PV Thinking and the Dynamic Tropopause

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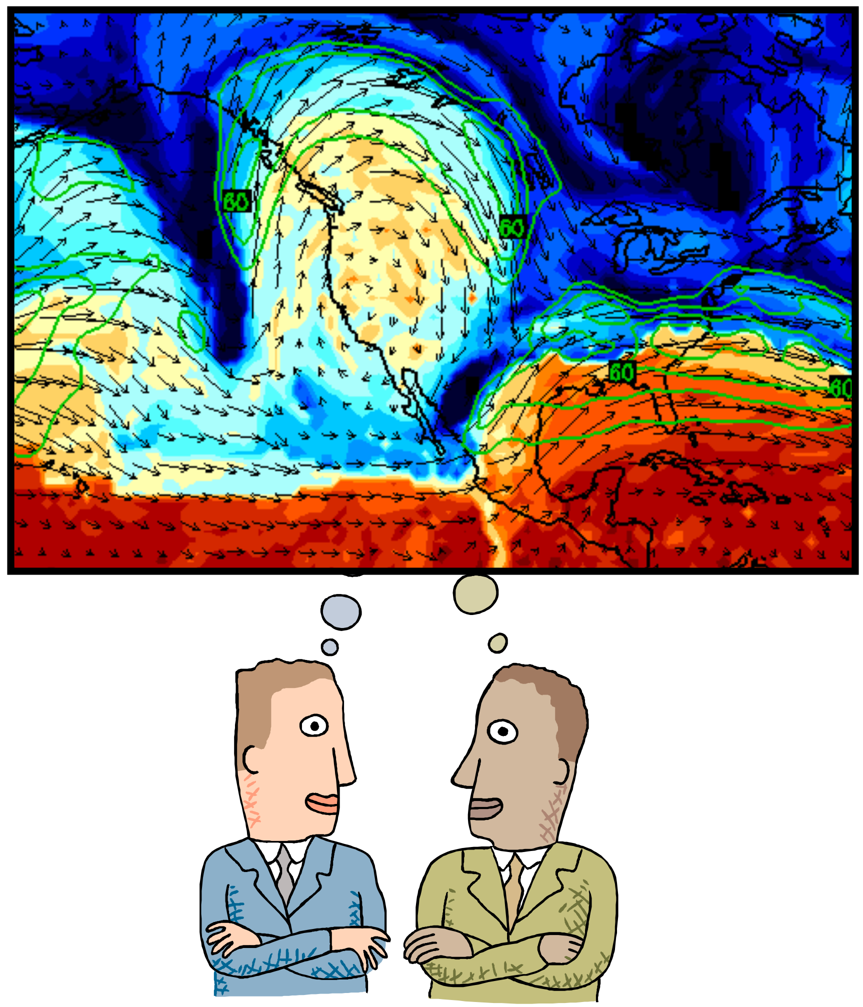
Supplemental Reading: Lackmann (2011) Chapter 4

What is PV Thinking?

The use of potential vorticity conservation and "invertability" for understanding large-scale atmospheric dynamics and the evolution of synoptic weather systems



Potential Vorticity

- Conserved following fluid motion for adiabatic, frictionless flow

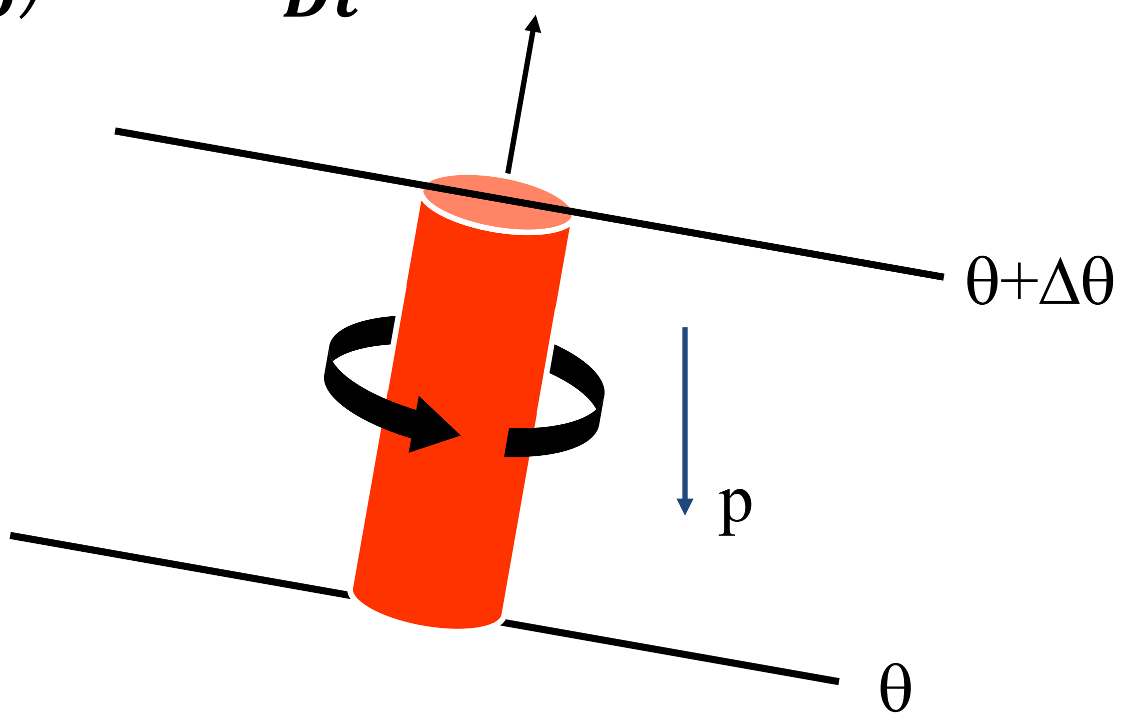
$$\boldsymbol{P = -g(\zeta + f)\left(\frac{\partial \theta}{\partial p}\right)} \qquad \boldsymbol{\frac{DP}{Dt} = 0}$$

