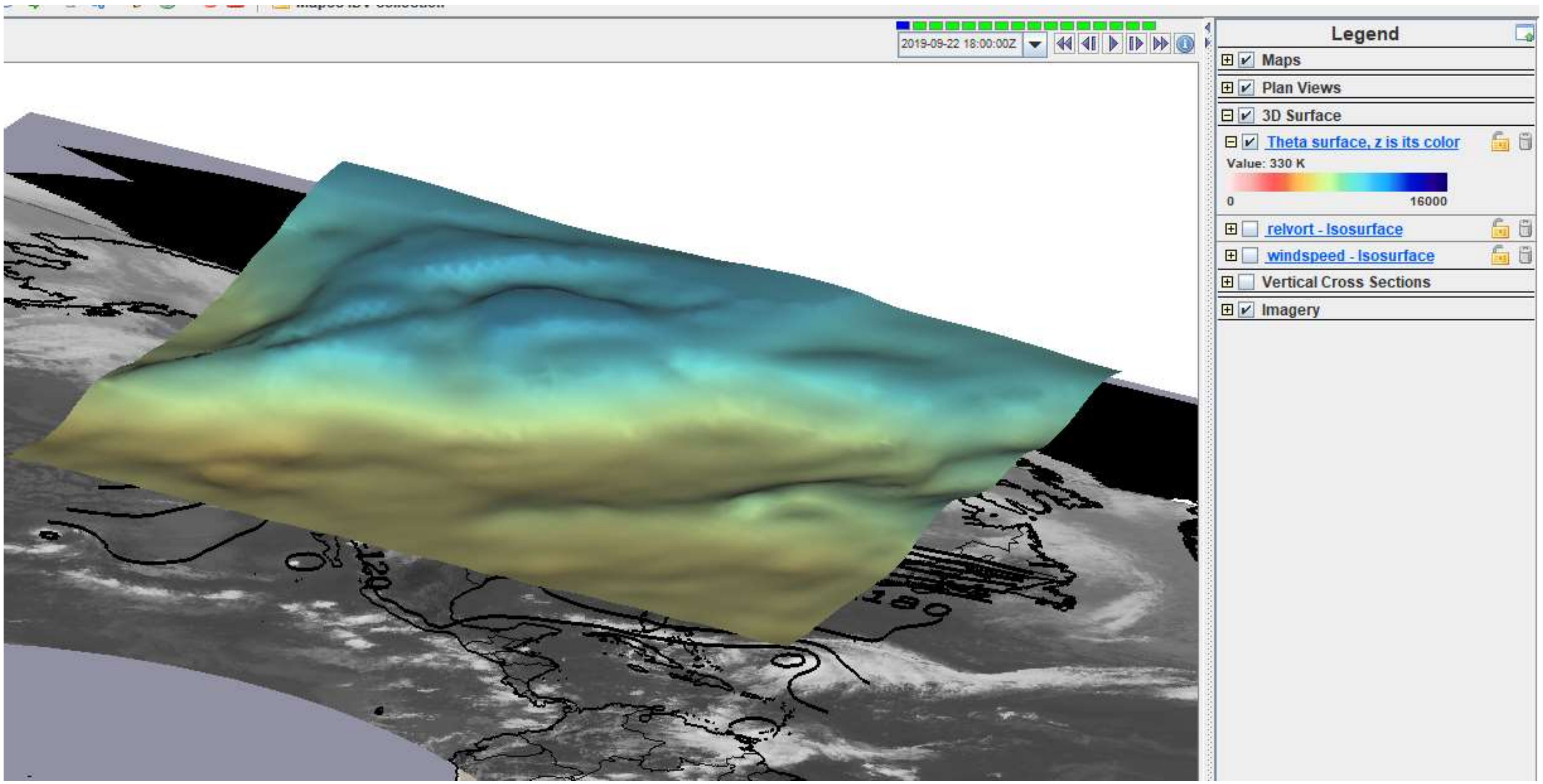


A peak on the 310K isosurface

- Cool core anticyclone vortex. This happens with the 310K isosurface, because the vortex is located on the lower levels and it has a trend to push 310 k isentrope line slightly up in the lower levels.

