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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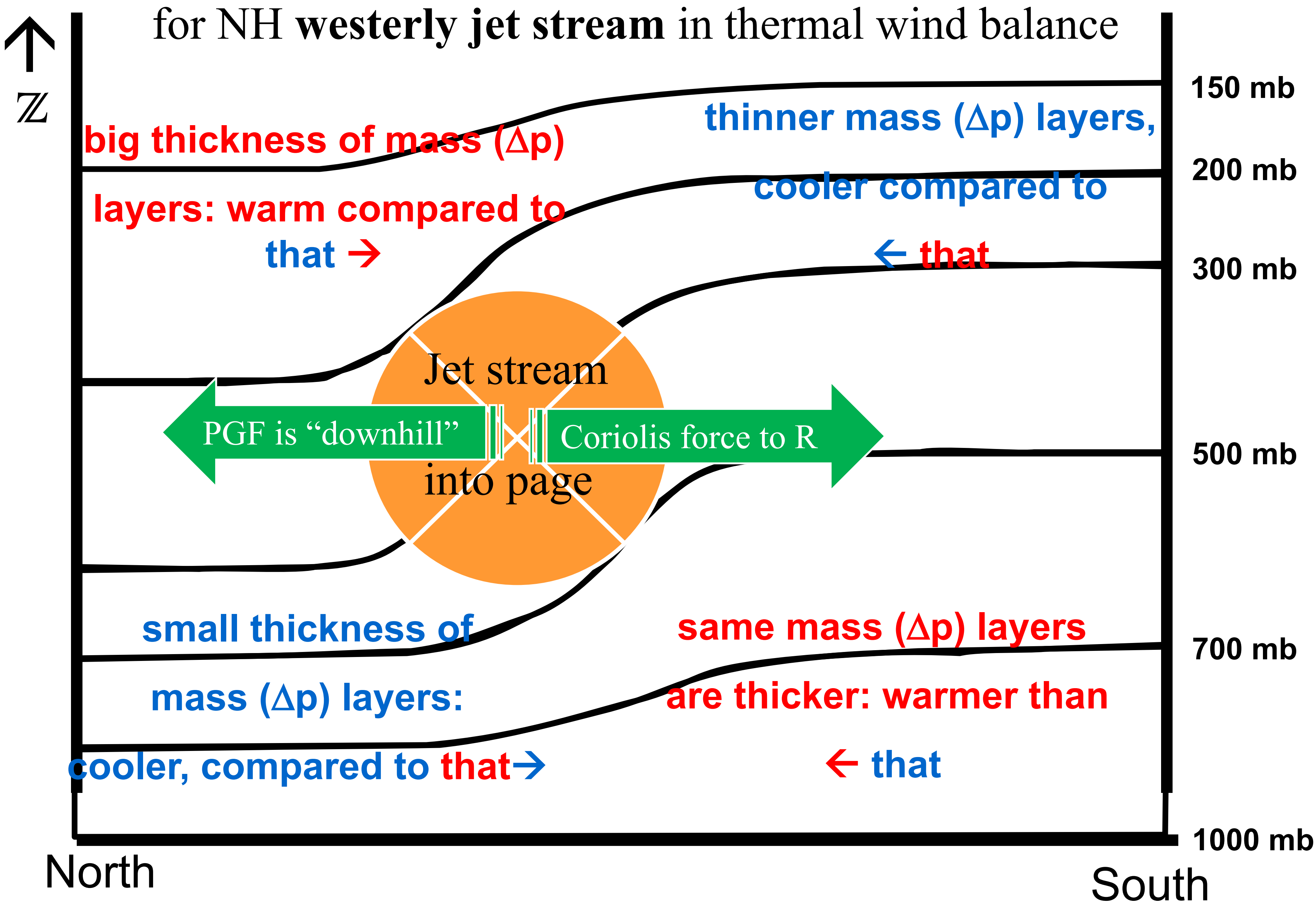
The big idea of it

- 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.

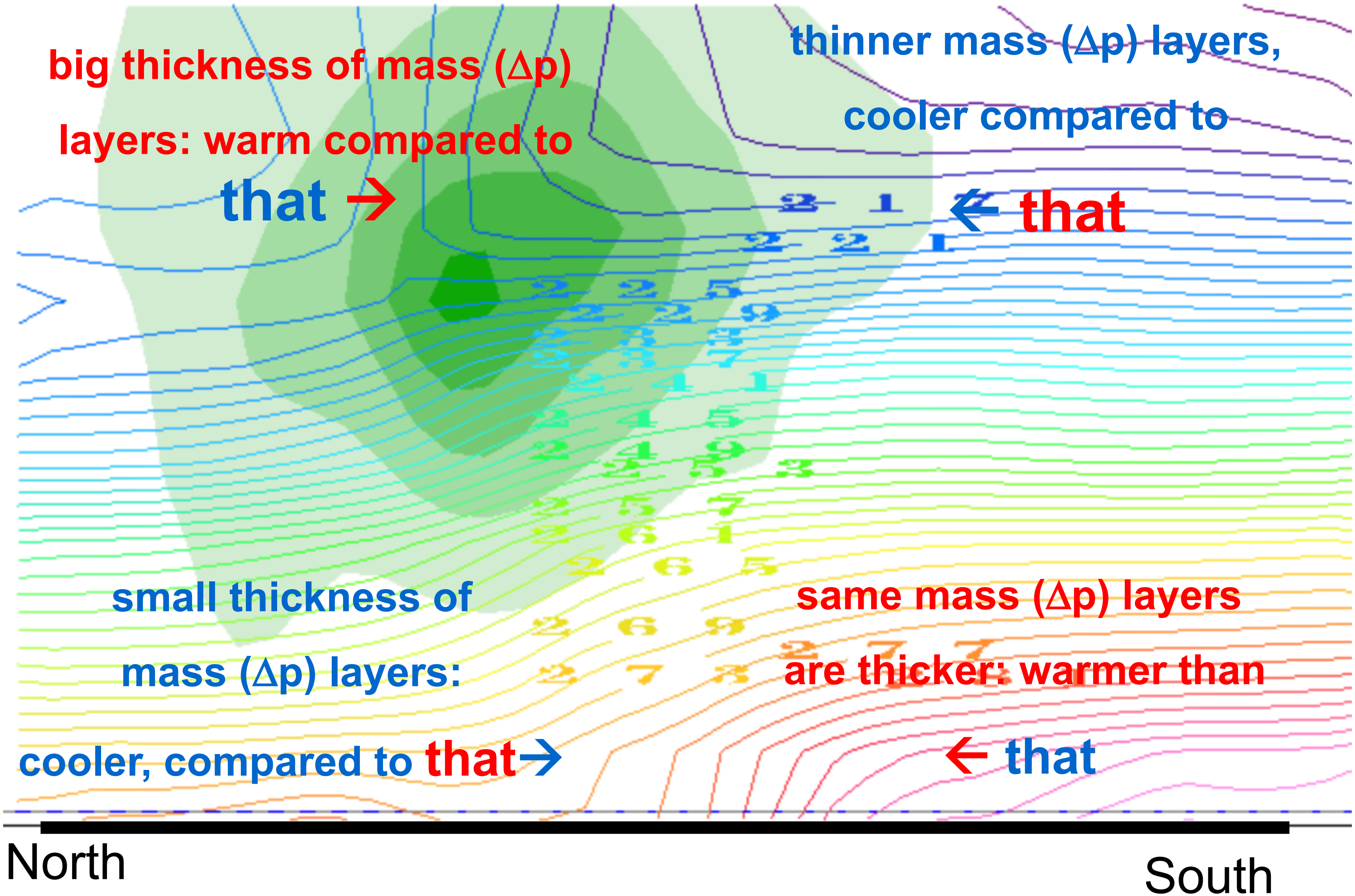
- But wind always blows in circuits (circulations), so it is often more useful to think of *vortices* (with vorticity as the budget equation) as the fundament of flow.
- Then T is understood in terms of warm and cool *cores.*

p surfaces on a z-coordinate diagram



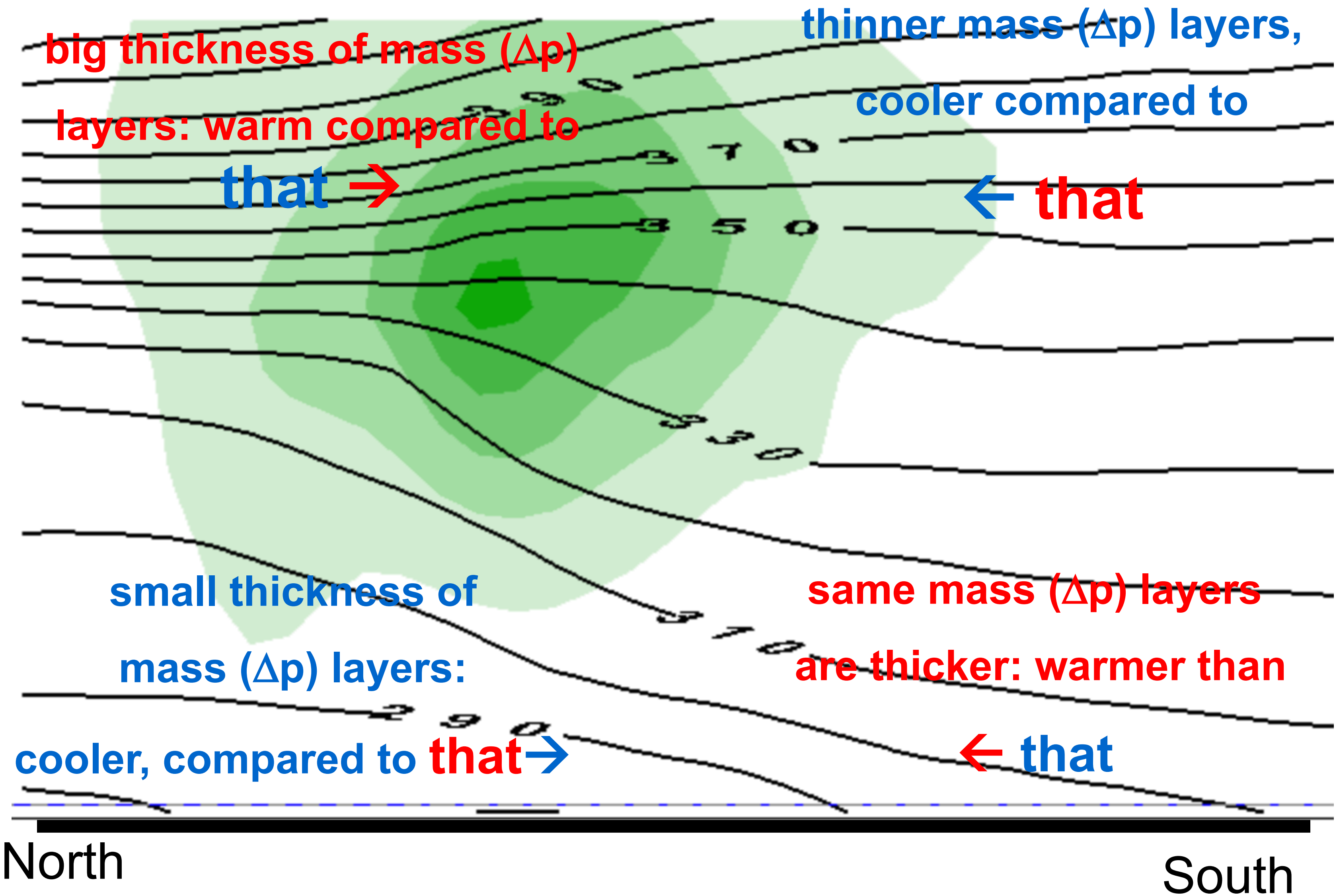
contours of T(K): it decreases with height

