Cyclogenesis

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Suggested reading: Lackmann (2011), Section 5.3

Motivation

We need a dynamically based conceptual framework to understand and diagnose the development and decay of surface cyclones and anticyclones.

Definitions

Cyclogenesis: The formation of a cyclone.

Cyclolysis: The decay of a cyclone.

Relationship between pressure, height, and vorticity tendencies

Conceptual frameworks for cyclogenesis are often based on vorticity rather than pressure. Pressure tendencies, height tendencies, and geostrophic vorticity tendencies are coupled through the geostrophic wind relationship so that:

$$\left(\frac{\partial p}{\partial t}\right)_z \propto \left(\frac{\partial Z}{\partial t}\right)_p \propto \left(\frac{\partial \zeta_g}{\partial t}\right)_z \propto \left(\frac{\partial \zeta_g}{\partial t}\right)_p$$

Thus, pressure, height, and geostrophic vorticity tendencies are intrinsically linked

- An increase in surface vorticity is associated with height and pressure falls
- A decrease in surface vorticity is associated with height and pressure rises

Vorticity perspective

Diagnoses cyclogenesis using the vorticity equation, which ignoring friction, tilting, and solenoidal effects can be written

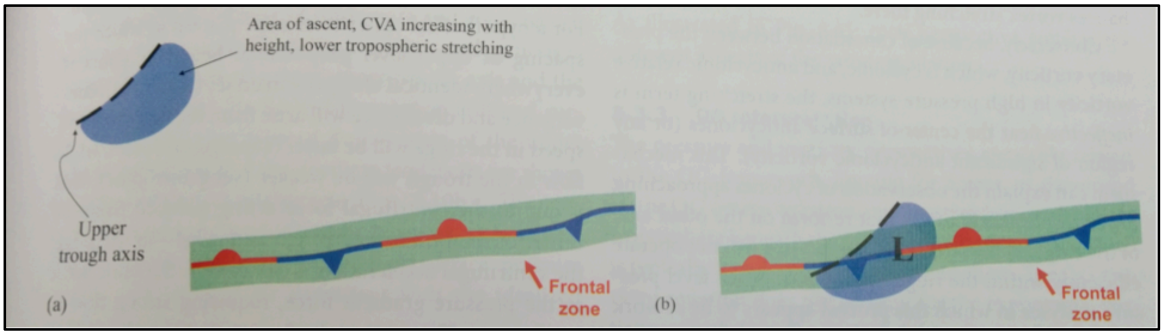
$$\frac{D(\zeta + f)}{Dt} = -(\zeta + f)\left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y}\right)$$

or, based on continuity

$$\frac{D(\zeta + f)}{Dt} = (\zeta + f)\left(\frac{\partial w}{\partial z}\right)$$

Thus, lower tropospheric stretching (i.e., ascent) is a mechanism for vorticity generation and cyclogenesis.

The example below from Lackmann (2011) shows an upper-level trough and associated area of CVA and ascent overtaking a low-level frontal zone. The low-level frontal zone is characterized by high initial absolute vorticity. Stretching associated with the upper-level trough most effectively generates vorticity along the front (due to the absolute vorticity multiplier in the vorticity equation), leading to cyclogenesis.



Pressure perspective

Assuming hydrostatic balance, pressure is simply the weight of the overlying atmosphere. Surface pressure changes are thus due to integrated mass divergence (or convergence). Cyclogenesis occurs when divergence aloft exceeds convergence at low levels, resulting in net mass divergence and surface pressure falls.

