MET 3502/5561 Synoptic Meteorology

Lecture 20:

Applications of Learned Tools in Evaluating & Diagnosing Vertical Motion, Upper-level Trough, and Surface Cyclones

Evaluating Vertical Motion (1)

1. Kinematic Method:

1) Use continuity equation to determine W from horizontal winds. The vertical motion at a given pressure level is directly related to the integrated divergence above that level. Mean divergence aloft → rising motion.

2) Difficult to apply to synoptic observations

3) Small observational errors result in large W errors.

Evaluating Vertical Motion (2)

2. Using Q. G. Omega equation: (W~differential vortocity advection and temperature advection)

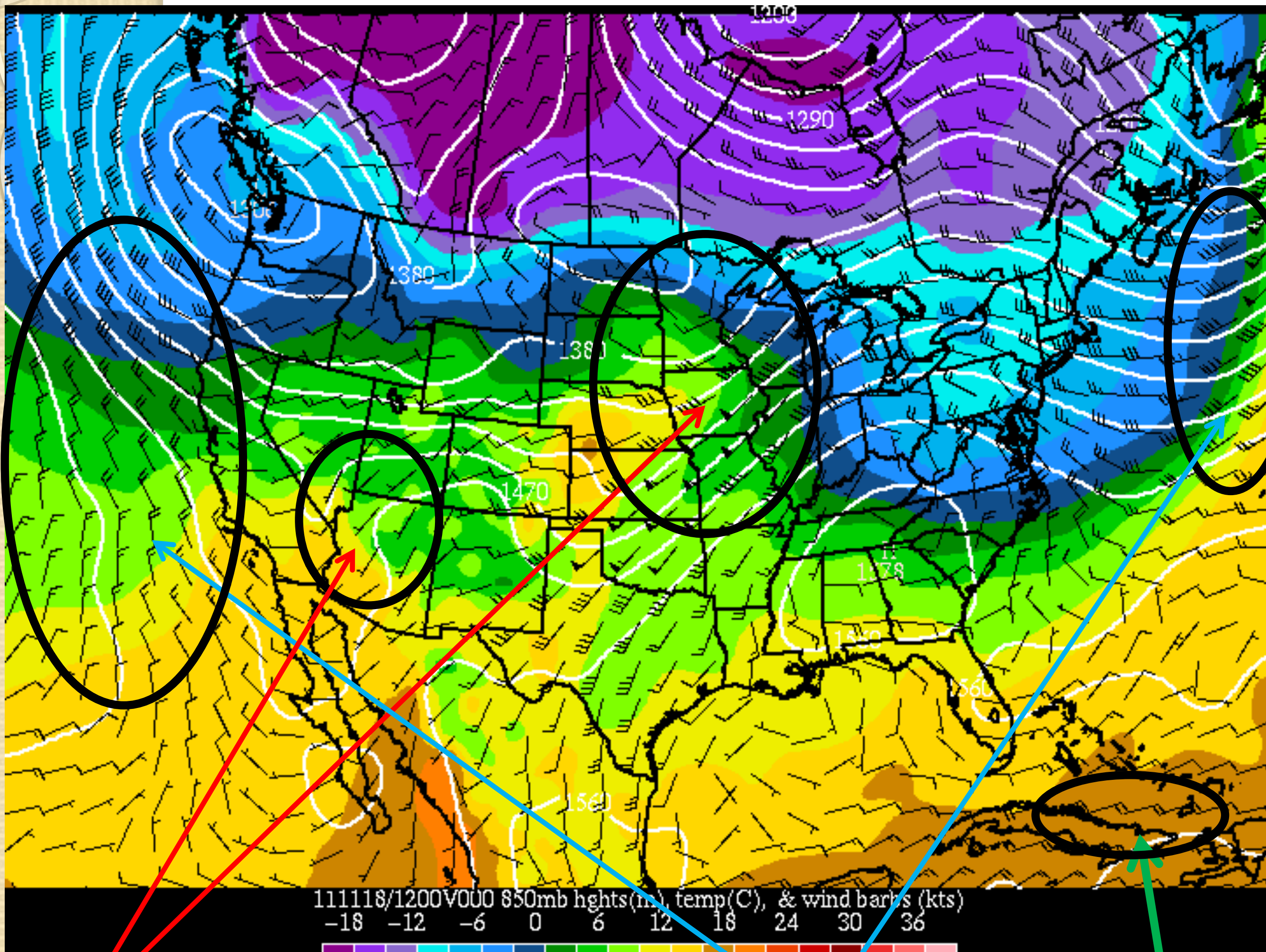
1) Based on QG theory; Can infer W from large scale analyses
500mb cyclonic vorticity advection (CVA) & lower to middle troposphere **warm advection** contribute to **rising motion**
500mb anticyclonic vorticity advection AVA & lower to middle troposphere **cold advection** contribute to **subsidence**

2) Errors arise from QG assumptions, simplification of equations for interpreting

3) Ideally need to look at multiple levels

4) Term cancellation is a pain

How to identify/estimate warm/cold temperature advection on a 850mb temperature weather map?



WAA (Warm Air Advection)

850 mb weather map showing temperature (color), wind bars, and geopotential height contours at 850-mb pressure surface

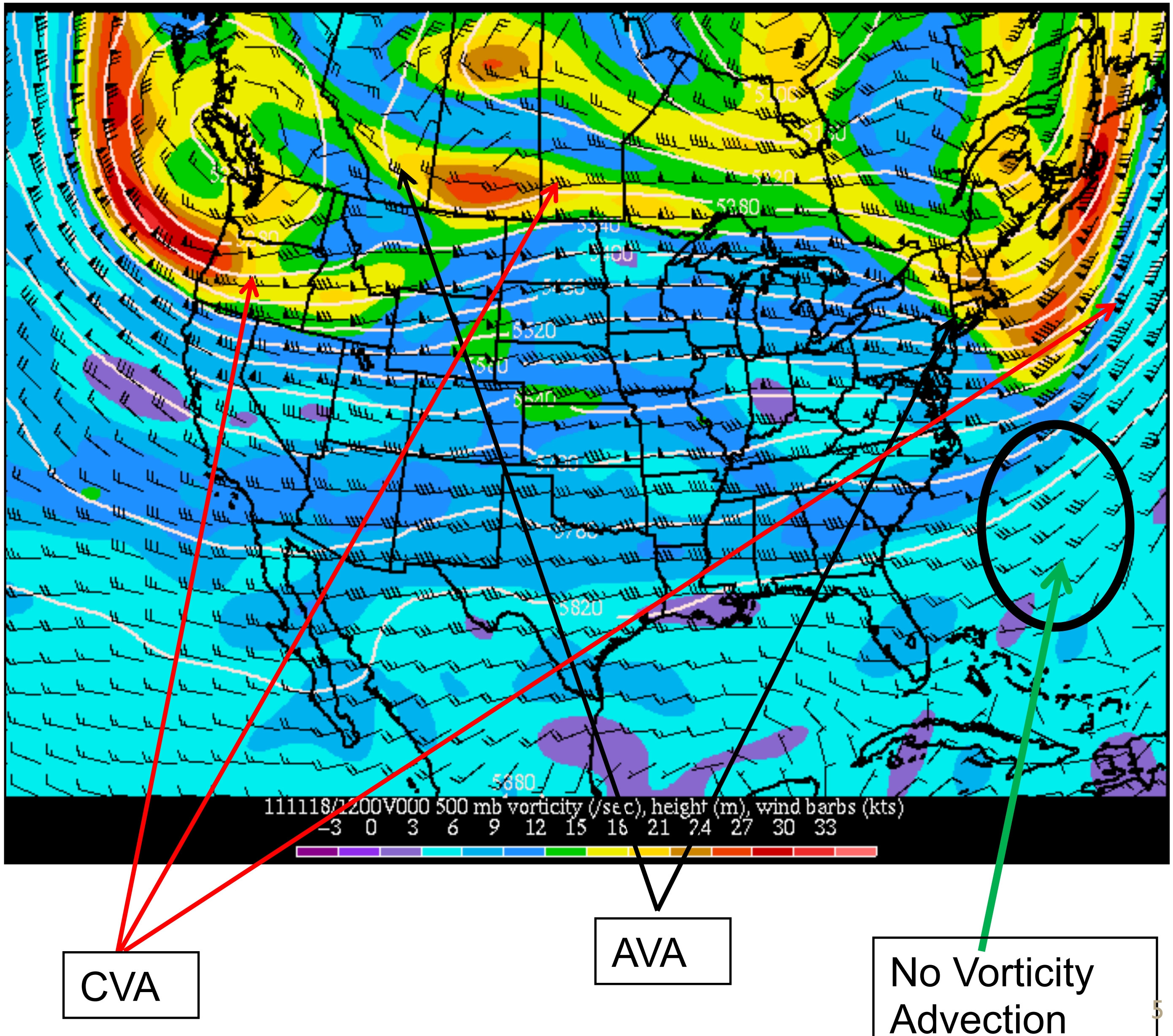
CAA (Cold Air Advection)

No Advection

1) In the location you are interested in, identify the wind direction and the temperature contours (different colors)
2) If the wind direction is parallel with the contours, no advection.
3) If not parallel, determine how the wind is blowing the cold or warm air mass.
If the wind is blowing cold (warm) air to your location of interest, then it's cold (warm) advection.
3) Temperature advection is large if the angle between wind direction and temperature contours is nearly 90 degree, or wind speed is large, or the temperature gradient is large (contours are very close to each other).
4) Temperature advection is zero if no temperature gradient (all same color in an area) or if the wind speed is zero.

How to identify/estimate CVA and AVA on a 500mb vorticity weather map?-- (similar to the analysis of cold/warm advection)

1) In the location you are interested in, identify the wind direction and the vorticity contours (different colors)
2) If the wind direction is parallel with the contours, no advection.
3) If not parallel, determine how the wind is blowing the positive or negative vorticity air mass. If the wind is blowing positive (negative) vorticity air to your location of interest, then it's CVA (AVA).
3Vorticity advection is large if the angle between wind direction and vorticity contours is nearly 90 degree, or wind speed is large, or the vorticity gradient is large (contours are very close to each other).
4) Vorticity advection is zero if no temperature gradient (all same color in an area) or if the wind speed is zero.

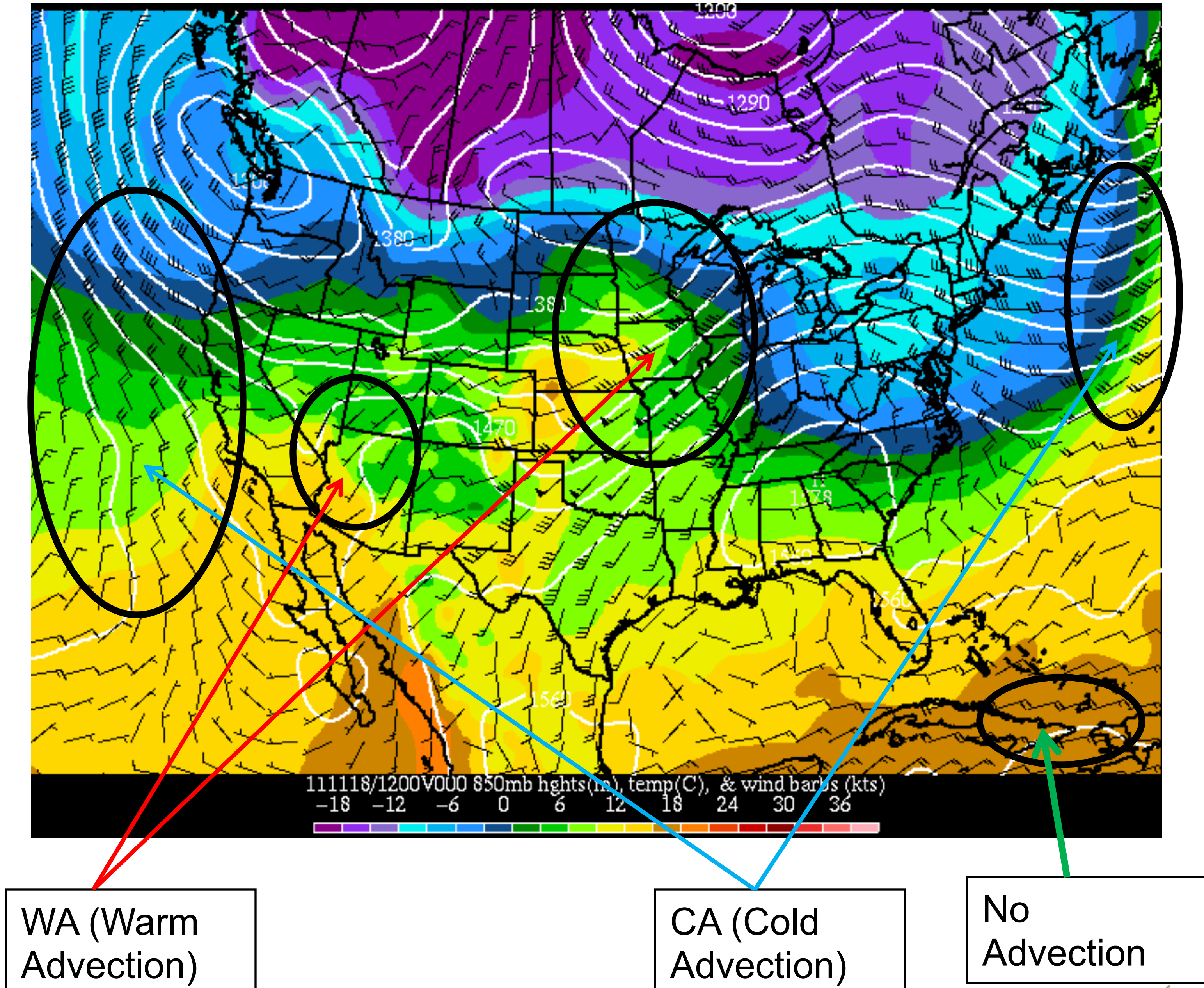


850mb warm advection:

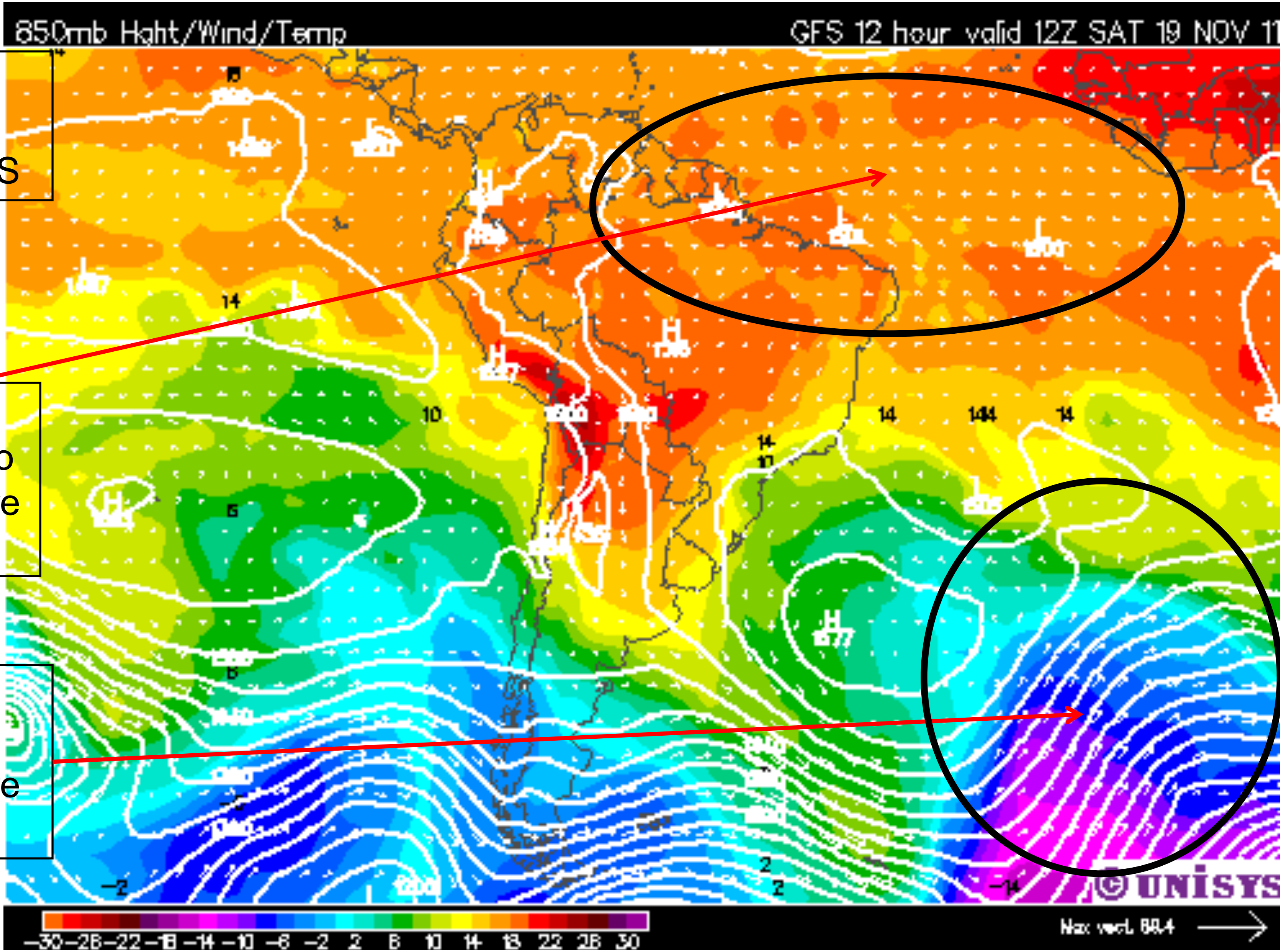
1) Find the location where wind directions have a large angle with the temperature contours.