- Components
  - Absolute vorticity

$$\boldsymbol{\zeta + f}$$

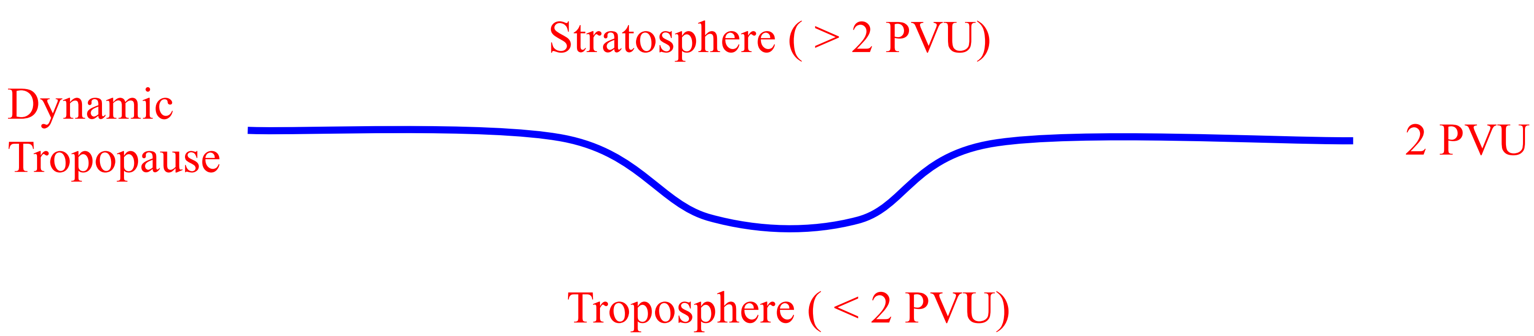
  - Static Stability

$$-\boldsymbol{\frac{\partial \theta}{\partial p}}$$

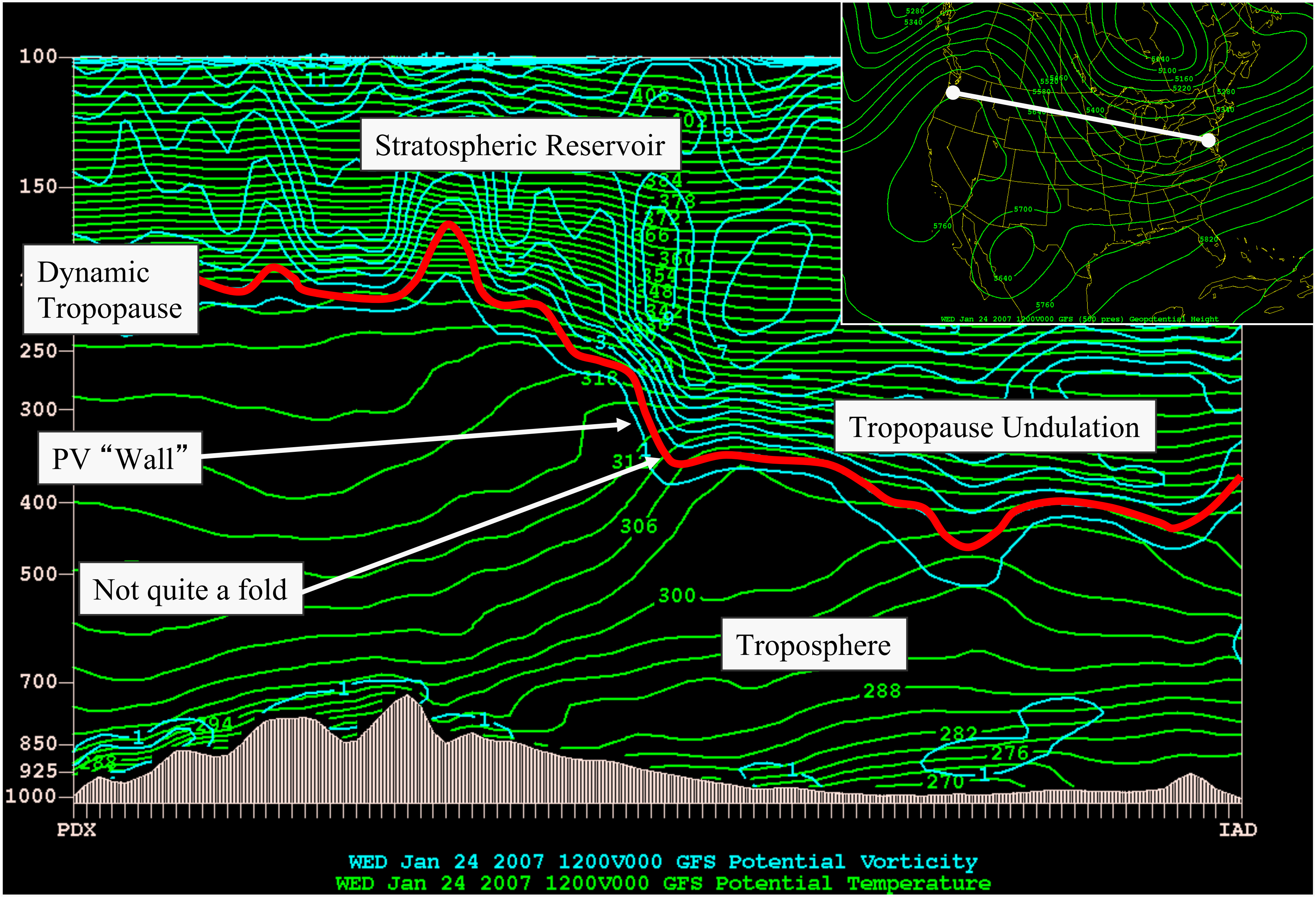


Potential Vorticity

- Units of K kg^{-1} m^2 s^{-1}
- Define 1 PVU = 10^{-6} K kg^{-1} m^2 s^{-1}
- PV is typically higher in the stratosphere (>2 PVU) and lower in the troposphere (< 2 PVU)
- Dynamic Tropopause – Tropopause defined using PV (I use 2 PVU, others 1.5)



