PV is conserved is our strongest statement to explain weather

But then where does PV come from?

ATM 405/561

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Outline

- Read this brief review of our journey from not-at-all-conserved *momentum*, to sorta-conserved *relative vorticity*, to more-conserved *absolute* vorticity, to most-conserved *potential* vorticity.
  - https://www.notion.so/miamimapes/Horizontal-vorticity-and-PV-as-explanations-for-cyclones-anticyclones-2e6d2c075dba44699dc822ca5748e2e8

Questions about it: write answers

- 1. Using the concepts from the reading, and earlier homework, explain how patches or elements of **relative vorticity** advect other patches of **relative vorticity**, under the assumption that **relative vorticity** is sorta almost conserved.
  – Patches of relative vorticity advect other patches of relative vorticity due to the convergence term that is brought into the equation, also advection occurs along a constant potential temperature field.
- 2. Using the concepts from the reading, and earlier homework, explain how **planetary vorticity** is converted to **relative vorticity,** so that their sum, the **absolute vorticity,** is almost conserved. Consider a loop of air moving in latitude, and explain how the different Coriolis force felt by its northern and southern edges acts as a torque on the fluid loop.
  – Planetary vorticity is converted to relative vorticity via the Coriolis effect on relative vorticity, where planetary vorticity is simply the Coriolis parameter f. For the loop of moving air, the northern end would experience strong Coriolis and increase the velocity and torque felt on the northern end, whereas the southern end would have less Coriolis, less torque, and a slower velocity.
- 3. Using the concepts from the reading, and the reading, explain how **static stability** is converted to **absolute vorticity,** so that **potential vorticity,** their **product,** arguably the truest essence of vortices (cyclones and anticyclones) is really really almost conserved.
  – Static stability (aka hydrostatic stability) uses gravitational forces to balance the vertical motion, and when scaled over an area of dp (height coordinate p), potential temperature surfaces can be used to conserve PV.
- 4. Based on the end of the reading, what you will look for in vertically resolved data about diabatic heating rate in the atmosphere to explain the ultimate source of PV?
  – PV tendency is positive where heating rate increases with height.

PV is conserved -- almost

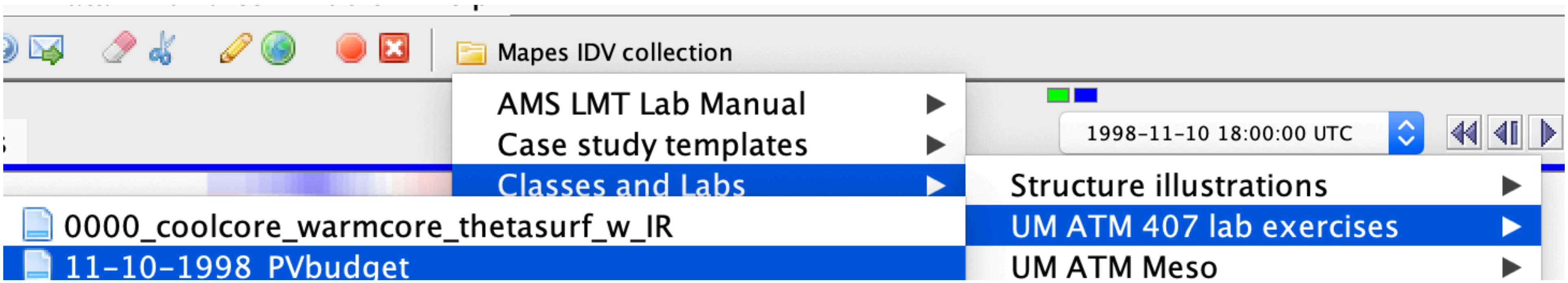
APPROXIMATE term that generates PV on the Earth

$$\frac{D}{Dt}(PV) = 0 \boxed{- g\zeta_a \frac{\partial \dot{T}_{diab}}{\partial p}}$$

Mostly, you are looking for WHERE THE DIABATIC OR PHYSICAL HEATING RATE INCREASES OR DECREASES WITH HEIGHT, weighted by (f+ζ). In both hemispheres… so be careful with ”cyclonic”.

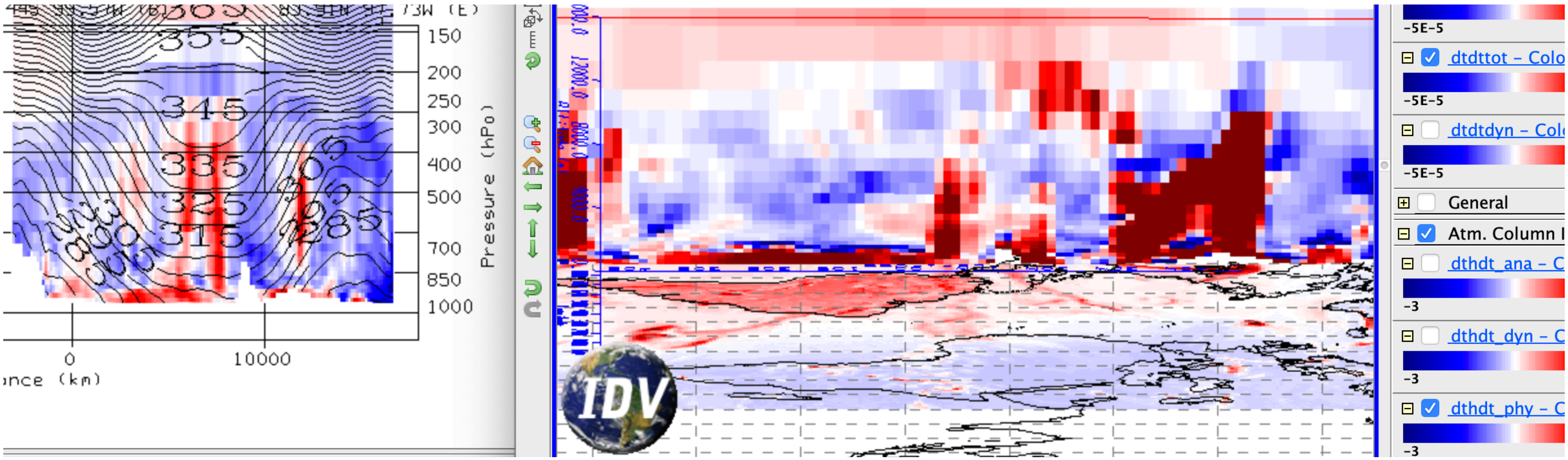
Assignment part 1: global view

- Open the bundle 11-10-98 PV budget



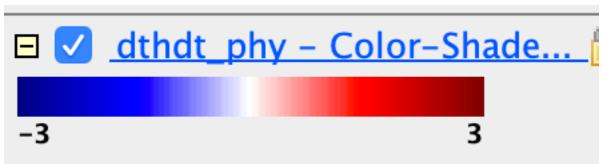
- Orient yourself to its displays, in **both windows**
  – a **pole-to-pole transect** of the **zonal mean** heating rates (averaged around the whole Earth)
  – A map view with many displays (including **movable cross sections**).

transect of *zonal mean* diab. heating, cross section of total diab. heating, map of column integral diab. heating



Assignment part 1: global view

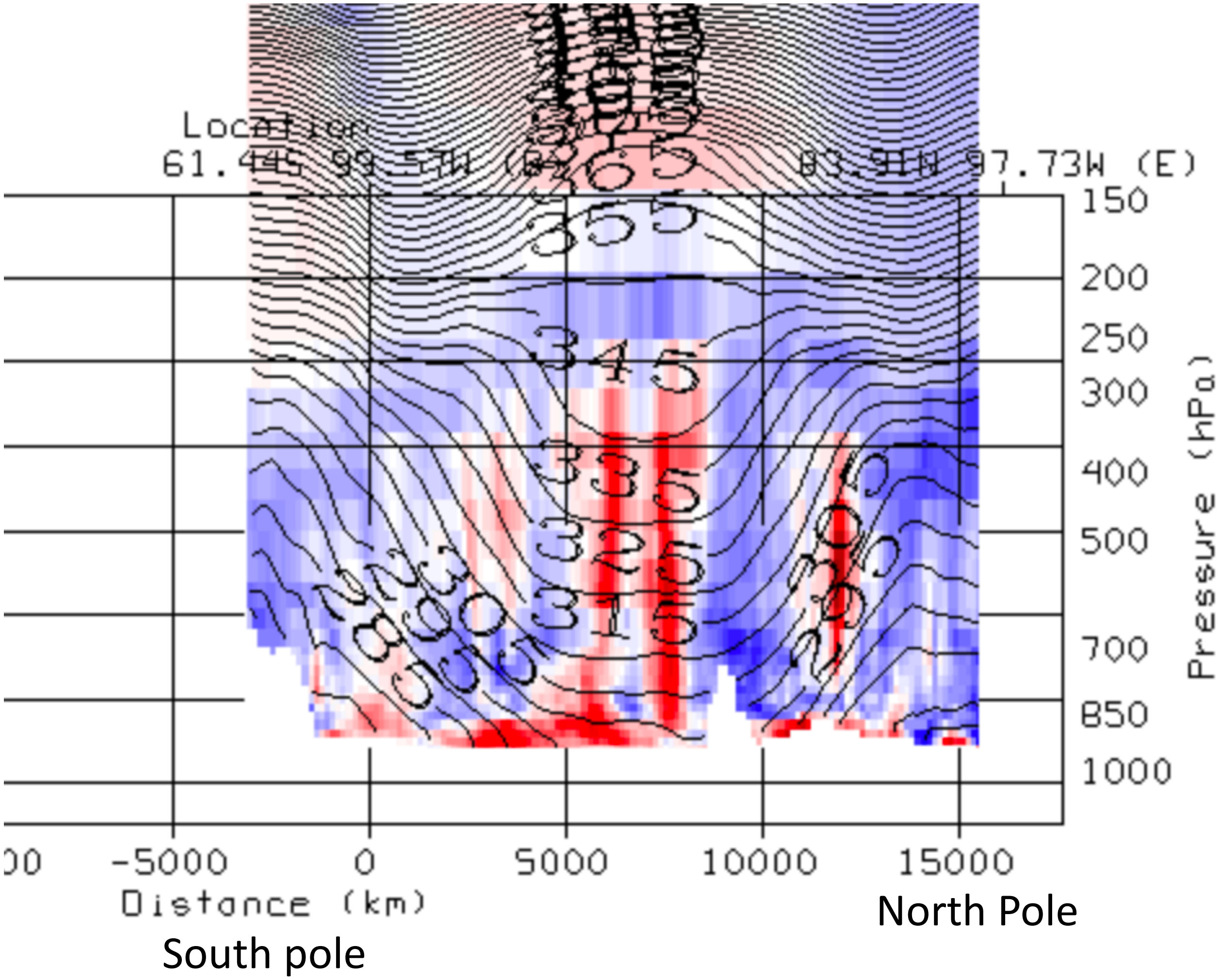
1. What time of year is it? How can you see that in the column-integrated heating rate map dthdt_phy, or other radiative heating rates?