2) If the wind direction is parallel with the contours, no advection.

3) Temperature advection is large if the angle is nearly 90 degree, wind speed is large, & the temperature gradient is large (contours are very close to each other).



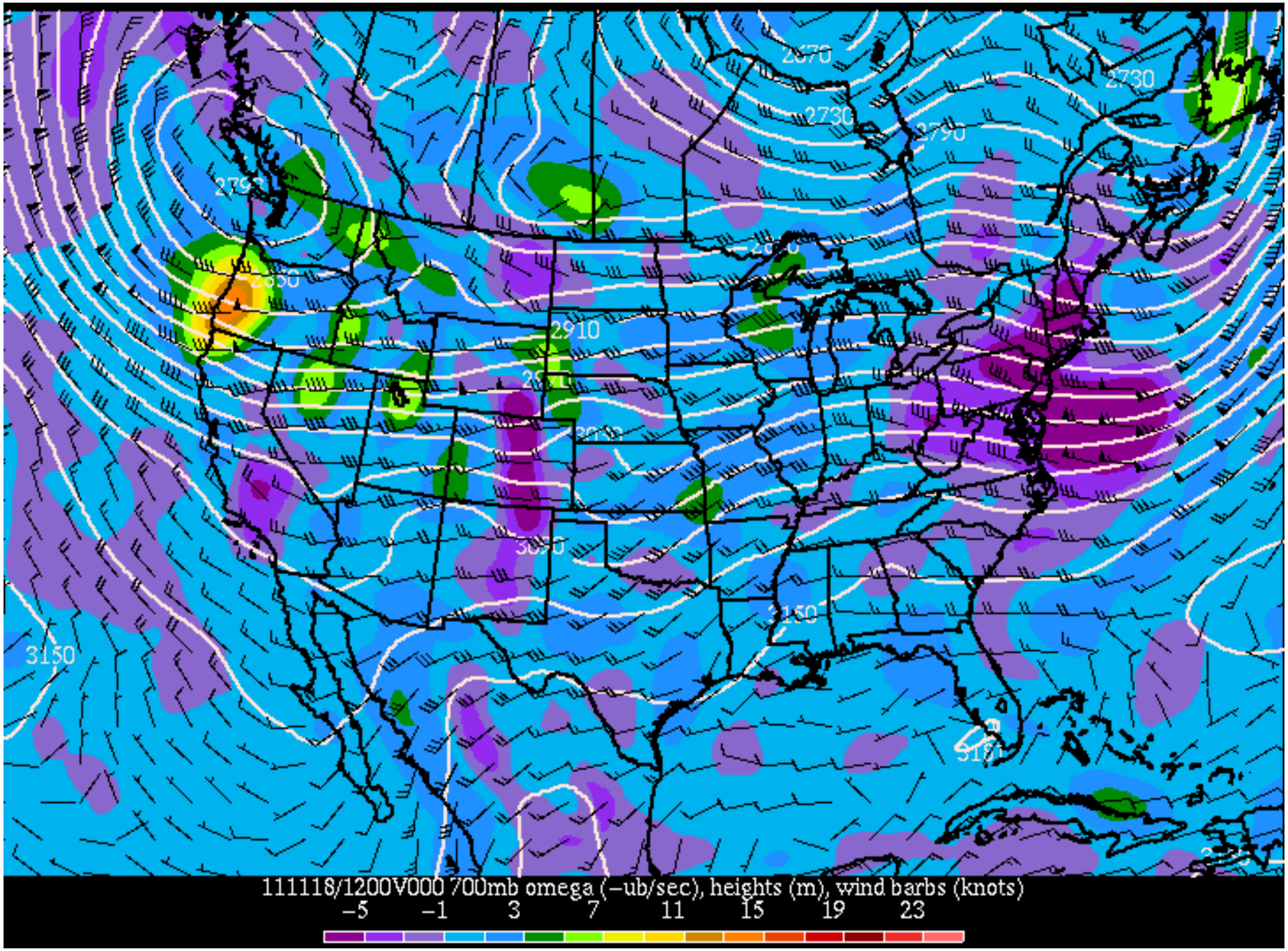
South American, 850mb GFS



Barotropic (small or no temperature advection)

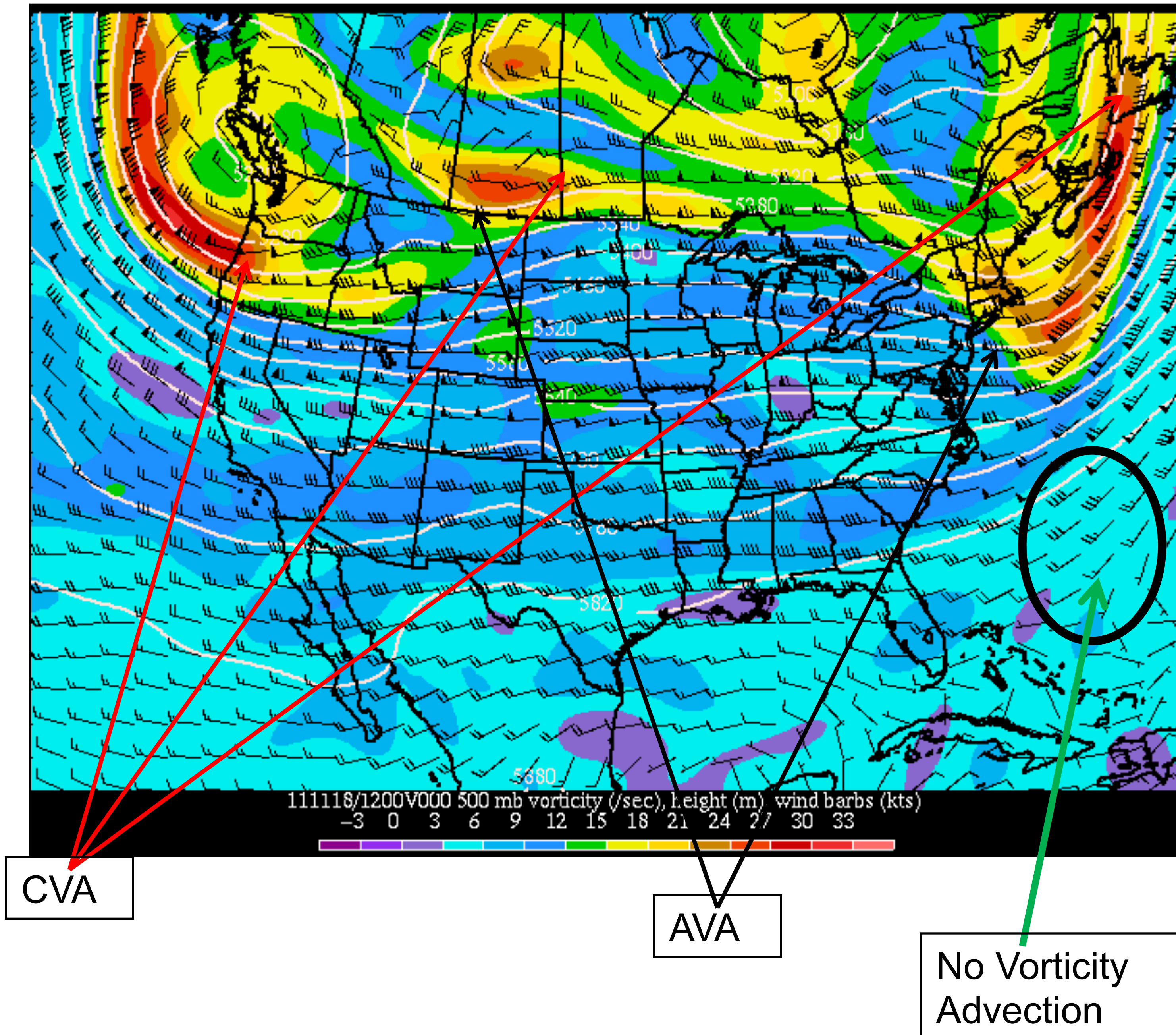
Baroclinic (strong temperature advection)

700mb vertical motion:



500mb CVA:
Always look at "ahead of a trough or behind a ridge"

1) Find the location where wind directions have a large angel with the vorticity contour curves.
2) If the wind direction is parallel with the contours, no vorticity advection.
3) Vorticity advection is large if the angel is nearly 90 degree, and wind speed is large, & the vorticity gradient is large (contours are very close to each other).

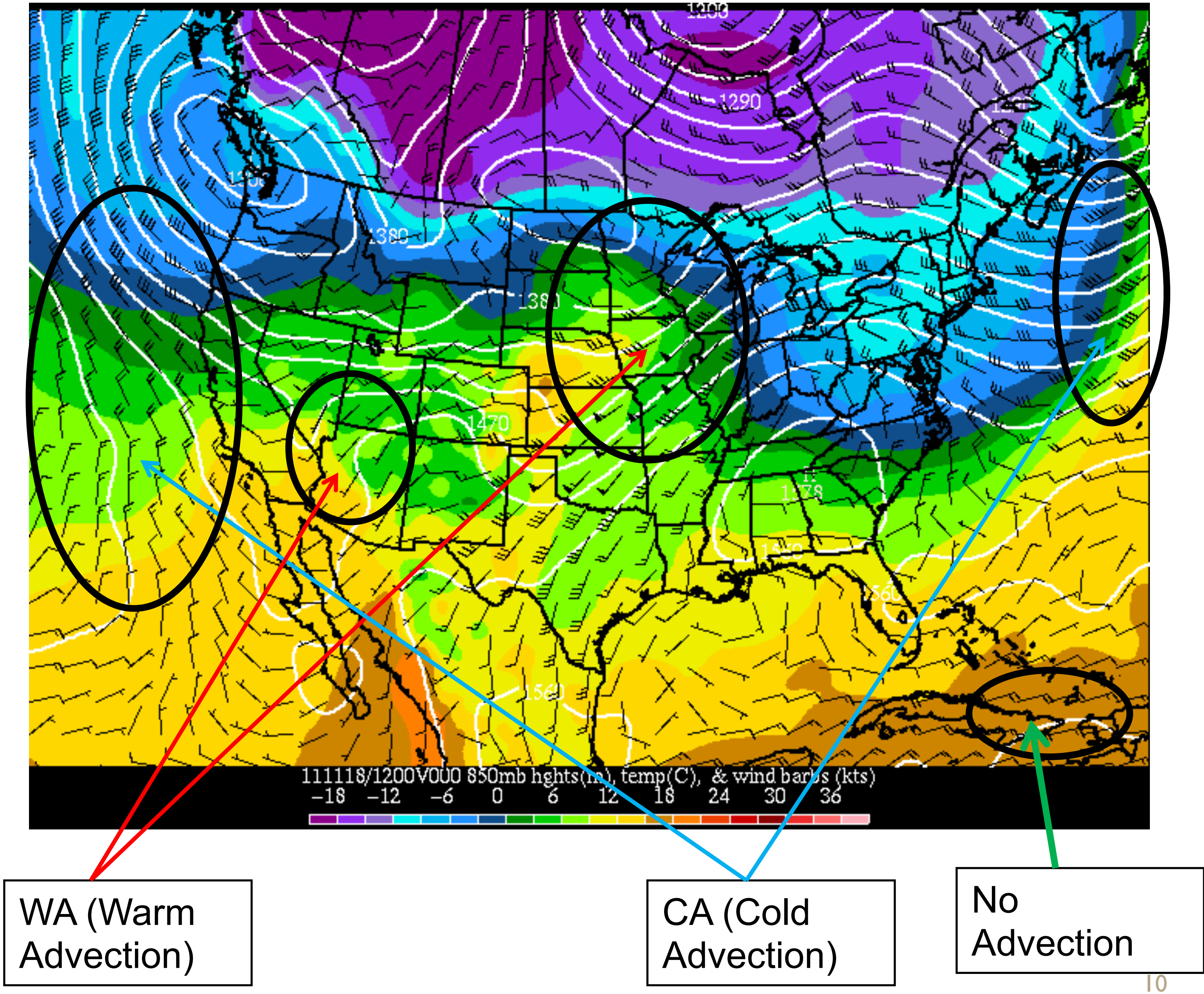


850mb warm advection:

1) Find the location where wind directions have a large angel with the temperature contours.

2) If the wind direction is parallel with the contours, no advection.

3) Temperature advection is large if the angel is nearly 90 degree, wind speed is large, & the temperature gradient is large (contours are very close to each other).



Evaluating Vertical Motion (3)

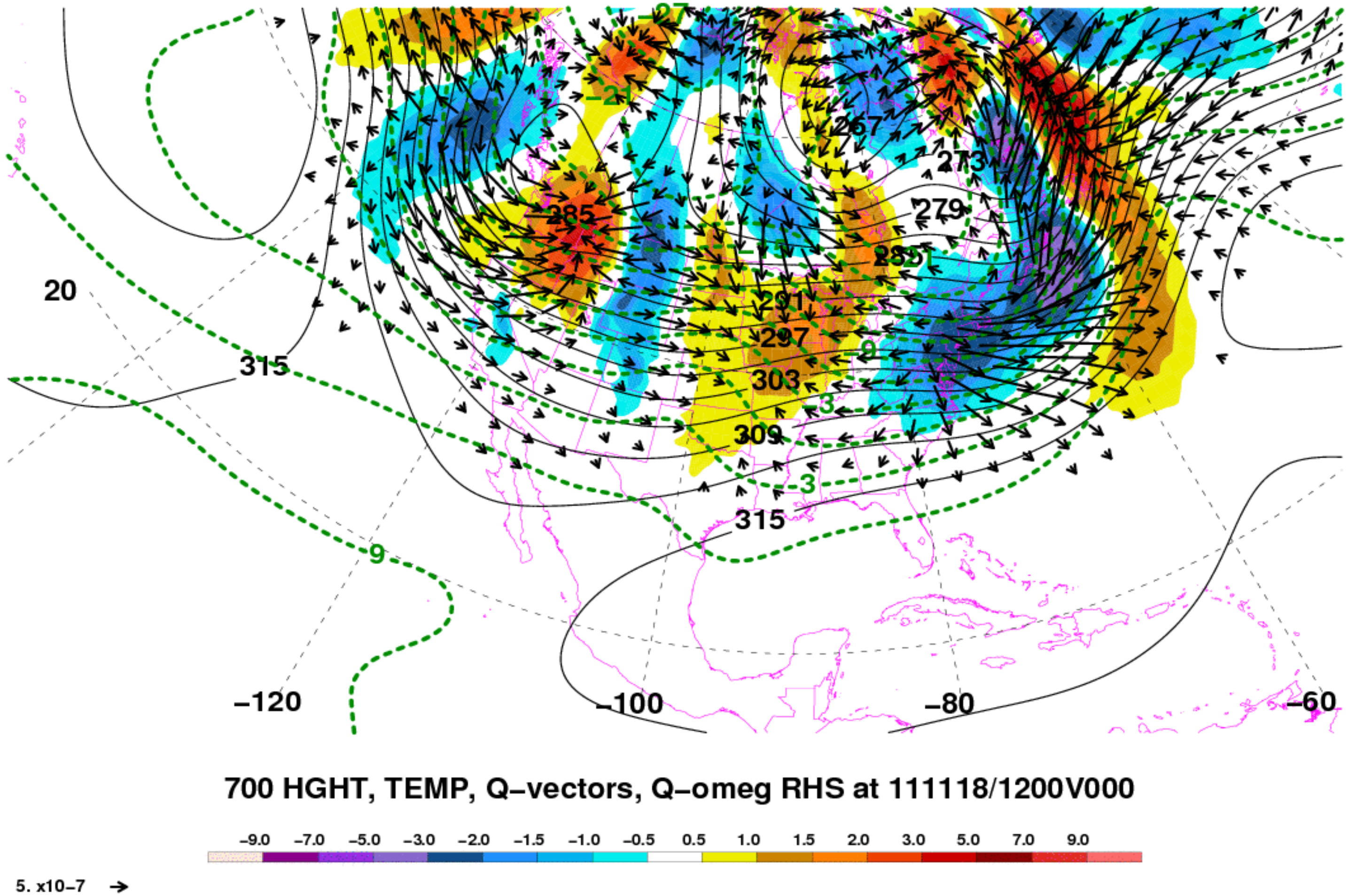
- 3. Q. vector:

1) Also based on QG theory: one more assumption (assume f is constant) in addition to traditional Omega Eq; Can infer W at a given level using Q-vector at that level

Q-vector convergence → **rising motion**

Q-vector divergence → **sinking motion**

2) No cancellation of terms as in traditional Omega Eq.
3) Difficult to evaluate without a computer
4) Can be noisy with high-resolution model output



Caption:

+700 hPa geopotential height (solid contours every 3 dam).

