Isentropic Analysis

We can look at weather data in other ways besides on constant-pressure surfaces!

Meteorology 411 – Iowa State University – Week 11

Bill Gallus

A brief history of meteorology…

- In the 1930s a debate raged in meteorology over what surfaces data should be plotted on
- The Germans used pressure (e.g. 500 mb)

  while the US/Britain used height and some potential temperatures (e.g. 18,000 ft, or 320 K maps)

Note about Isentropic analysis

- Keep in mind (from dynamics?) that when isentropic surfaces are used, the field plotted that behaves like pressure/height is Ψ, the Montgomery stream function, where $\Psi = c_p T + \Phi$

More History

- In 1945, as World War II ended with the US winning, guess who won the meteorological war?
- We started following the Germans and stopped using Z and Θ.
- This is unfortunate because there are some good reasons to use Θ surfaces – isentropic surfaces/isentropic analysis.
- Best reason is that it shows air movement if things are adiabatic.

Arguments

- DISADVANTAGES OF ISENTROPIC SFCs

  1) Atmosphere isn't completely adiabatic, especially near the surface and convection

  2) θ sfcs can intersect ground (bad since there is no data underground)

  3) θ sfcs can extend from very high up to very down low and do not represent a quasi-horizontal surface

Arguments

- ADVANTAGES OF ISENTROPIC SFCs

  1) Atmosphere is as much adiabatic as it is quasigeostrophic (so adiabatic approximation works fine)

  2) Vertical motion can be shown explicitly (GREAT!)

  3) Isentropic flow presents a truer picture of 3D air motion than isobaric surfaces – so we don’t really care if it is steeply sloped

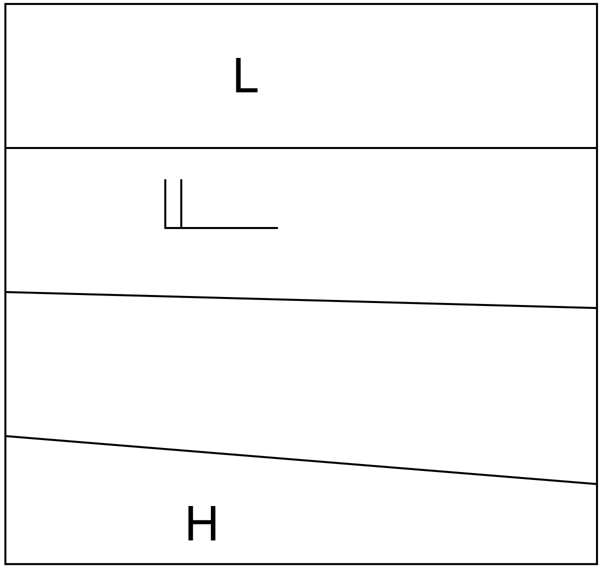
Important Equations

- Potential Vorticity Conservation:

  $d/dt([\xi+f]\ \partial\Theta/\partial p) = 0$
- Vertical Motion: $\omega = (\partial p/\partial t)_{\Theta} + \mathbf{V}_g \overline{\nabla}_{\Theta} p + D\Theta/Dt\ \partial p/\partial\Theta$ but the first and third terms are often ignored

Determining vertical motion

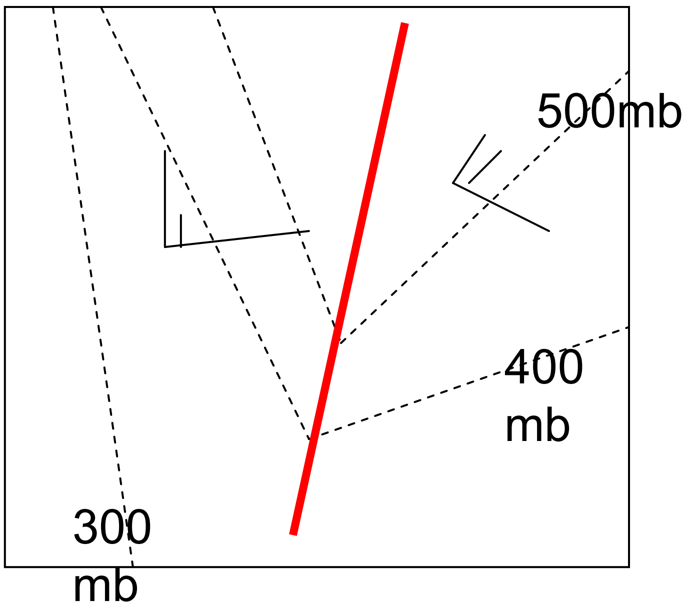
If you had a 500 mb map like…



With normal parameters plotted on it, how could you tell what the vertical motion is? You can't – at least not directly, which is why we make qualitative estimates using the quasigeostrophic omega equation

Vertical motion on isentropic surfaces

If you had an insentropic surface, like this 320 K surface…



If the flow and pressures of the surface were plotted (typical), you could see exactly what the vertical motions were. We'd have rising here east of the red line, and sinking west of it.