Time of year is wintertime, specifically November. In dthdt_phy, you can see that the northern hemisphere is colder than the southern, meaning it is winter in the northern and summer in the southern.

Assignment part 1: global view

- Now turn to the Transect View window, showing average cross sections all around the Earth. Create a slide showing the transect of total diabatic heating. Label it: where is the south pole, the north pole? Hint: Antarctica is mountainous.
- The units of all heating rates are are K/s. What is the color range in K/day?



Color range is -5e-5 → 5e-5 K/S

Assignment part 1: global view

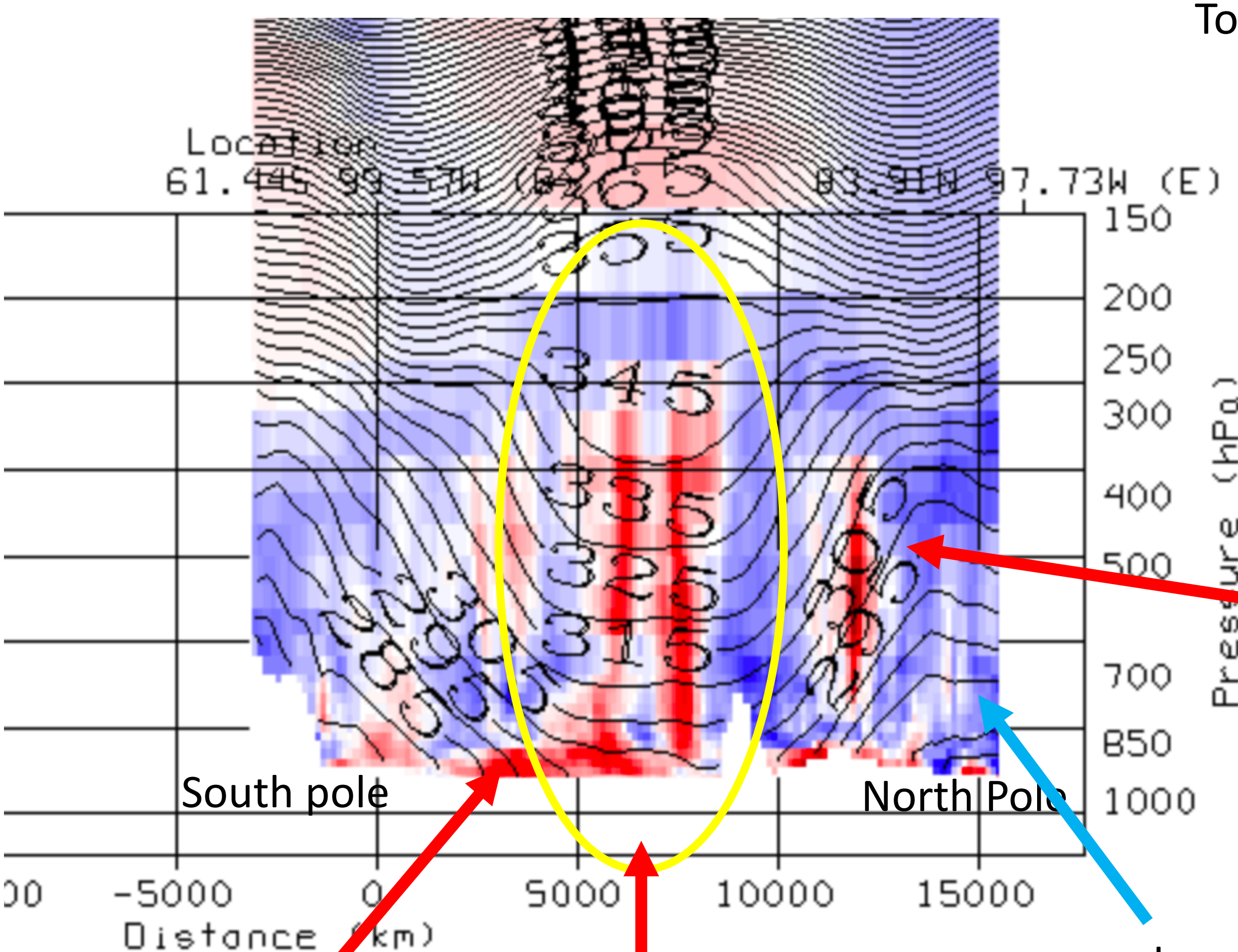
- Create slides with transect images showing individual terms of the zonal mean heat budget.
- Use that imagery to explain the nature of all the main features in your total diabatic heating slide.
  - for instance, slides might have the total heating image repeated in one corner, and individual terms one per slide.
  - Write enough narrative words that a reader can see the sense of your work and
- These equations relate all the terms displayed there:

  $\partial T/\partial t$ = dynamical + diabatic + analysis

  diabatic = moist + radiative + turbulence

  radiative = longwave + solar

Total Diabatic Heating



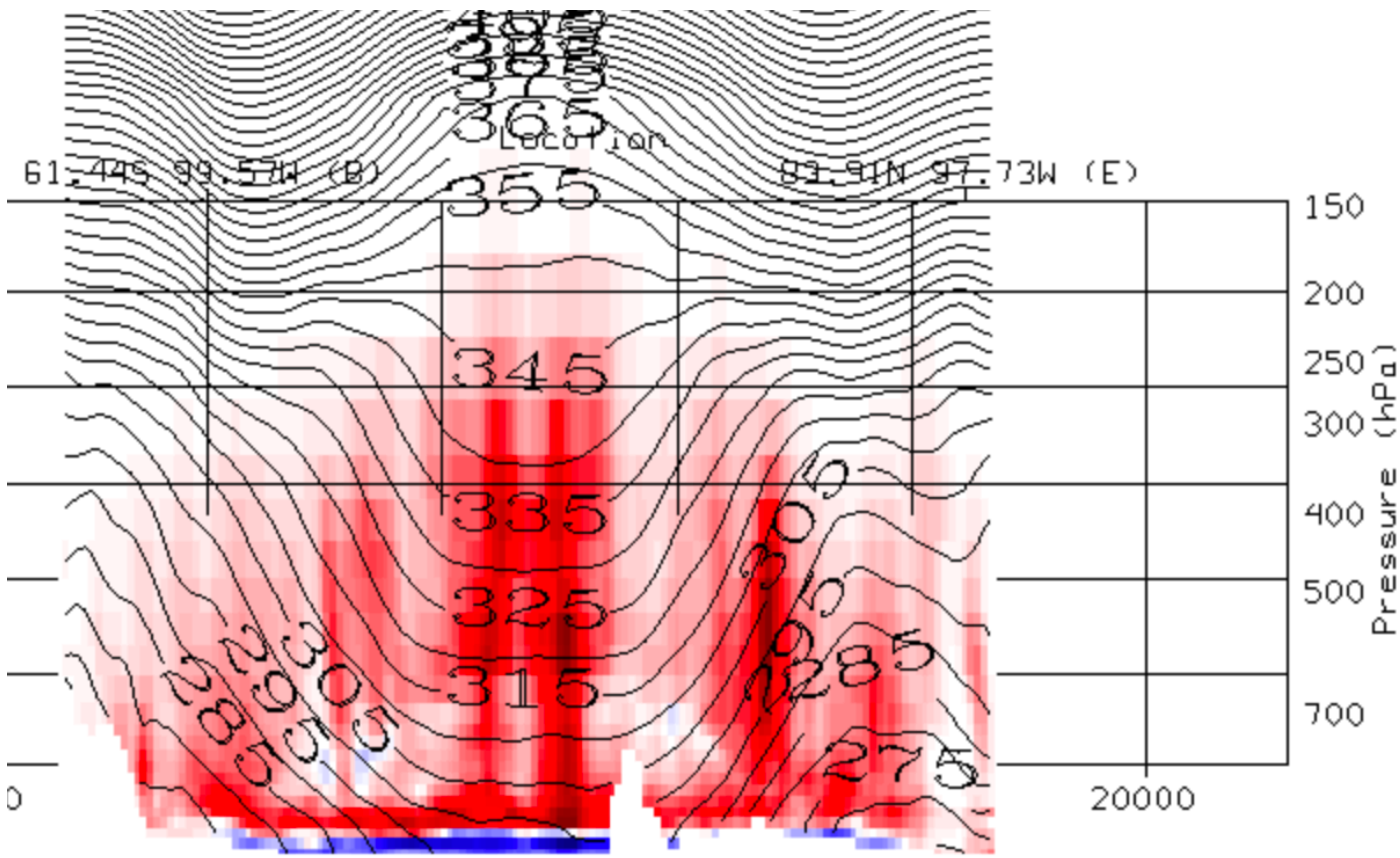
High diabatic heating in upper level due to thermal wind from jet stream