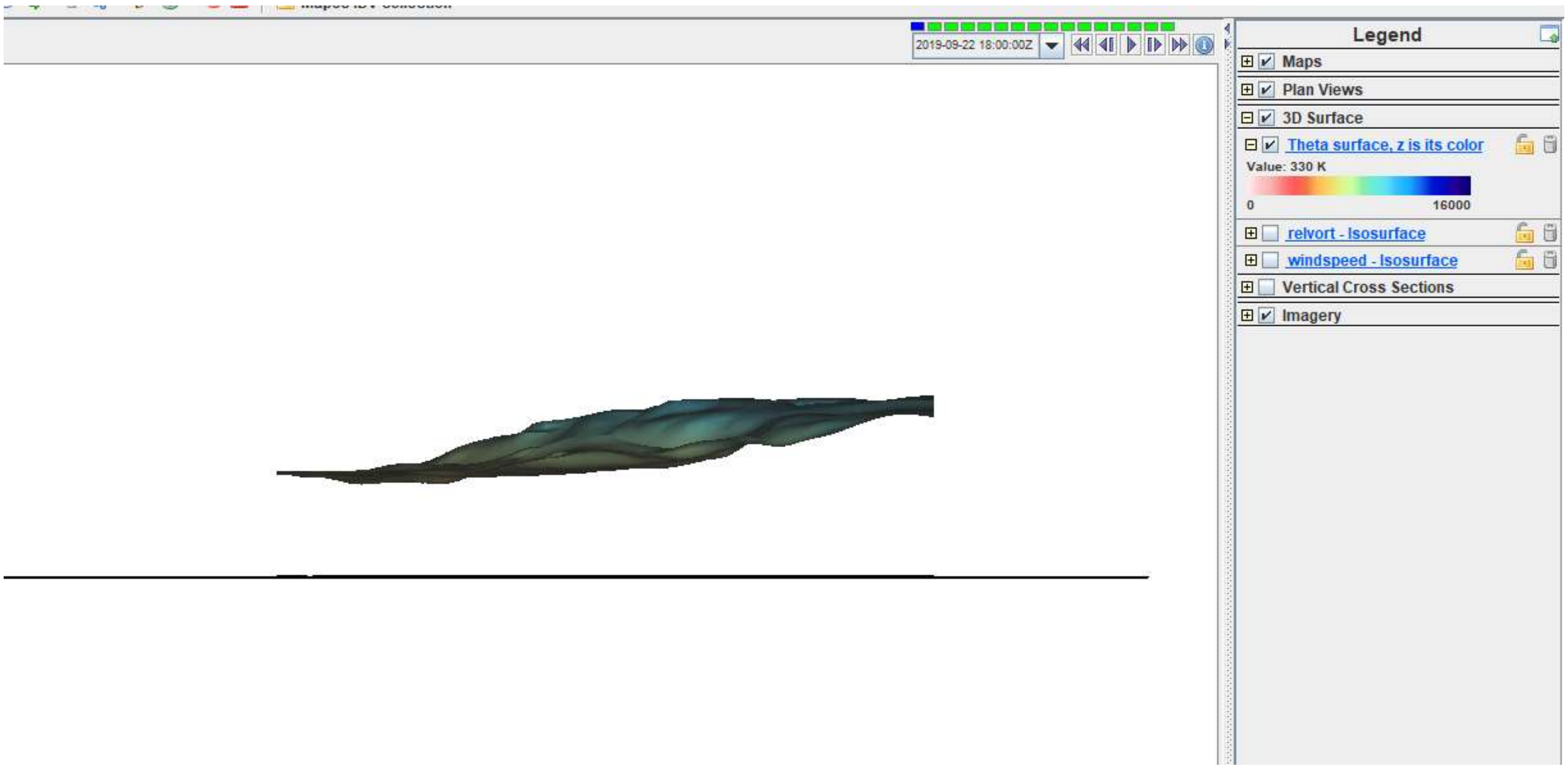


Mean slope of the 330K isosurface



Mean slope of the 330K isosurface

$$\frac{\Delta z}{\Delta y} = \frac{Z2 - Z1}{y2 - y1} = \frac{9500m - 6000m}{65° - 12°} = \frac{3500m}{43°} = 81.39\ m/°$$