Ultimately, the vorticity and pressure perspectives are consistent

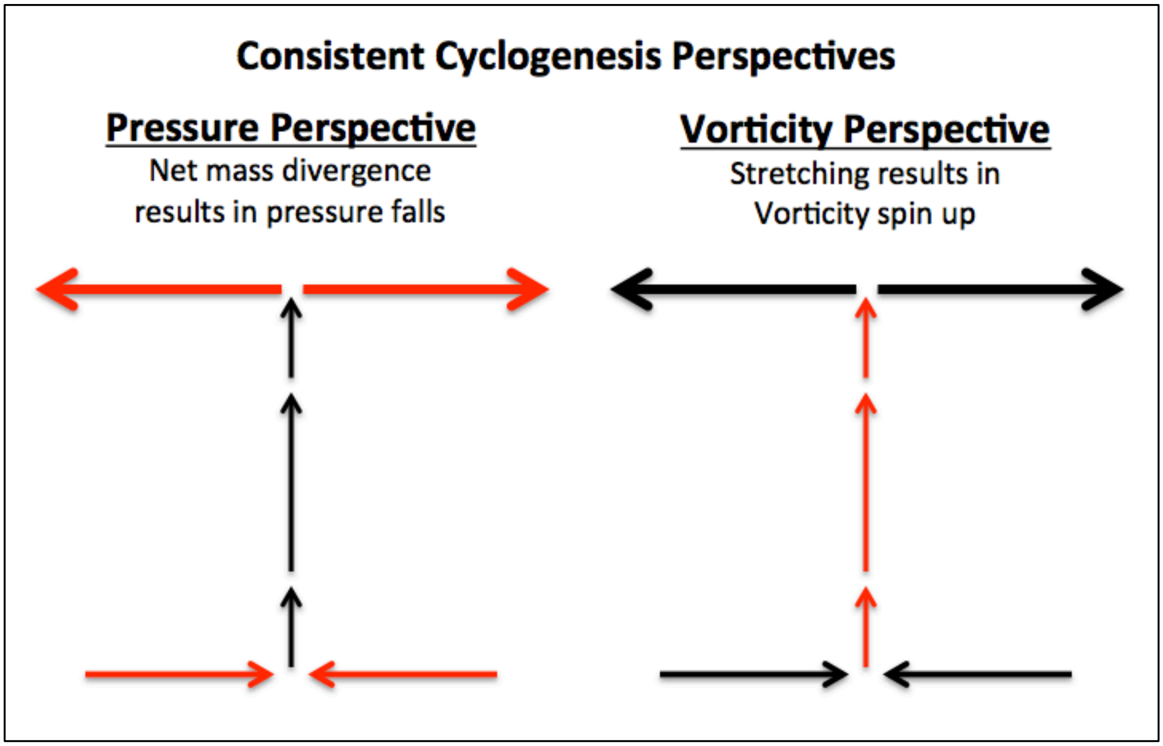


Figure adapted from Lackmann (2011) course notes

<u>QG perspective (omega equation)</u>

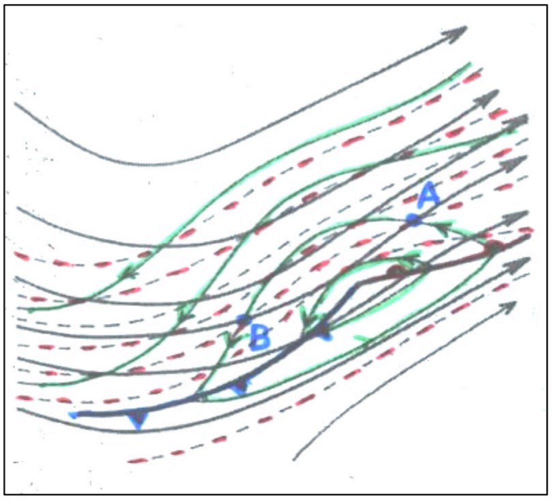
QG ascent results in stretching and pressure falls. Ignoring friction, the following can contribute to ascent, pressure falls, and cyclogenesis:

- Vorticity advection becoming more cyclonic (or less anticyclonic) with height
  - Typically look for CVA @ 500 mb
- A local maximum in temperature advection
  - Typically look for warm advection, such as along a warm front or occluded front
- A local maximum in diabatic heating
- These effects are most pronounced when the static stability is low
  - e.g., an upper-level trough can induce cyclogenesis more easily if the static stability is low than high