Low diabatic heating in pole due to lack of solar heating during winter season

High diabatic heating due to summer season in S. Hemisphere

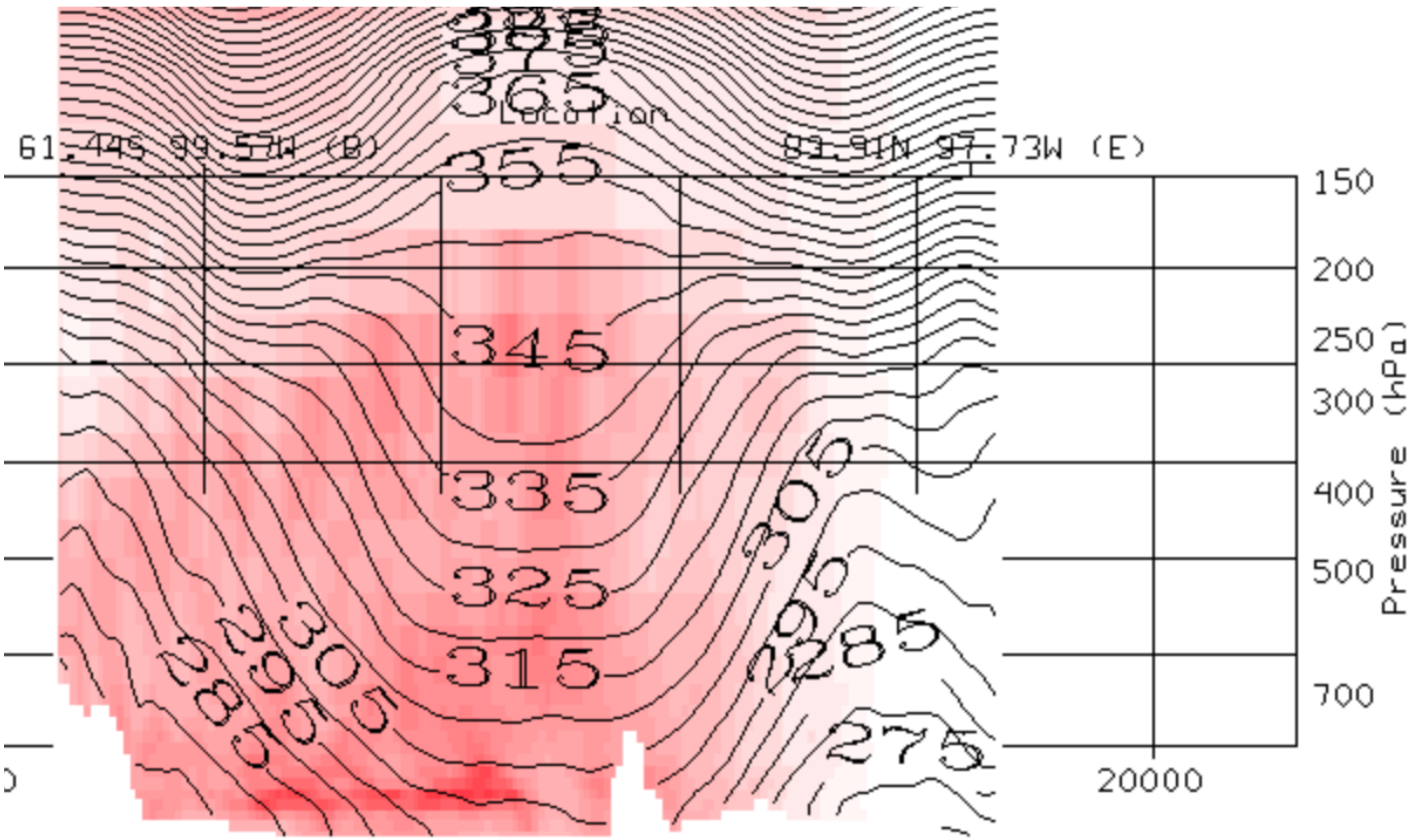
High diabatic heating rate at the equator due to high insolation

Moist heating



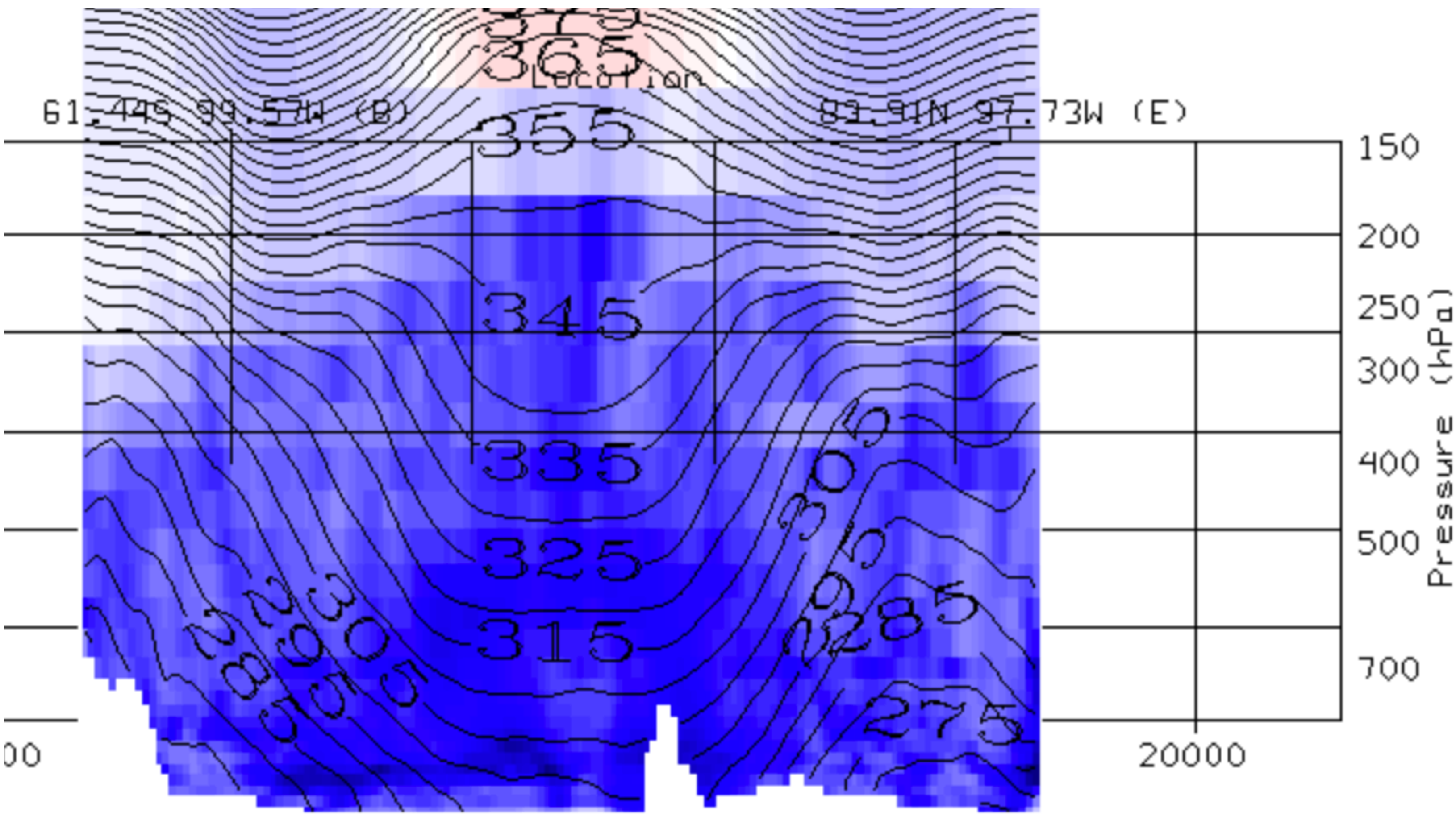
Moist heating highest in areas of surface convergence, where air is being brought aloft, i.e. ITCZ

Solar Heating



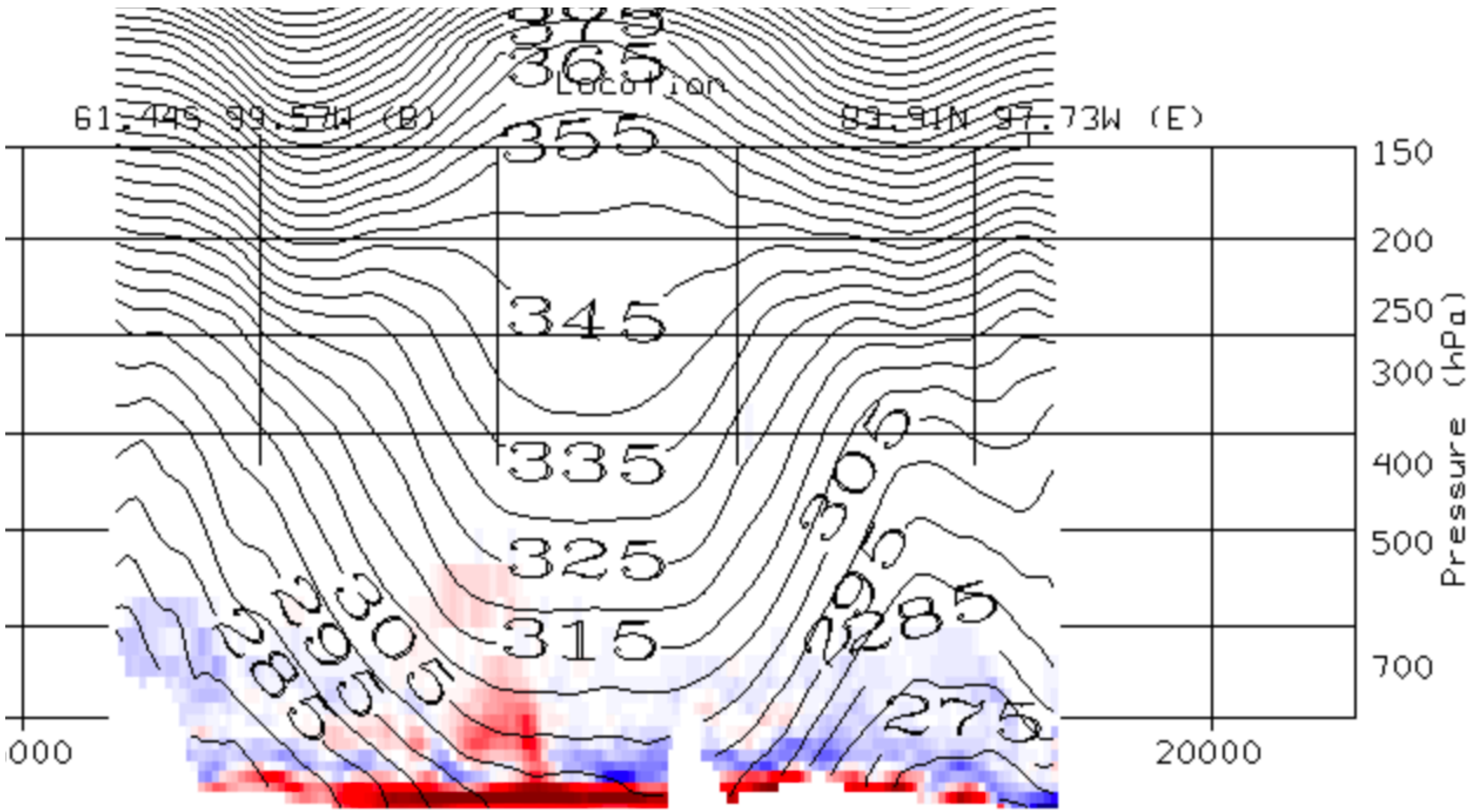
Solar heating highest in S. Hemisphere due to summer season

Longwave Heating



Heating shown as more cooling via longwave radiation, since LW beams are going from Earth's surface to space. More cooling in the S. Hemisphere due to the increased incoming radiation from the summer season.