Example


Stratospheric Reservoir
Dynamic Tropopause
PV "Wall"
Not quite a fold
Tropopause Undulation
Troposphere
100
150
250
300
400
500
700
850
925
1000
PDX
IAD
WED Jan 24 2007 1200V000 GFS Potential Vorticity
WED Jan 24 2007 1200V000 GFS Potential Temperature

Key Features

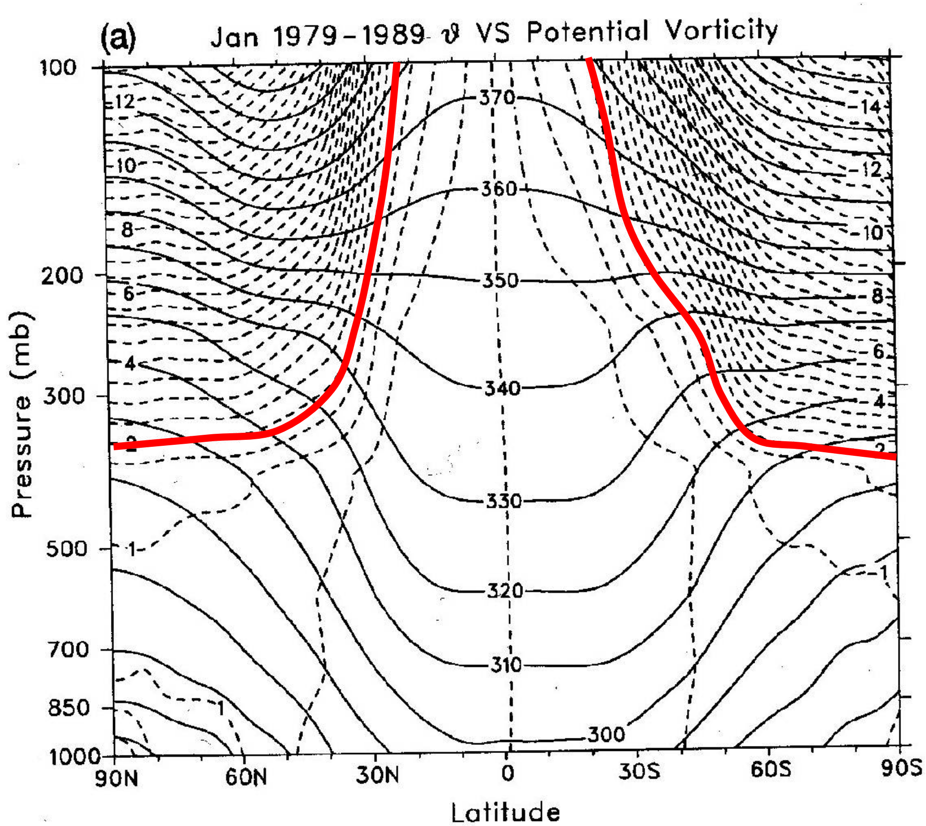
- Dynamic tropopause – tropopause defined using potential vorticity (i.e., 1.5 or 2.0 PV surface)

- Stratospheric reservoir – region of high PV in the stratosphere

- Tropopause undulation – wave-like undulation in the tropopause

- Tropopause fold – area where stratospheric air folds under tropospheric air

Mean Distribution of PV



- DT height is high in tropics, low in high latitudes
- DT pressure is low in tropics, high in high latitudes
- DT potential temperature is high in tropics, low in high latitudes
- On an isentropic surface (e.g., 320 K) PV increases toward the poles

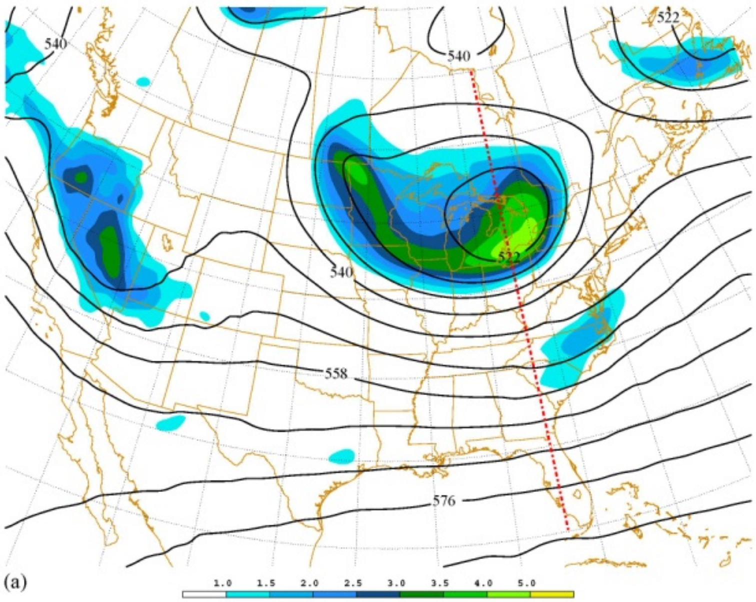
Bluestein (1993)