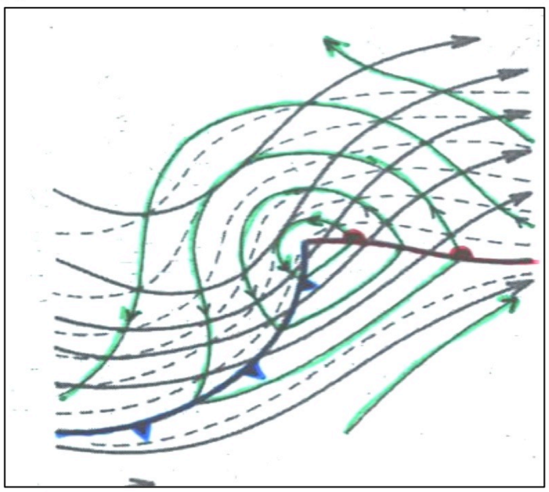
Synoptic experience (cyclogenesis):

1. CVA downstream of an upper-level trough contributes to pressure falls and cyclogenesis
2. Warm advection along a warm or occluded front contributes to pressure falls and cyclogenesis
3. Diabatic heating contributes to pressure falls and cyclogenesis
4. In frontal cyclone development, all three processes contribute to a mutual amplification of the surface cyclone and upper level wave
5. You get more bang for the buck if the static stability is low
6. Stretching downstream of topography can also contribute

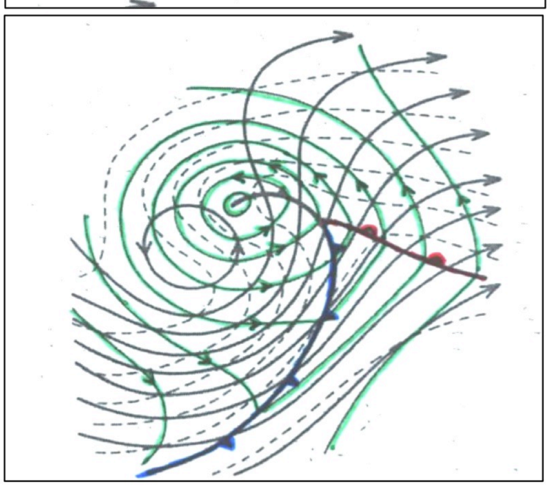
Idealized example (from Lackmann 2011 course notes)



- 500-mb CVA contributes to surface cyclogenesis
- Low-level warm advection ahead of cyclone amplifies downstream ridge
- Low-level cold advection behind cyclone amplifies upper-level trough



- Wavelength of upper-level wave shortens
- CVA intensifies
- Surface development continues
- Low-level warm and cold advection intensify
- Surface cyclone and upper-level trough mutually amplify
- Ddiabatic heating along warm/occluded front to further enhances surface development and upper-level wave amplification



- Cyclone becomes vertically stacked
- QG forcing for ascent weakens
- Development ceases

Synoptic experience (anticyclogenesis):

1. AVA downstream of an upper-level ridge contributes to pressure rises and anticylogenesis
2. A local minimum in cold advection contributes to pressure rises and anticyclogenesis
3. Diabatic cooling (e.g., radiational cooling) contributes to pressure rises and anticyclogenesis
4. Compression upstream of topography can also contribute

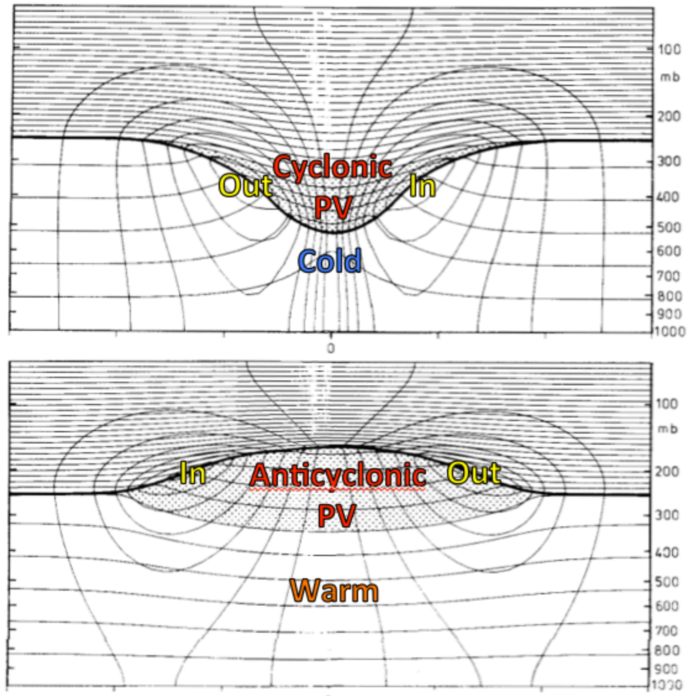
Class activity:

Using the IDV Global-10day diagnostic, examine and describe a cyclogenesis and an anticyclogenesis events from a QG perspective.

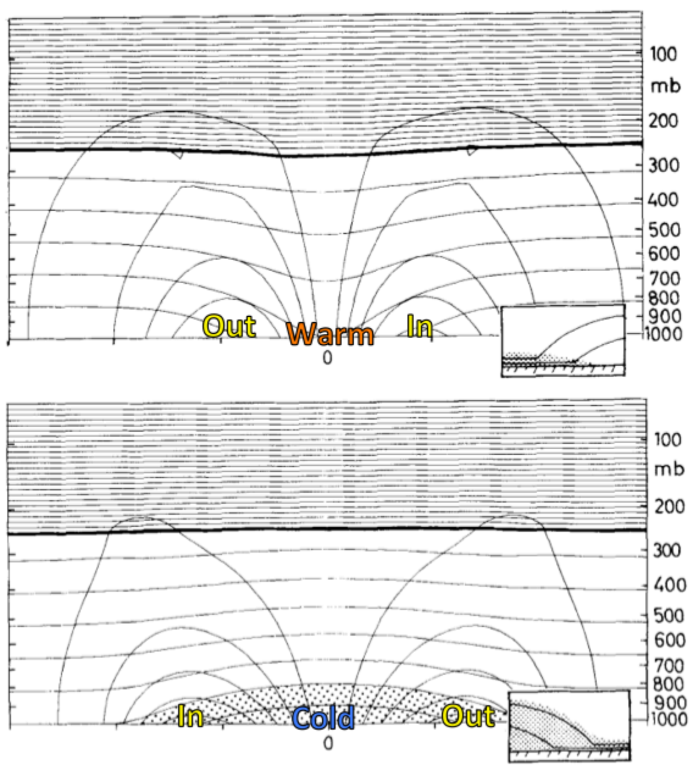
PV perspective

Cyclogenesis results from the coupling and mutual amplification of surface temperature and upper-level cyclonic PV anomalies, with contributions from diabatically generated PV cyclonic anomalies.

PV Anomalies (from Thorpe 1985 via Hoskins et al. 1985)



A surface warm anomaly acts like a cyclonic PV anomaly and a surface cold anomaly acts like an anticyclonic PV anomaly (from Thorpe 1985 via Hoskins et al. 1985)



Cyclogenesis from a PV perspective:

1. Upper-level cyclonic PV anomaly overtakes a low-level frontal zone
2. Cyclonic circulation associated with upper-level PV anomaly induces a warm tongue along the frontal zone
3. Warm tongue acts like a cyclonic PV anomaly, inducing a cyclonic circulation that extends upward and further amplifies the upper-level cyclonic PV anomaly
4. The upper-level and surface thermal anomalies become phase locked and mutually amplify, resulting in cyclogenesis
5. Diabatically generated PV can be a third building block in this process