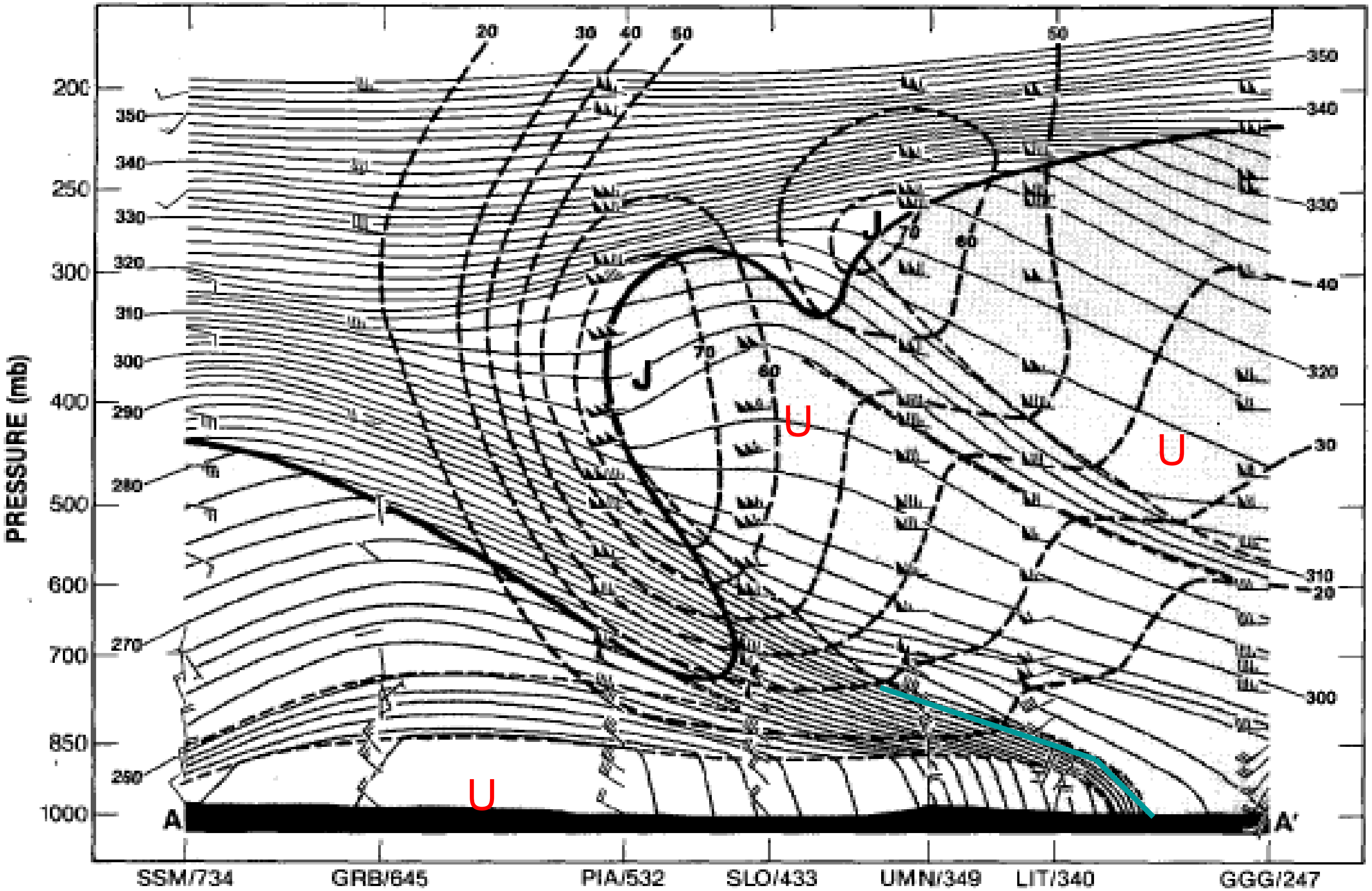


FIG. 9. Cross-section analysis of potential temperature (K, thin solid lines) and wind speed (m s^{-1}, heavy dashed lines) between Sault Sainte Marie, Michigan, and Longview, Texas, along the projection line AA′ of Figs. 7 and 8 at 0000 UTC 20 January 1985. Heavy solid line marks the tropopause (10^{-7} K s^{-1} mb^{-1} isopleth of potential vorticity). Thin dashed lines indicate the tropospheric frontal and stable layer boundaries. Wind vectors are the same as in Fig. 2.