Dynamic Tropopause (DT) Analysis

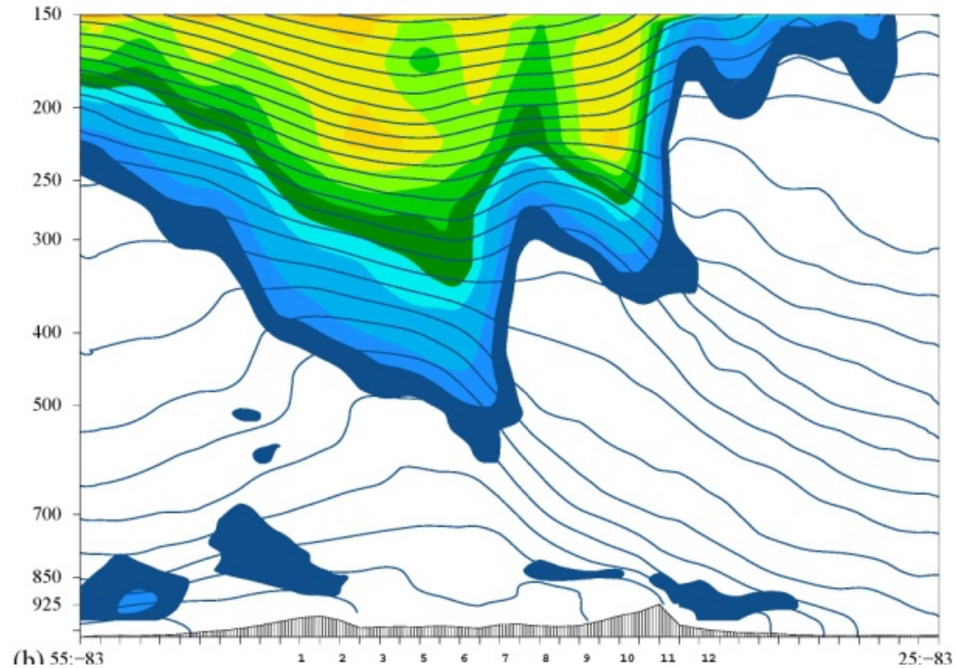
- An analysis of variables (e.g., wind, pressure) on the dynamic tropopause

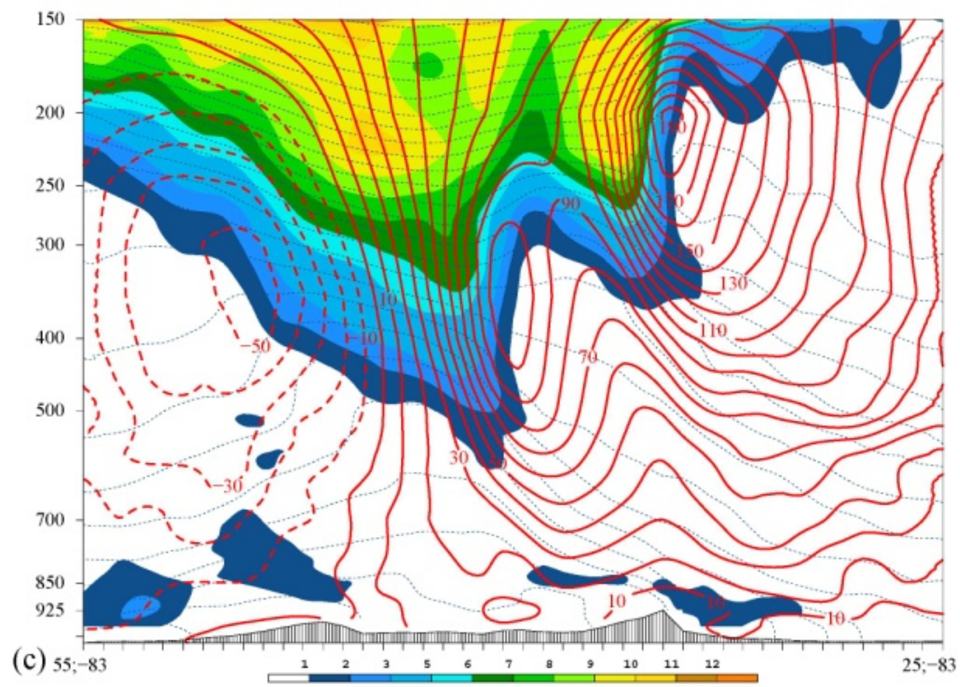
- Advantages
  - Jets (subtropical and polar) are frequently at differing pressure levels, but are typically near the dynamic tropopause
  - Tropopause pressure or potential temperature can be used to identify PV “anomalies” & upper-level troughs and ridges
  - Contain a huge amount of information about the upper-levels on a single map