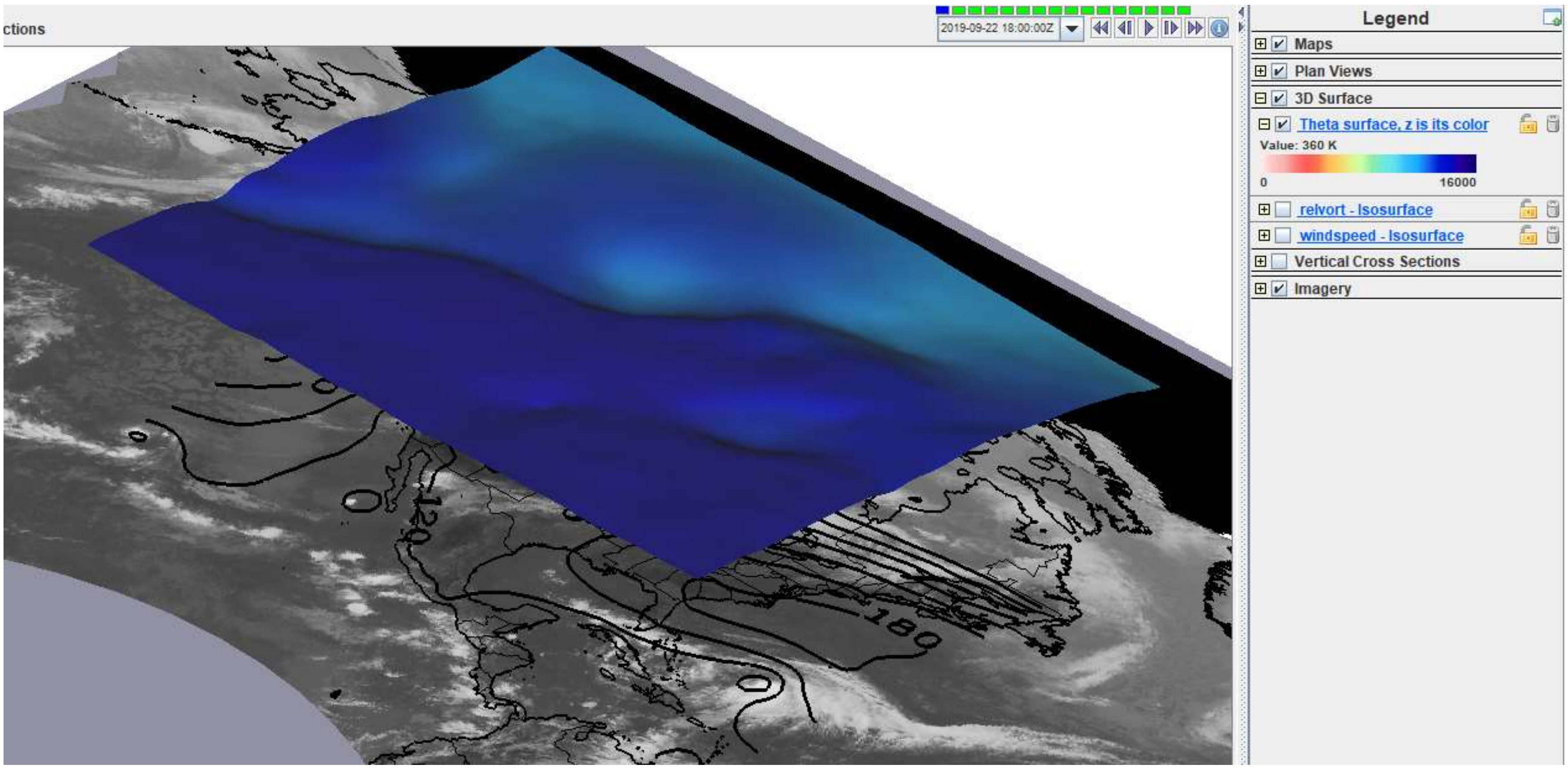
A depression in the 330K surface

- For the vortexes chose, none of them generated a depression in the 330 K surface or the variation was difficult to observed.