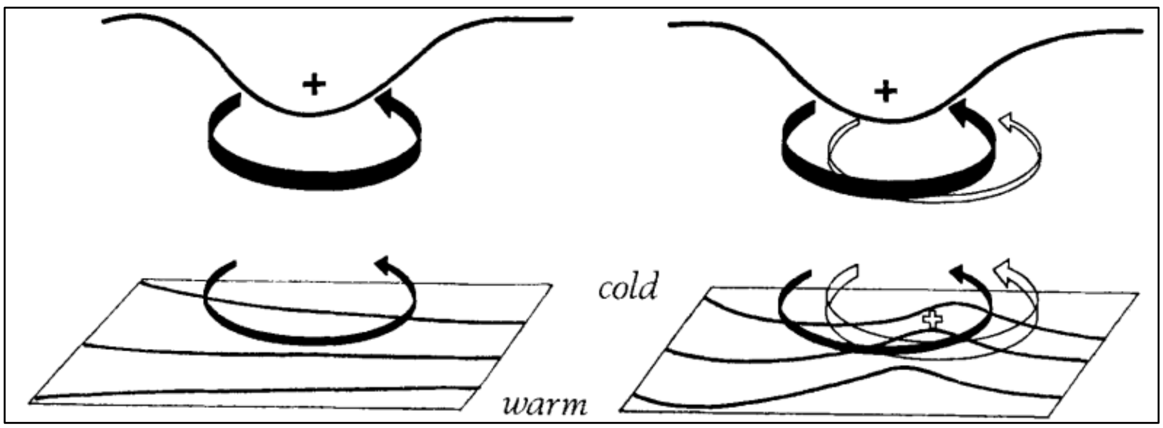


Figure from Hoskins et al. (1985)

Another perspective:

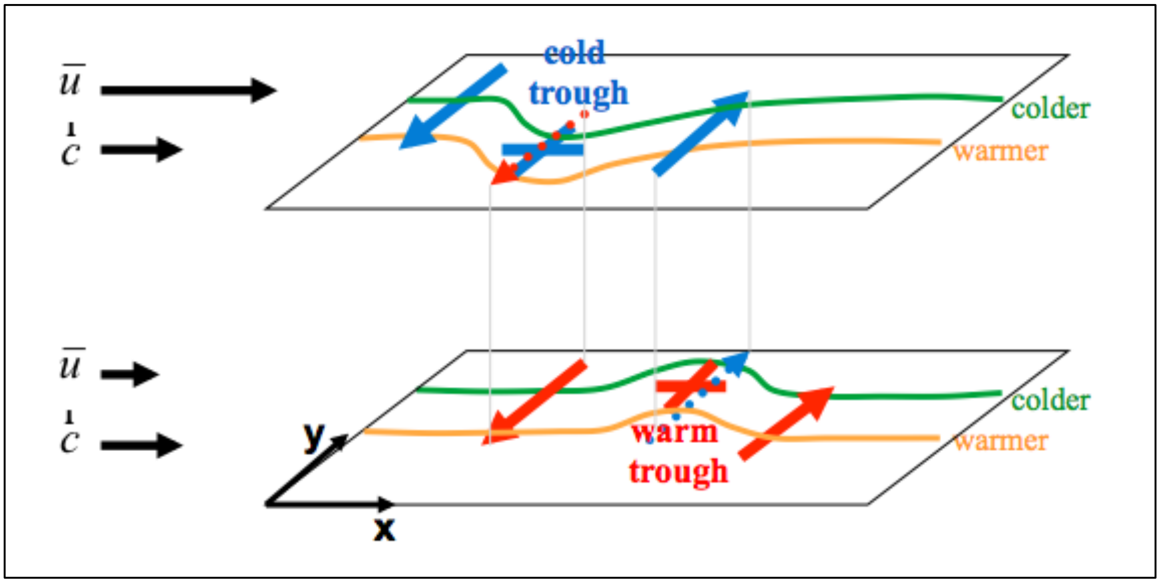


Figure from Lackmann (2011) lecture notes

Typical PV distribution in an extratropical cyclone