+700 hPa temperature (dashed contours every 3°C).

+700 hPa Q-vectors (arrows > 2.5×10^{-7} Pa m^{-1} s^{-1}).

+Total RHS of the Q-vector form of the QG Omega equation [shaded according to the colorbar (10^{-12} Pa m^{-2} s^{-1})]. Warm (cold) colors denote regions of forcing for 700 hPa ascent (descent).

+Image was generated from 1.0x1.0° NCEP-GFS data smoothed by a Gaussian filter with a weight of 25.

Evaluating Vertical Motion (4)

- 4. Jet Max:

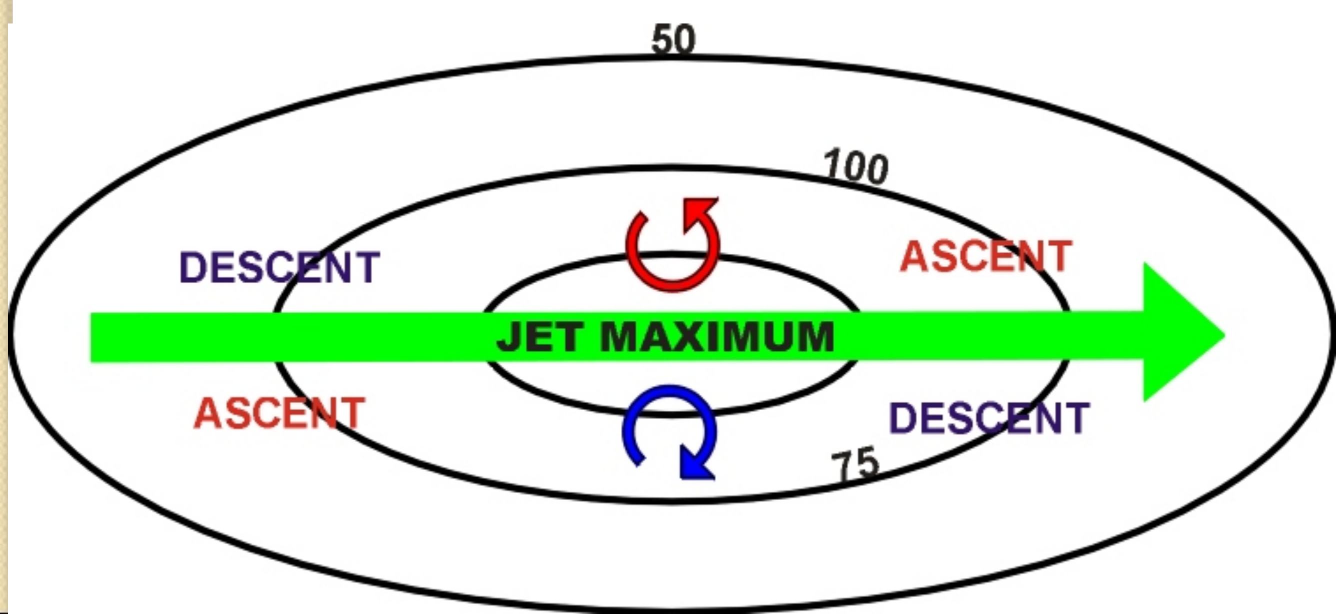
1) 4-quandrant model:

Rising motion: Right Entrance and Left Exit

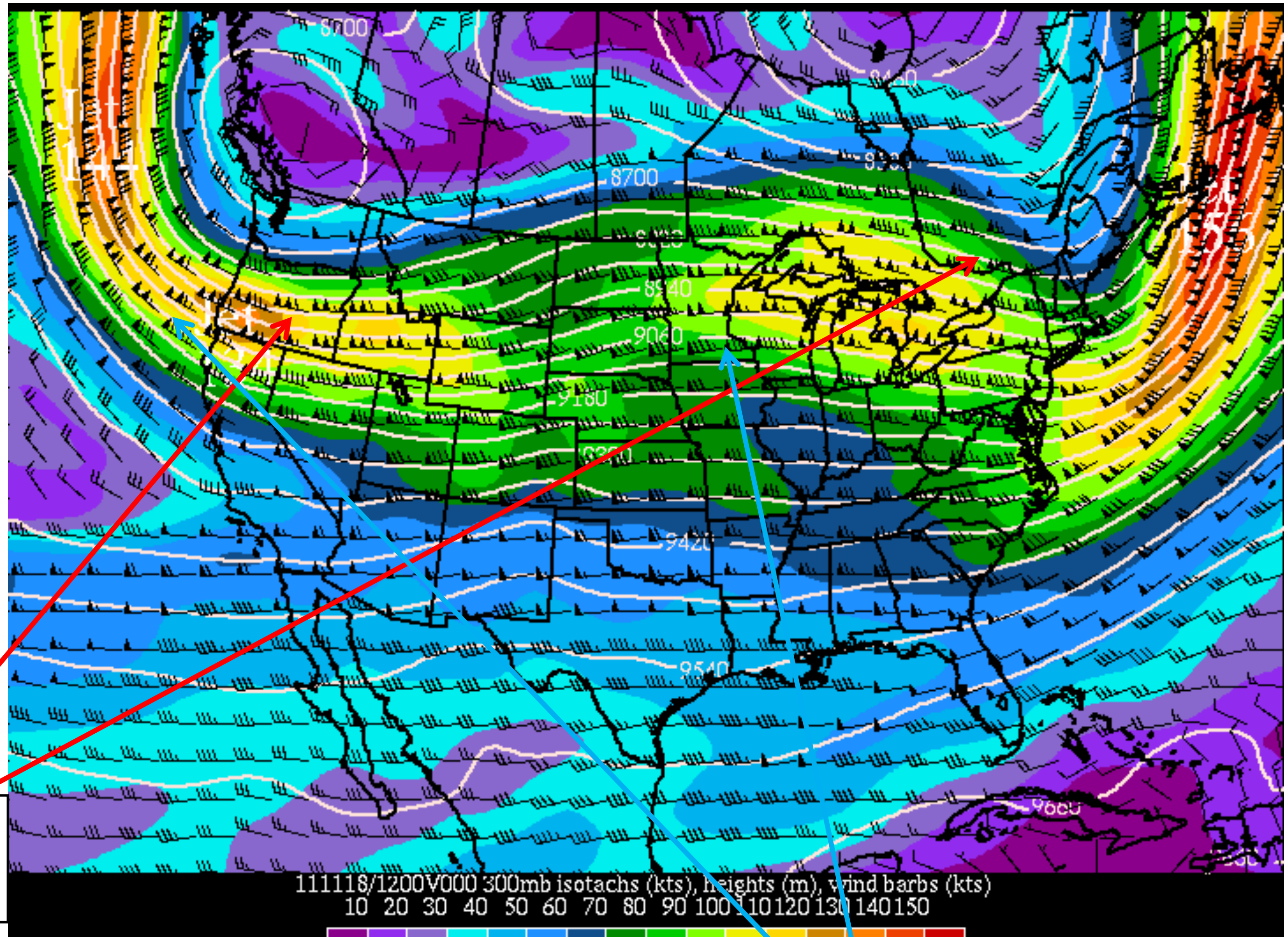
Sinking motion: Left Entrance and Right Exit

2) Can only be applied when strong Jet Max exists.

3) Not as good as using 500mb CVA & 850 mb WA if Jet is not strong or not in right location