(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!**

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

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

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

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

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

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

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

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

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

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

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

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

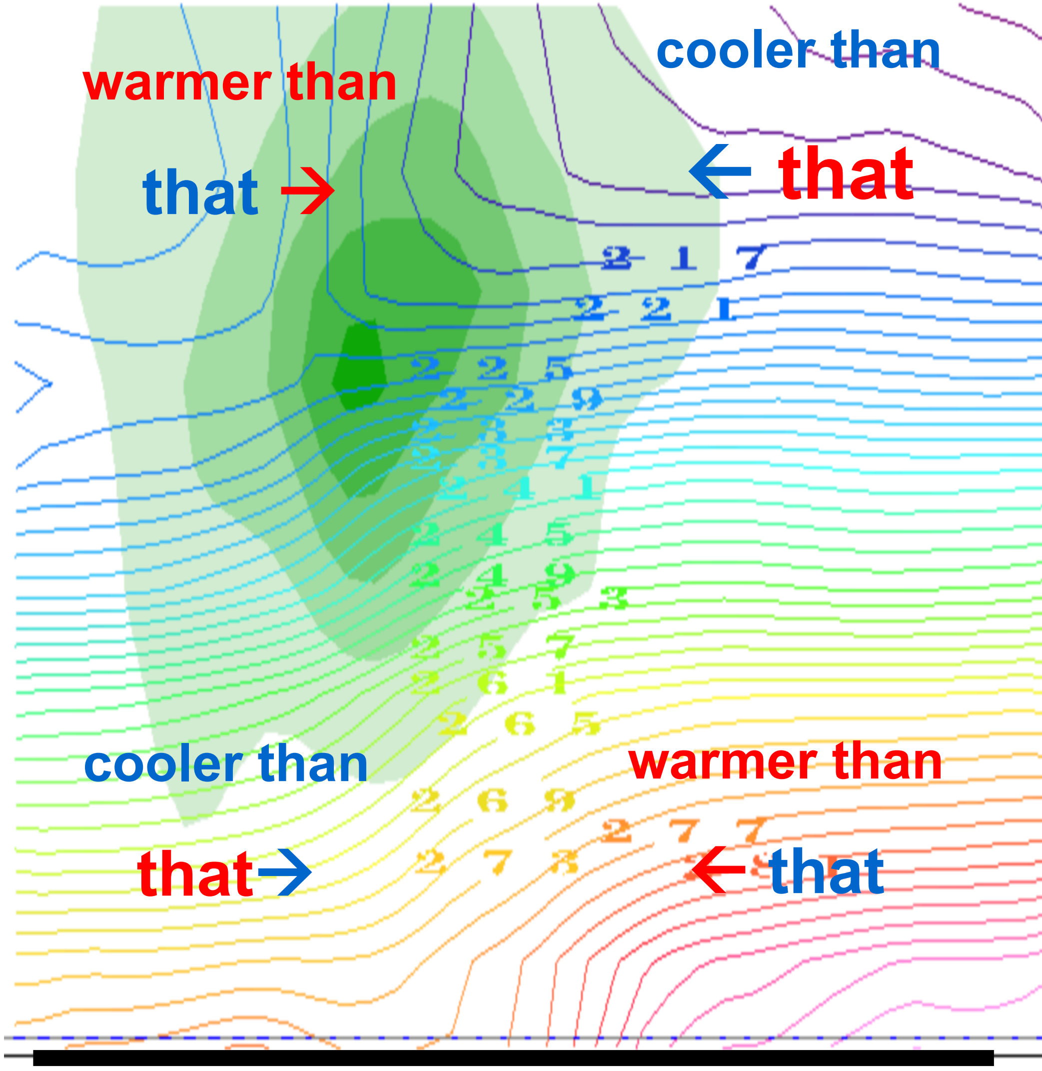
$$D\zeta/Dt = 0 + complications$$

- 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?

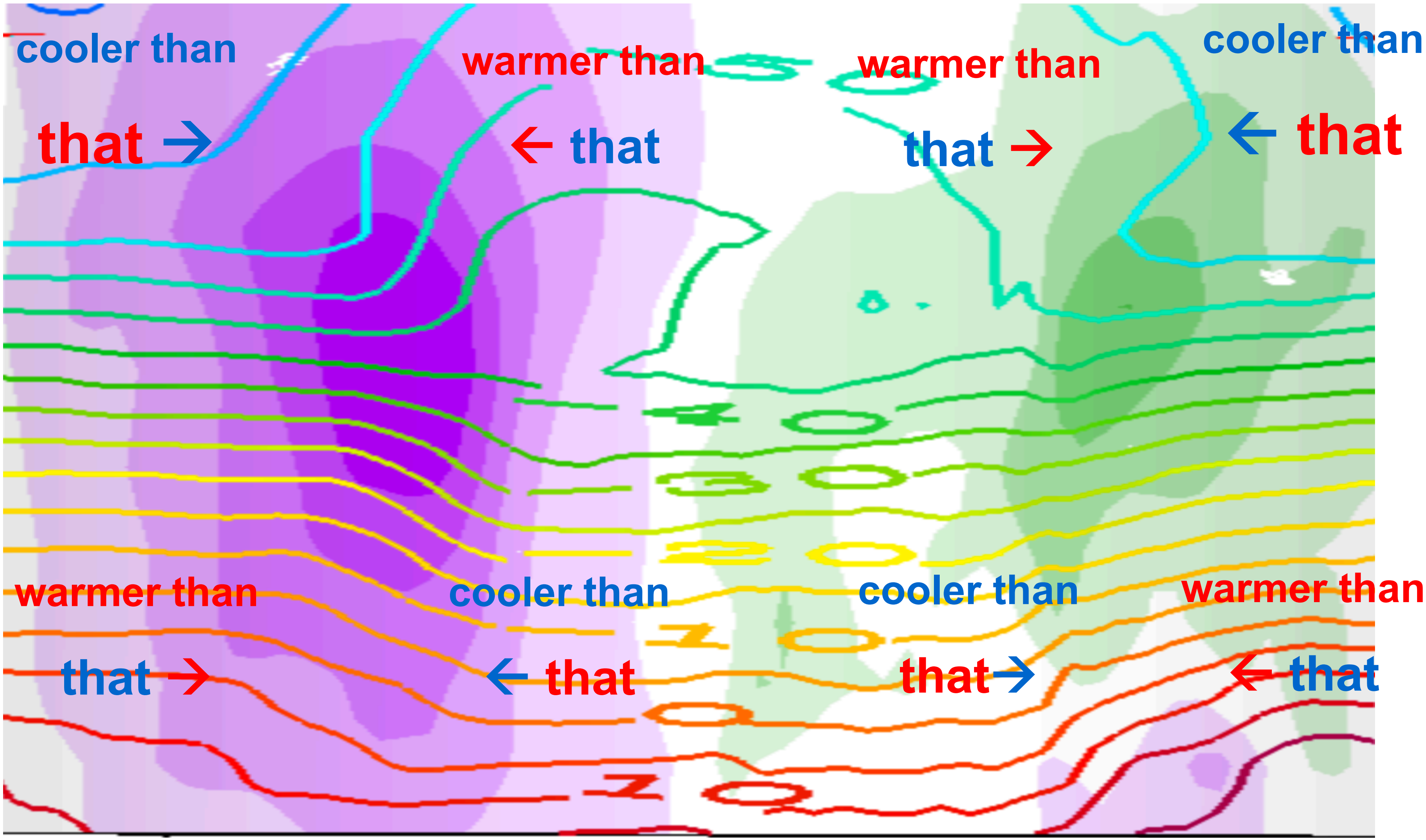
- In this case, one near the tropopause (like the jet stream)

This is only half the story of a vortex



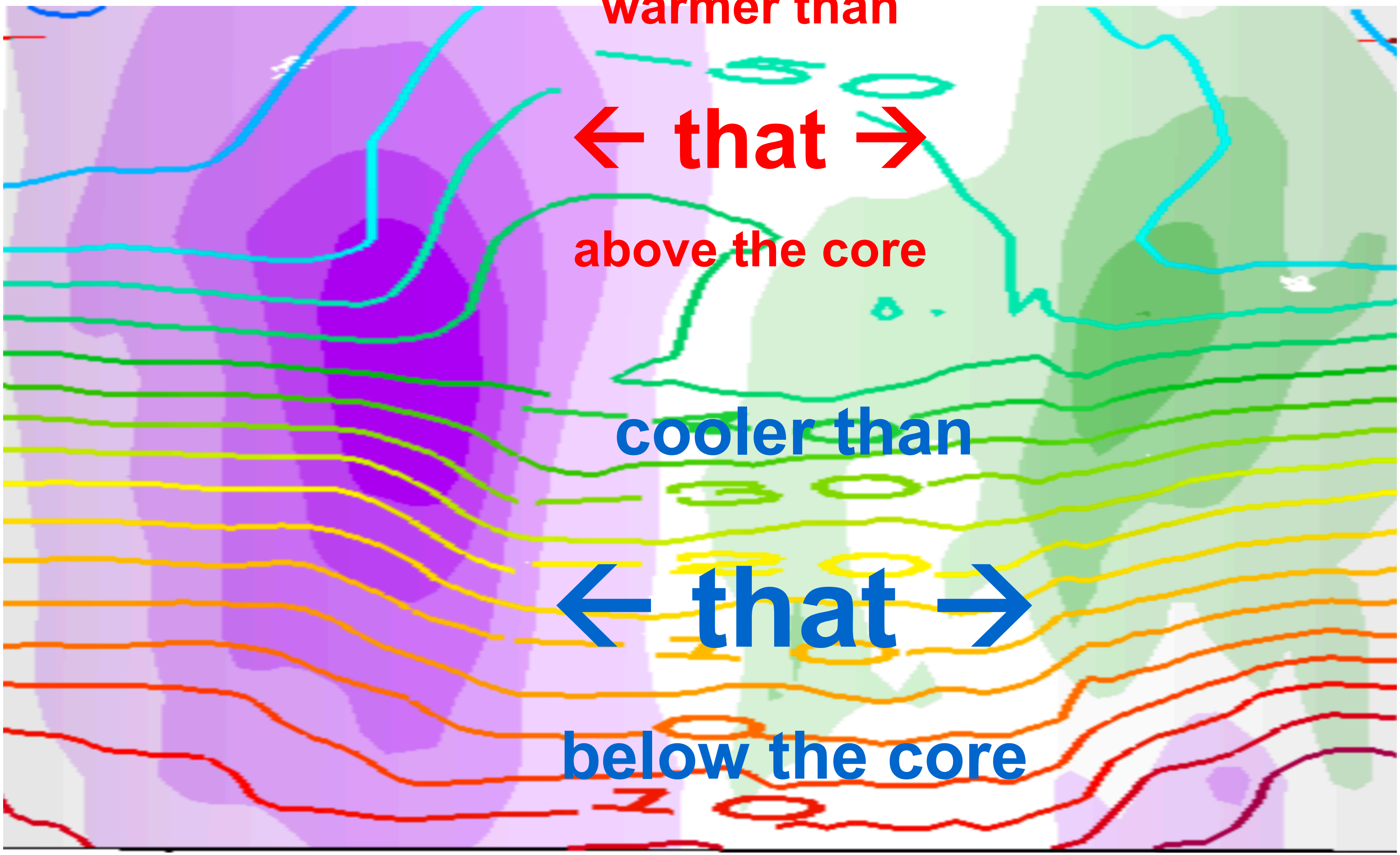
This is a whole vortex (two jets)