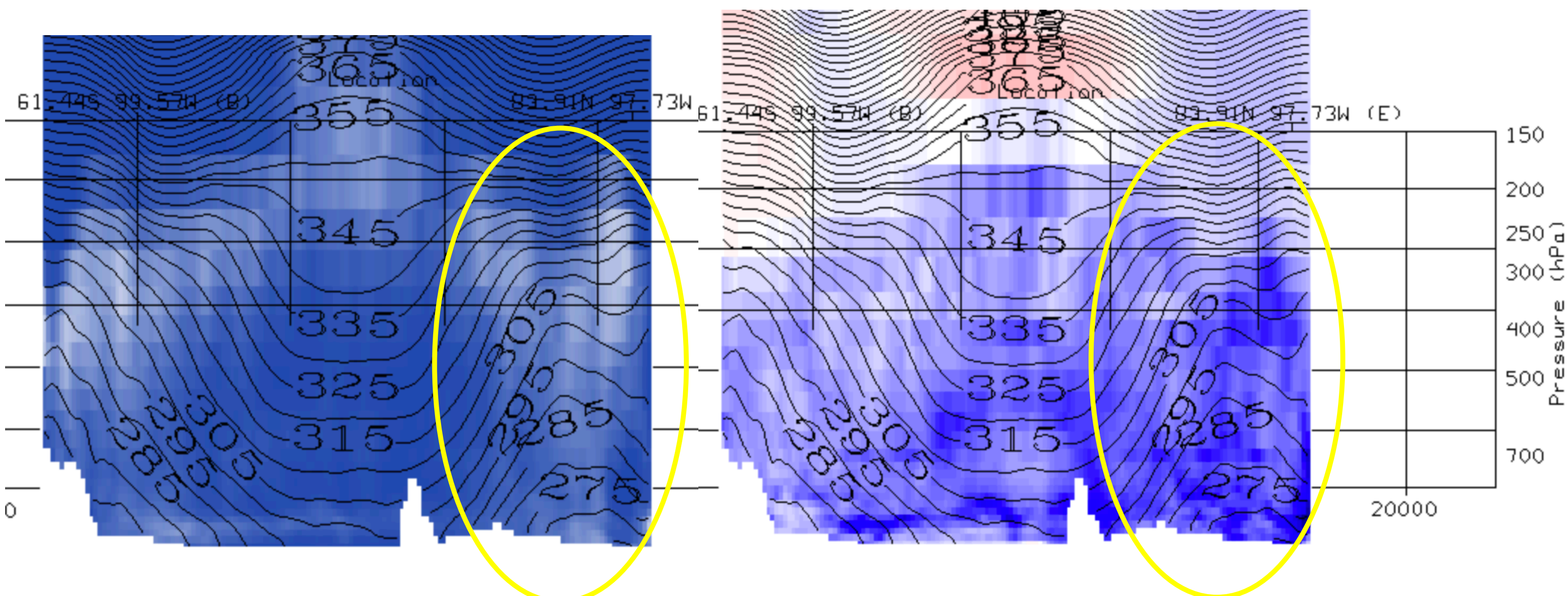
Turbulence



Heating at surface due to ocean-air interactions and heat dissipation. High heating south of equator due to shifting of ITCZ poleward and increased convective turbulence

Assignment part 1: global view

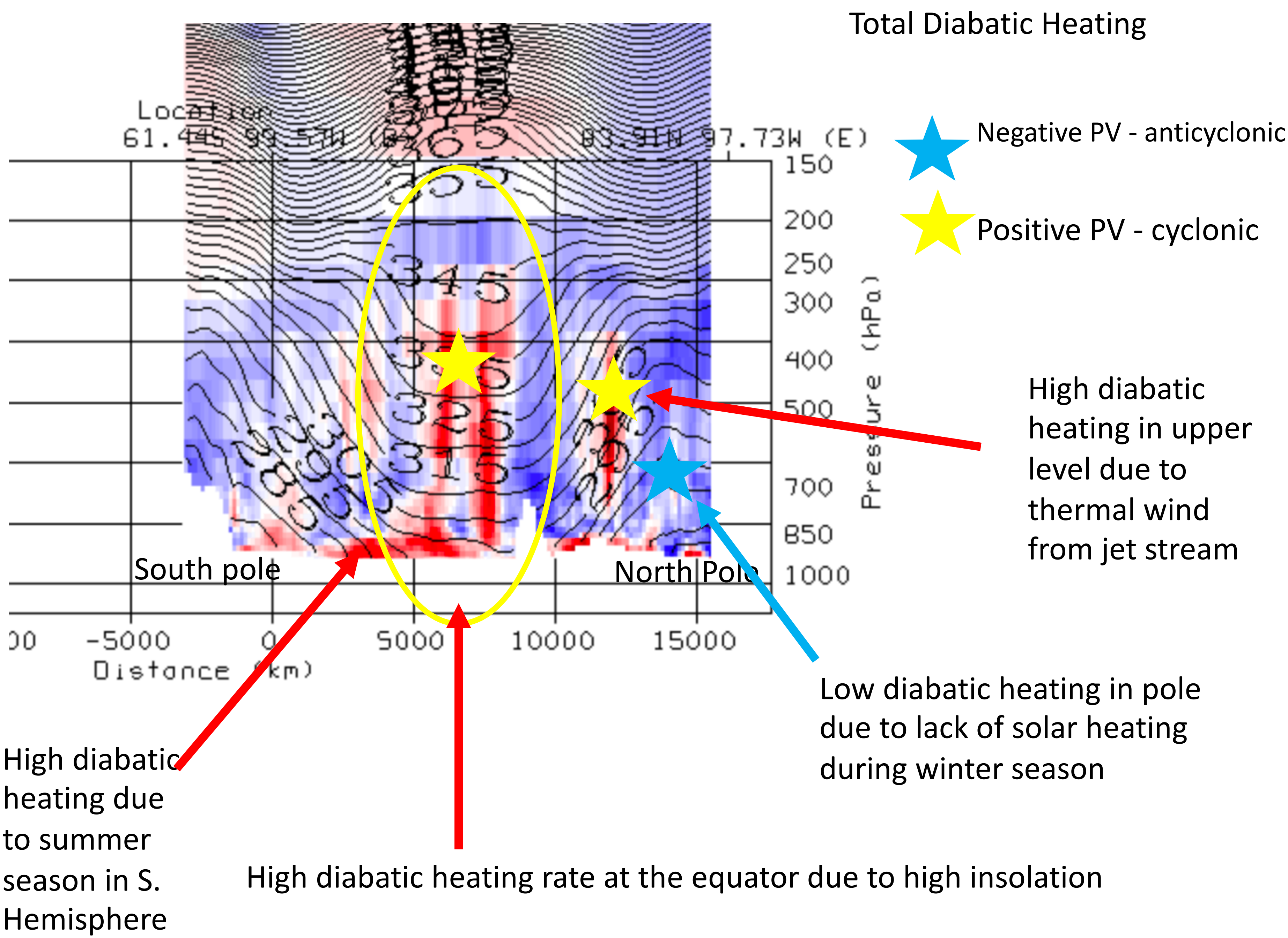
- Radiation and clouds:
  - Toggle the cloud fraction display with the radiative heating rate displays. Can you see any features that clearly indicate how clouds affect radiation?
    - clouds scatter solar photons, which are absorbed by vapor, especially at low levels.
    - clouds cool by emitting longwave from their tops
    - clouds absorb upwelling longwave from the surface at their bases (hard to see in the zonal mean, clearer in individual cross sections in Part 2)