A peak on the 330K isosurface

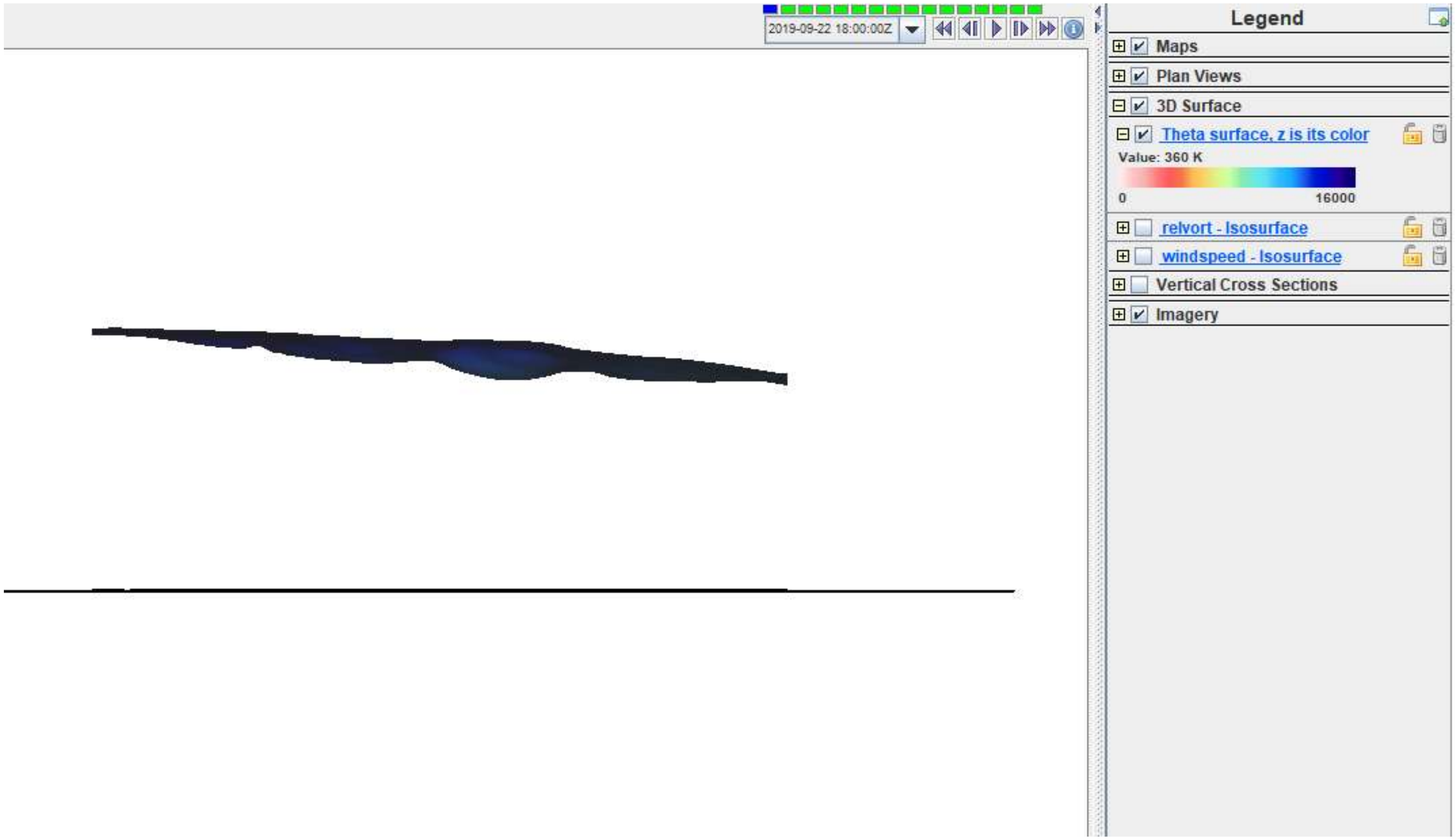
- For the vortexes chose, none of them generated a peak in the 330 K surface or the variation was difficult to observed.

Mean slope of the 360K isosurface



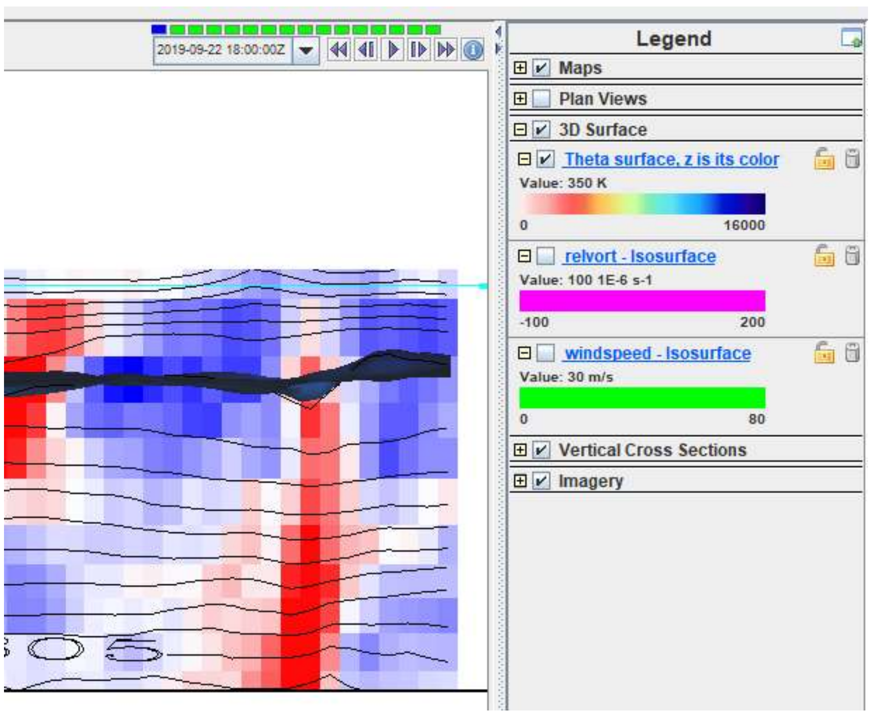
Mean slope of the 360K isosurface

$$\frac{\Delta z}{\Delta y} = \frac{Z2 - Z1}{y2 - y1} = \frac{11500m - 14500m}{65° - 12°} = \frac{-3000m}{43°} = -69.76\ m/°$$