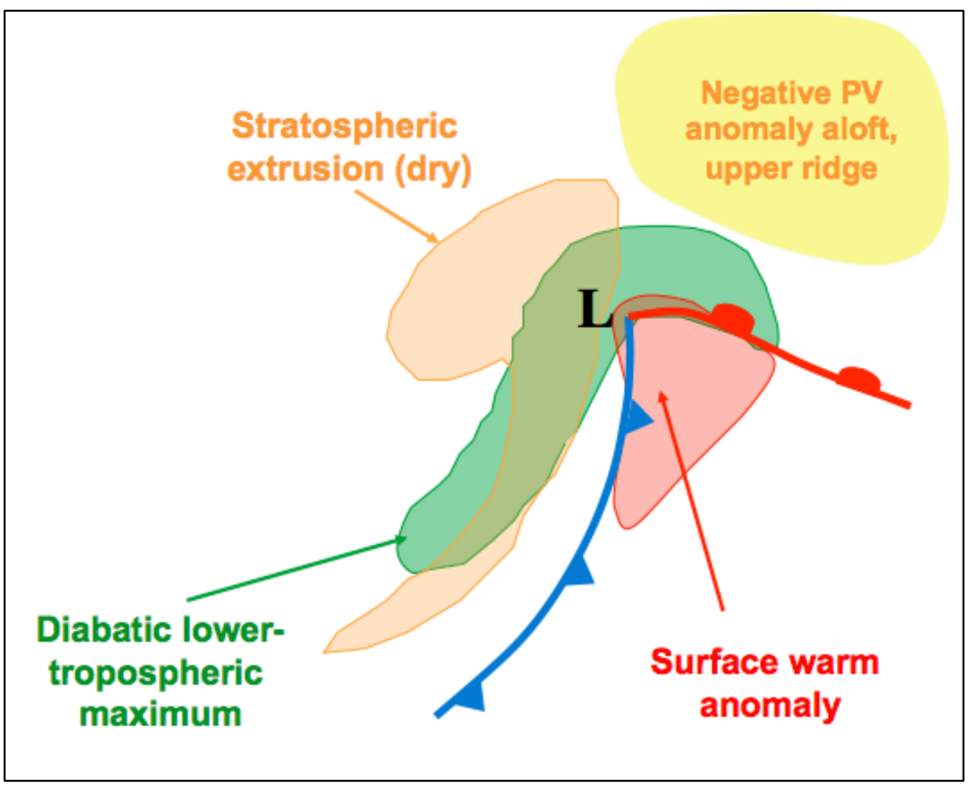
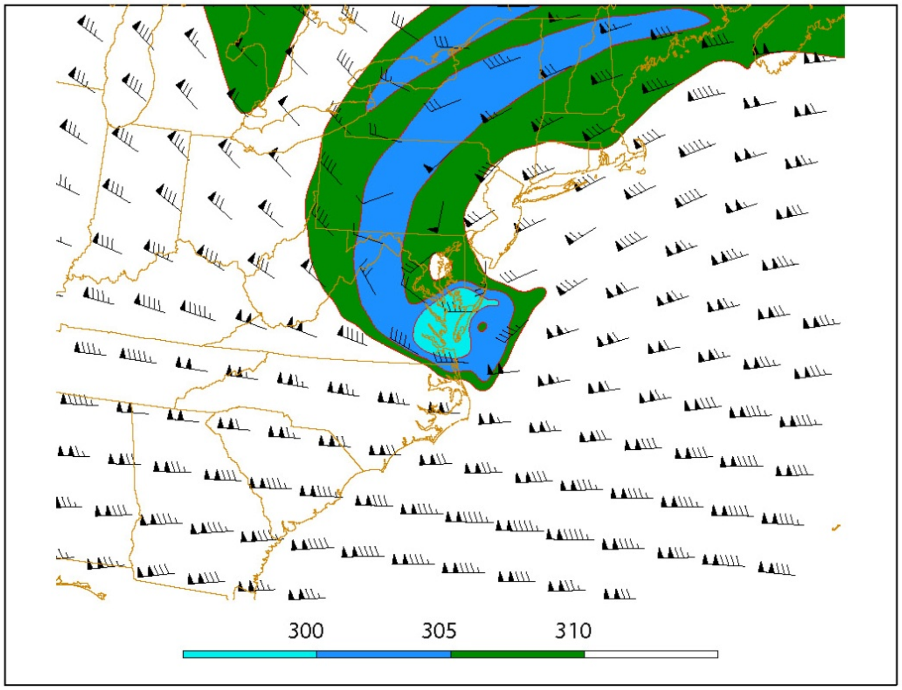
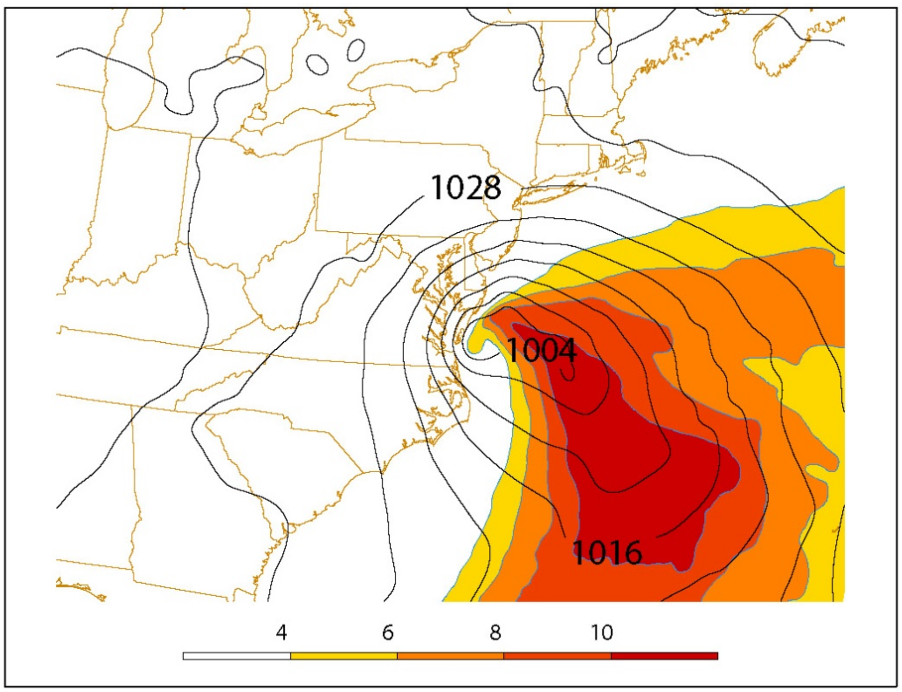