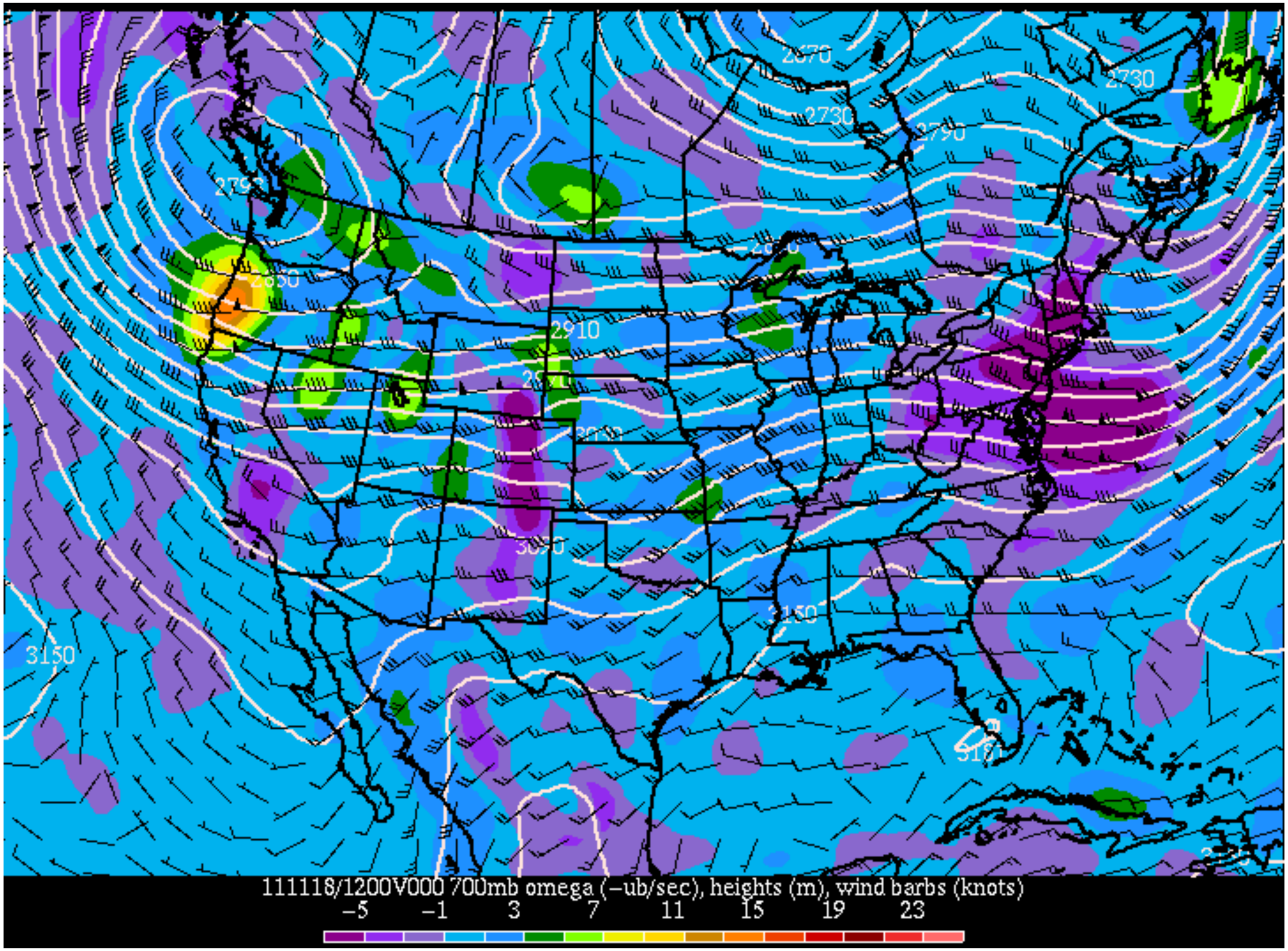
300mb Jet: 12 Z Nov. 18



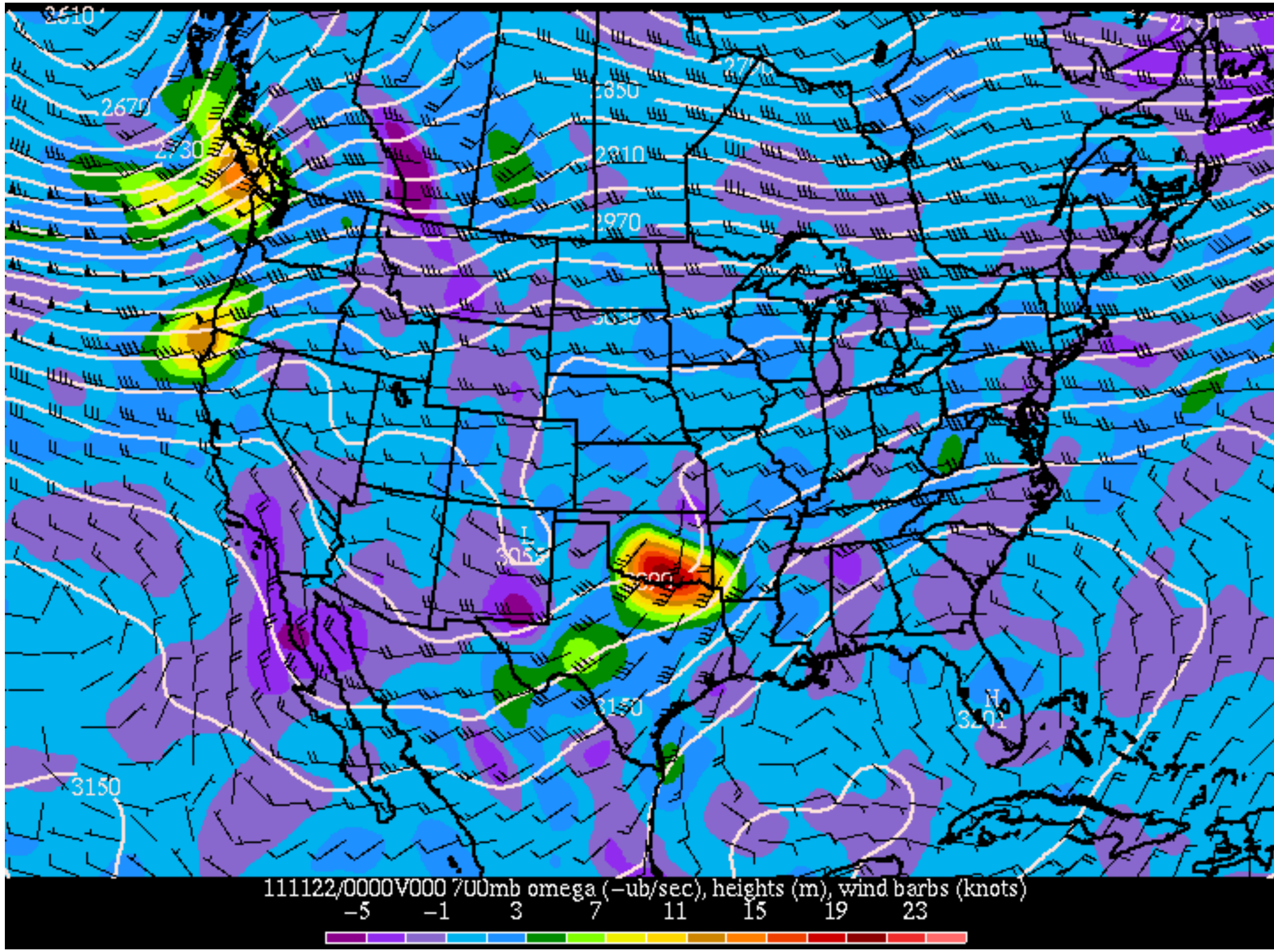
Left Exit: Rising Motion

Right Entrance: rising Motion

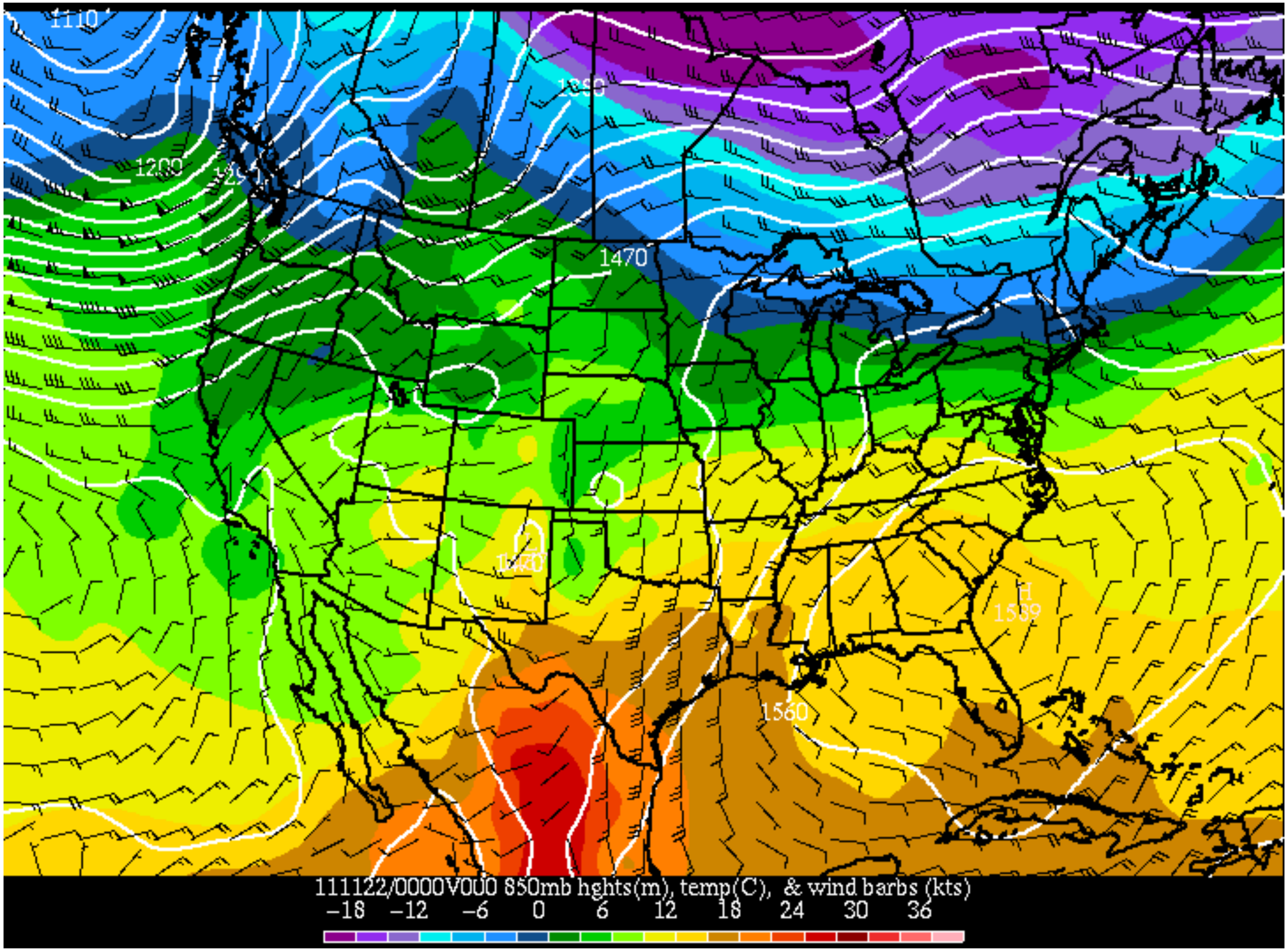
700mb vertical motion: 12 Z Nov 18



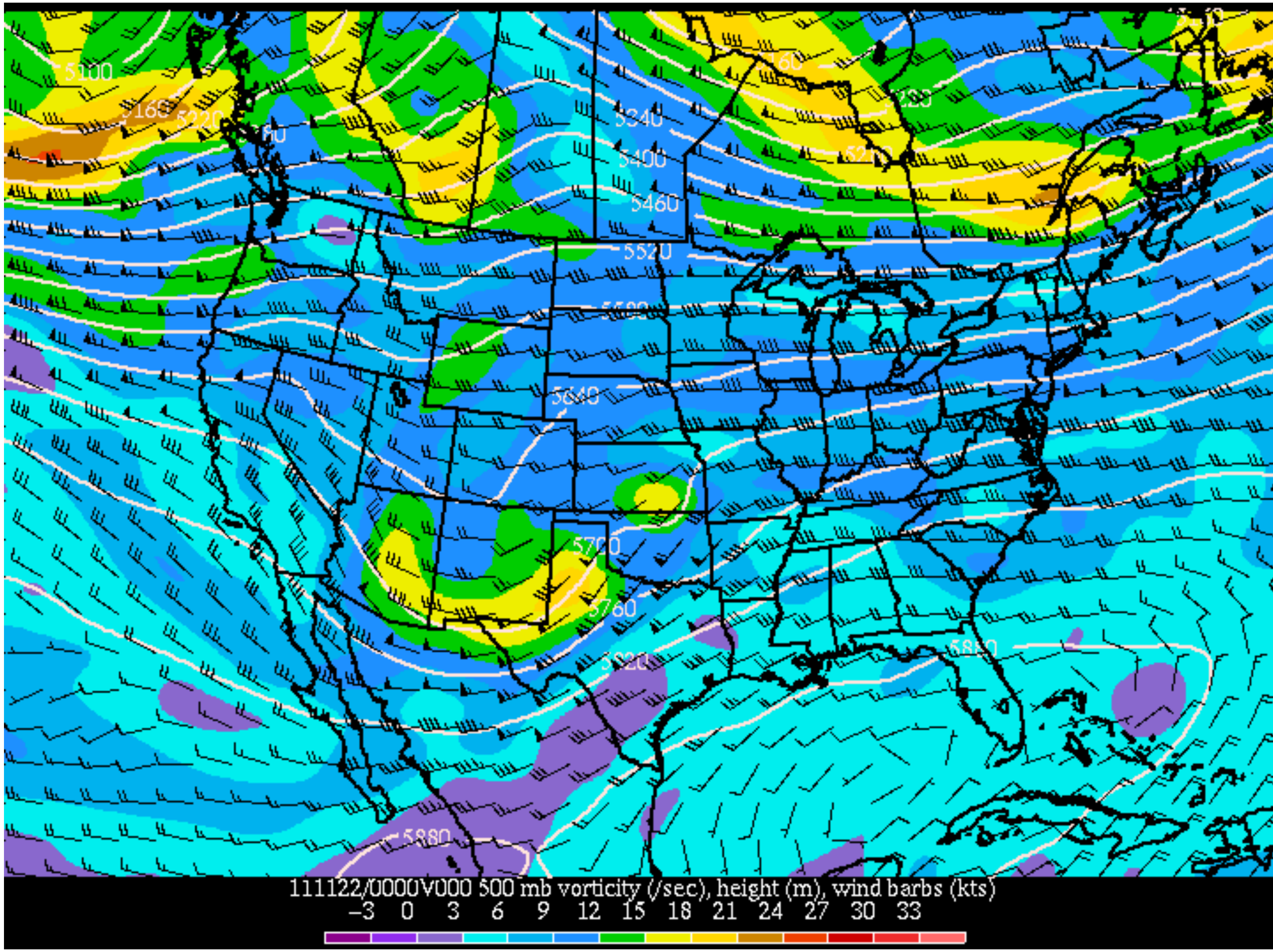
2011 Nov. 22
00 Z maps
700 mb
Vertical
motion



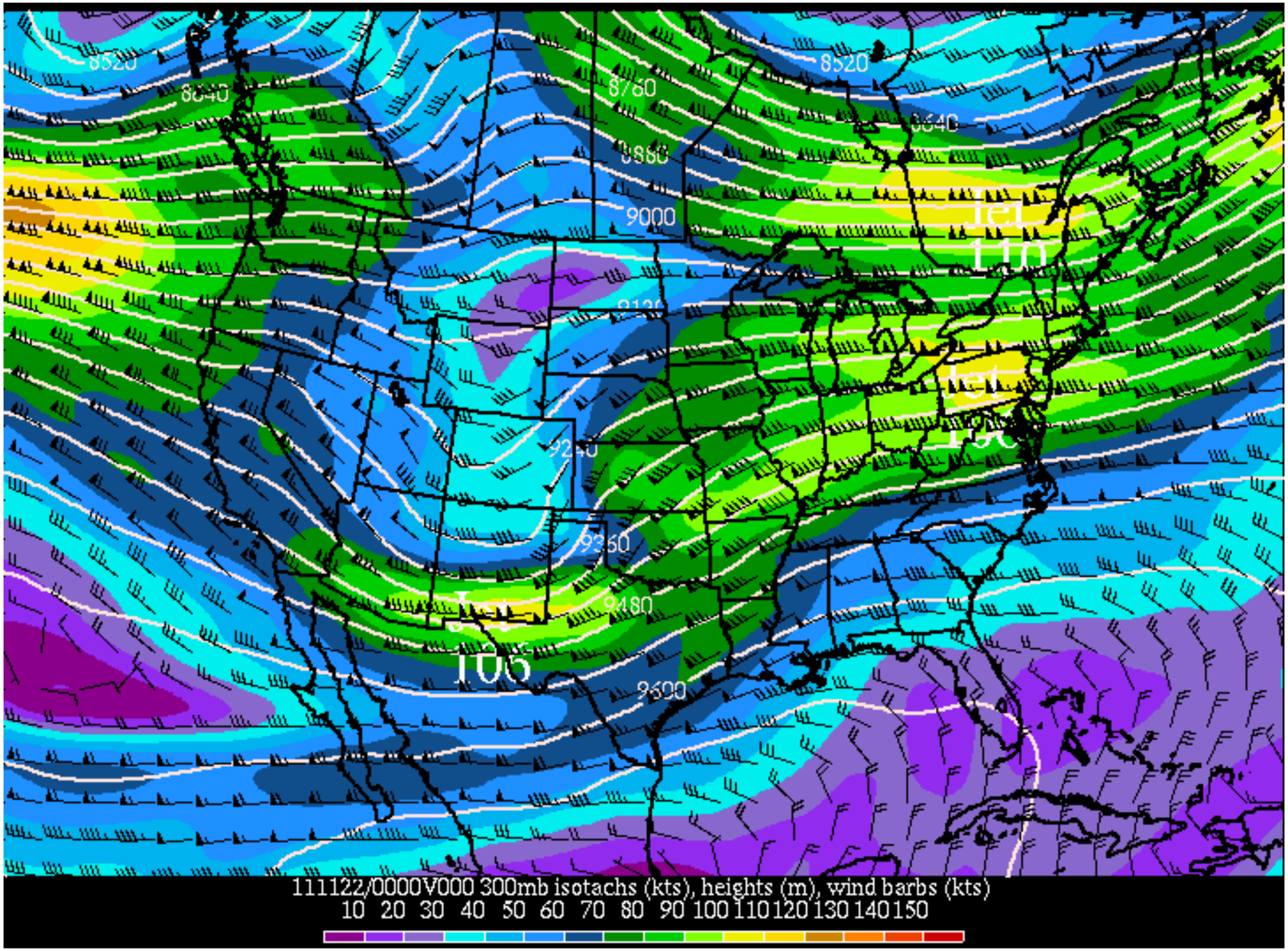
2011 Nov. 22
00 Z maps
850 mb
Temperature



2011 Nov. 22
00 Z maps
500 mb
Vorticity



2011 Nov. 22
00 Z maps
300 mb Jet



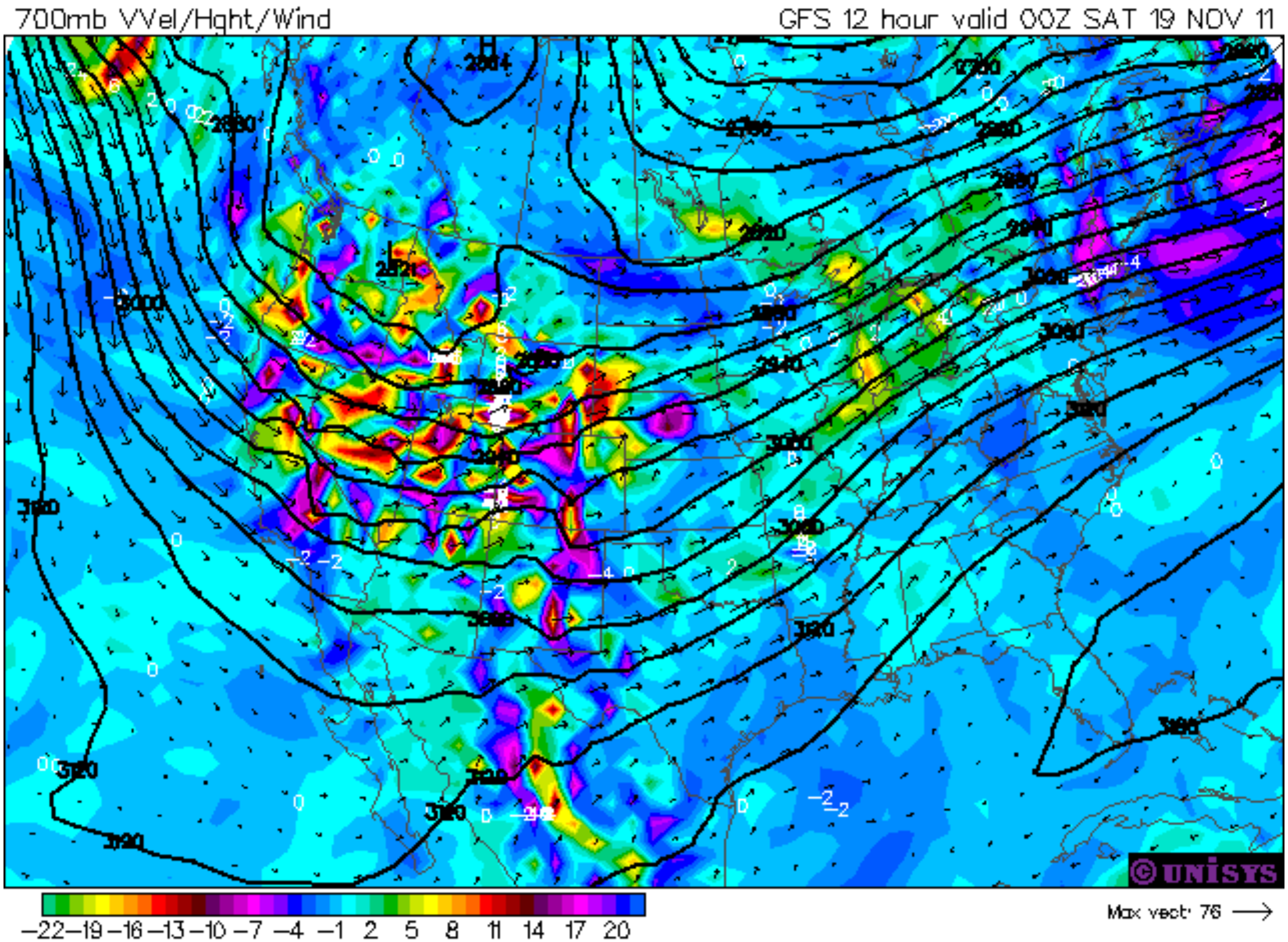
Evaluating Vertical Motion (5)

- 5. Raw model output:

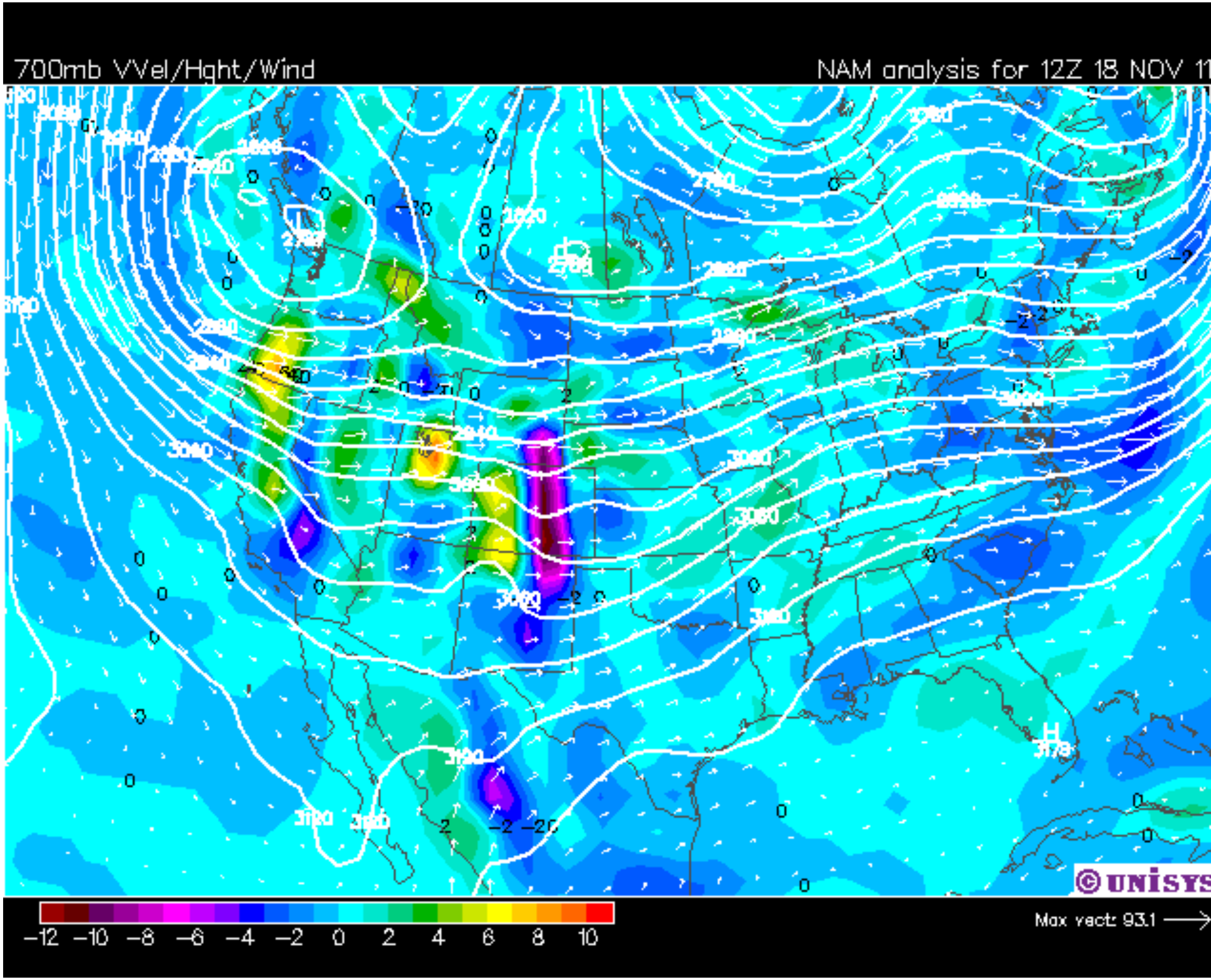
  1) Typically uses kinematic method, nonhydrostatic models explicitly solve for W or Omega
  2) Gives you a “full” physical W
  3) Subject to model errors arising from initial condition uncertainty, error growth, problems with model physics, & poorly resolved terrain
  4) Model analysis Omega not based on a dynamically adjusted flow field

- Conclusion: Do not rely on any one technique. Know the strength & weakness of each method.