T(K) contours



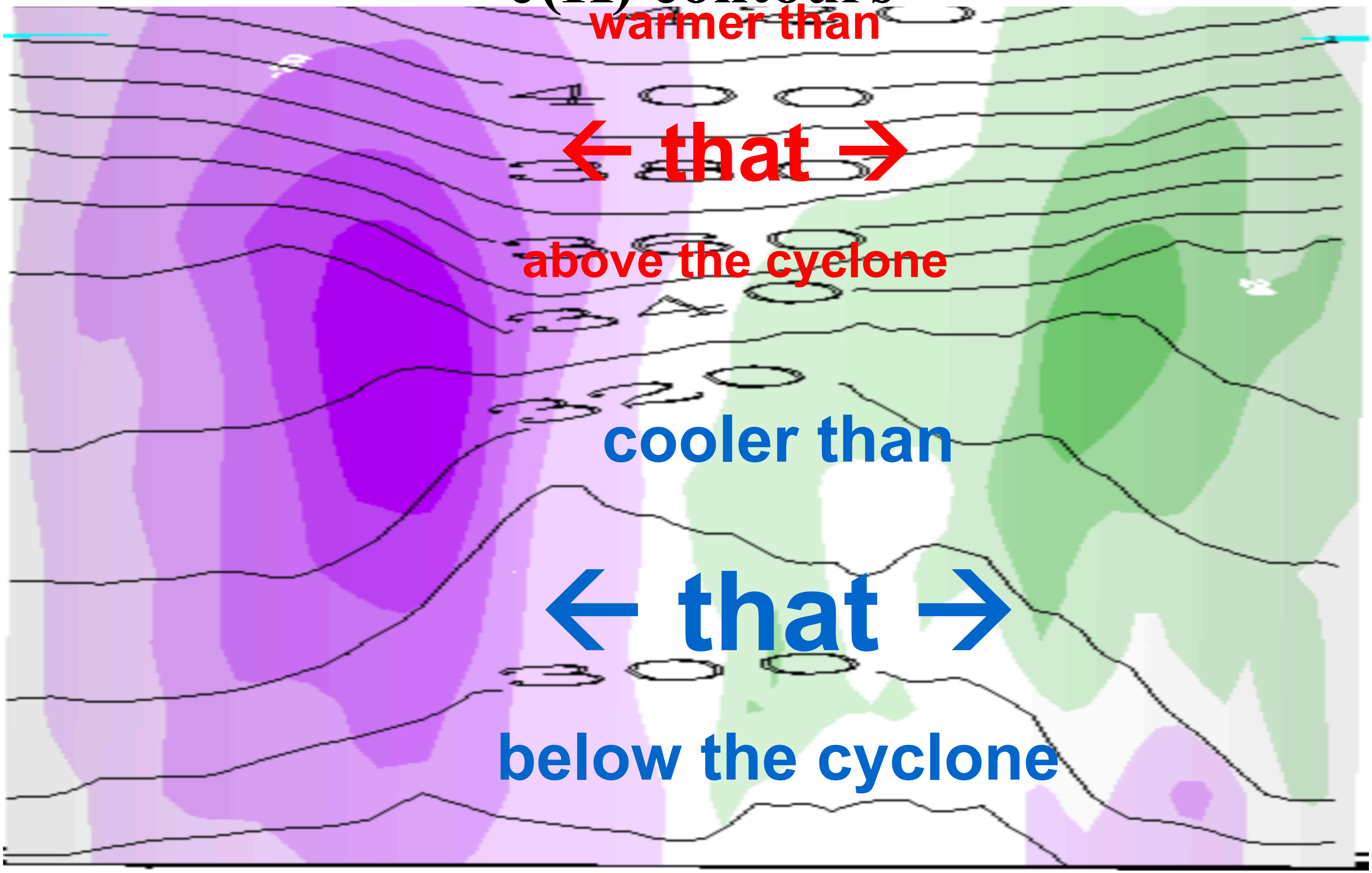
This is a whole vortex (two jets)

T(K) contours

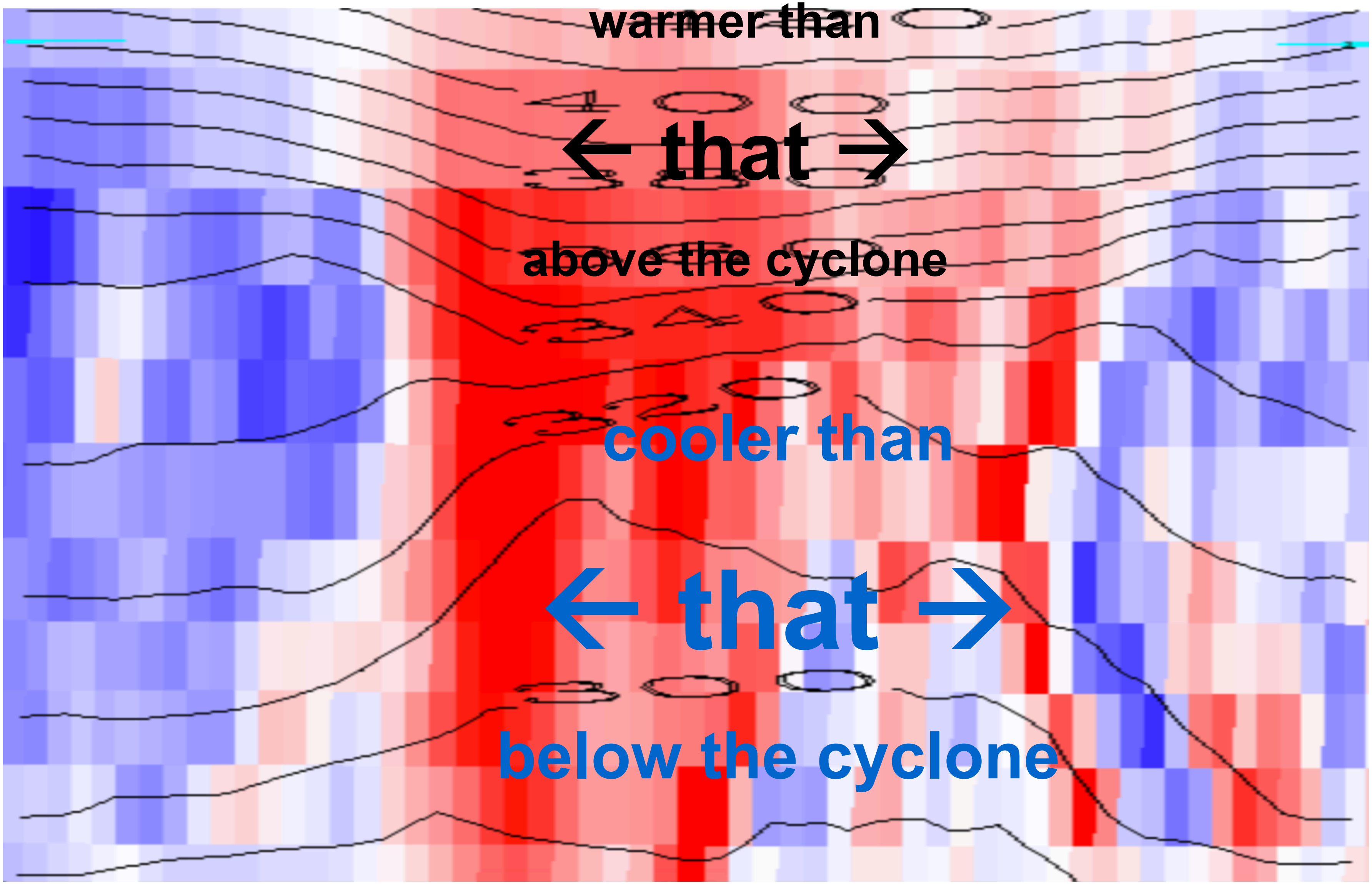


This is a whole vortex (two jets)