Figure from Lackman (2011) lecture notes

Example: 1979 President's Day Storm

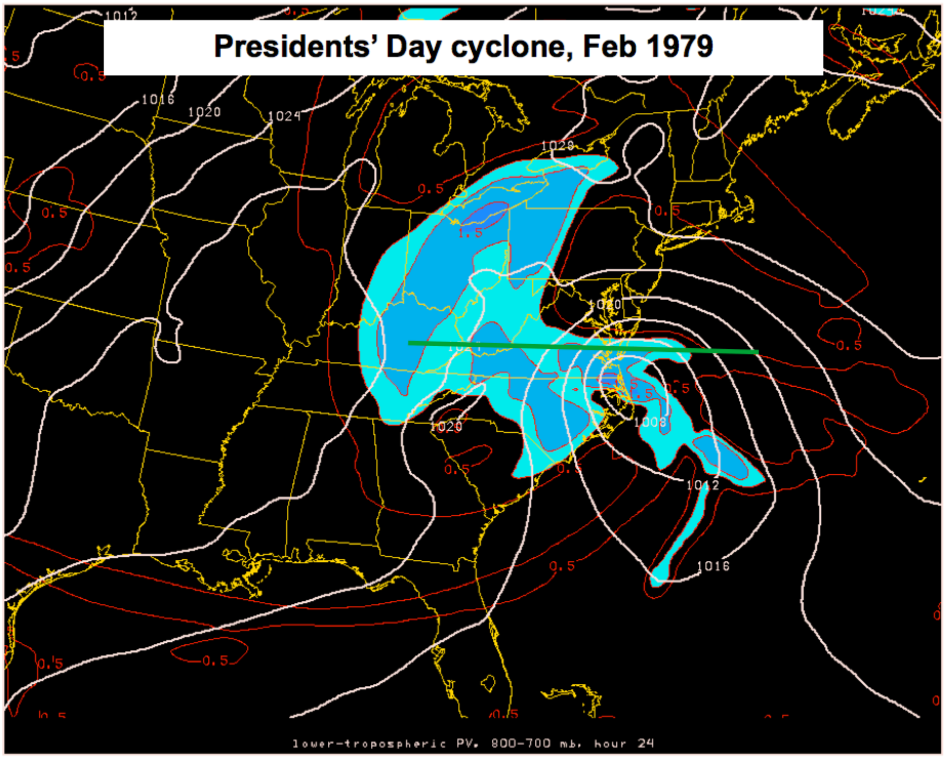


Dynamic Tropopause Potential Temperature (from Lackmann 2011 lecture notes)



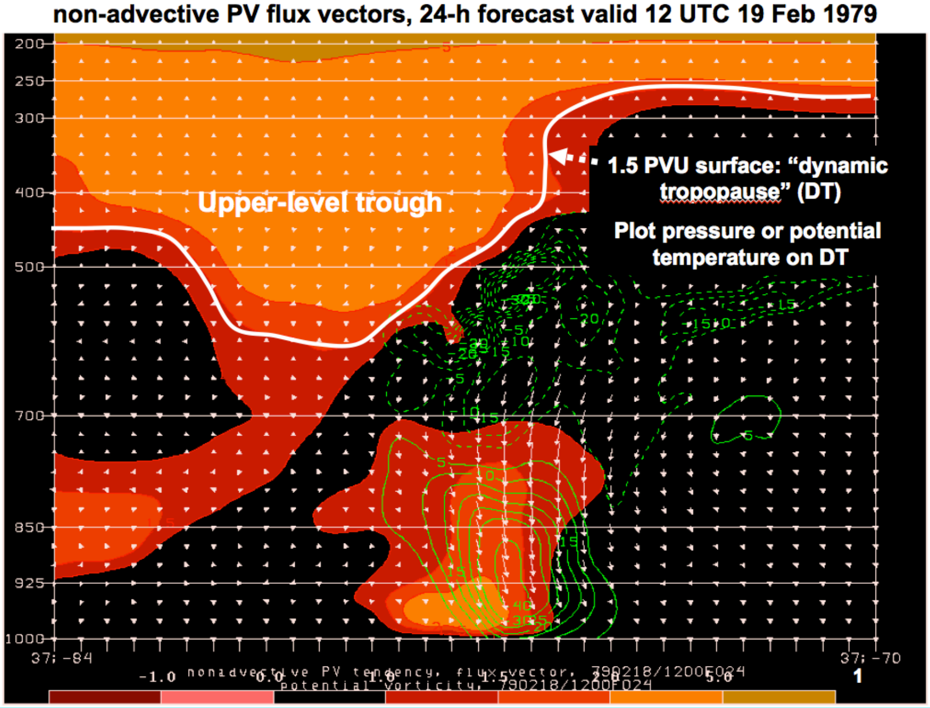
SLP and Sfc Potential Temperature (from Lackmann 2011 lecture notes)

Lower tropospheric PV (700-800 mb layer, red contour and shaded), SLP (white)
24-h forecast valid 12 UTC 19 Feb 1979



Diabatic lower-tropospheric PV (from Lackmann 2011 lecture notes)

Cross section of PV (Shaded), non-advective PV tendency (green contours), and non-advective PV flux vectors, 24-h forecast valid 12 UTC 19 Feb 1979



Cross section (green line in above, from Lackmann 2011 lecture notes)

Class activity:

Using the IDV Global-10day diagnostic and/or the weather.utah.edu GFS DT and Surface diagnostic for a selected region, examine and describe a cyclogenesis and an anticyclogenesis events from a QG perspective.