GFS Model (hydrostatic model)



NAM (non-hydrostatic model)



Diagnosing Upper-level troughs and ridges

- QG Height Tendency Eq.:

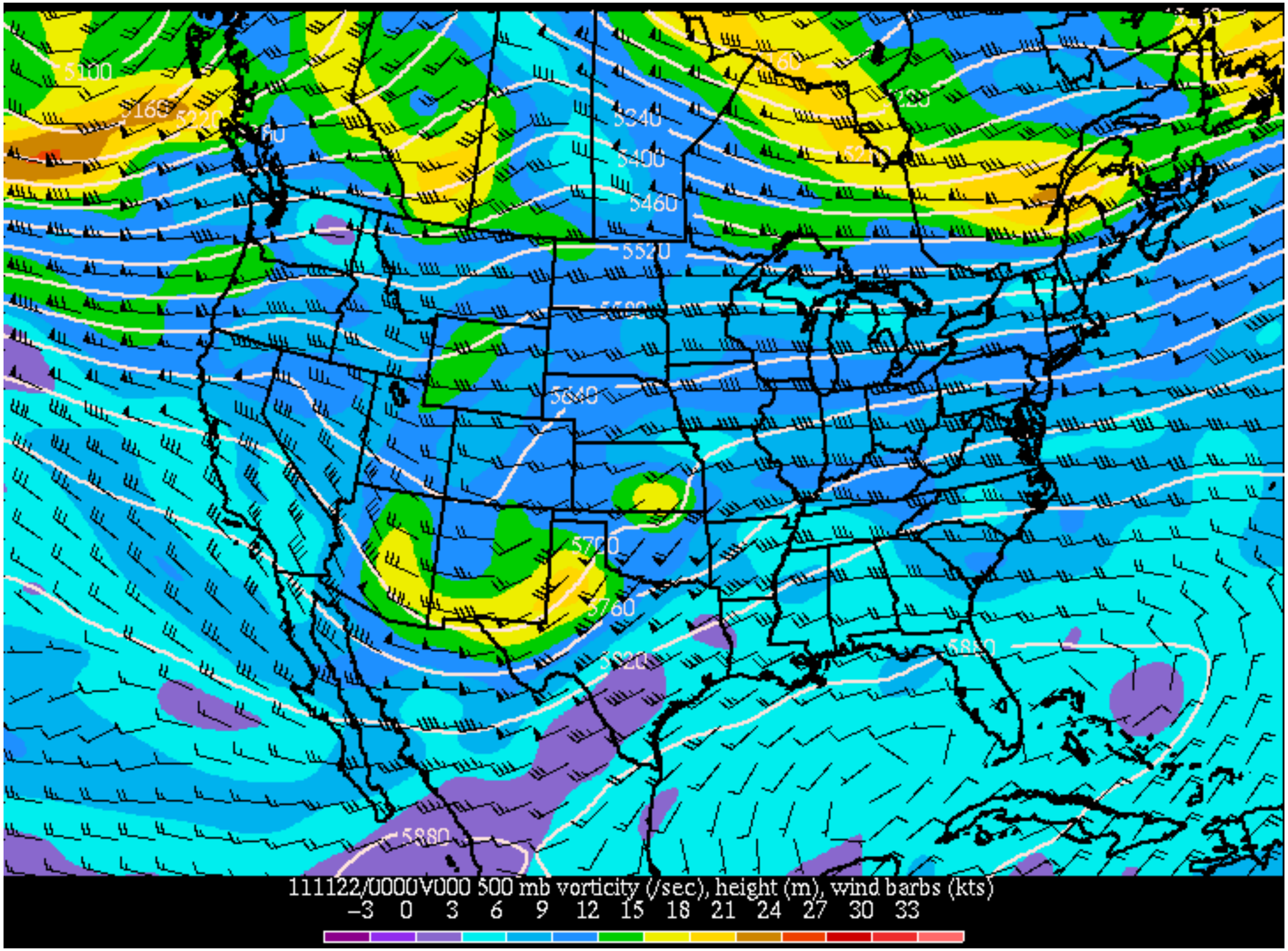
1) X is proportional to (geostrophic vorticity advection) =>
   - CVA → **Height falls**
   - AVA → **Height rises**
2) X is proportional to (differential temperature advection with respect to height =>
   - Positive differential temperature advection (increasing with height) -> X<0 → **Height falls**
   - Negative differential temperature advection (decreasing with height) -> X>0 → **height rises**

QG Height Tendency Equation

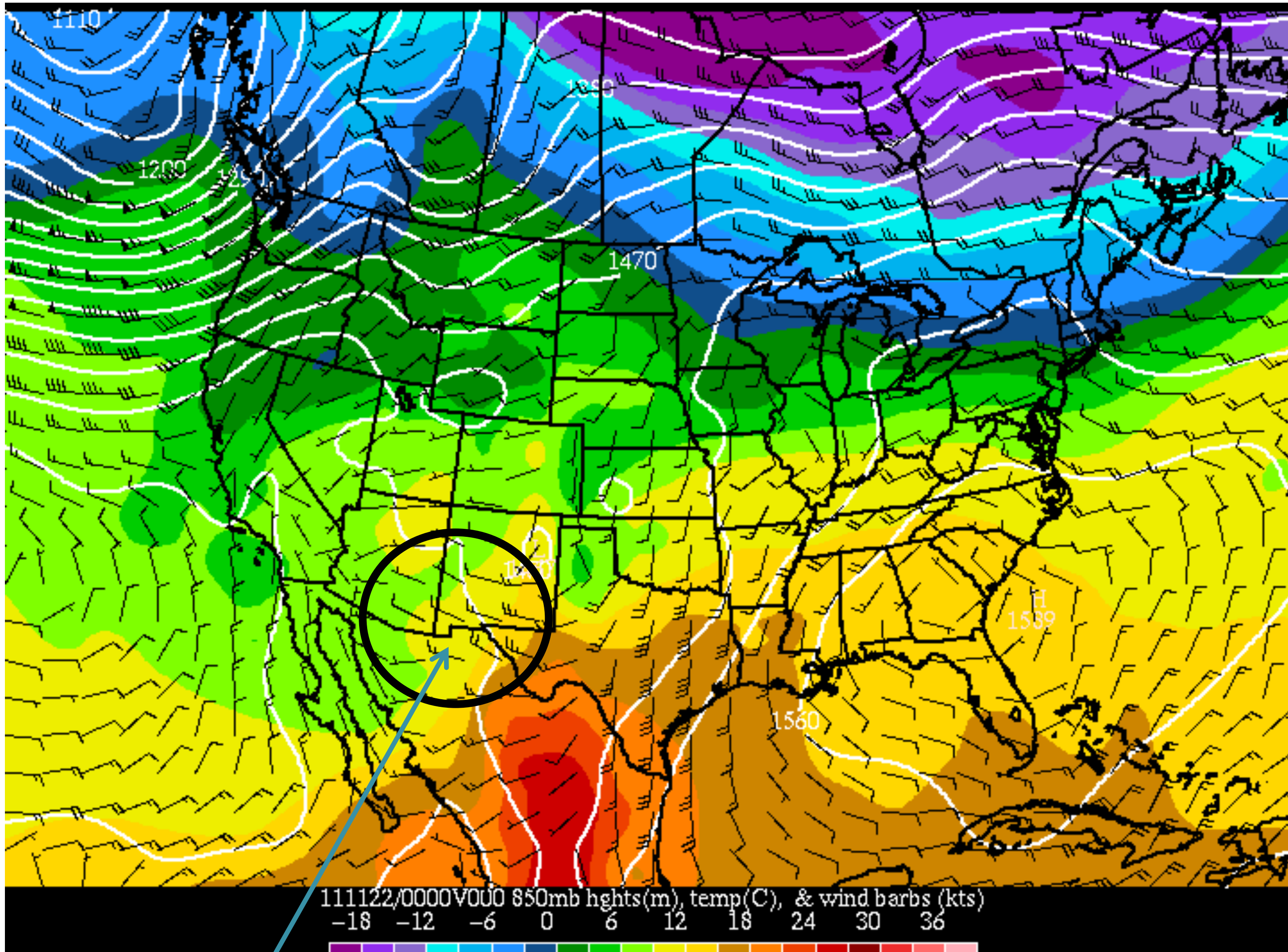
- Synoptic Applications:
  - 1) Warm advection above an upper level trough will tend to deepen the trough
  - 2) Cold advection above an upper level ridge will tend to build the ridge
  - 3) Cold advection beneath an upper level trough will tend to deepen the trough
  - 4) Warm advection beneath an upper level ridge will tend to build the ridge
  - 5) Best situation for building an upper-level ridge is lower level warm advection & upper level cold advection
  - 6) Best situation for deepening an upper-level trough is lower level cold advection & upper level warm advection
  - 7) Always remember it is how the advection changes with height matters!

A weak, opposite case:

500 mb @00Z Nov. 22

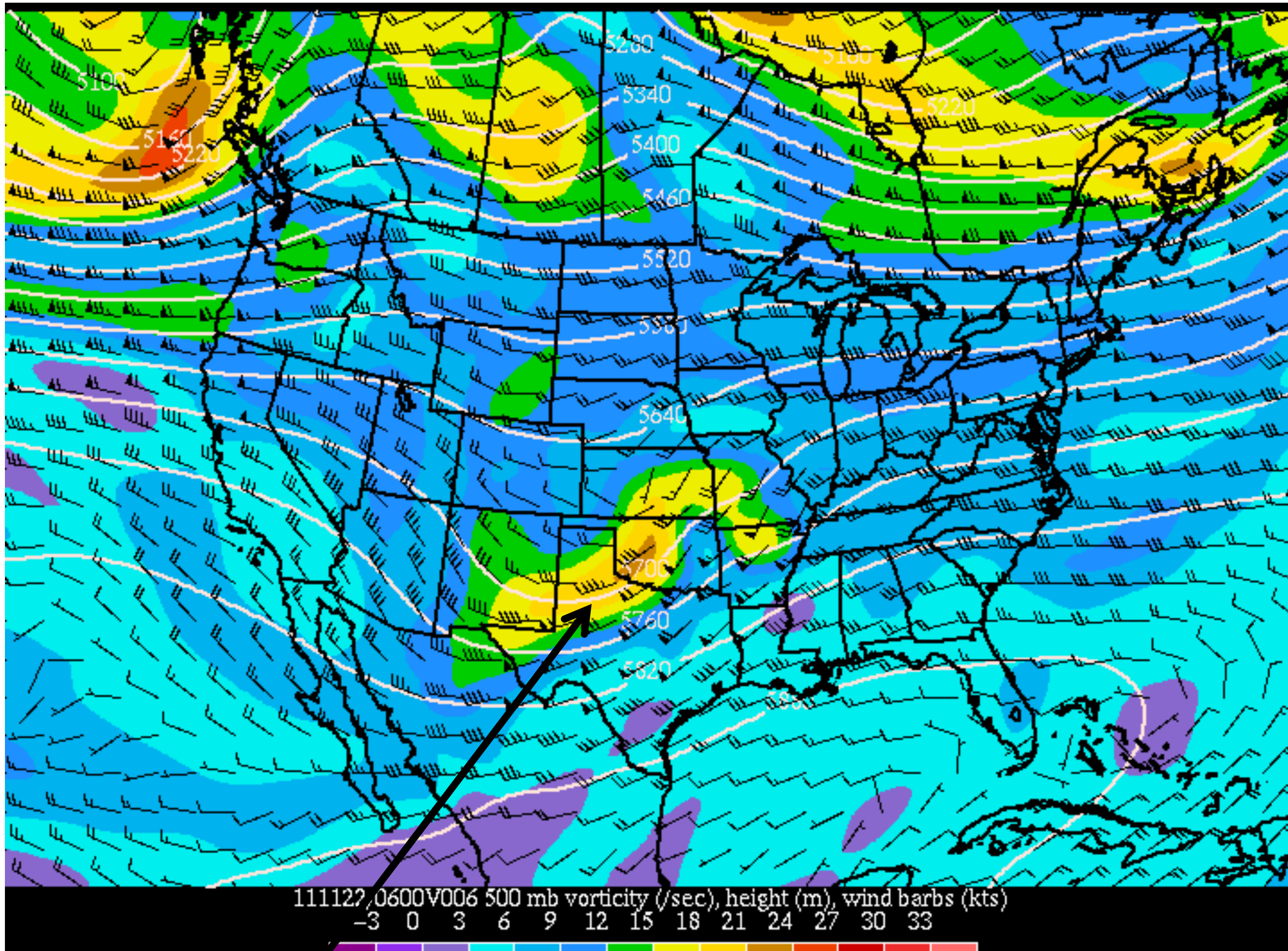


850 mb
@00Z Nov. 22



Cold advection beneath the trough

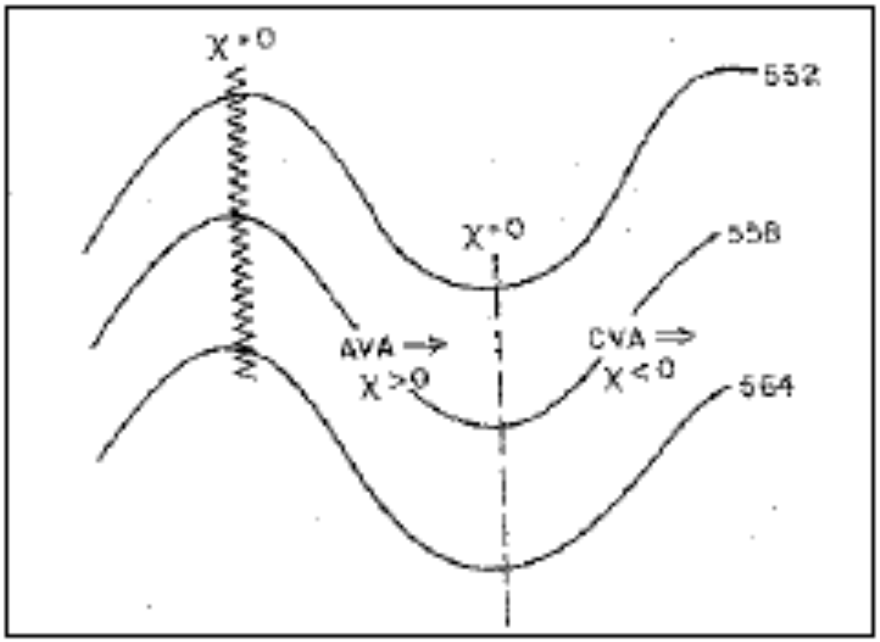
500 mb 00Z Nov. 22 6-h forecast for 06 Z Nov. 22



The trough fills (weakens) 6-h later, Why? – need to look at different levels; also there could be term cancellations. Need consider vorticity advection as well.