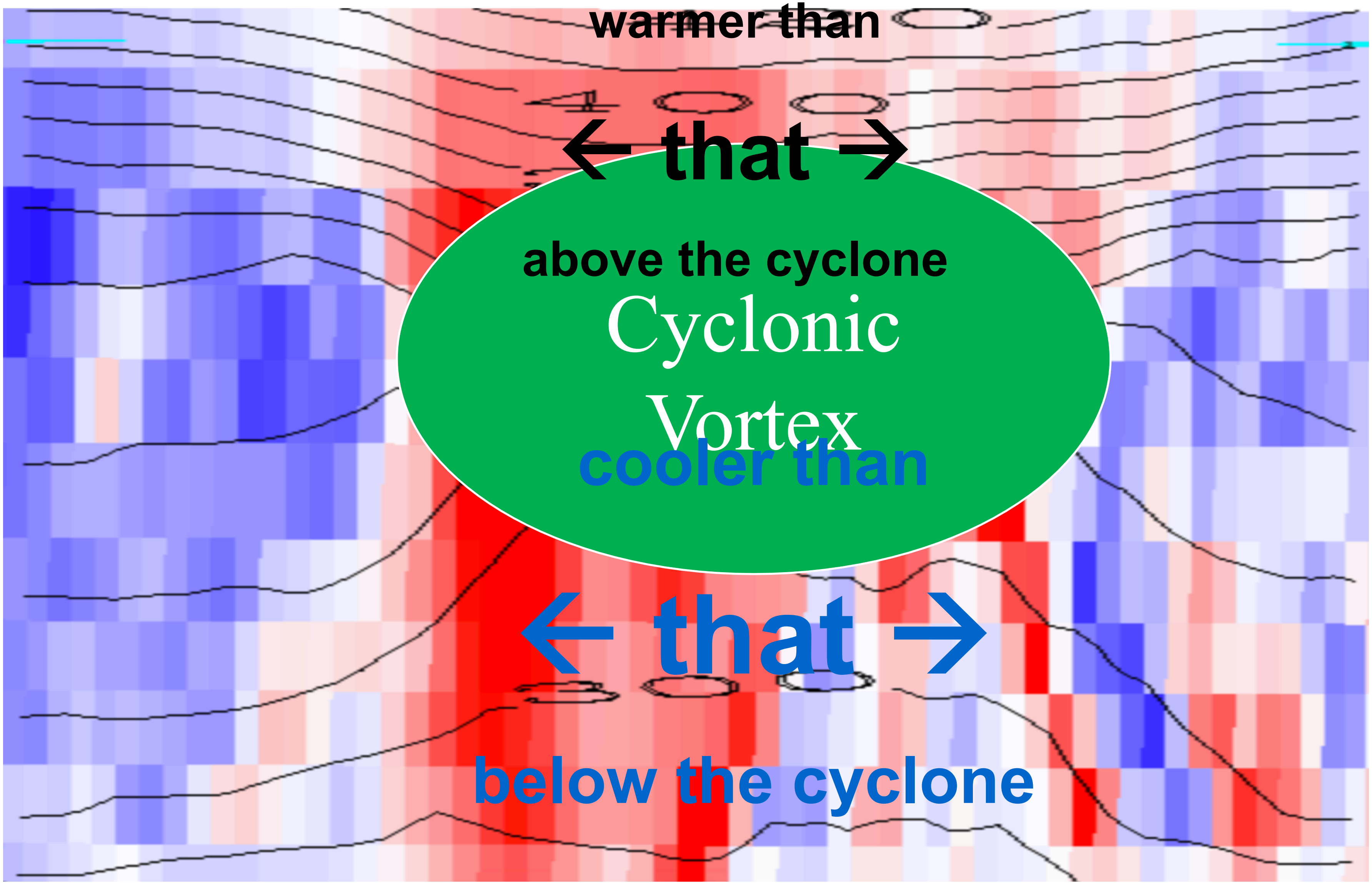
θ(K) contours



Red is positive vorticity , θ(K) contours

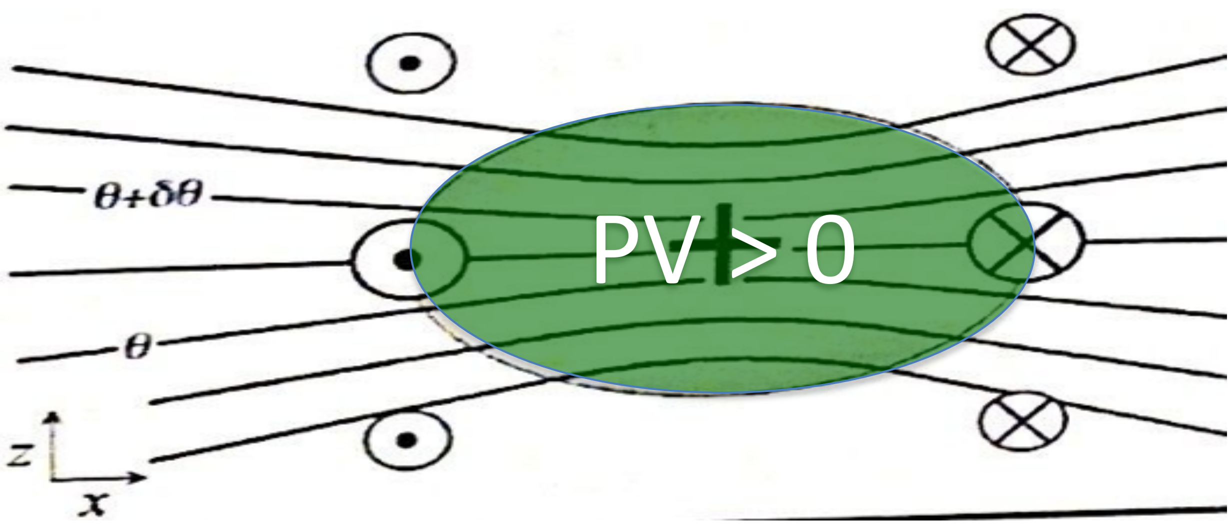


<u>Red is positive vorticity</u> , θ(K) contours



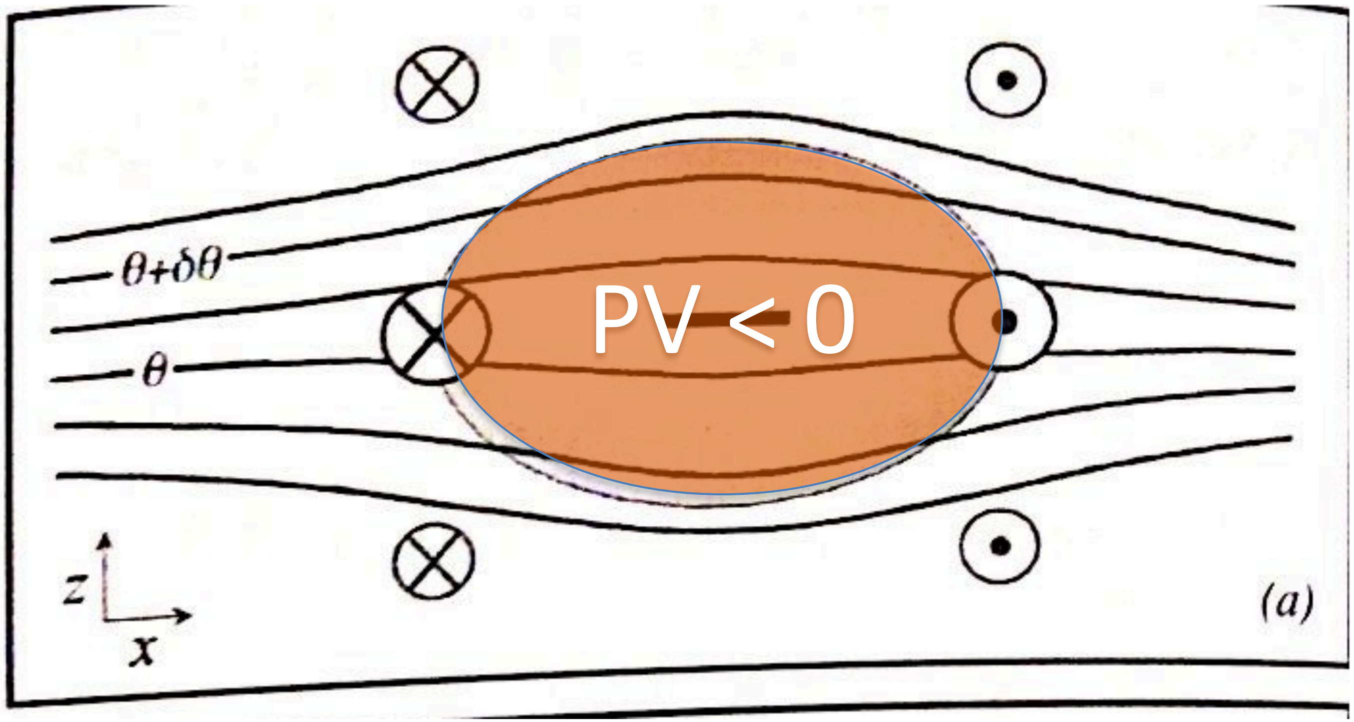
Generalization: *PV*

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):

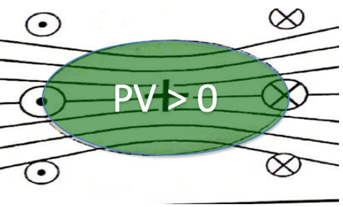


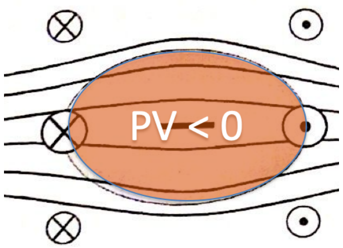
Balanced anticyclones exist too...

- Just the opposite of a cyclone...



Vorticity (or PV) blobs





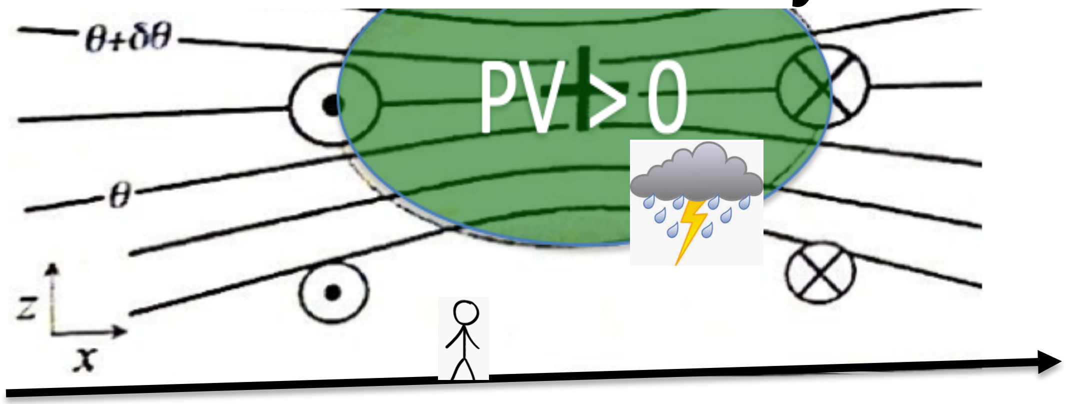
- Where do they come from?
- How do they interact?
  - (this we studied, in the horizontal plane)
- Do they get destroyed?

- (Soon: tackling the complications)