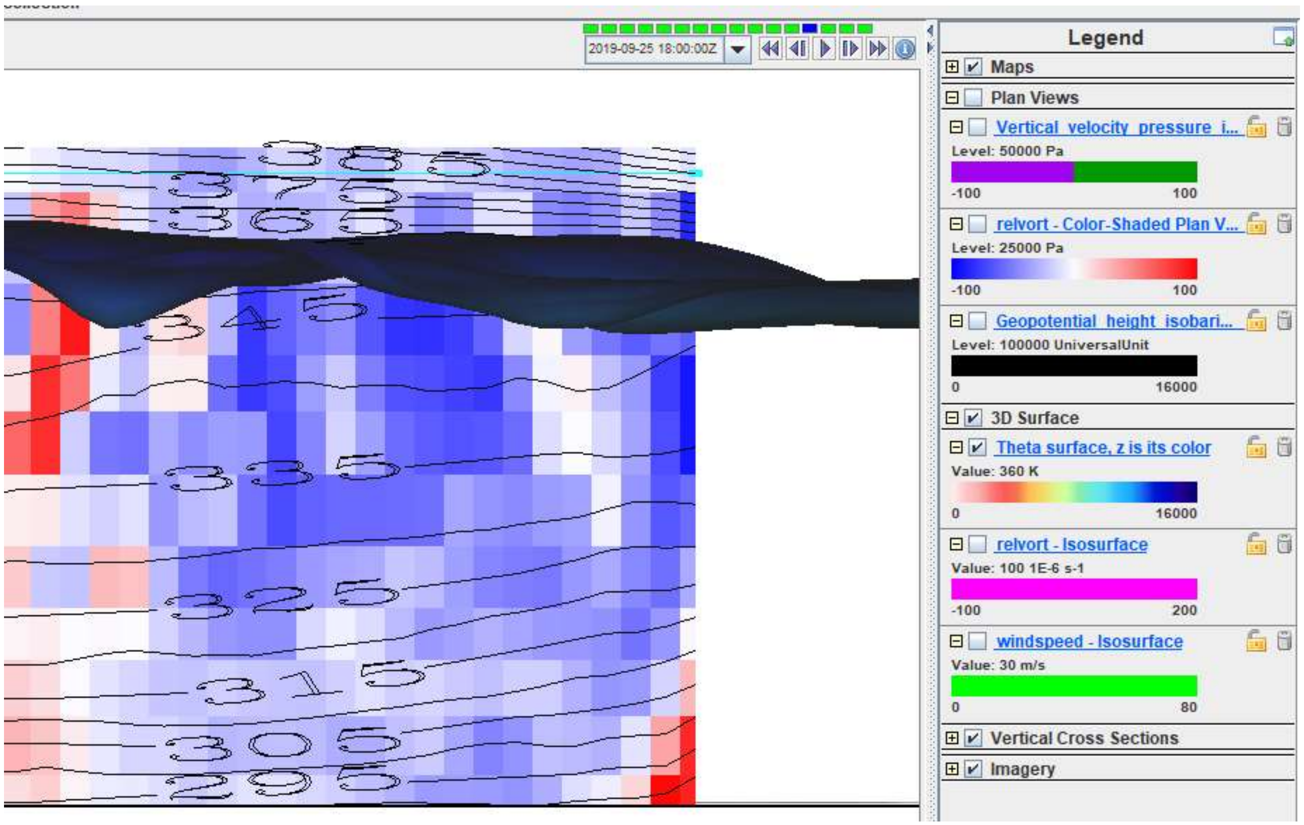
A depression in the 360K surface

- For this specific case of warm core cyclone, the cyclone is located underneath the 360K surface. Therefore, the influence of this vortex is not felt on this surface, however, a depression is observed if considered the 350K surface because the warm core vortex tend to pull down the isentrope lines in the upper levels.



A peak on the 360K isosurface

- In a war core cyclone, the cortex would originate a pear on the 360K isosurface because the vortex is located right below this surface and it tends to push the isentrope lines away from the vortex.



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