The Dynamic Tropopause



500-mb height and PV



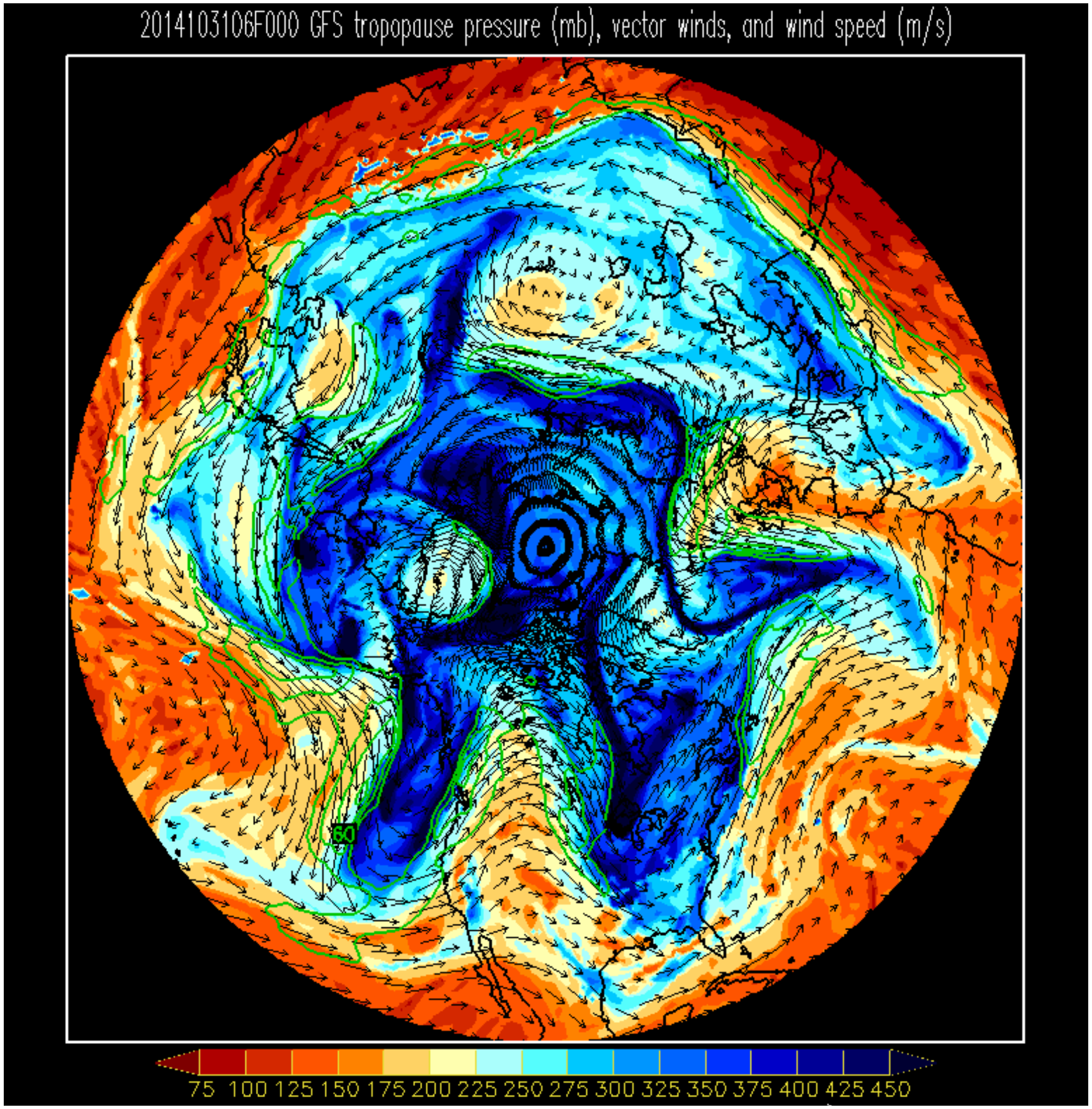


Note how jet cores all intersect same PV isosurface: Dynamic tropopause

GFS 144-h forecast valid 12 UTC 10 Feb 2010

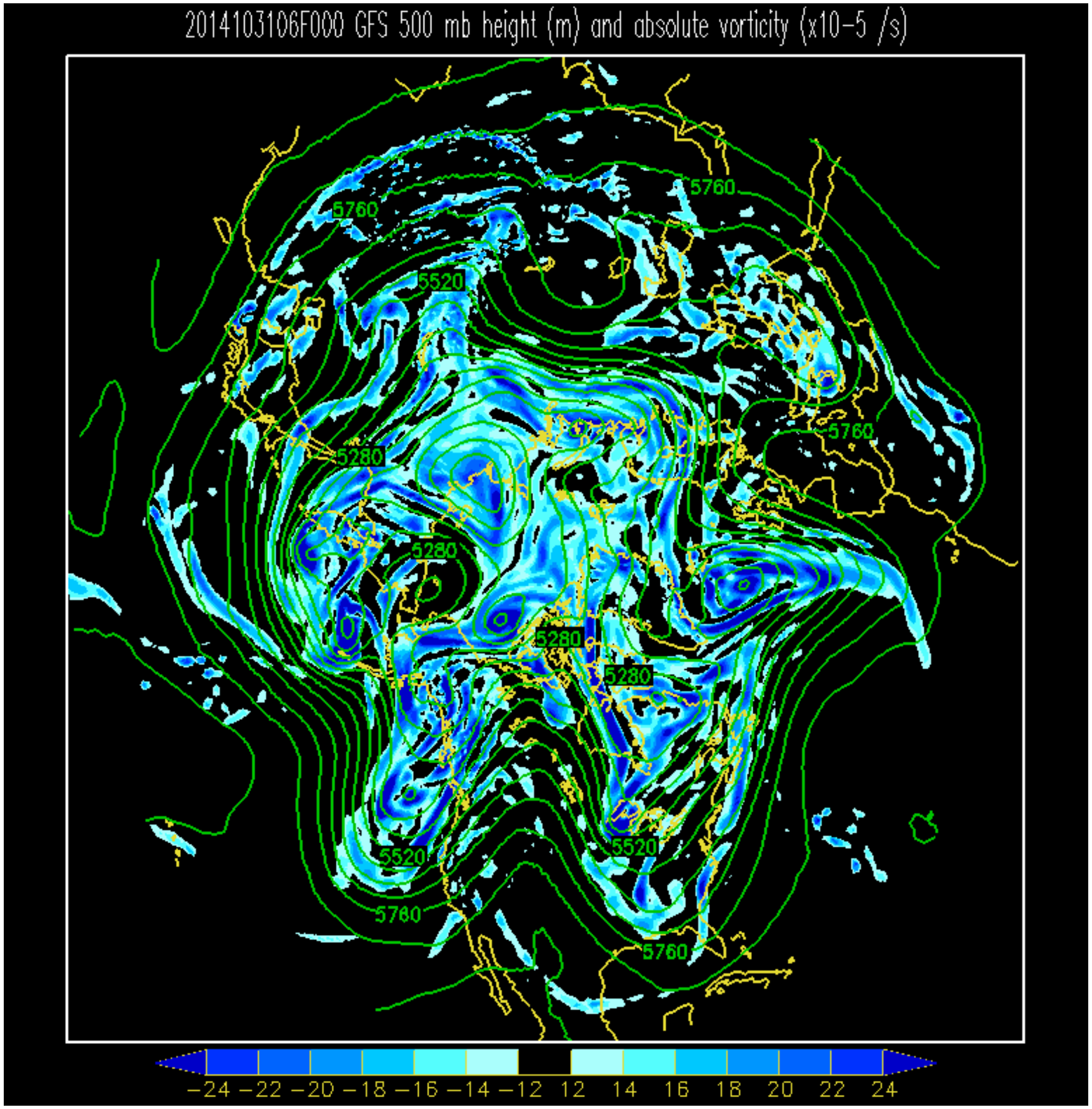
From Lackmann (2011) Lecture Notes

Dynamic Tropopause Pressure

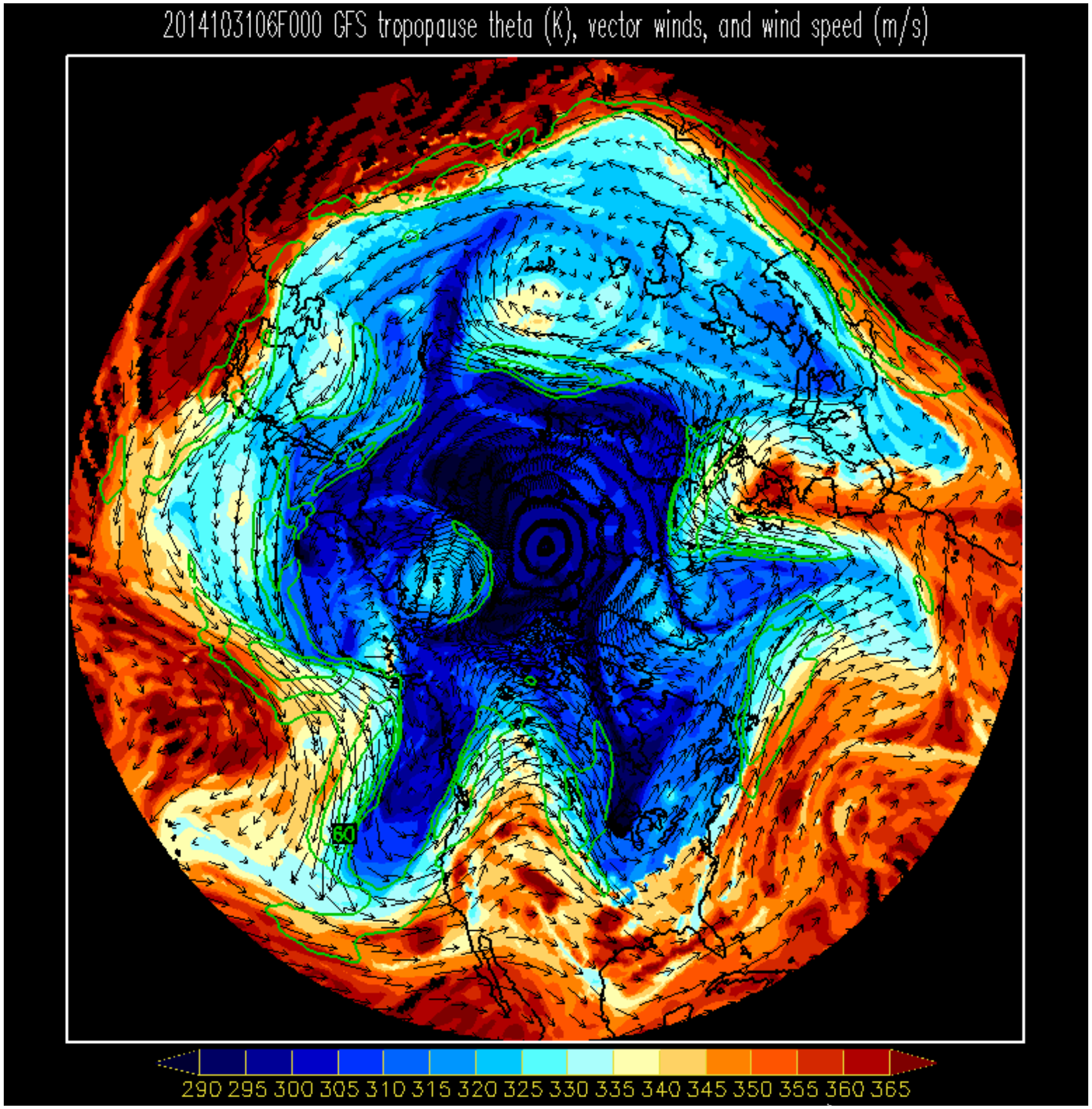


Conceptually straightforward, but not conserved

Correspondence with 500 mb

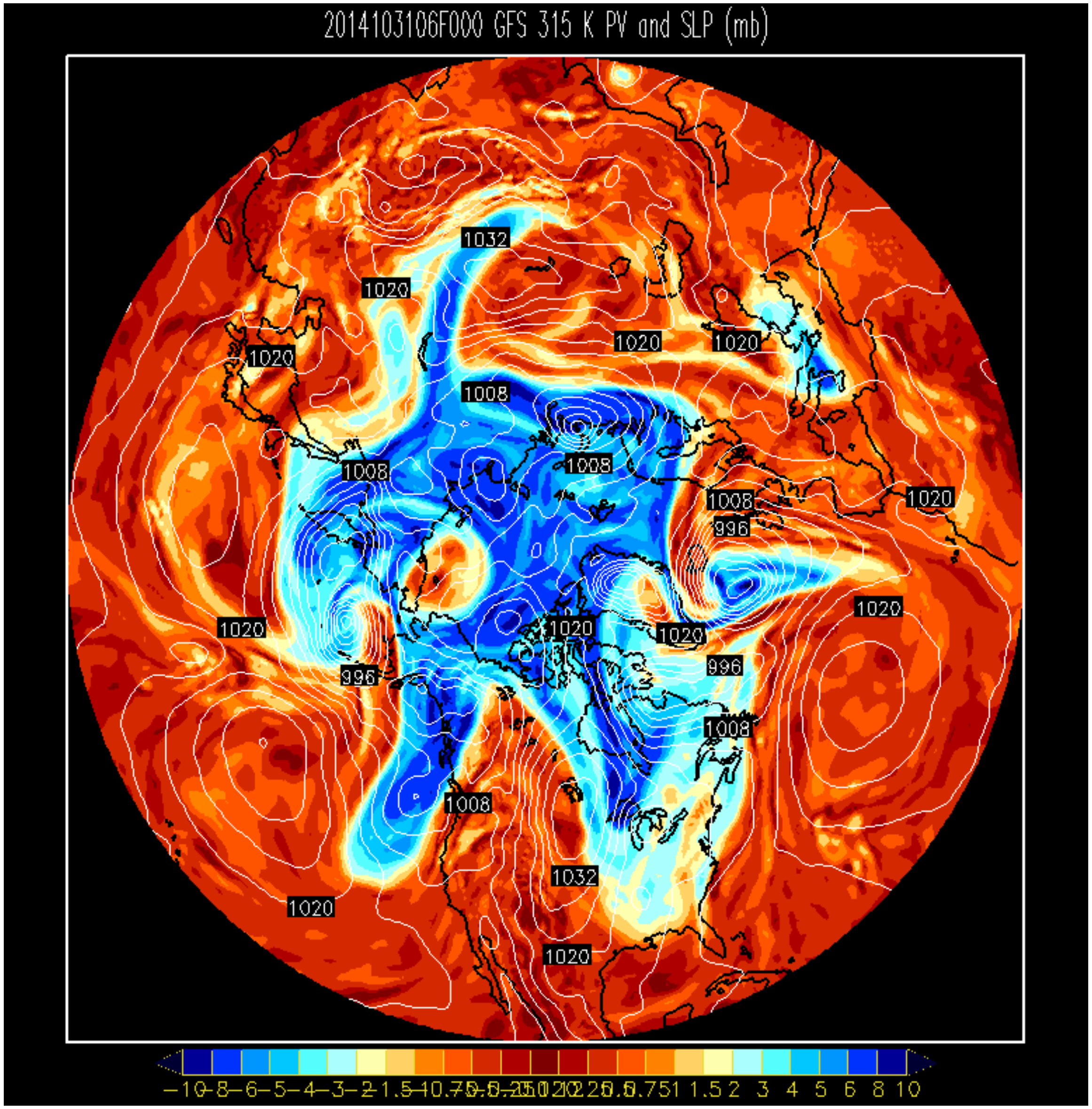


Dynamic Tropopause Theta