Diagnosing Upper-level troughs and ridges

Effect of Vorticity Advection

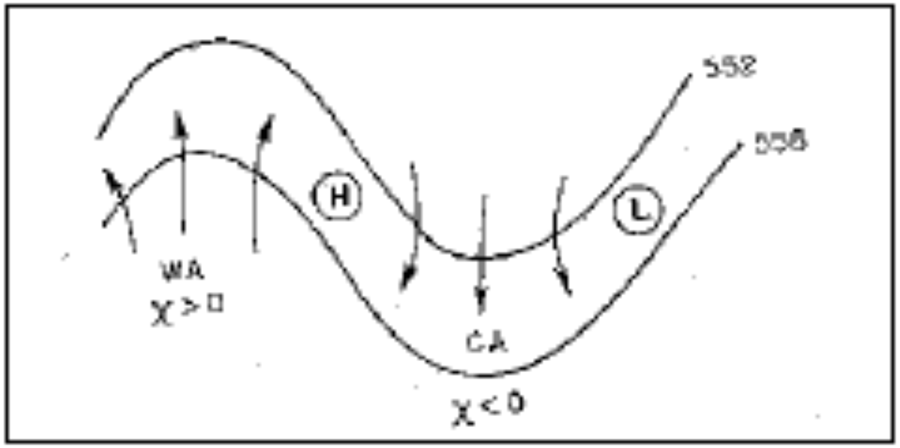


Bluestein 1993

- Idealized upper-level wave
- No geostrophic vorticity advection along trough/ridge axes
- Vorticity advection does not amplify wavetrain
- Vorticity advection results in eastward trough/wave movement

Diagnosing Upper-level troughs and ridges

Effect of Temperature Advection

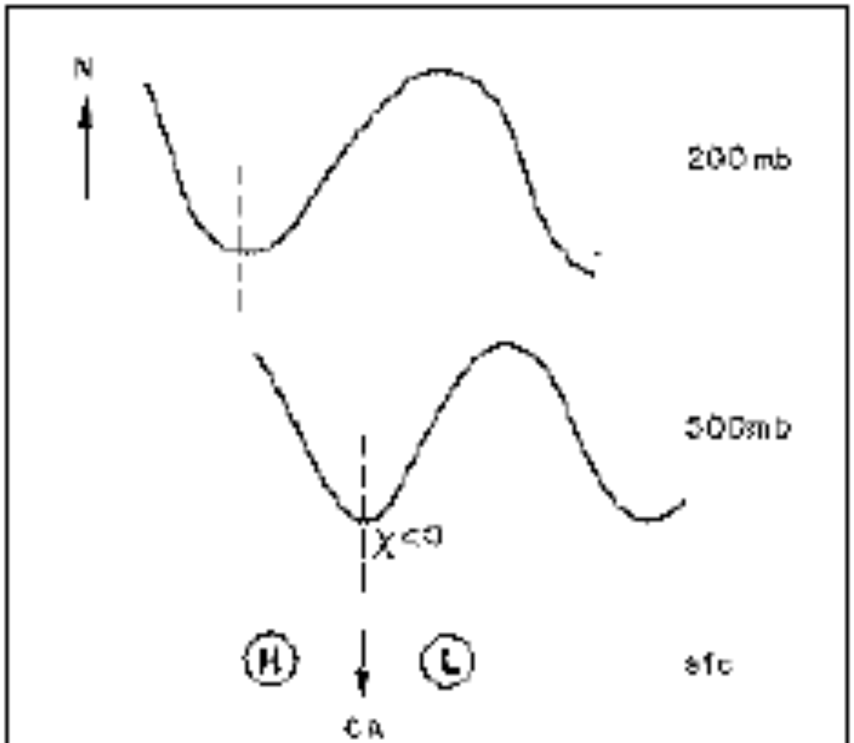


Bluestein 1993

- Idealized upper-level wave with low-level low/high pressure systems
- Temperature advection deepens trough, builds ridge

Diagnosing Upper-level troughs and ridges

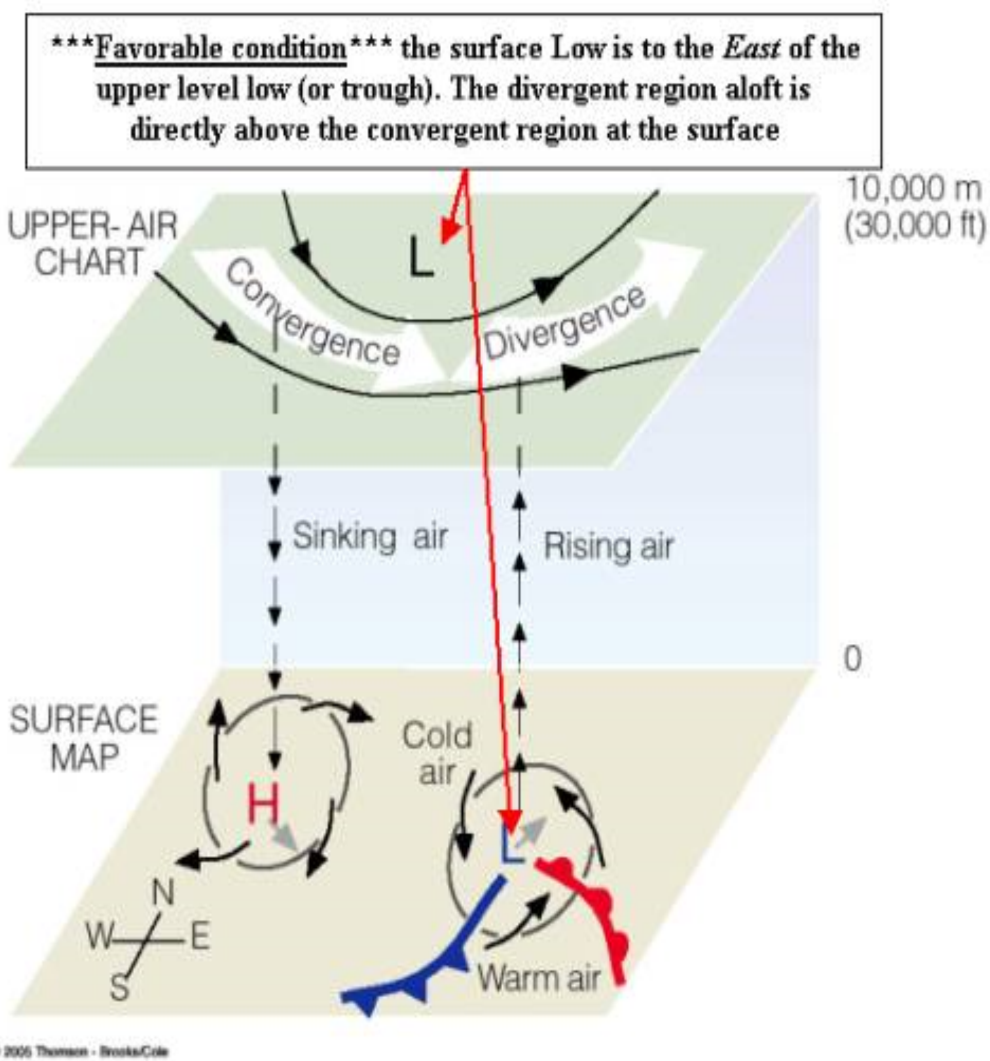
Effect of Vertical Tilt



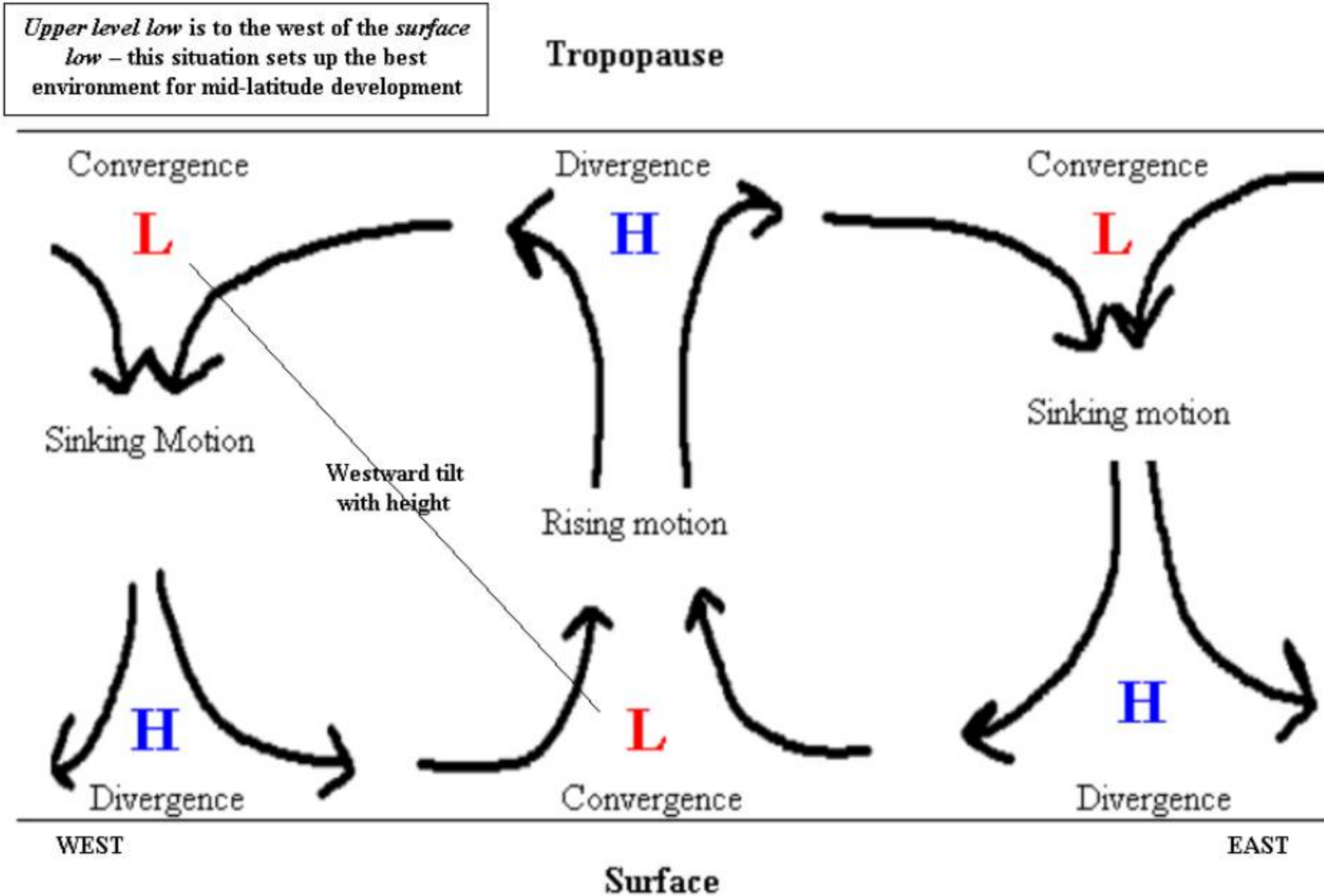
Bluestein 1993

- Low-level cold advection beneath 500-mb trough
- Upper-level warm advection above 500-mb trough
- Optimal situation for height falls in base of 500-mb trough

Best Situation for Surface Cyclone Development



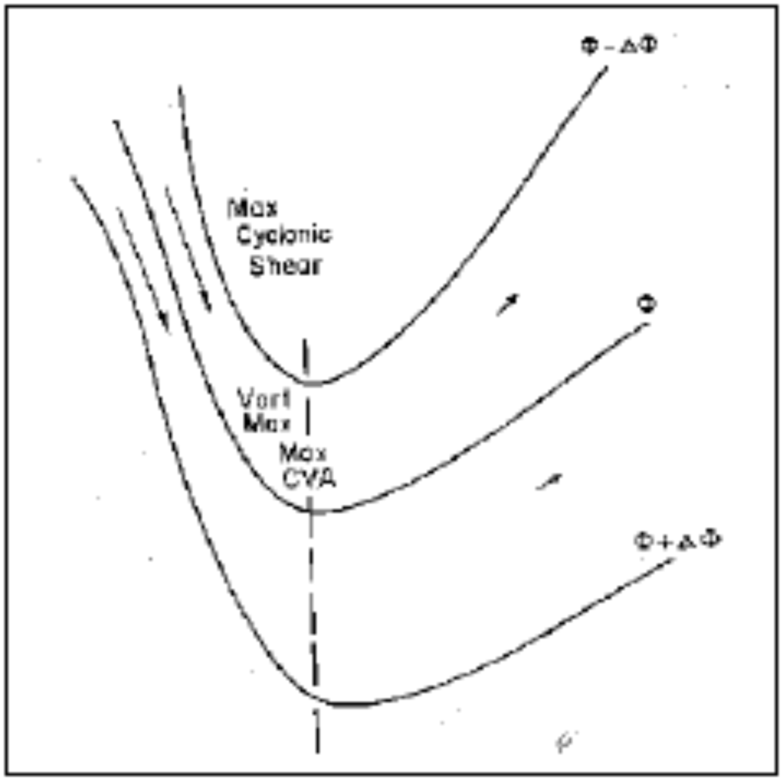
- The best situation for surface cyclone development is the upper level low is to the west of the surface low.
- In a curved upper-level flow, the wind is subgeostrophicon the trough axis, and supergeostrophic on the ridge axis, causing convergent flow upstream of a trough and divergent flow downstream of a trough.
- In this situation, the upper-level divergence is right above the surface low, and is favorable for the rising motion above the surface low.



Upper level low is to the west of the *surface low* – this situation sets up the best environment for mid-latitude development
Tropopause
Convergence
Divergence
Convergence
L
H
L
Sinking Motion
Westward tilt with height
Rising motion
Sinking motion
H
L
H
Divergence
Convergence
Divergence
WEST
EAST
Surface