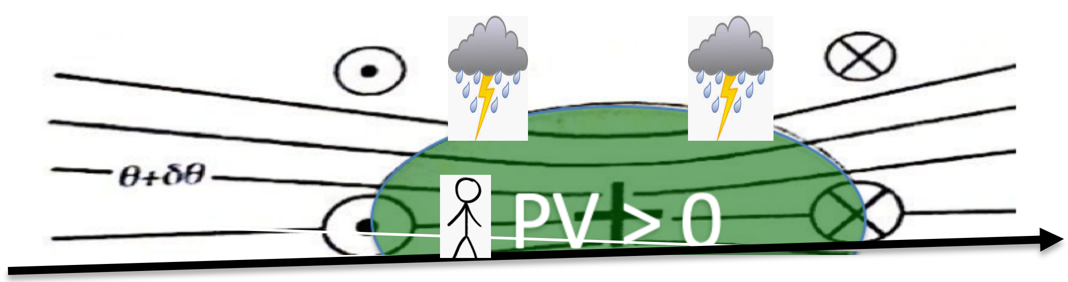
$$D\zeta/Dt = 0 + complications$$

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

- This is called a *cool core cyclone:*

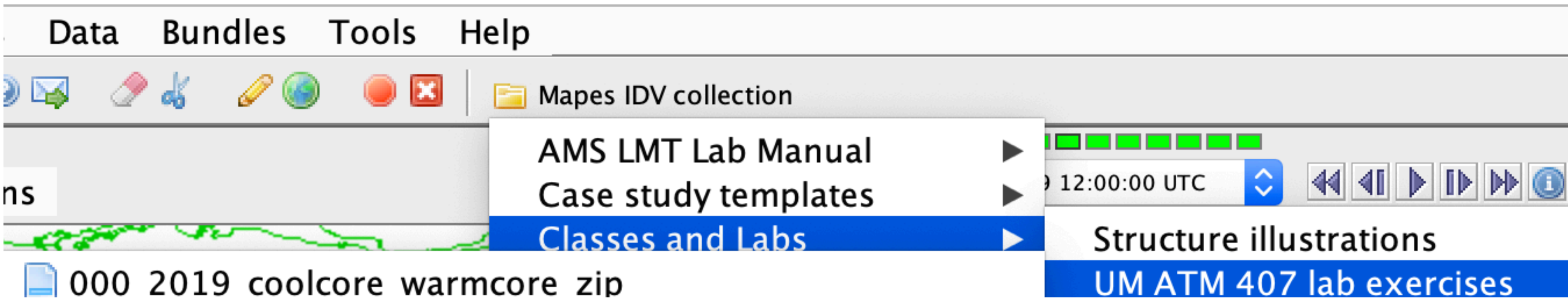


- This is called a *warm core cyclone:*



IDV lab assignment -- part 1

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

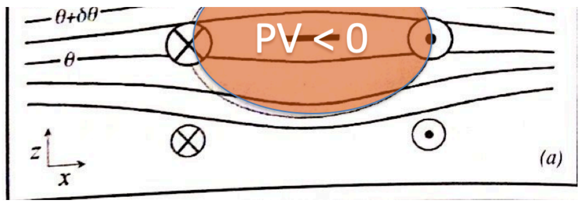


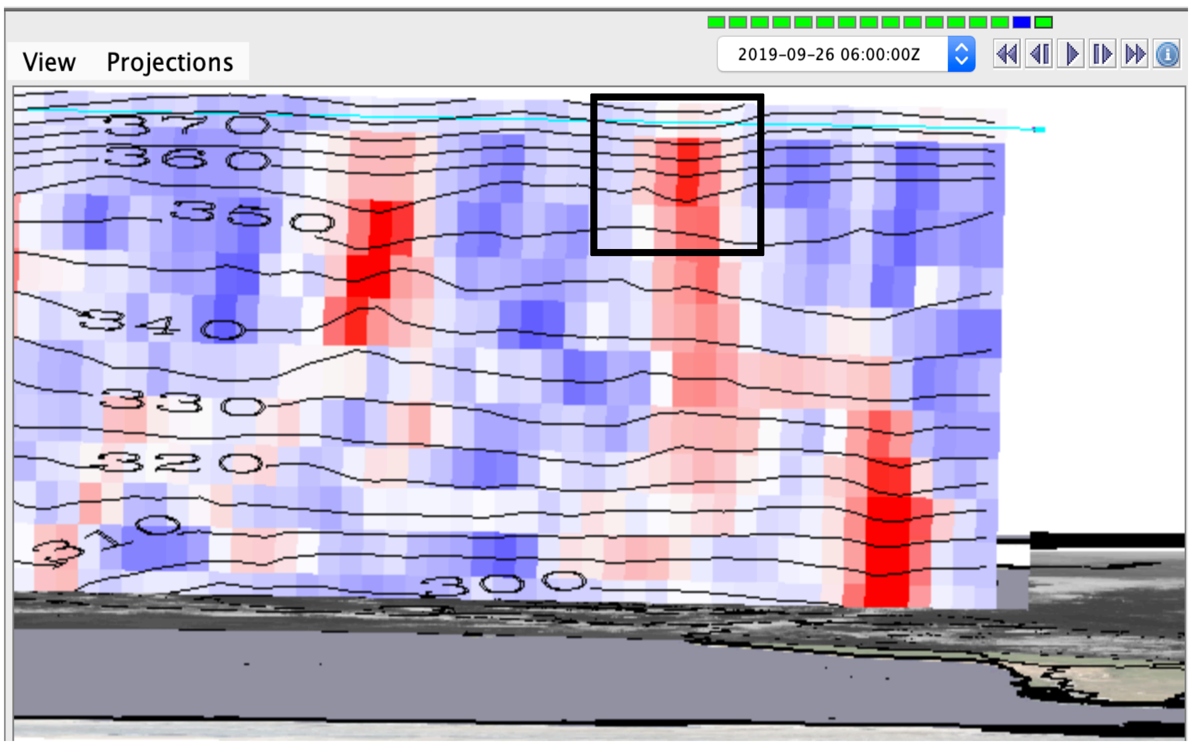
Explore ALL of its displays, at ALL of its times (loop the animation). Learn to use the IDV. The Help menu has pan-zoom help on top. A mouse is a HUGE help for 3D views.

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

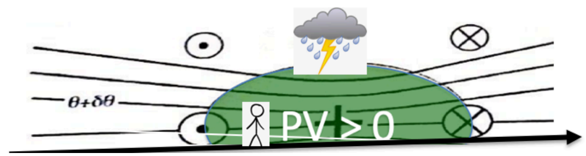


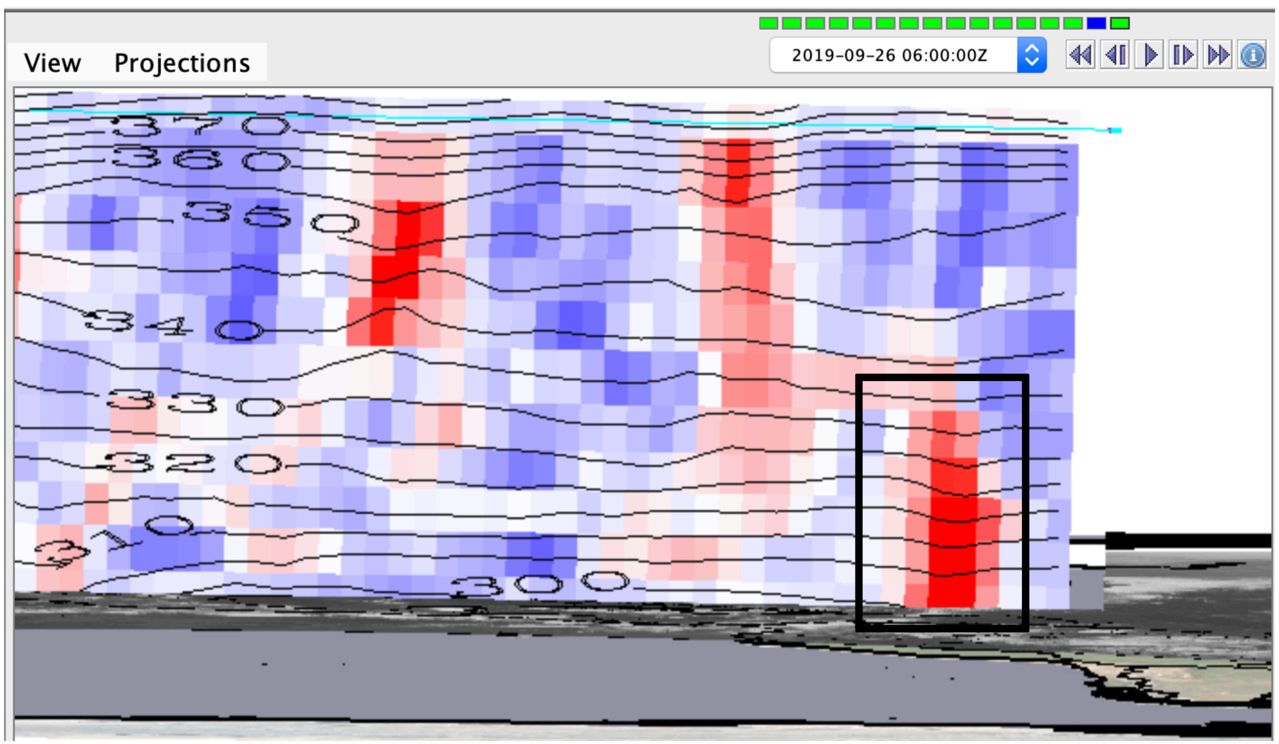


- **Where? Describe the situation.**
- The warm core anticyclone is occurring at the 355K -370K potential temperature contours in the region I've boxed.
- This region is located over the Atlantic Basin. To the east of this region there is a tropical disturbance over open ocean waters.
- There is subsiding vertical motion in the troposphere.
- Radiative heating/vertical mixing in the boundary layer do not allow for the warm core anticyclone to stretch down to the surface

A warm core cyclone

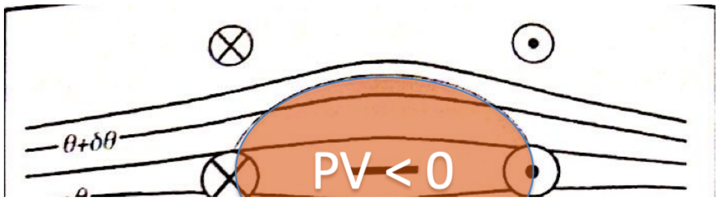
This is called a *warm core cyclone:*

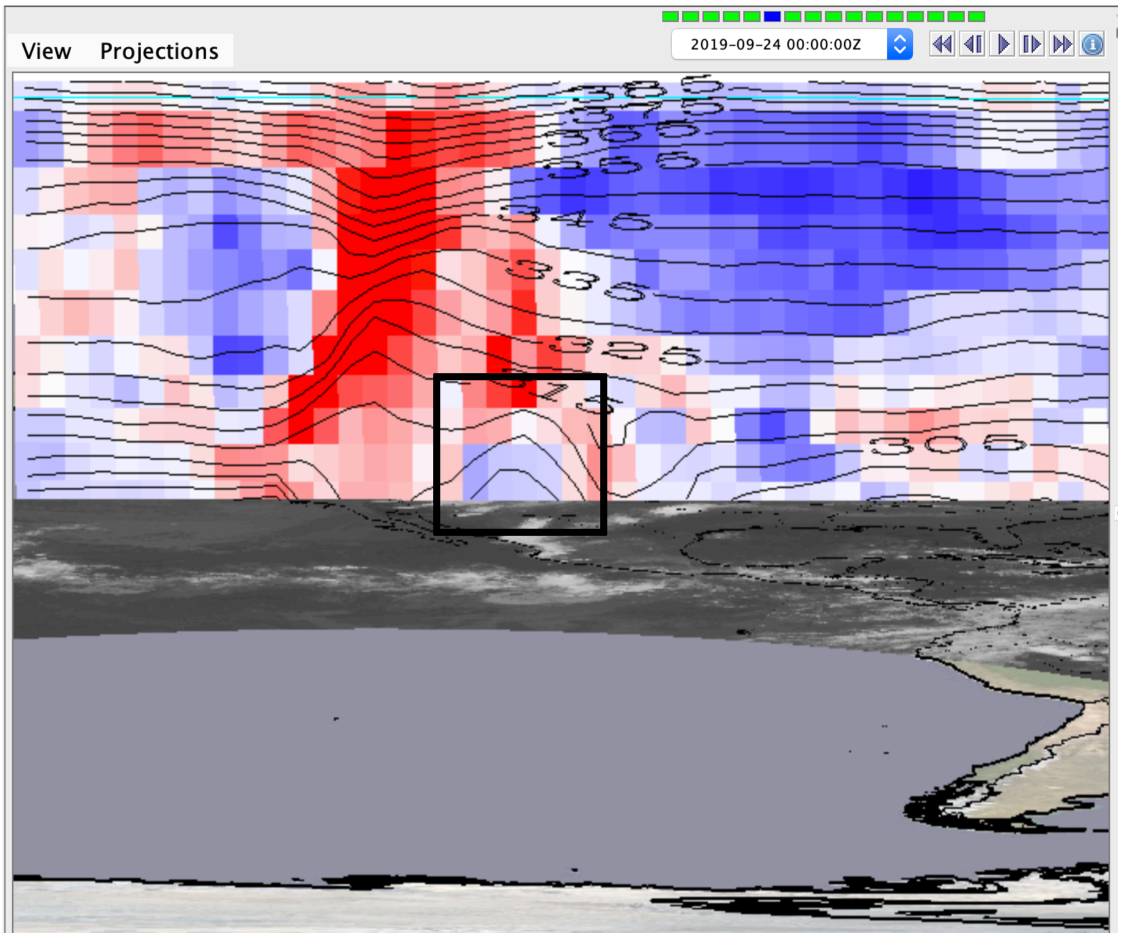




- **Where? Describe the situation.**
- The warm core cyclone is occurring at the 300K - 330K potential temperature contours in the region I've boxed.
- This region is located over the Atlantic Basin. There is a tropical disturbance that is allowing for this feature to be seen.
- There is counterclockwise wind movement allowing us to understand it is a low pressure system.
- Warm core cyclones need weak vertical shear throughout the troposphere to sustain themselves.