Conserved for adiabatic, frictionless flow (can use advection to explain/anticipate changes)

PV on an Isentropic Surface (315 K)



Conserved for adiabatic, frictionless flow (can use advection to explain/anticipate changes)

PV Thinking

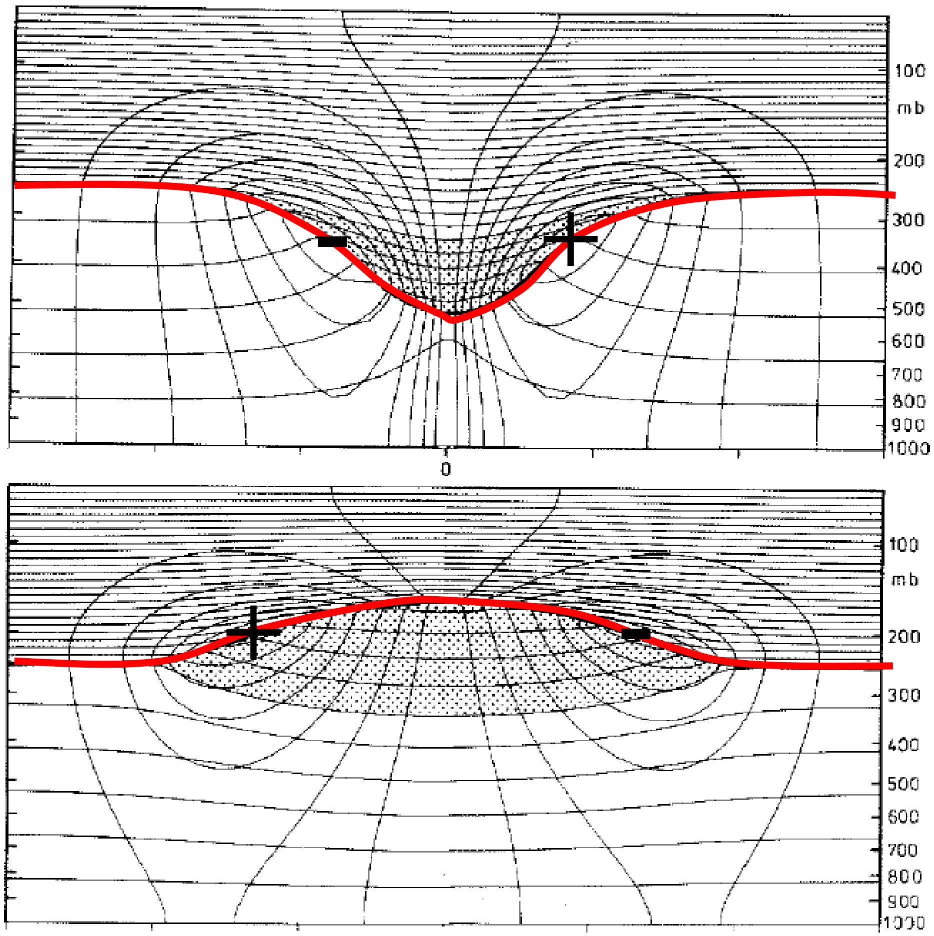
- Under adiabatic conditions, the evolution of PV is controlled by advection
  - Changes in DT potential temperature (or PV on an isentropic surface) can be anticipated based on advection

- PV can be “inverted” to deduce the the wind and thermodynamic fields
  - Changes in the large-scale flow can be anticipated based on these advective changes in DT potential temperature

- Non-conservation of PV (i.e., changes in DT potential temperature not explained by advection) can be used to understand how diabatic processes influence large-scale systems

- Phenomena that can be diagnosed in this manner include cyclogenesis, trough and ridge amplification, trough fracture, trough merger, downstream development, etc.