Diagnosing Upper-level troughs and ridges

The Digging Upper-Level Trough

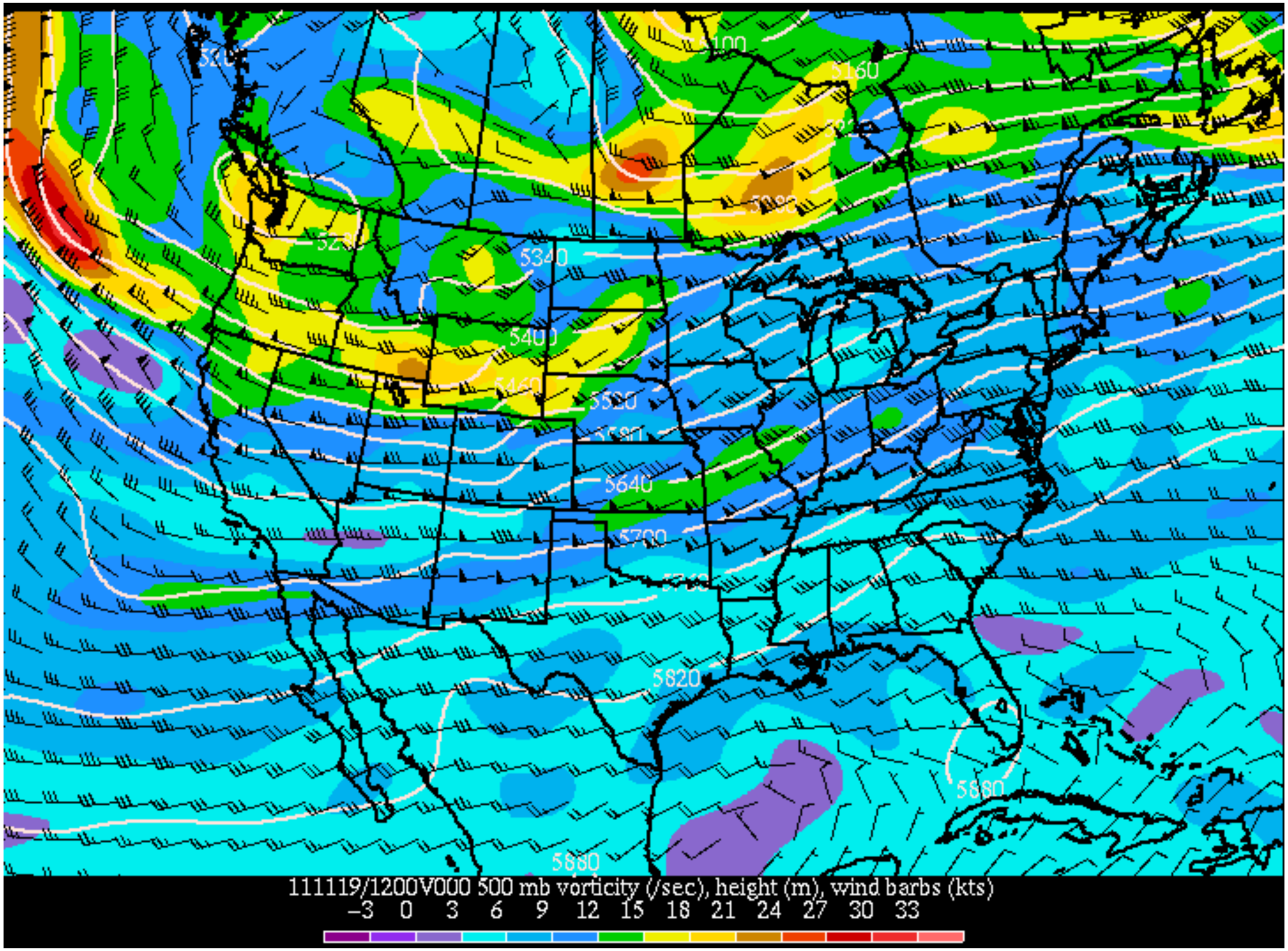


Bluestein 1993

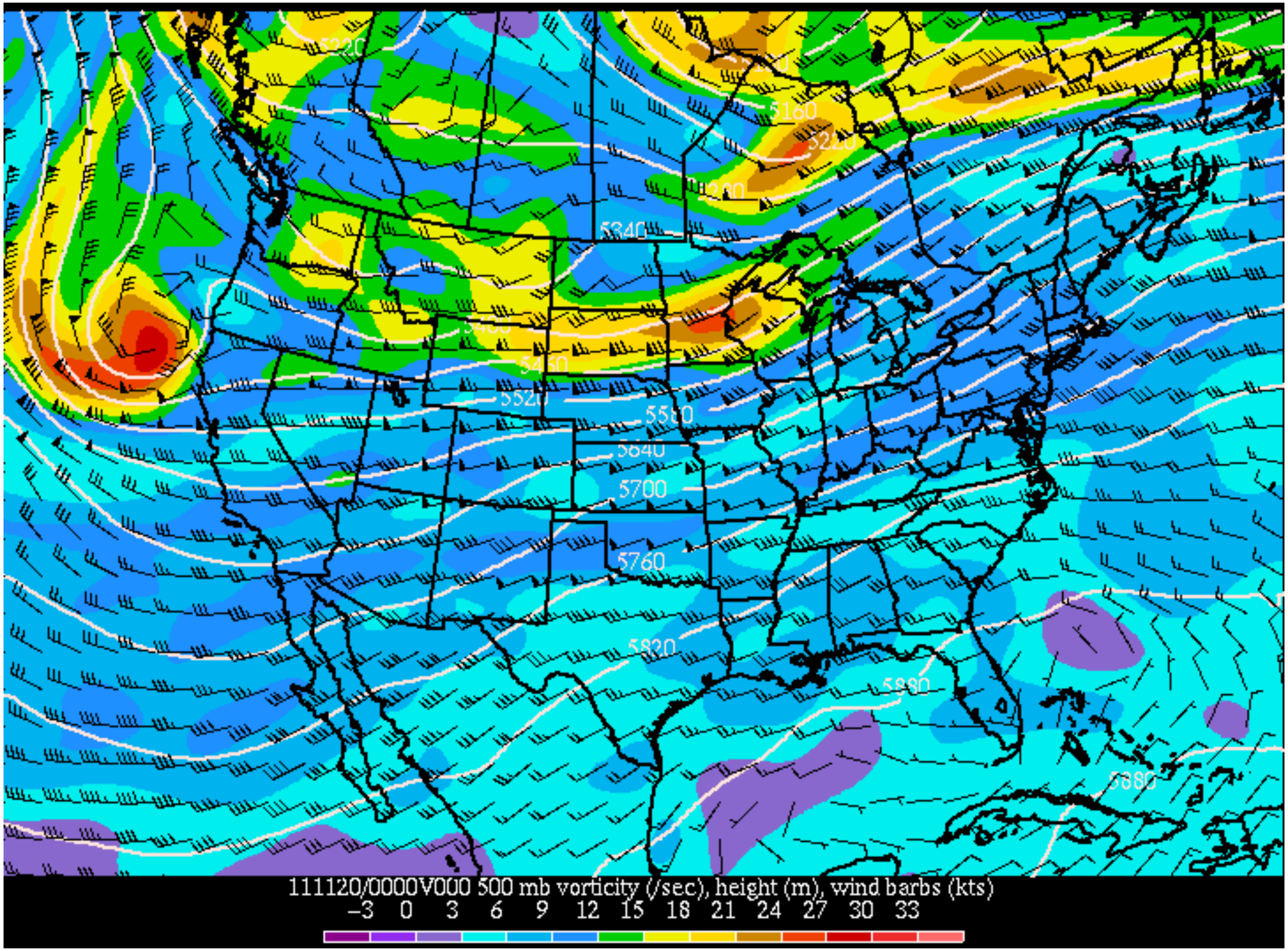
- Diffluent upper-level trough with upstream winds that are stronger than downstream winds
- Due to speed shear, vort max is now upstream of trough axis
- CVA and height falls are along trough axis
- Trough amplifies and has an equatorward component of motion ("amplify and dig")

500mb:

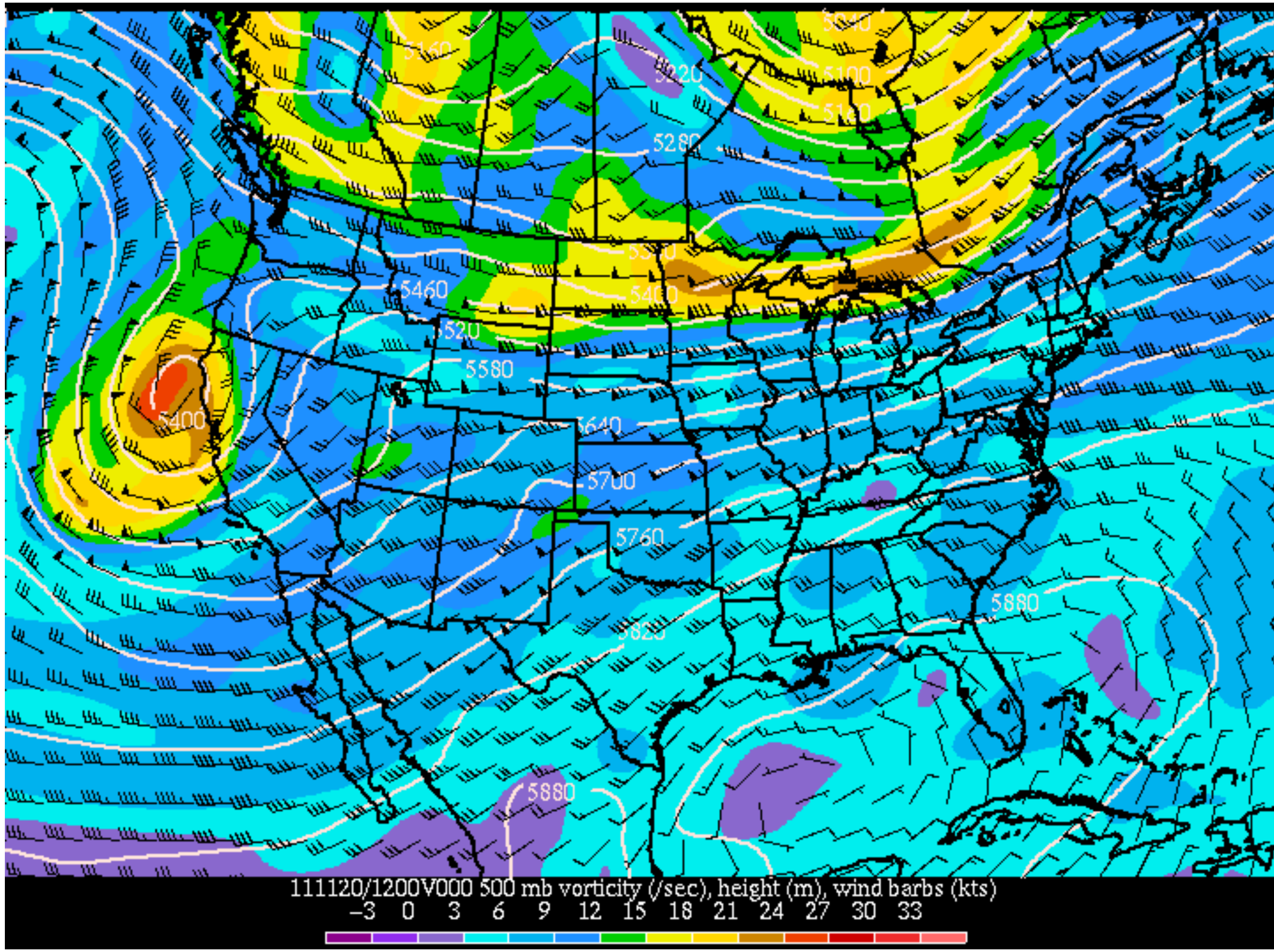
Digging Trough
12Z Nov. 19



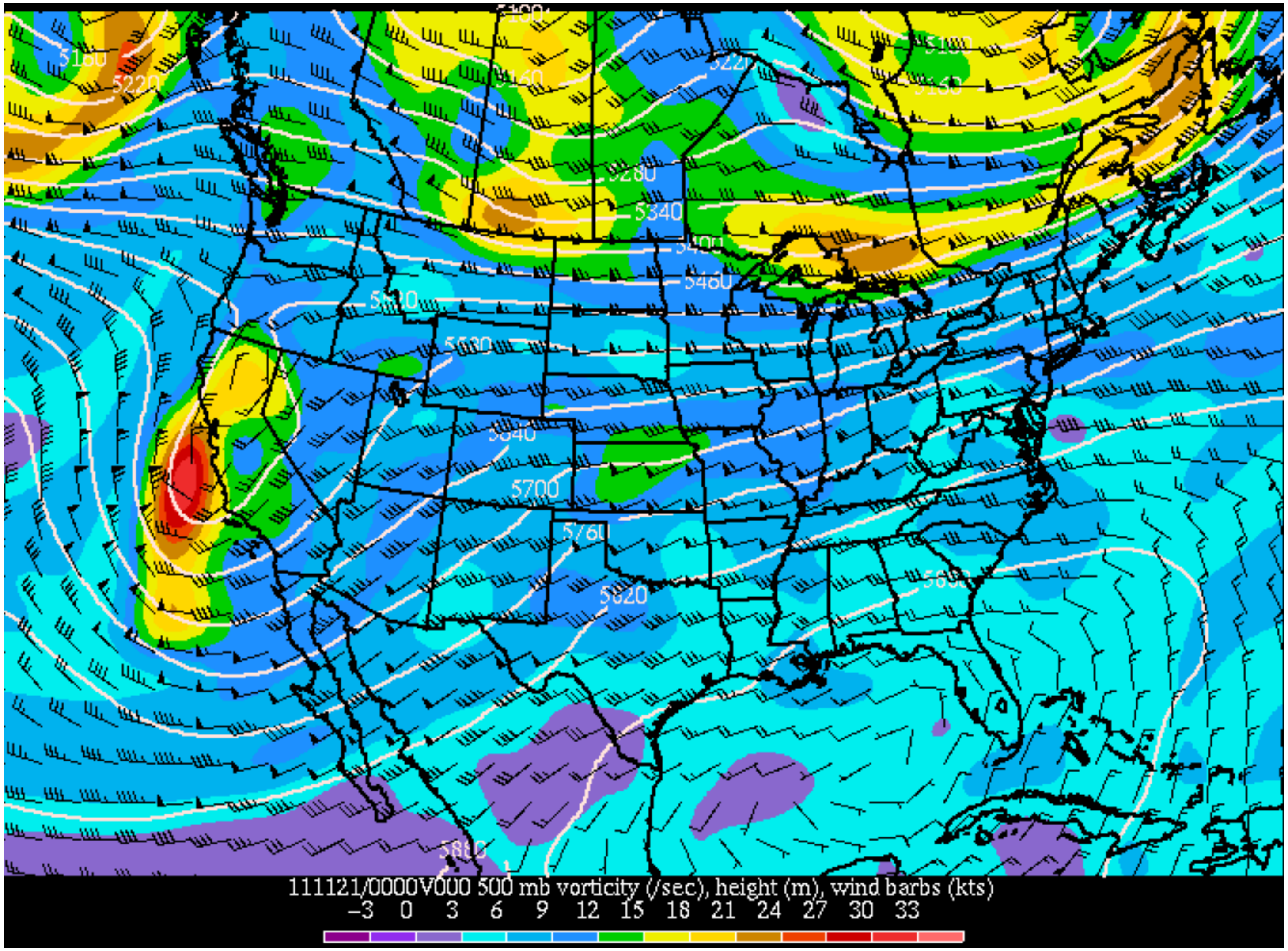
500 mb
12-h later
@00Z Nov. 20



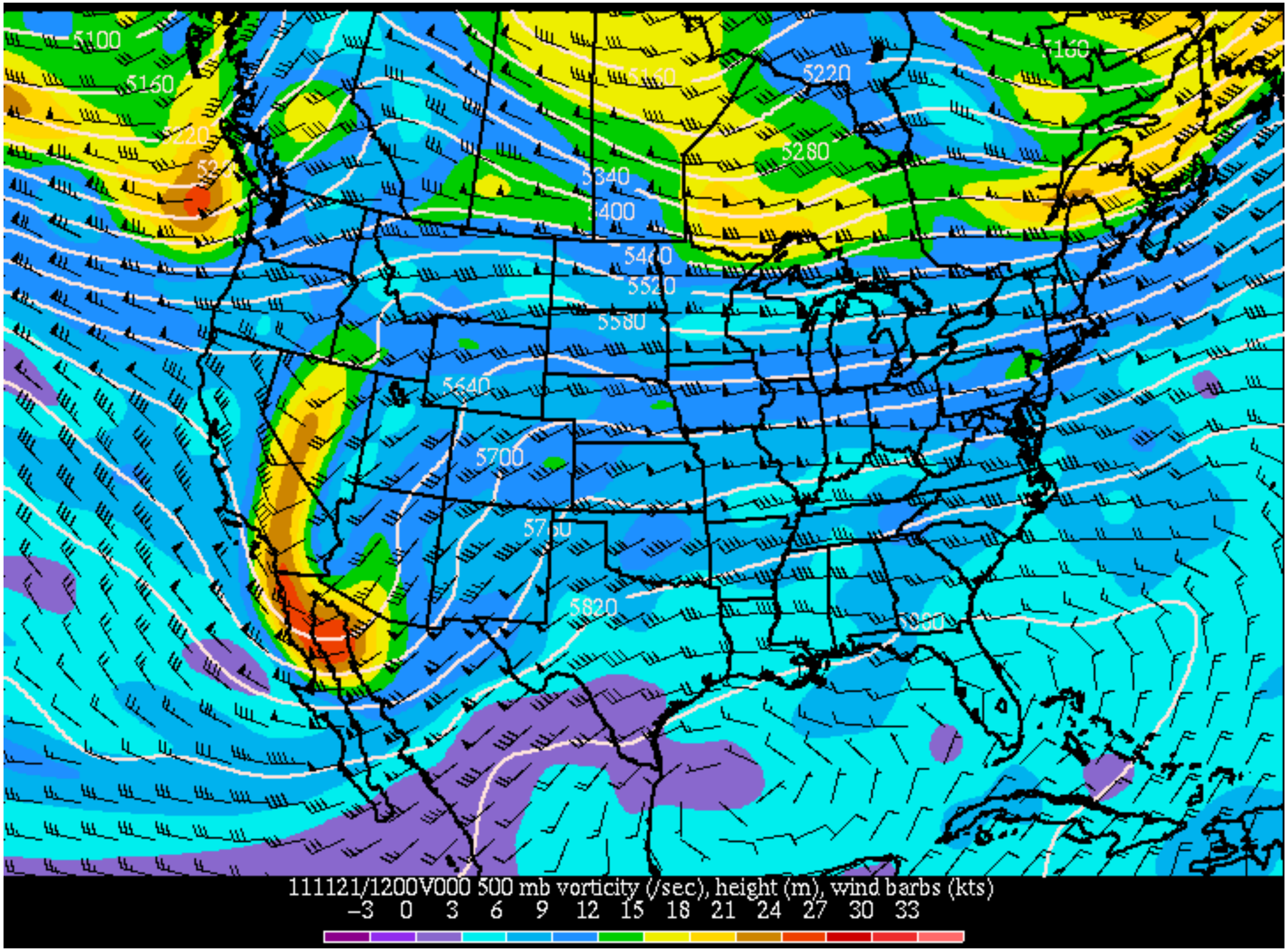
500 mb
24-h later
@12Z Nov. 20



500 mb
36-h later
@00Z Nov. 21

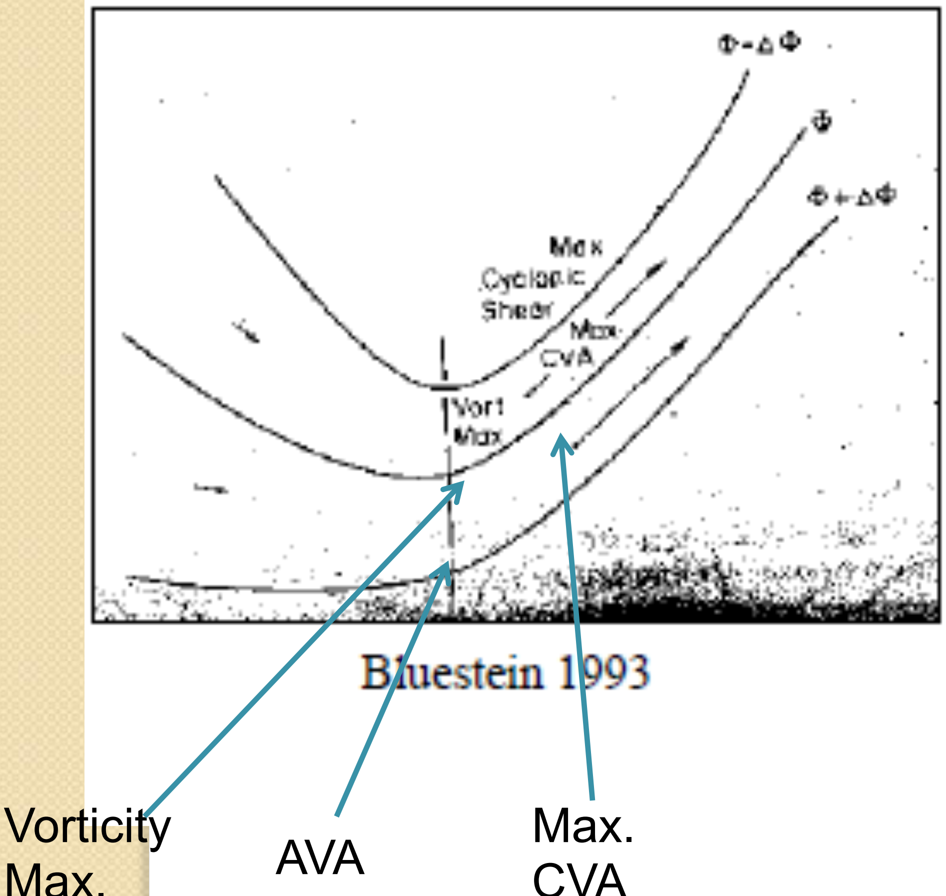


500 mb
48-h later
@12Z Nov. 21



Diagnosing Upper-level troughs and ridges

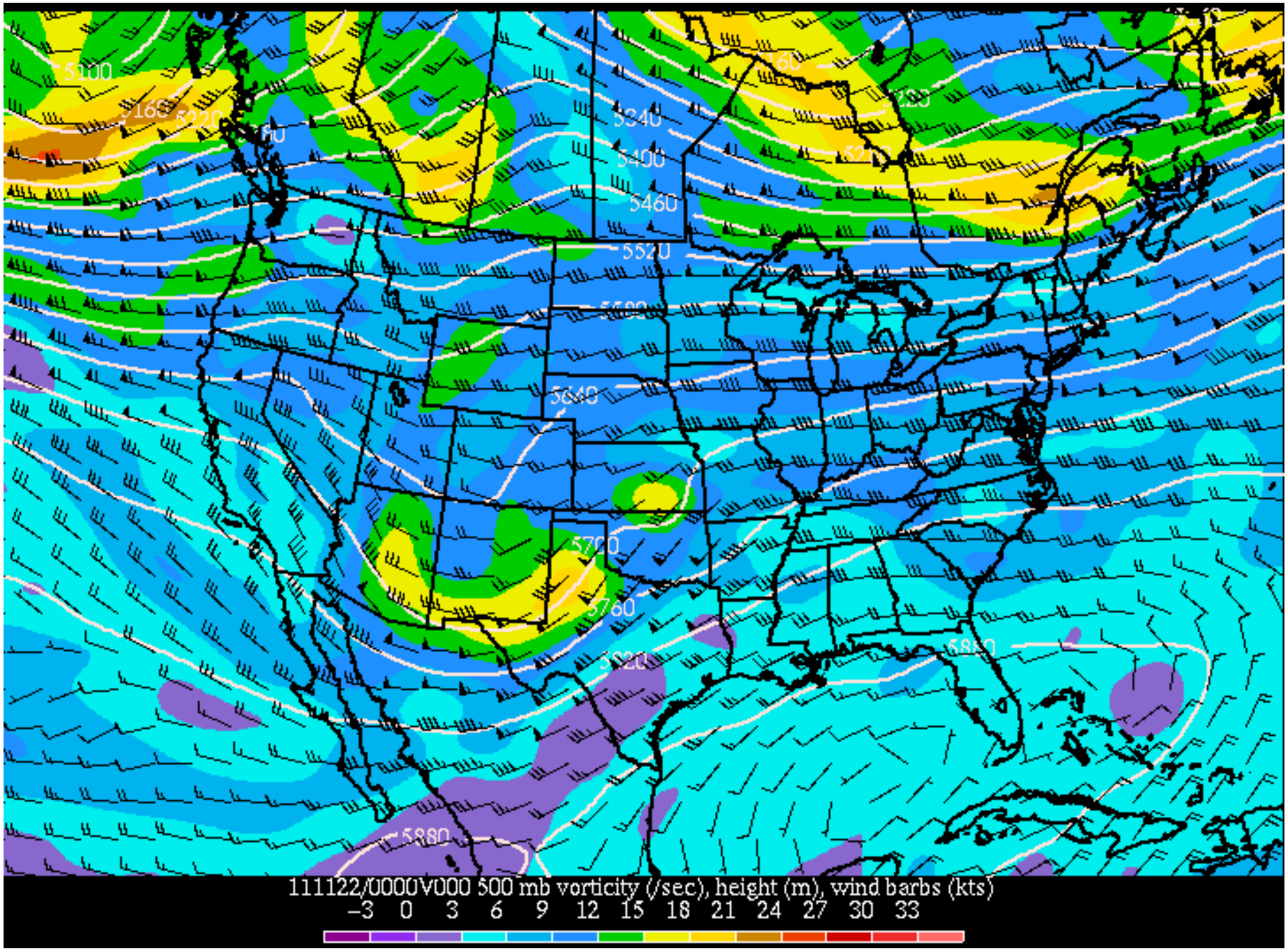
The Lifting Upper-Level Trough



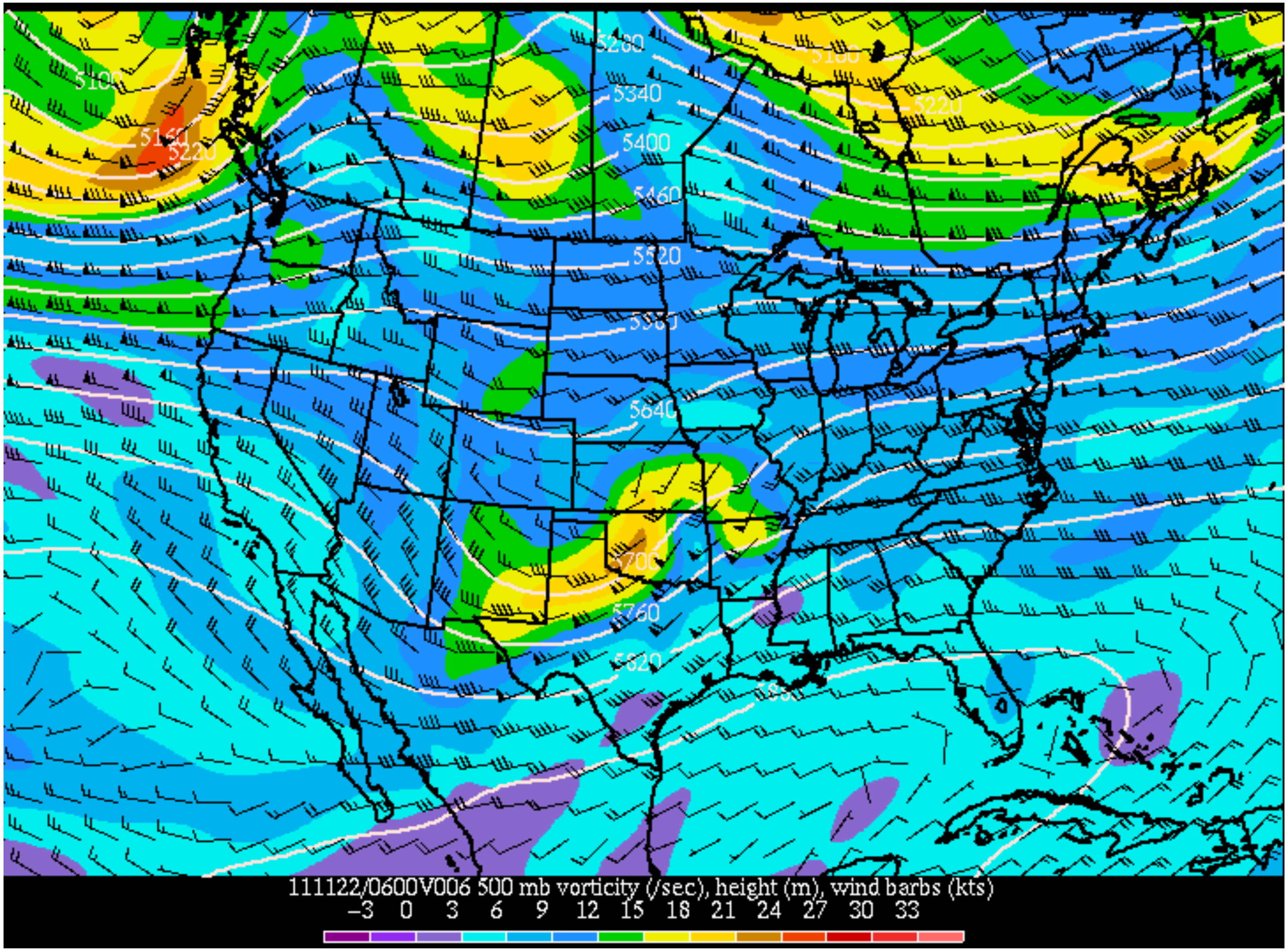
Bluestein 1993

- Confluent upper-level trough with downstream winds that are stronger than upstream winds
- Due to speed shear, vort max is now downstream of trough axis
- AVA and height rises are along trough axis
- Trough weakens and has a poleward component of motion ("lifts and fills")

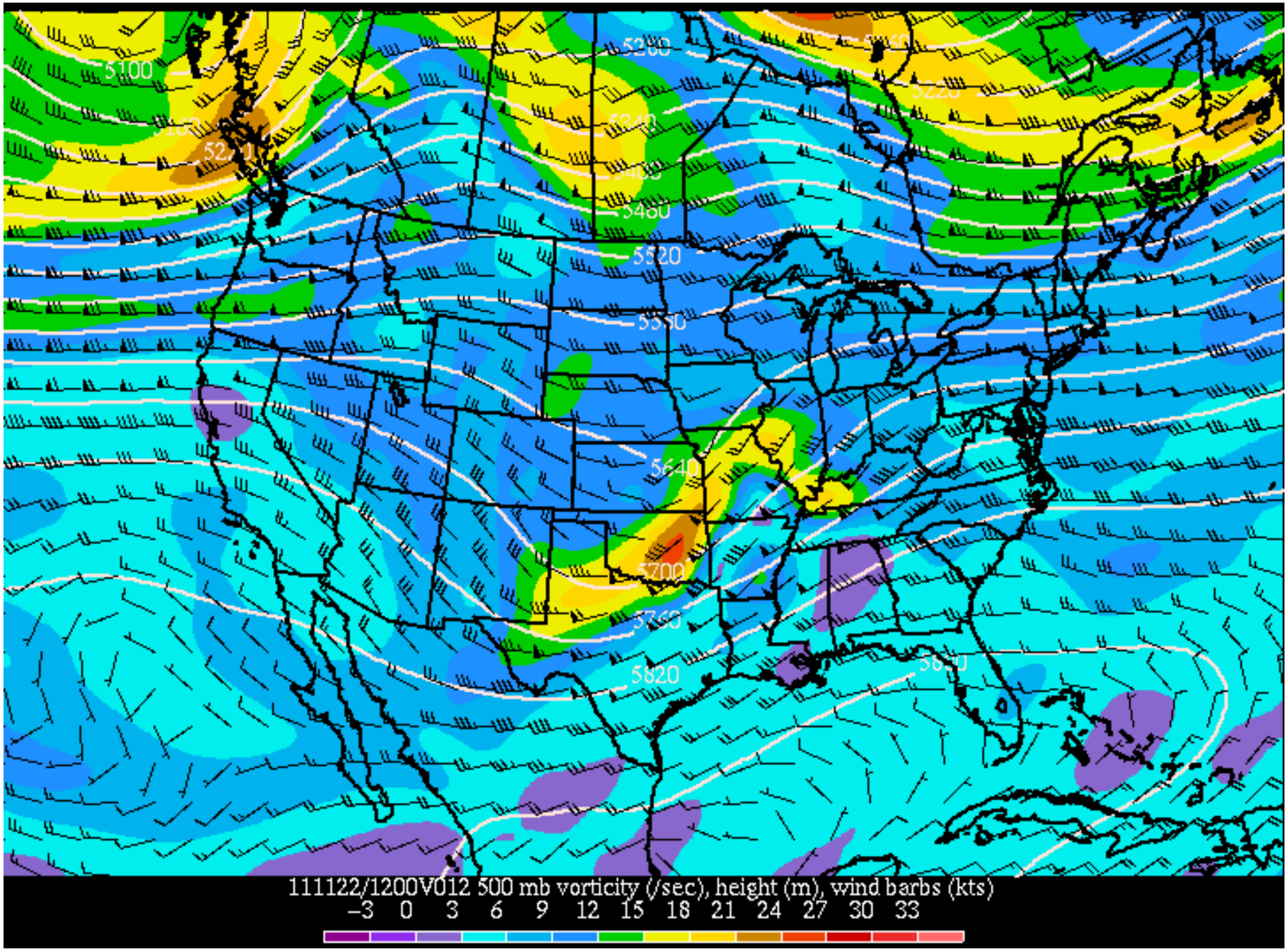
500 mb
60-h later
@00Z Nov. 22



500 mb 00Z Nov. 22 6-h forecast for 06 Z Nov. 22



500 mb 00Z Nov. 22 12-h forecast for 06 Z Nov. 22



Diagnosing Upper-level troughs and ridges

The Kicker

Bluestein 1993

Kicker

Stationary long-wave trough

- Short-wave trough (the "kicker") approaches stationary long-wave trough
- Wavelength shortens
- Stationary long-wave trough becomes progressive
- Henry's Rule: A stationary trough will be kicked out over SW U.S. when the kicker gets within 200 km upstream of it.

Upper-Level Trough Evolution

- Troughs tend to fill if there are slow wind speeds entering on the northwest side of the trough
- Cold advection from the surface to 500 mb entering the west side of the trough or directly underneath it will deepen the trough
- Warm advection near the tropopause entering the west side of a trough will deepen the trough
- If the AVA behind a trough is stronger than the CVA ahead of it, the trough is weakening
- If the CVA behind a trough is stronger than the AVA ahead of it, the trough is deepening
- Most short-wave troughs tend to follow the long-wave pattern
- The shorter the wavelength, the faster the trough

Evolution of Upper-Level Ridges

- Lower-to-middle tropospheric warm advection moving into the western part of a ridge will build the ridge
- Upper-tropospheric cold advection moving into the western part of a ridge will build the ridge
- Lower-to-middle tropospheric cold advection moving into the western part of a ridge will weaken the ridge
- Upper-tropospheric warm advection moving into the western part of a ridge will weaken the ridge
- When a ridge builds in the western Gulf of Alaska, expect a ridge to build over the western United States
- A Gulf of Alaska ridge can be anticipated when a deep trough develops over the western Pacific Ocean

Evolution of Cut-Off Lows

- Strong northerlies entering the west side of a trough will deepen the trough, which may cut off
- If the strongest winds approaching an upstream ridge are from the southwest, the northern end of the downstream trough is often sheered off, leaving a cut-off in the southwest U.S.
- When cut-off or closed lows move, they tend to move over the lowest elevation regions
- A strong jet stream rounding the south periphery of a cut-off may kick the cut-off out

Diagnosing the Formation of Surface Pressure Systems (tool 1)

- The relationship between vorticity changes, height falls, & pressure falls:

$$\left(\frac{\partial P}{\partial t}\right)_z \propto \left(\frac{\partial \Phi}{\partial t}\right)_p \propto -\frac{\partial \zeta_g}{\partial t}$$

- Surface pressure , surface vorticity, & low-level (1000mb) geopotential height changes occur hand-in-hand: ***An increase in surface vorticity would be associated with pressure/height falls; A decrease in surface vorticity would be associated with pressure/height rises.***
- ➔ To understand the development/decay of surface pressure systems, we can use the QG vorticity Eq.

Diagnosing the Formation of Surface Pressure Systems (tool 2)

- QG vorticity equation:

$$\frac{\partial \xi_g}{\partial t} = -V_g \cdot \nabla\left(\xi_g + \mathrm{f}\right) + f_0 \frac{\partial \omega}{\partial p}$$

- To change vorticity, and thus pressure and height, at a point, you can either:

  -- Advect vorticity (i.e., system translation)

  -- Convergence/divergence (Strech/compress fluid columns)

- ➔ In the absence of topogrophy [so W near the ground is small]

  -- Lower-to-middle tropospheric ascent contributes to increasing surface vorticity & pressure falls

  -- Lower-to-middle tropospheric subsidence contributes to decreasing surface vorticity & pressure rises

- → We can use the QG Omega eq. to determine what factors contribute to the development/decay of surface pressure systems.

Diagnosing the Formation of Surface Pressure Systems (tool 3)

- QG Omega equation:

W ~ differential vorticity advection, temperature advection, differential friction, and diabatic heating

- **Contributors to rising motion, pressure falls, & cyclogenesis**

-- Vorticity advection becoming more cyclonic with height (CVA @ 500 mb)

-- A local maximum in temperature advection (warm advection @ 800-700mb)

-- A local maximum in diabatic heating (need a lot of moisture to get diabatic heating)

-- The net effect of friction is to weaken the cyclone

Diagnosing the Formation of Surface Pressure Systems (tool 3)

- **Synoptic experience**
  1) CVA downstream of an upper-level trough tends to cause falling pressure & contribute to the formation of a surface cyclone or trough.
  2) Warm advection along a warm frontal zone results in ascent, pressure falls, & cyclone translation, & possible intensification.
  3) Localized diabatic heating contributes to pressure falls & possibly cyclone development or intensification.
  4) Cyclones tend to deepen on lee slopes of mountain ranges & fill on windward slopes due to vortex stretching & compression, respectively.
  5) Cyclones tends to form in low stability region (unstabe means stronger vertical motion. For example, the shortwave trough moving from over the continent to over the Gulf stream).
  6) Explosive cyclogenesis typically occurs when 1-3 occur in concert with low static stability.

Diagnosing the Formation of Surface Pressure Systems (tool 3)

- **Contributers to anticyclogenesis**

-- Vorticity advection becoming more anticyclonic (or less cyclonic) with height (AVA @ 500 mb)

-- A local minimum in temperature advection (cold advection @ 800-700mb)

-- A local minimum in diabatic heating (for example, stromg radiational cooling)

--Overall, although surface friction produces PBL divergence and subsidence that acts to make an anticyclone more cyclonic, the direct effects of friction drag & convergence at the top of the PBL act to **weaken the anticyclone**.