Vertical cross-sections of Θ can show us a lot. If we knew flow was blowing from left to right, we would see upward motion below 500 mb in left part of figure, and much downward in right. We can see less stable areas marked U, fronts with blue line, and tropopause with black

From Shapiro et al (1986)

Summary

- So, vertical motion can be seen on any isentropic map if pressures are plotted along with some depiction of the flow (such as wind barbs, streamlines, Montgomery Streamfunction contours).
- If the atmosphere is not adiabatic, air parcels won’t stay at that isentropic value and would rise above it for diabatic heating, or sink below it for diabatic cooling

Summary

- Tropopause can be seen on isentropic vertical cross-sections where Θ lines are packed closely together at high levels
- Stability is related to $\partial\Theta/\partial z$, so if Θ lines are far apart in vertical direction, $\partial\Theta/\partial z$ is small and things are relatively unstable
- From thermal wind, we know a horizontal temp gradient leads to a change in $\mathbf{V}_g$ with height. Thus jet maxes should be at top of zones where you see tilted Θ lines

Summary

- Tilted Θ lines intersecting ground indicate a surface front (if there is enough Θ gradient in the horizontal)
- If flow is along the vertical cross-section, you know the vertical motion field because air will follow the Θ lines. Remember Θ is coldest near the ground, warmest aloft.

“IPV Thinking”

- Some researchers are really pushing for the use of maps of isentropic potential vorticity (IPV) since this field can be “inverted” to diagnose temperature and wind parameters everywhere. Plus, IPV is a function of the 2^{nd} derivative of height, and 2^{nd} derivatives show much more detail than the original field.

IPV

- $IPV = -g(\xi+f)\partial\Theta/\partial p$
- Magnitude and units are roughly
  $(10\ m/s)(10^{-4}s^{-1})10K/100mb \approx$
  $10^{-6}m^2s^{-1}Kkg^{-1}$
  This unit is pretty ugly and we define it to be called 1 PVU (PV Unit)
- IPV > 1.5 PVU usually assumed to represent stratospheric air

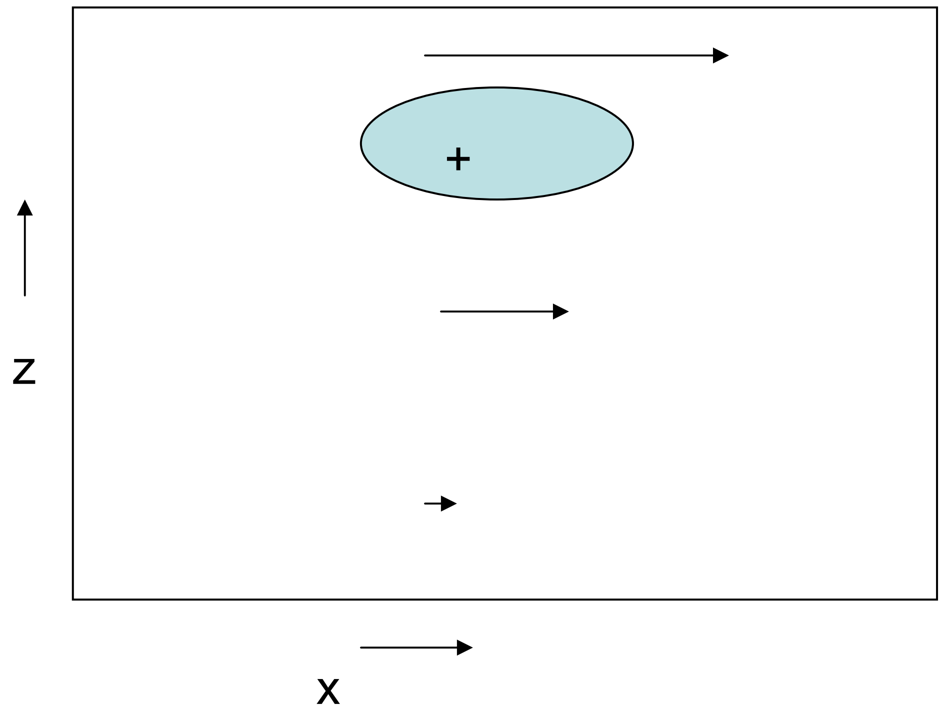
Interpretation of IPV anomalies

- Keep in mind that it is hard to get very much IPV unless stability is very large, which means the large values are usually confined to the stratosphere where things are very stable.

Interpretation of IPV anomalies

IPV max aloft

Typical flow is shown



Assume you are riding along with the PV max, which moves faster than the air below it So, relative to the max, the low level flow will appear to rush in from the front.

This is like having negative vorticity advection at low levels ahead of the IPV maximum, and would give convergence at low-levels. This would yield upward motion. Opposite is true for an IPV min aloft.