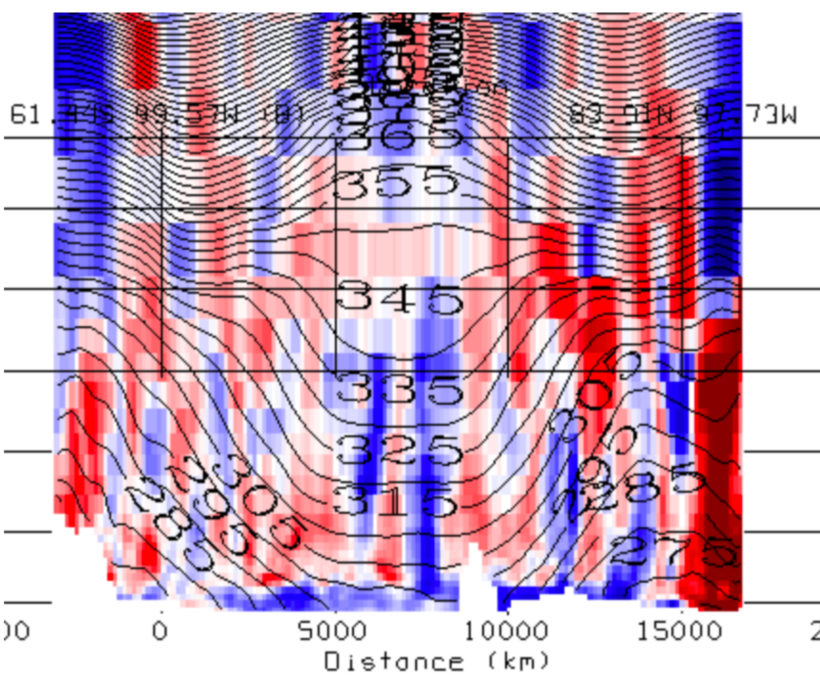


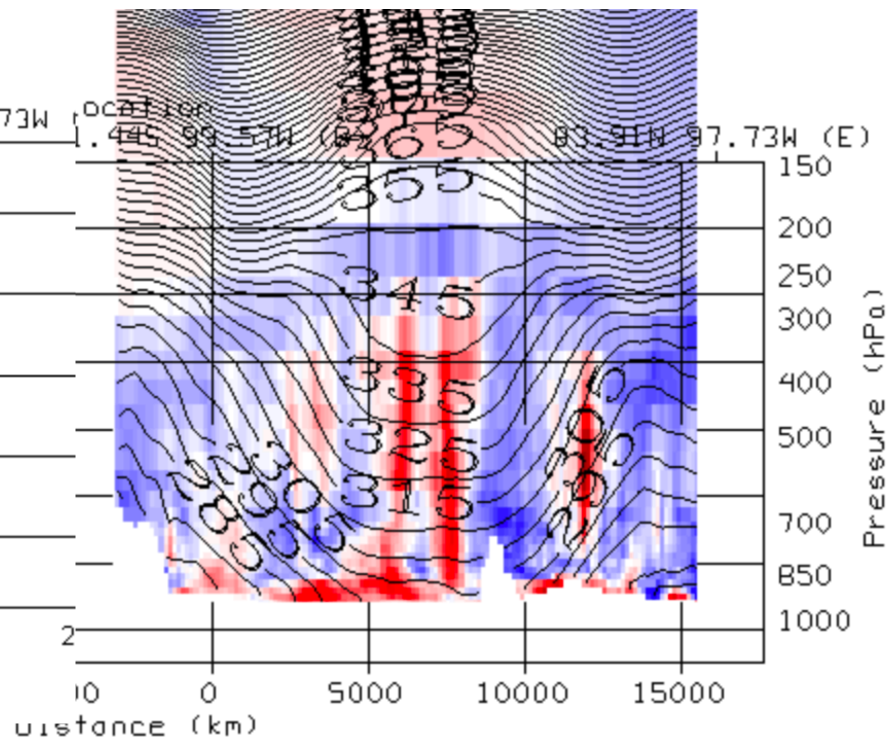
Low radiative heating corresponds with increased cloud fraction

Assignment part 1: global view

- From your total diabatic heating, indicate areas where PV tendency is positive and negative. Also label these areas as cyclonic or anticyclonic tendencies.
- Does the zonal mean PV transect resemble areas where your PV *tendency* is strong? It's not so simple: PV has a long lifetime in the stratosphere, so a large source is not required to explain a large value.
- How does this zonal-mean PV show the imprint of both its vorticity factor and its static stability factor? Label an image to explain your answer.


Total Diabatic Heating
Negative PV - anticyclonic
Positive PV - cyclonic
Location:
97.73W (E)
150
200
250
300
400
500
700
850
1000
Pressure (hPa)
-5000
0
5000
10000
15000
Distance (km)
South pole
North Pole
High diabatic heating in upper level due to thermal wind from jet stream
Low diabatic heating in pole due to lack of solar heating during winter season
High diabatic heating due to summer season in S. Hemisphere
High diabatic heating rate at the equator due to high insolation





Dynamical is opposite of the Diabatic, which is proven true via the equation where PV is:

$$d/dt(PV) \simeq -gf\frac{\partial}{\partial p}\dot{T}_{diabatic}$$

Using both vorticity (f) and static stability (g)

Assignment part 2: Local sections

- Now explore the *cross section displays in the Map View window.*
- You can drag the cross section around to storms or other features. Drag them to north-south positions that slice through tropical and higher latitude weather features that interest you (perhaps guided by other displays).

Legend explanation for cross sections

$\partial T/\partial t$ = dtdt_tot (physics) + dtdt_dyn (advection) + dtdy_ana

(ana is *analysis*; a ”missing” tendency needed to make the tendencies add up to the observed evolution $\frac{\partial T}{\partial t}$; indicative of the sum of all model errors)

diabatic tot = moist (mst) + radiative (rad) + turbulence (trb)

rad = lwr + swr

longwave

shortwave

analysis (0 for perfect model)

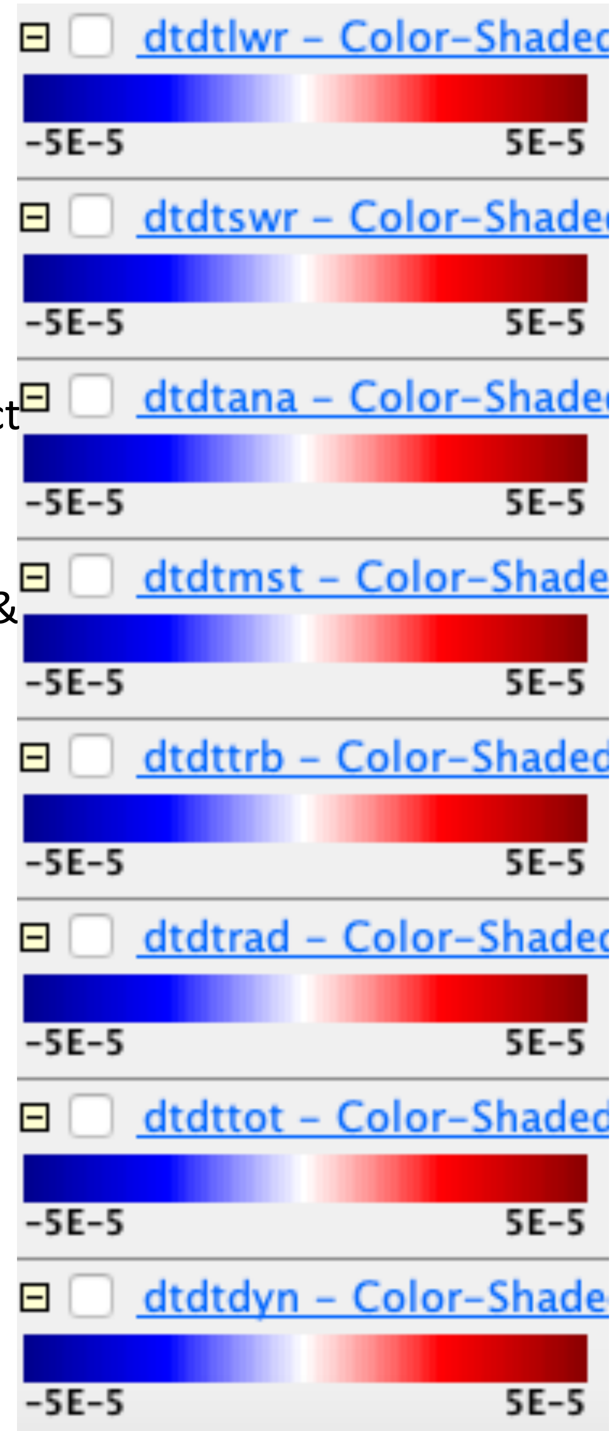
moist mst (convection & cloud cond.)

turbulence (PBL)

SW+LW radiation

total physics (”diabatic”)

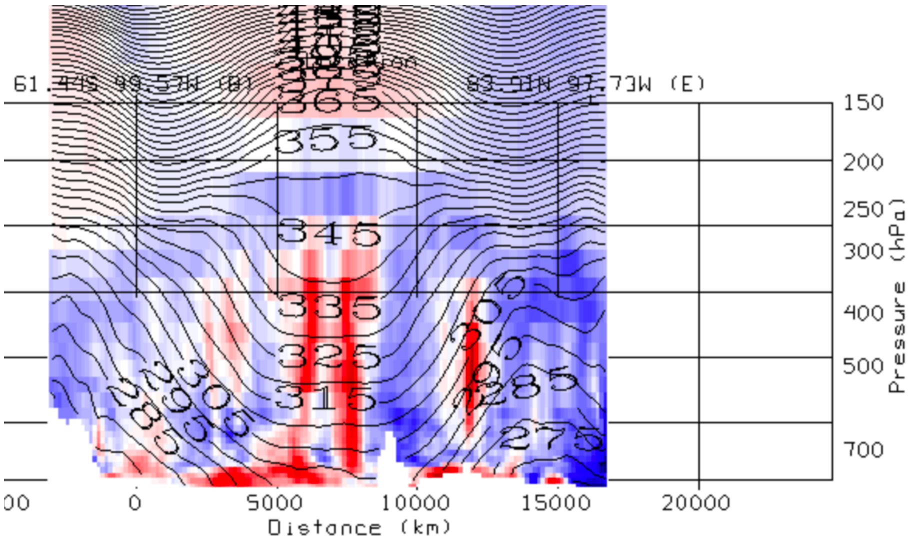
dynamic (advective)