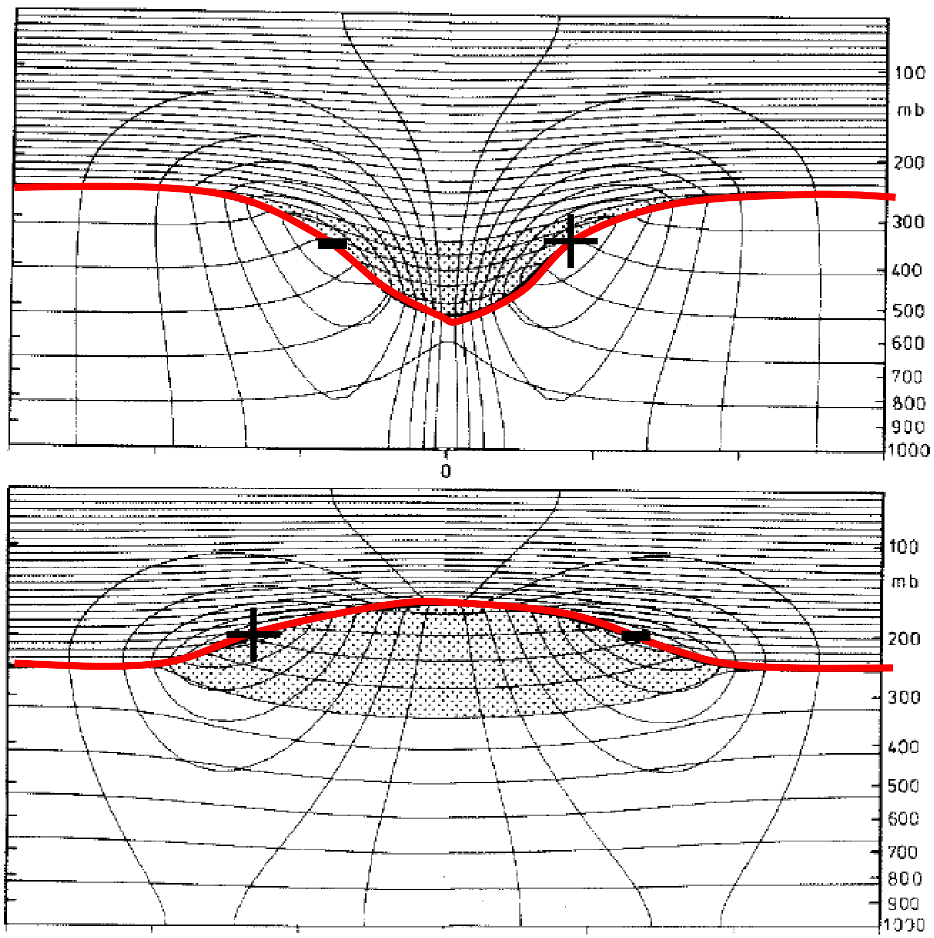
PV Inversion



- PV can be inverted assuming a suitable balance condition
- Cyclonic PV anomalies (i.e., locally high PV) induce a cyclonic circulation
- Anticyclonic PV anomalies (i.e., locally low PV) induce an anticyclonic circulation

Hoskins et al. (1985)

PV Inversion



- The induced cyclonic circulation and temperature anomalies are strongest near the PV anomaly and spread horizontally and vertically

- Vertical penetration is inversely proportional to stability
  – High stability = weak penetration
  – Low stability = strong penetration

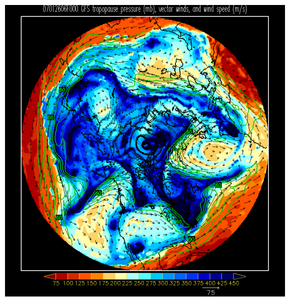
Hoskins et al. (1985)

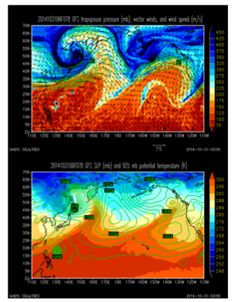
Synoptic Application

- Regions of low DT potential temperature (high DT pressure) are cyclonic PV anomalies and accompanied by upper-level troughs/cyclones
- Regions of high DT potential temperature (low DT pressure) are anticyclonic PV anomalies and accompanied by upper-level ridges/anticyclones
- Amplification (weakening) of a cyclonic PV anomaly is an indication of a developing (decaying) trof
- Amplification (weakening) of an anticyclonic PV anomaly is an indication of a developing (decaying) ridge
- Strong jets are usually found in regions of large tropopause pressure gradients (a.k.a. the PV Wall)
- Covered in a future lecture: Cyclogenesis from a PV perspective

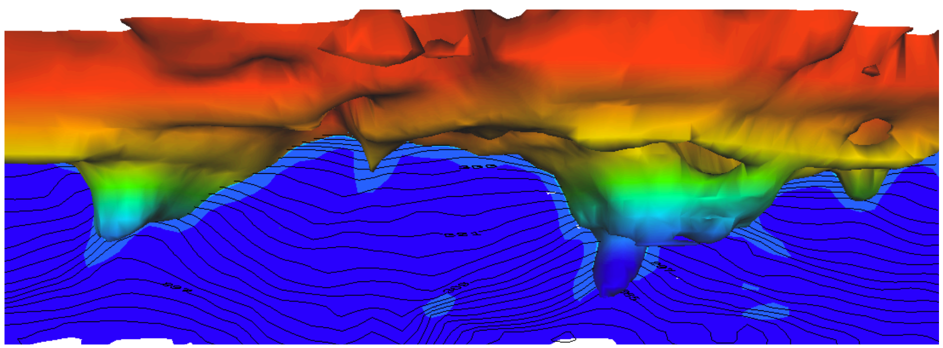
Class Activity: Real-Time Examples

- weather.utah.edu graphics





- IDV



Bundles -> Real-Time-WX -> Diagnostics -> PV-Thinking

Class Activity: Real-Time Examples

- Identify the following on a DT pressure and DT theta analysis/forecast loop or using IDV 3-D visualization
  - A cyclonic PV anomaly and upper-level trough
  - An anticlonic PV anomaly and upper-level ridge
  - A PV wall
  - A tropopause fold
  - A subtropical jet
  - A polar jet
  - An upper-level cyclonic PV that contributes to surface cyclogenesis
  - An example of PV filament forming due to deformation
  - An example of ridge development amplified by non-conservative processes