Tropopause folds

- Very strong IPV max aloft may form a tropopause fold. These are normally associated with explosively deepening cyclones, strong winds and very stormy conditions. In a fold, stratospheric air with high IPV values can be drawn down to around 500 mb or so.

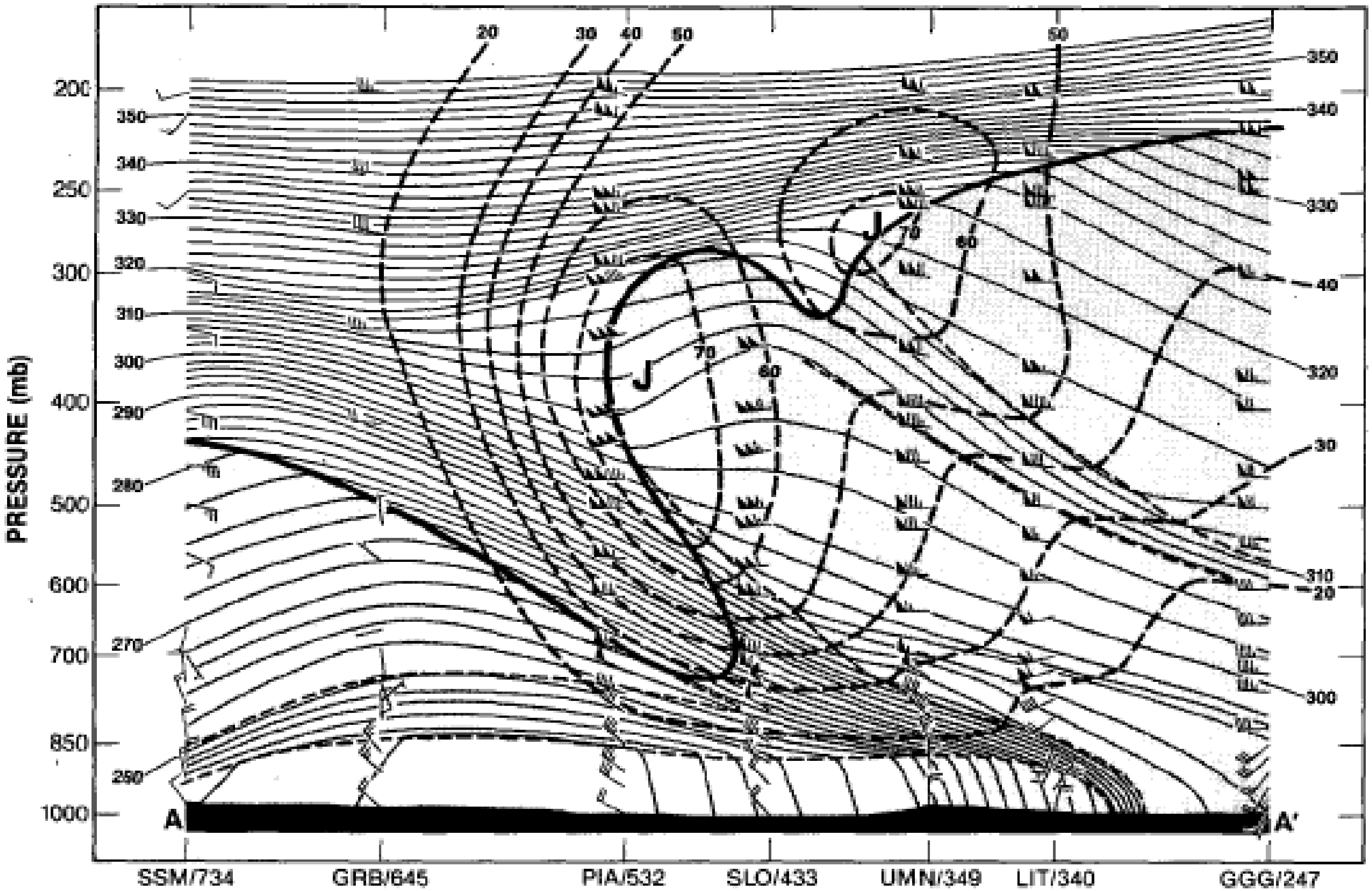


FIG. 9. Cross-section analysis of potential temperature (K, thin solid lines) and wind speed (m s^{-1}, heavy dashed lines) between Sault Sainte Marie, Michigan, and Longview, Texas, along the projection line AA′ of Figs. 7 and 8 at 0000 UTC 20 January 1985. Heavy solid line marks the tropopause (10^{-7} K s^{-1} mb^{-1} isopleth of potential vorticity). Thin dashed lines indicate the tropospheric frontal and stable layer boundaries. Wind vectors are the same as in Fig. 2.

Tropopause fold (from Shapiro et al. 1986) in a strong storm system