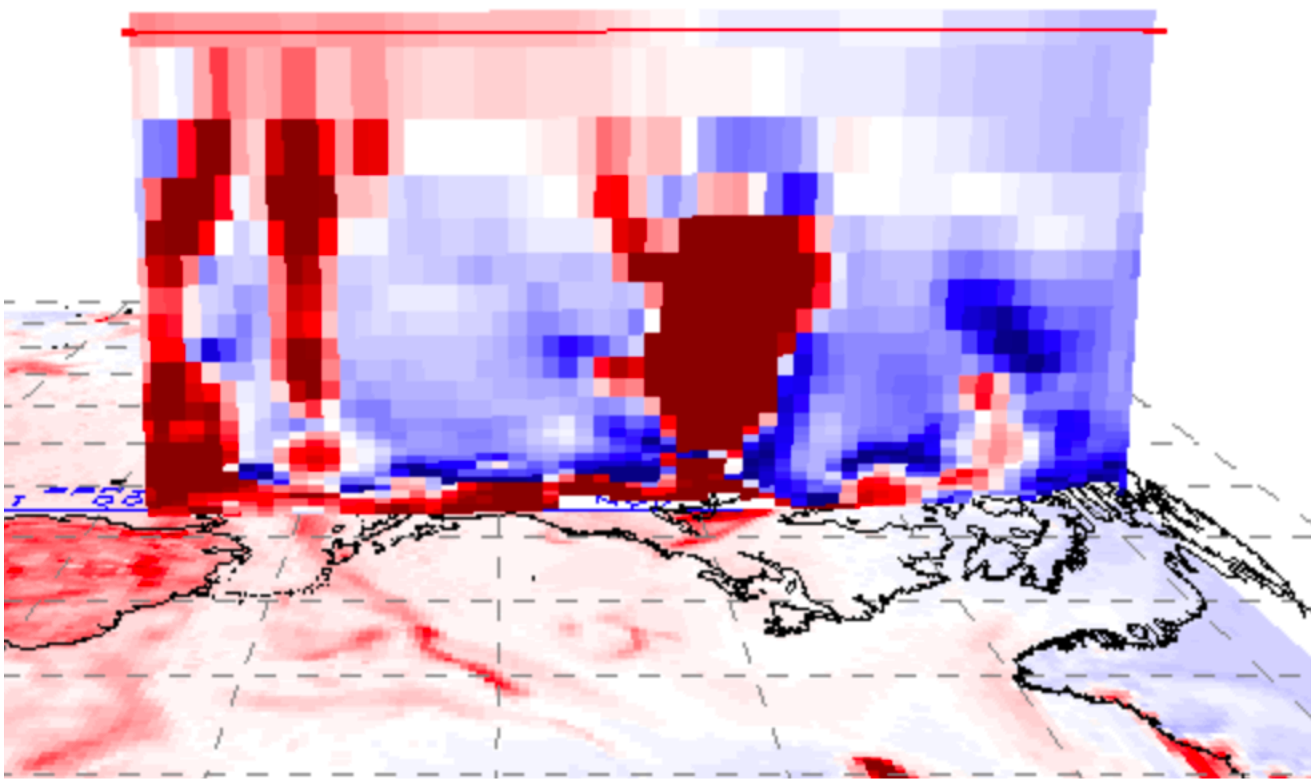


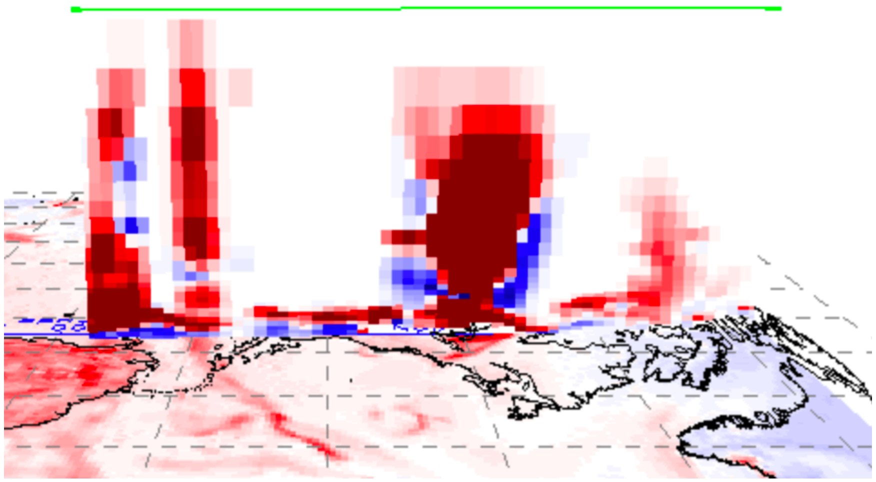
Assignment part 2: Local view

- Make comparison slides juxtaposing the zonal-mean transects and your local cross-sections, like in slide 6 above.
- Toggle the various terms making up the total diabatic heating, in order to explain
  - Which is more variable (more spatially concentrated): radiative or moist heating? Illustrate your answer with images.

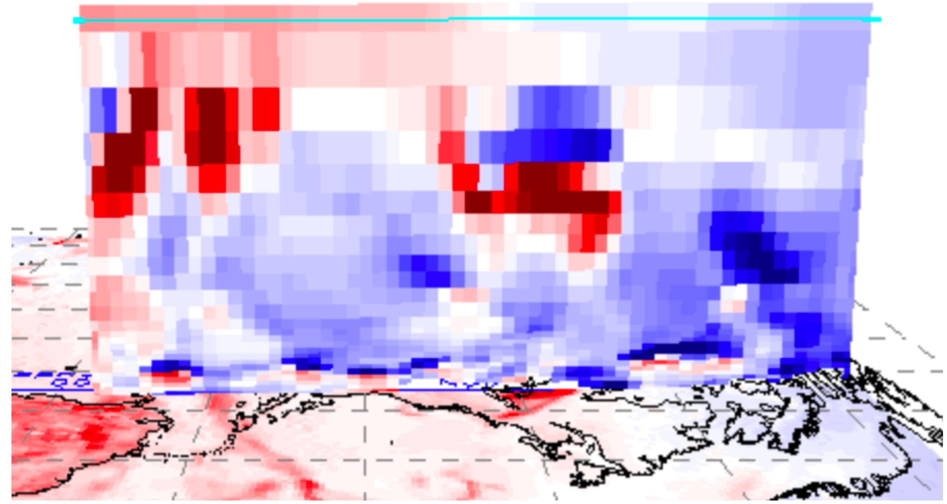
Total Diabatic



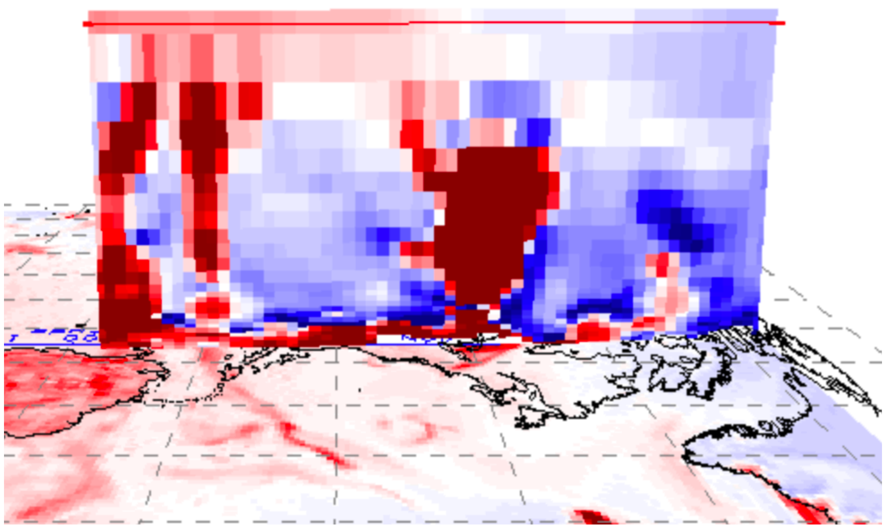




Moisture



Radiative

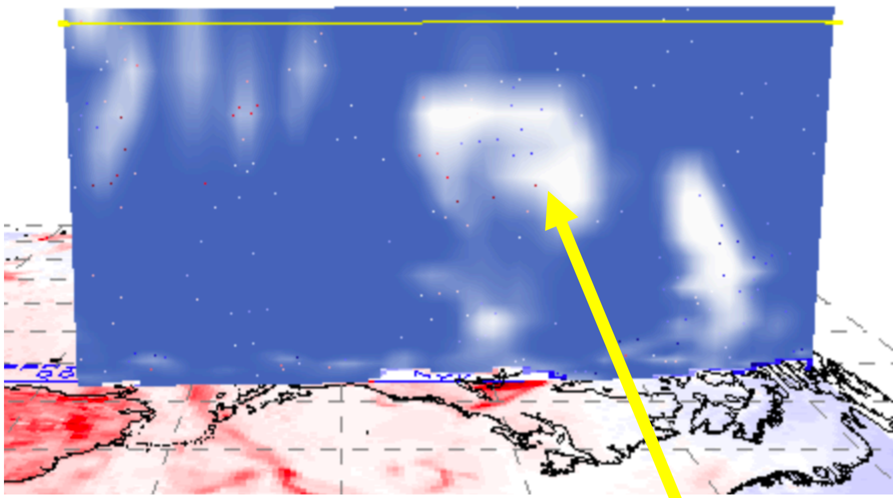


Total

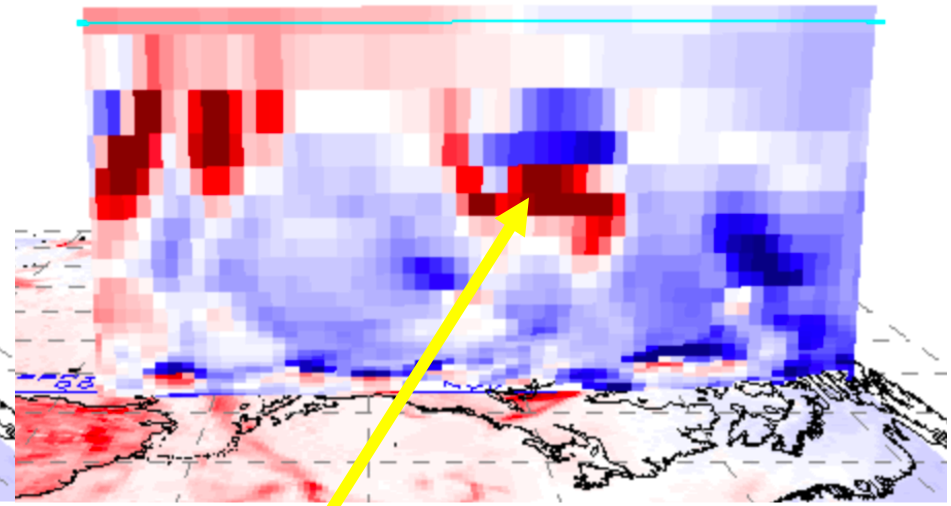
Moisture is definitely the larger component of total heating for this transect. Radiative heating comes into play for higher altitudes, above cloud tops theoretically