A cool core anticyclone





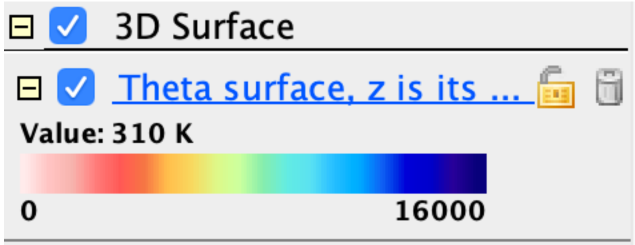
- **Where? Describe the situation.**
- The cool core anticyclone is occurring at the 300K -315K potential temperature contours in the region I've boxed.
- This region is over Arizona and New Mexico
- As per the infrared imagery there is a noticeable disturbance over this area.
- Shallow systems in the lower troposphere with anticyclonic circulation

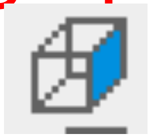
Isentropic surfaces

- 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)

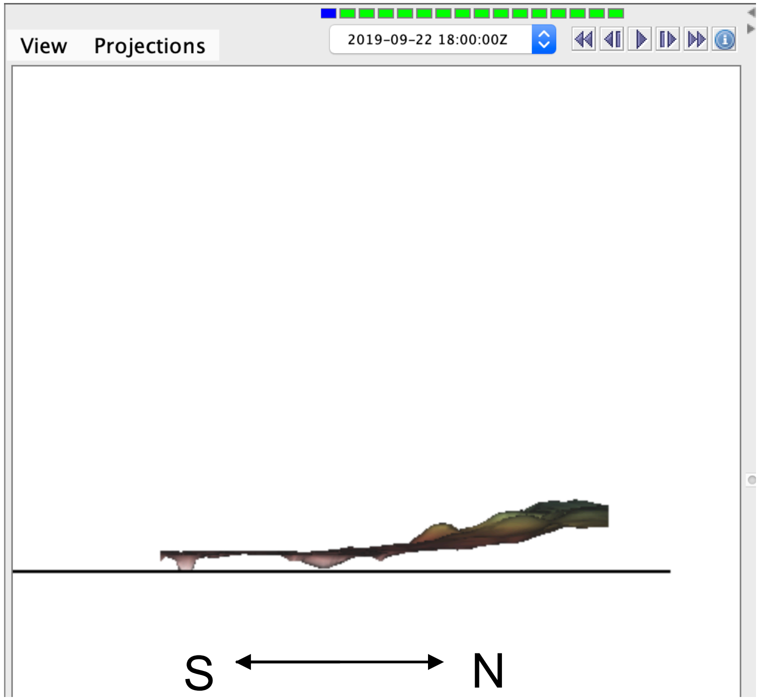
IDV Lab assignment part 2

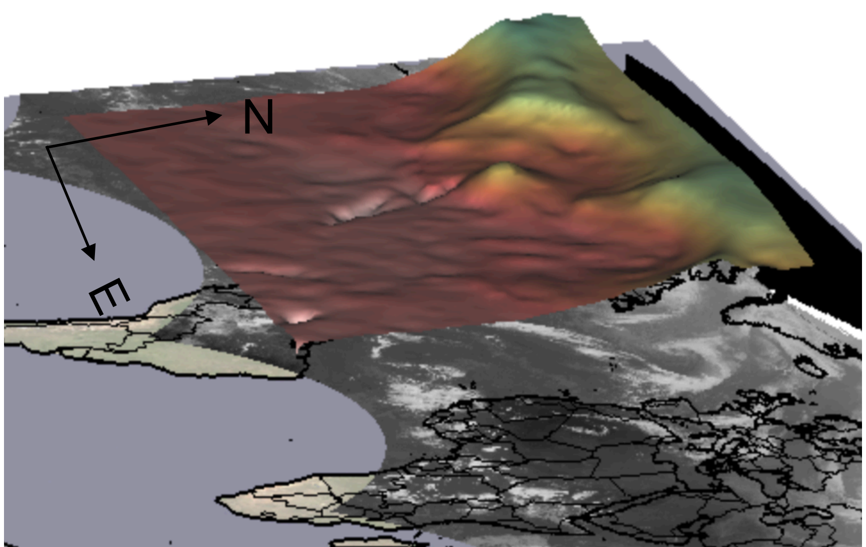
- In the same bundle, activate (check) the display called “Theta surface, z is its color”



- 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

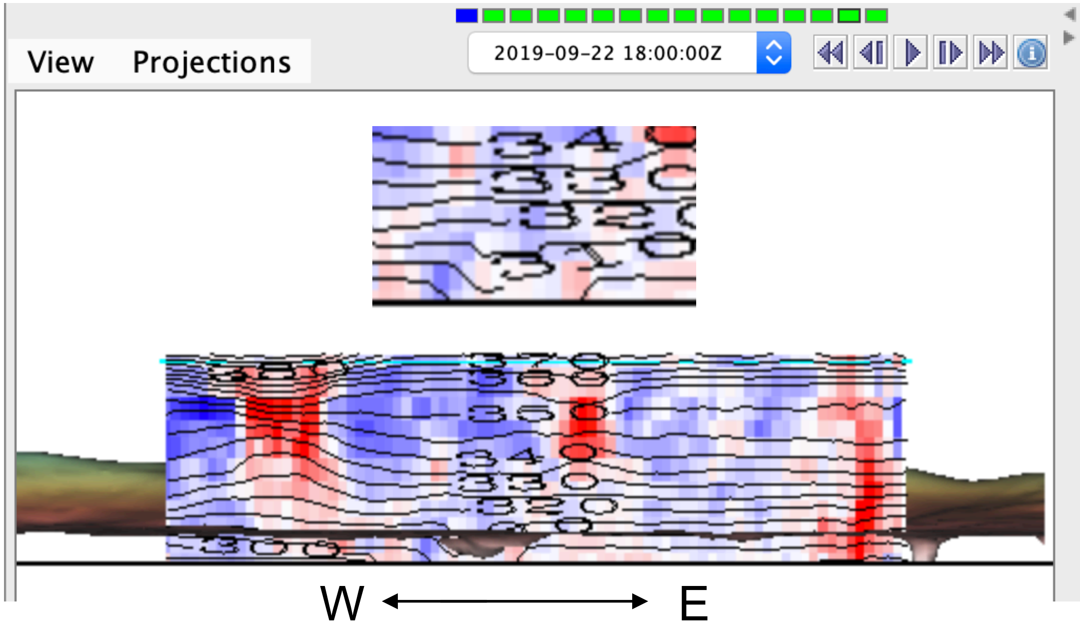


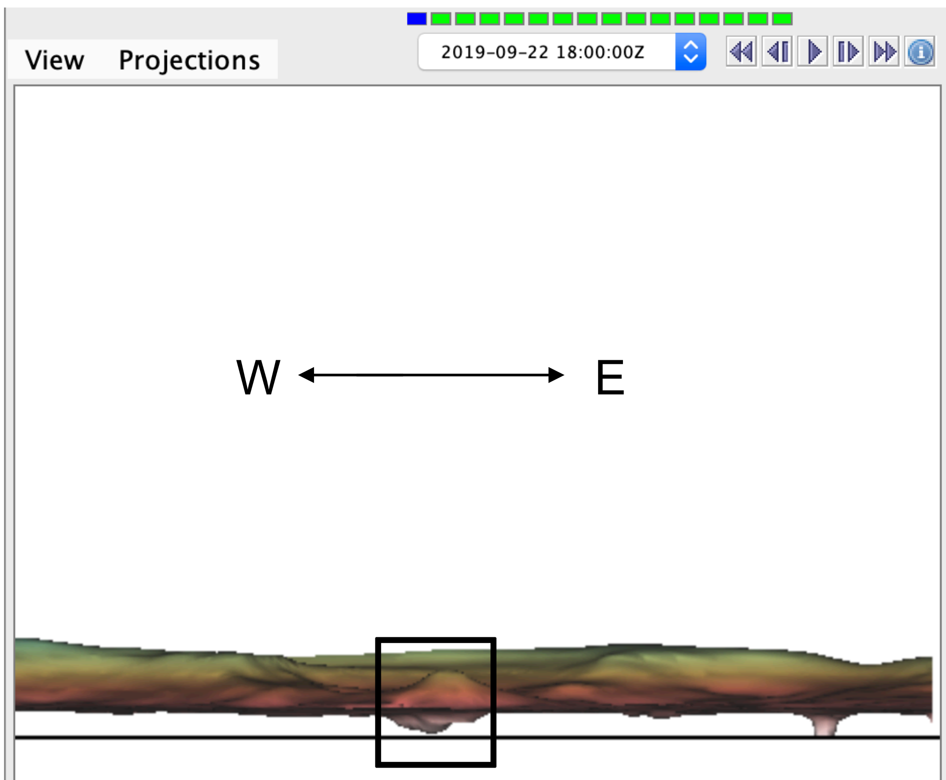


- Is there a mean north-south slope?
- The slope profile shows a positive slope going northward.
- There is a drastic raise in the 310K isosurface slope as you move from south to north as you can see depicted in both images to the left

A depression in the 310K surface

Where? Describe the situation

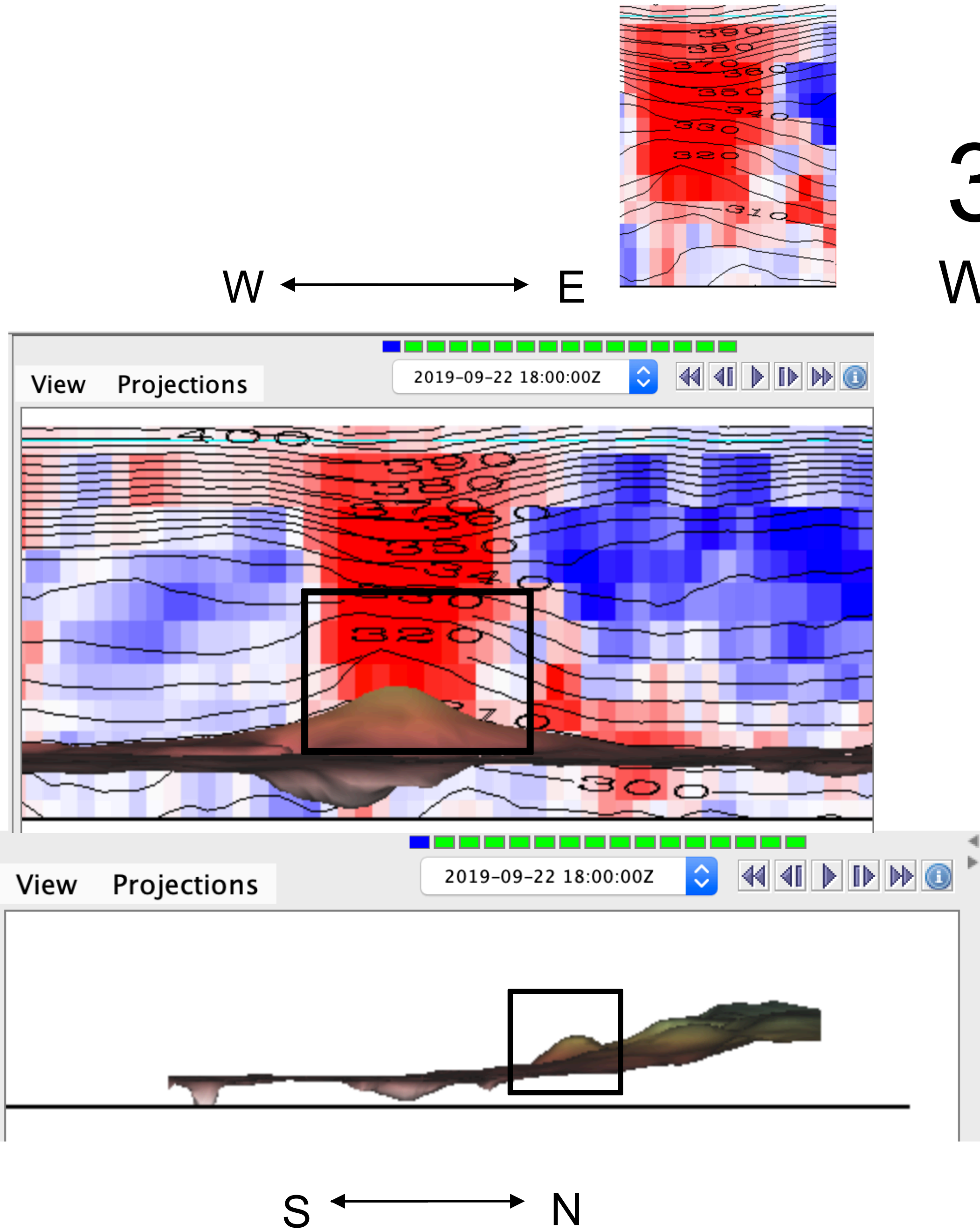




- What vorticity features (Part I) explain dimples?
- This profile was taken at 18Z on 9/22
- The location of interest: southeast of a low pressure system in northern Mexico
- The top image shows the profile of the relative vorticity and you can see that there is a bowed down cold feature.
- This can be recognized as a cold core low. Coldest air at the center throughout the troposphere.