Assignment part 2: Local view

- Revisit cloud-radiative interactions
  - LW radiation can be understood as water vapor cooling, cloud top cooling, and cloud base warming. Toggle the layers to find a good example, then juxtapose cloud fraction and radiative heating cross-section images to show an example of a place where cloud effects are dominant



Cloud Fraction



Radiative Heating

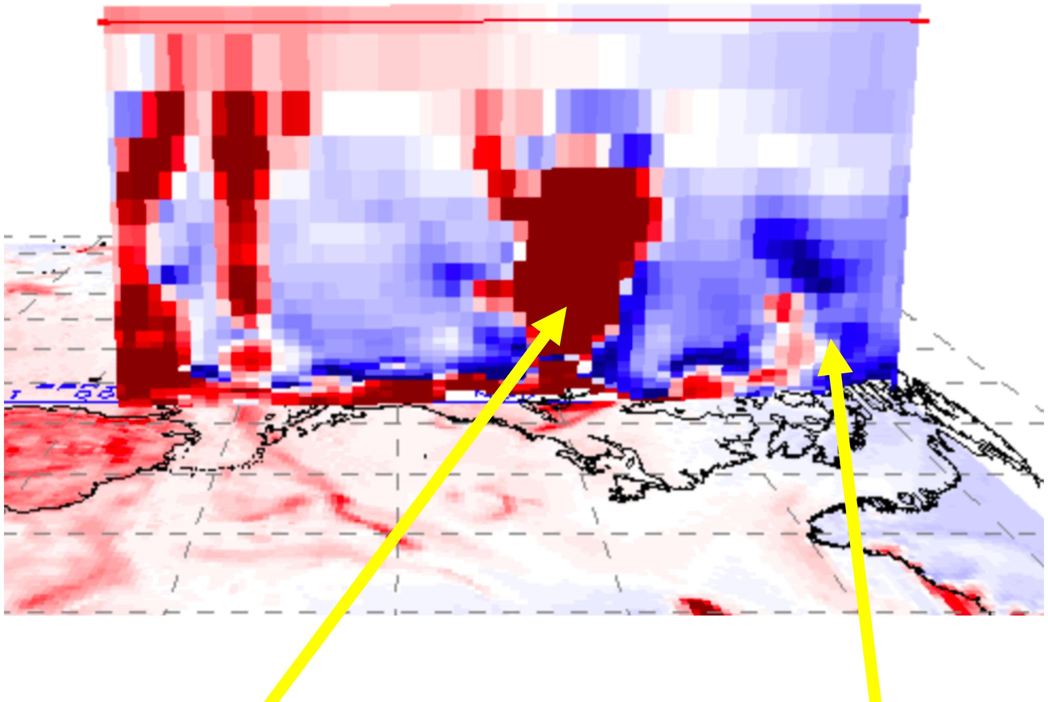
The midlatitude storm is an excellent place for radiative heating, shown in the center of the cross section. Heating occurs within the system, while cooling occurs at the top of the system along the top of the cloud.

Assignment part 2: Local view

- Consider the PV source term motivating this exploration.
  - Where does the vertical gradient of heating imply large PV sources? Use arrows to annotate a couple positive and negative source regions.

  - Can you find a weather situation where this source term is a positive feedback on PV?
    - Supercell development? Anticyclone development? Bringing heat and moisture aloft

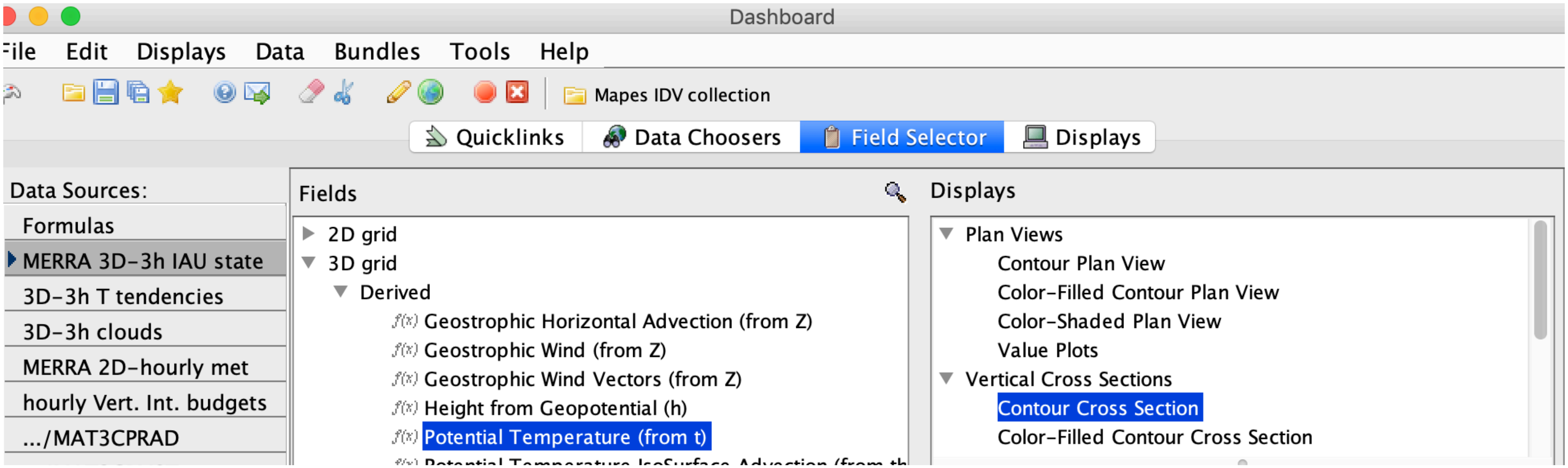
Total Diabatic



Positive PV shown through heating rate increasing with height

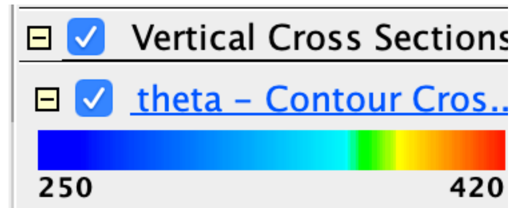
Negative PV shown through heating rate decreasing with height

Create a new cross section of potential temperature contours

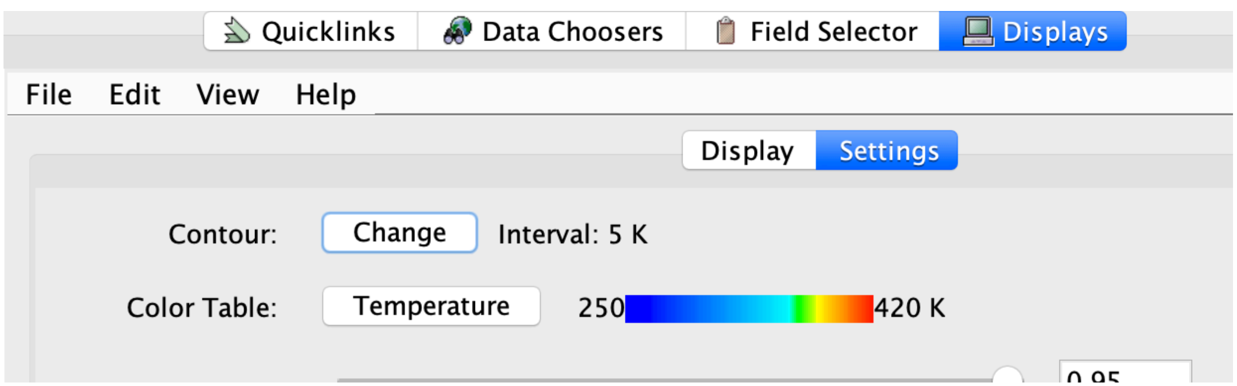


Create a new cross section of potential temperature contours

- Now click its Legend entry to pop up its Display Controls.

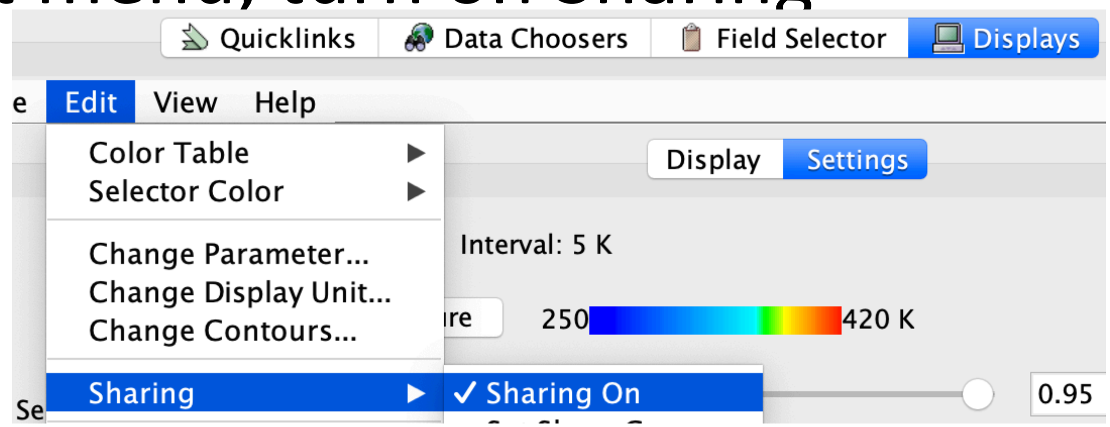


- Change the contour interval to 5K. Change the Color to Black. Change their label size to 20.



Create a new cross section of potential temperature contours

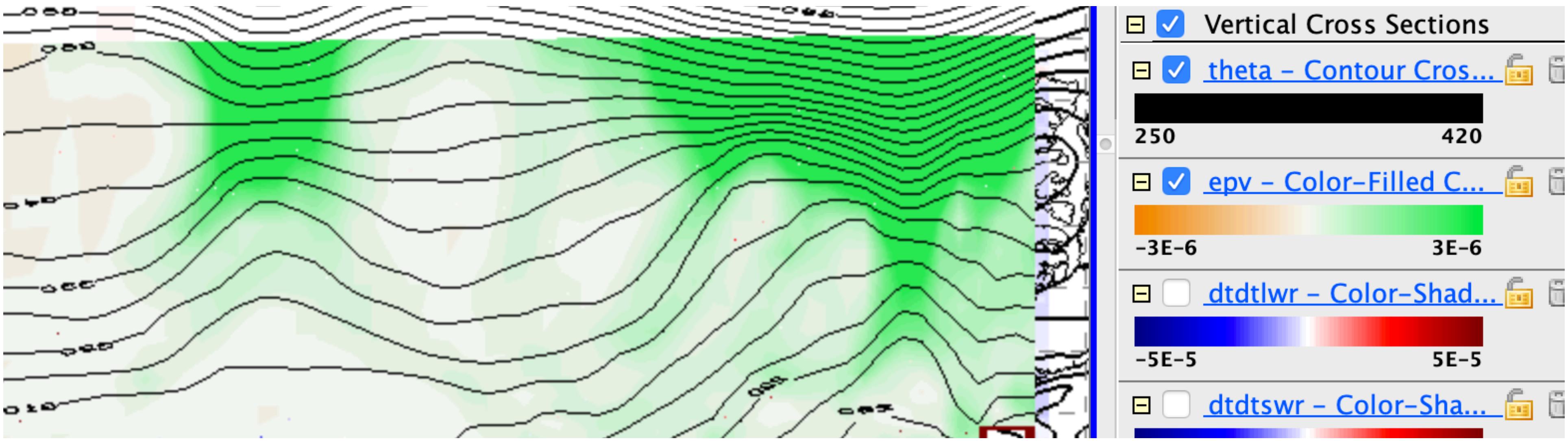
- Again click the Legend entry to pop up the Display Controls.
- Under the Edit menu, turn on Sharing



- Move the main north-south cross section slightly. This will make your new theta contour section snap into place with it.

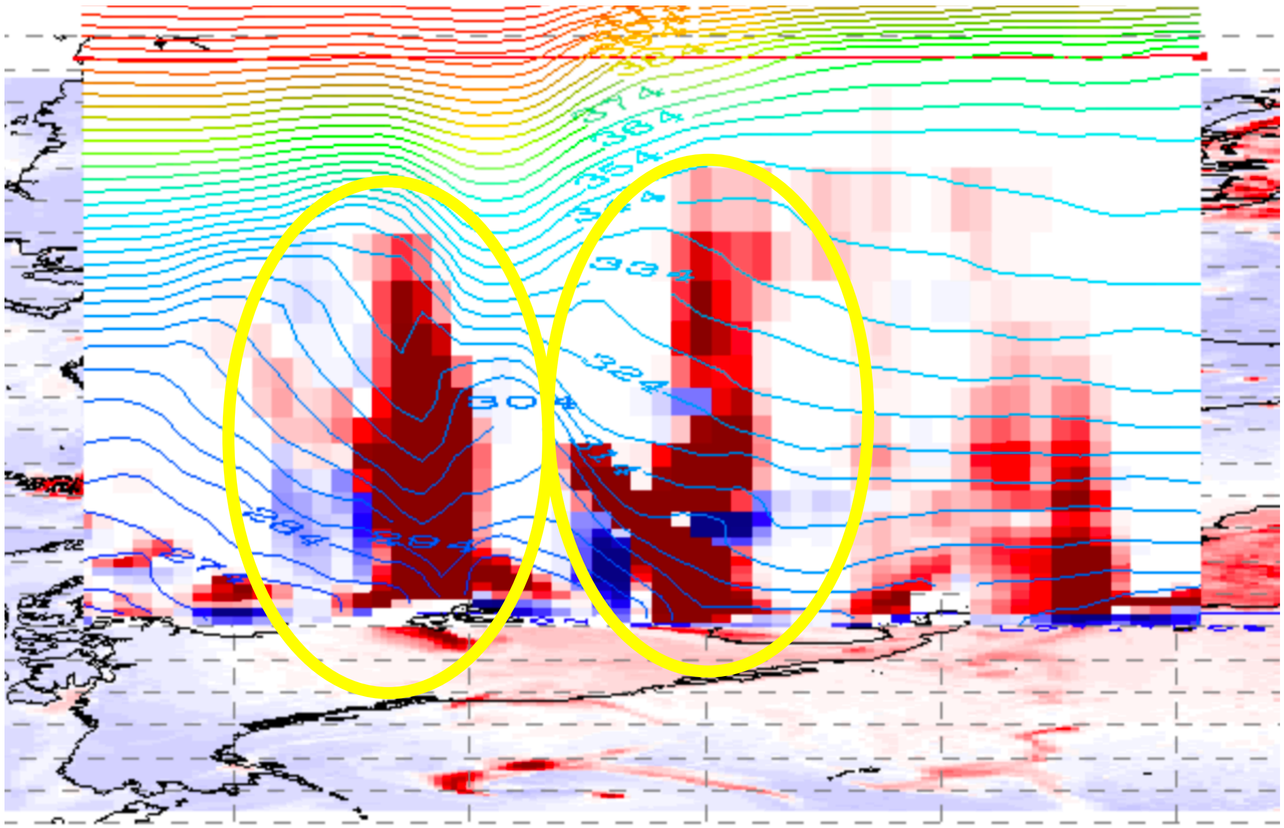
Create a new cross section of potential temperature contours

- You should see our familiar relation between theta surfaces and (most clearly) upper-level cool core cyclones:



Warm and cool cores & condensation heating

- Use the cross section with theta contours and the moist-processes heating rate (dtdtmst) to find an example
  - with the condensation heating in a warm core storm, like the one halfway to Ireland
  - how does the PV source term from latent heating feed back on such a warm core storm?
    - Latent heating energy transferred into condensation, these storms have lots of precipitation associated with them because of this

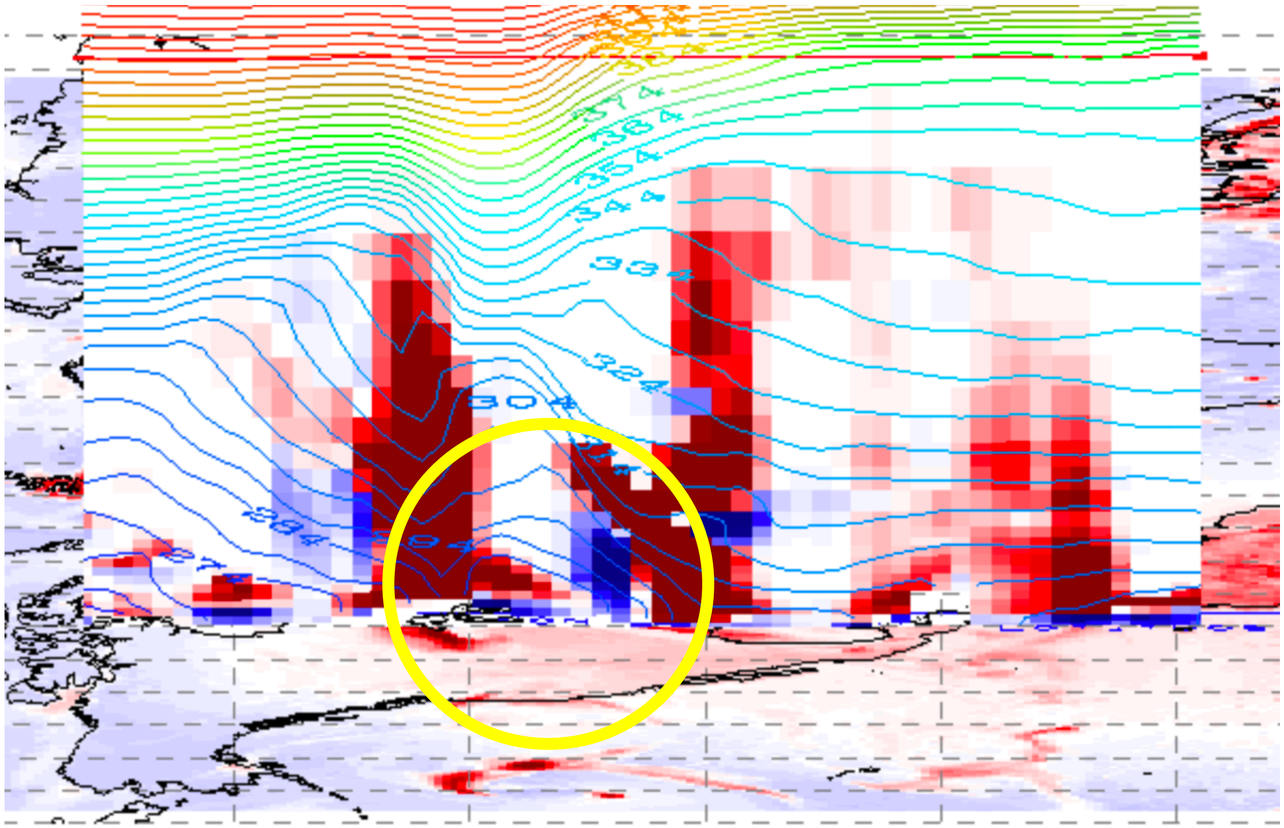


Moist-process heating rate

Warm cores associated with positive heating rate

Warm and cool cores & condensation heating

- Use the cross section with theta contours and the moist-processes heating rate (dtdtmst) to find an example
  - where a cool core cyclone (lifted isentropes, cyclonic PV aloft; a tentacle of the polar vortex) may be gently lifting air to its condensation level, releasing some latent heating
  - how does the PV source term from latent heating feed back on such a cool core storm?



Cool core found at surface, theta surfaces are bunched up

PV source term of moisture heating, or cooling in this instance, attributes to a lack of latent heat compared to the warm core, meaning this core is relatively dry.