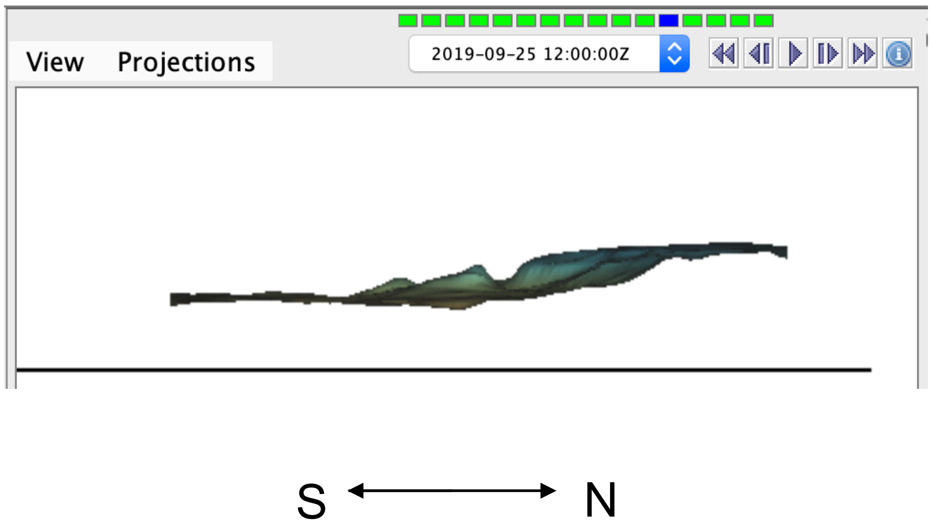
A peak on the 310K isosurface

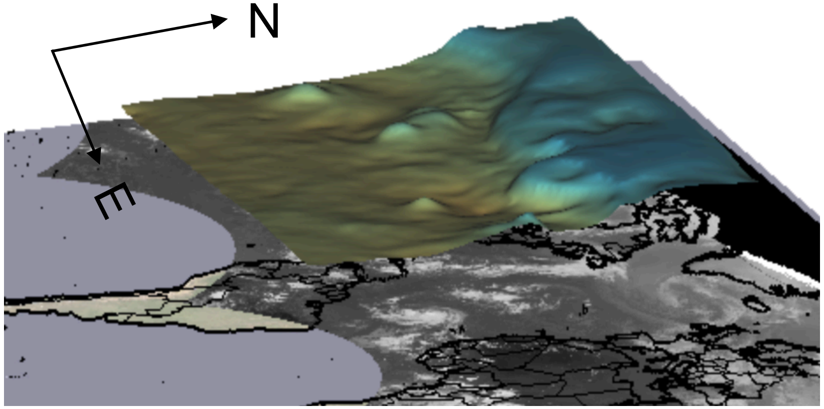
Where? Describe the situation



- What vorticity features (Part I) explain peaks?
- Air behind a frontal system. System is pushing east through the US with the peak on the 310K isosurface being in Canada.
- This is a good representation of a warm upper-level low and warm lower level high
- The theta contours are tightly bowed up/down in the area of interest.

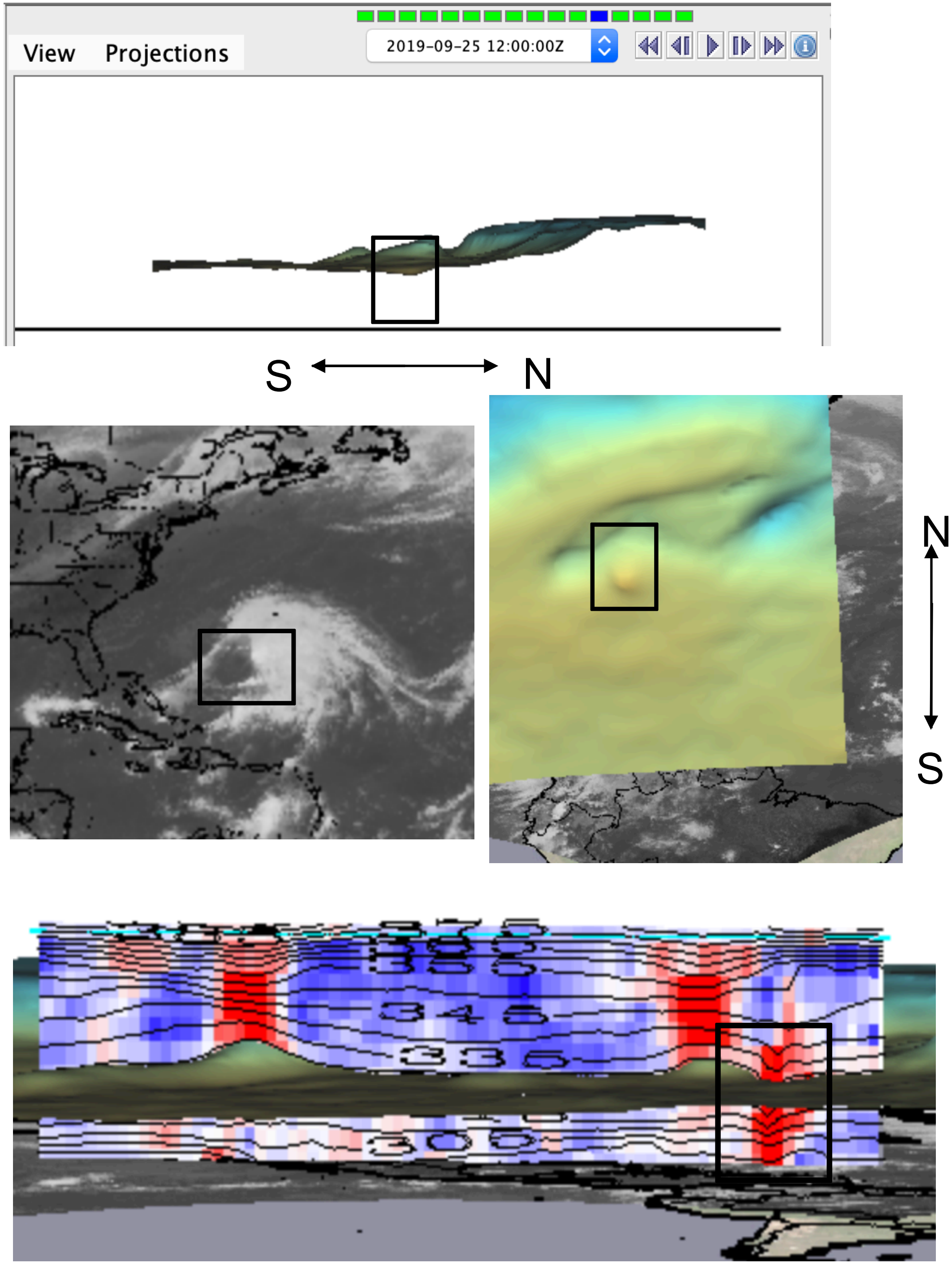
Mean slope of the 330K isosurface





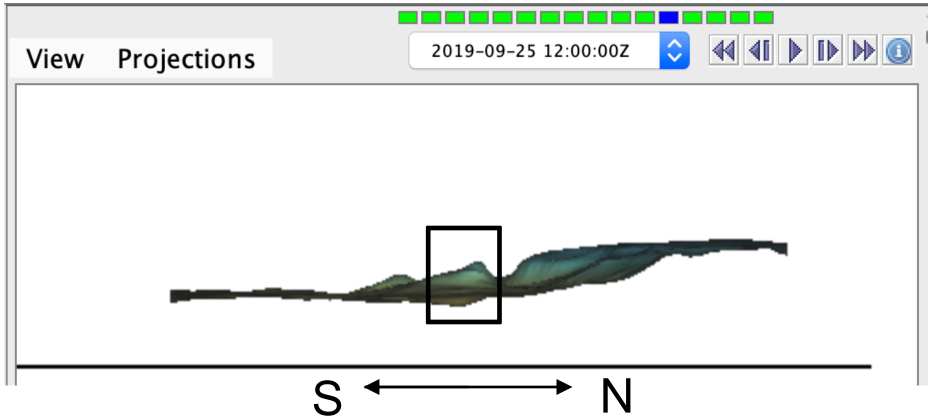
- Is there a mean north-south slope?
- The slope profile shows a positive slope going northward.
- This is not as steep of a slope as the 310K isosurface
- There is a raise in the 330K isosurface slope as you move from south to north as you can see depicted in both images to the left

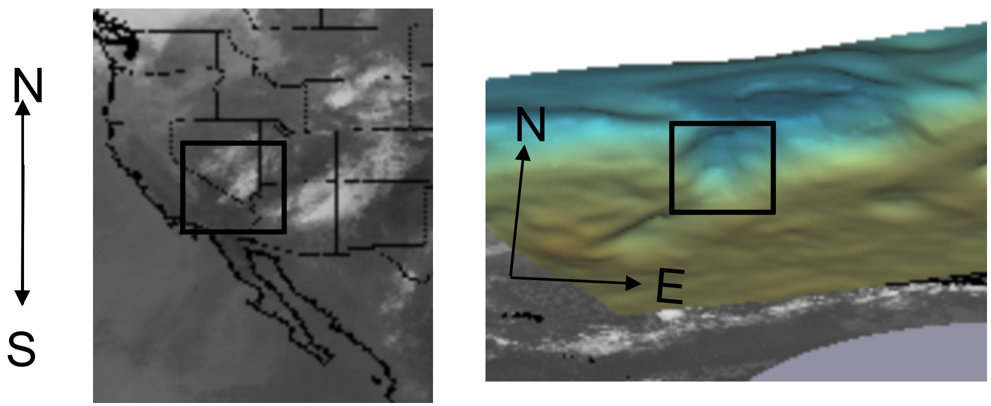
A depression in the 330K surface

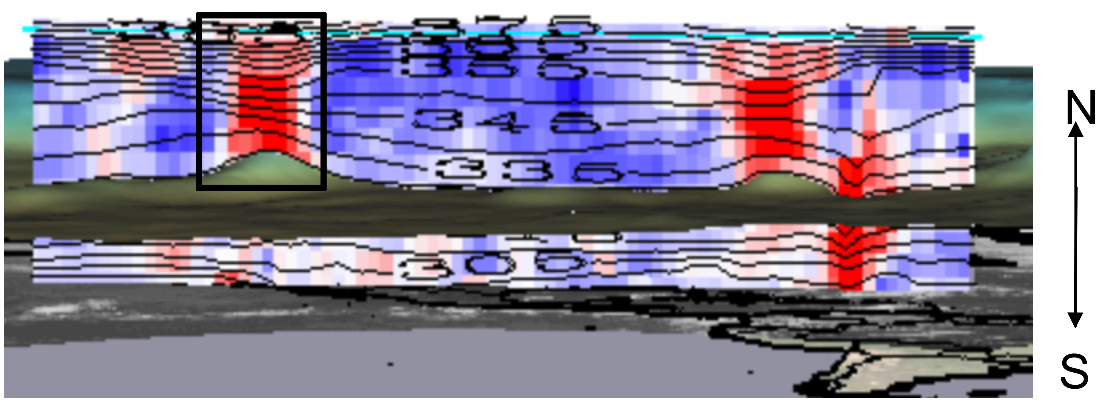


- What vorticity features (Part I) explain dimples?
- The dimple shows there is a warm core cyclone occurring in the region I've boxed.
- This region is located over the Atlantic Basin. There is a tropical disturbance that is allowing for this feature to be seen.
- There is counterclockwise wind movement allowing us to understand it is a low pressure system.
- It's interesting to see that it's not a completely stacked warm core cyclone and tapers off around the 345K surface

A peak on the 330K isosurface

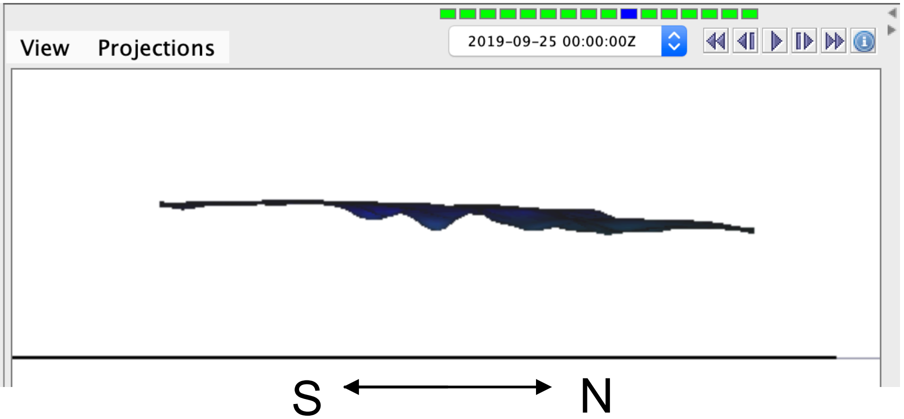




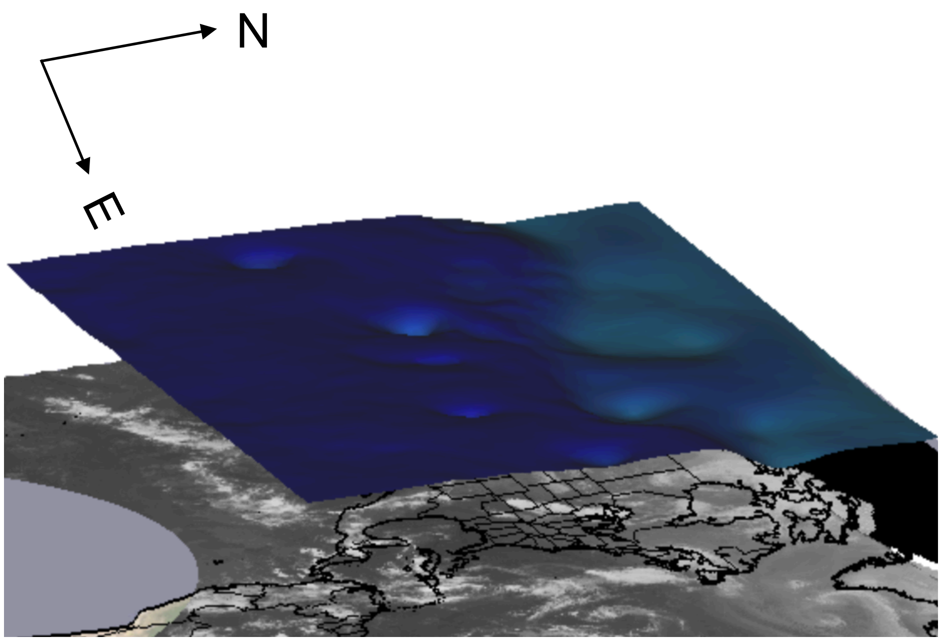


- What vorticity features (Part I) explain peaks?
- There is a strong warm core anticyclone occurring at the in the region I’ve boxed.
- This region is located over southern Nevada where there seems to be a disturbance
- There is subsiding vertical motion in the troposphere.
- Radiative heating/vertical mixing in the boundary layer do not allow for the warm core anticyclone to stretch down to the surface

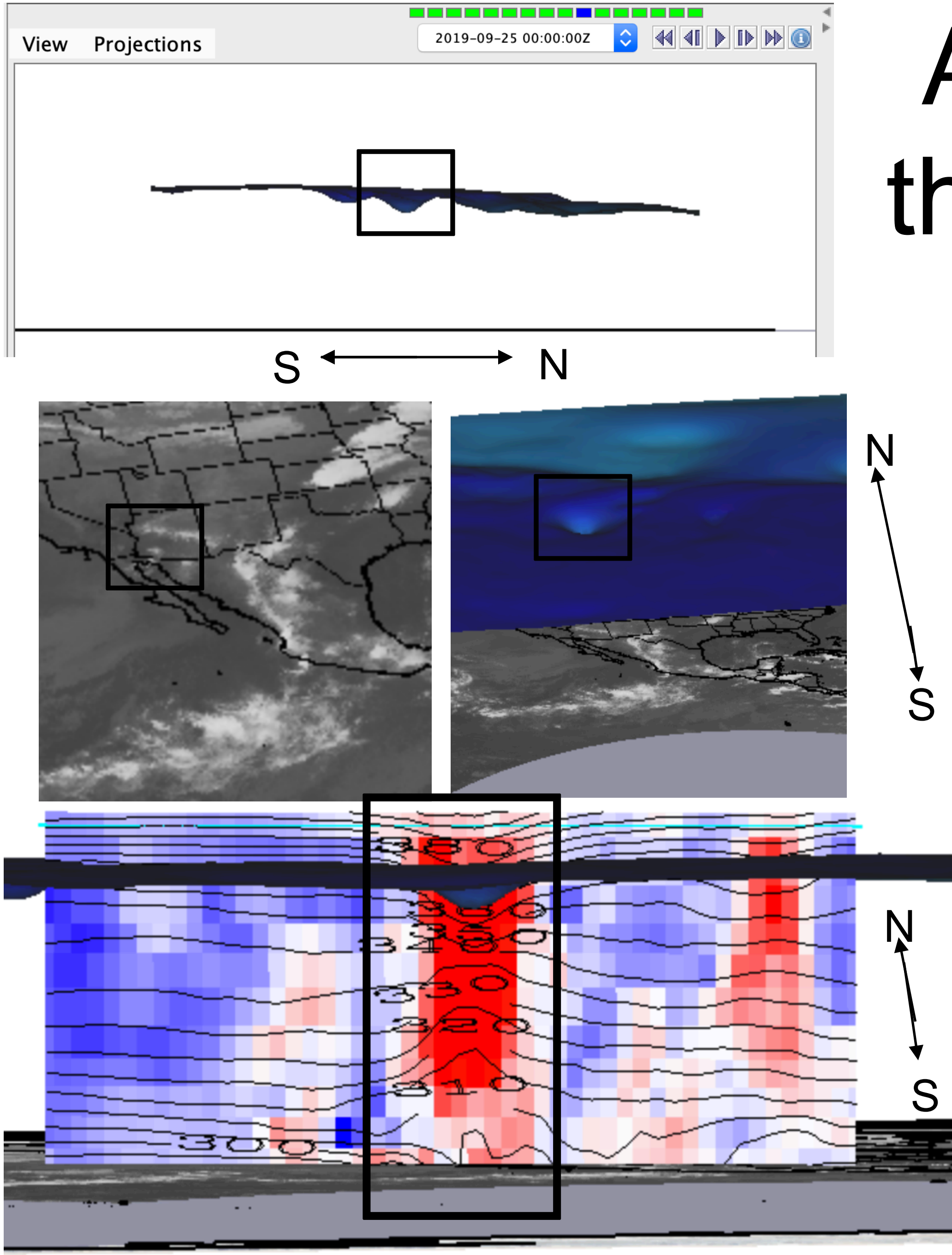
Mean slope of the 360K isosurface



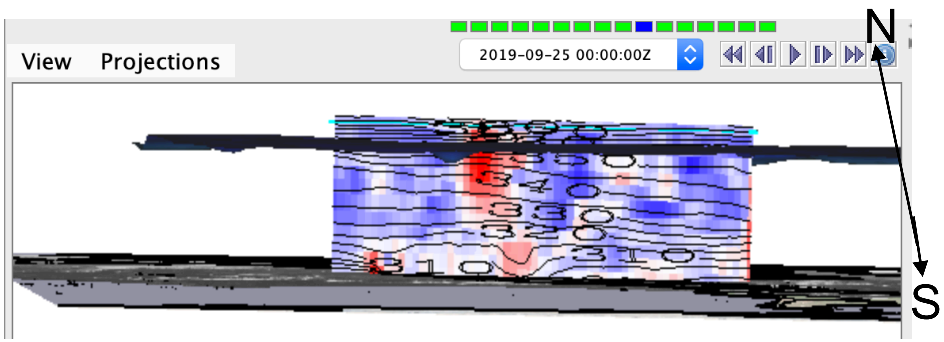
- Is there a mean north-south slope?
- The slope is relatively nonexistent. There is a slight downward slope as you go northward.

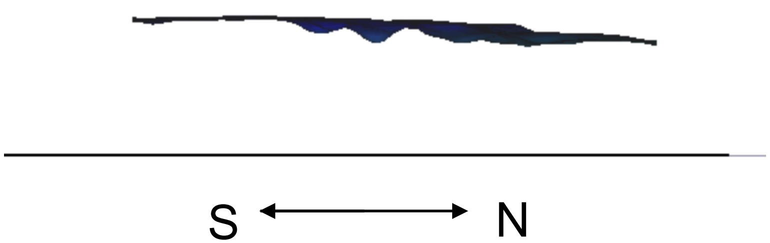


A depression in the 360K surface



- What vorticity features (Part I) explain dimples?
- Over northern Baja California and Northern Mexico there is a dramatic depression in the 360K surface.
- The vertical profile of the relative vorticity shows that there is a warm core anticyclone stacked up on top of a warm core cyclone.
- The warm core component is quite significant.





A peak on the 360K isosurface

- What vorticity features (Part I) explain peaks?

- There weren't any pronounced peaks at the 360K isosurface.
- The images included to the left are the profiles from the 360K isosurface that show a virtual plateau with no significant peaks.

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