Synoptic Meteorology Lab 7
8 April 2015, due Monday 20 April

A. Frontogenesis

Today we analyze 2D frontogenesis, the relationship between 2D frontogenesis and Q vectors, and the relationship between 2D frontogenesis and the frontolytic response of the vertical motion. Before you start, please

- read chapter 6.3 in the textbook Lackmann (2011)
- watch the meted module by Jim Moore on frontogenetical circulations and stability (http://www.meted.ucar.edu/norlat/frontal_stability/)

These provide essential background information.

Please construct five maps, all at 900 mb, at 12 Z on 20 December 2012. Please zoom in the domain a bit more than usual (e.g. garea=24;-105;46;-70 and proj=lcc/25;-88;55). We do not plot isentropic surfaces – just isobaric ones.

map A1. Map geopotential height (thick black contour, 30 m interval), temperature C (red contour, 3K interval) and frontogenesis [frnt(thta,wnd)] (color fill) and the actual wind vectors. Please scale the vectors so they don't criss-cross. Also note that frontogenesis can be negative; in that case, the flow is frontolytic. Therefore it is useful to use a color table that has two core colors (e.g. red and blue), with increasing hues away from the 0 value.

map A2. as above, but for geostrophic frontogenesis [frnt(thta,geo)], i.e. frontogenesis by the geostrophic wind. The vector field should be the geostrophic wind.

For both maps, note that the frontogenesis function is expressed in units of K/(100 km) /(3 hours).

We have shown (or will show) in class that geostrophic frontogenesis is proportional to the cross-isentrope component of the Q vectors, with Q vectors pointing to the warm air in case of frontogenesis ($F_{geo}>0$). To test this,

map A3. same as map 2, but substitute the Q vectors for the wind vectors. Make sure the Q vectors are long enough in the vicinity of the fronts. They are auto-scaled by gempak depending on the highest value, which may be an outlier at the boundary. Vector length is controlled by SCALE, eg SCALE=/2

map A4. same as map 1, but ageostrophic frontogenesis [frnt(thta,age)], and the ageostrophic wind vectors.

As usual, please write (or type) figure captions to help you and me with the interpretation. Note that the gempak frontogenesis function **frnt** corresponds with an eqn derived in class,

$$F = -\frac{1}{2}\left|\nabla_p \theta\right|\left(D\cos 2b - \delta\right)$$

(δ=divergence, D=total deformation, b= angle between axis of dilatation and isotherms), i.e. it is just the frontogenesis due to the horizontal flow (2D frontogenesis $\mathfrak{F}_{2D}$):

FRNT Frontogenesis (K / 100 km / 3 h)
FRNT (THTA, V) = 1/2 * CONV * MAG (GRAD (THTA)) * (DEF * COS (2 * BETA) - DIV)
where
CONV = unit conversion factor = 1.08E4 * 1.E5
BETA = ASIN ((- COS (DELTA) * DDX (THTA) - SIN (DELTA) * DDY (THTA) / MAG (GRAD (THTA)))
DELTA = 1/2 ATAN (SHR / STR)
DIV(V) = DDX (u) + DDY (v)
SHR(V) = DDX (v) + DDY (u)
STR(V) = DDX (u) - DDY (v)
DEF(V) = (STR (V) ** 2 + SHR (V) ** 2) ** 0.5

Questions

Q1. Explain why 2D frontogenesis occurs where it does, in terms of the horizontal wind field. [hint: look for convergence and deformation flow]

Q2. Verify that that the low-level isentropes are steeply tilted in the same regions where the 2D frontogenesis term is large. (examine the 290K IPV map in Lab 5)

Q3. Explain the difference between total and geostrophic frontogenesis, especially in the vicinity of any fronts. Verify that the ageostrophic flow generally strengthens the geostrophic frontogenesis in the vicinity of fronts.

Q4. Does it appear that geostrophic frontogenesis is proportional to the magnitude of the cross-isentrope component of the Q vectors? Does the Q vector direction across the isotherms say something about the sign of the frontogenesis?

Q5. Examine Q vector convergence relative to the cold front. Where do you see QG ascent and descent relative to the front, according to the Q vectors. Does this make sense?

B. Frontogenetic circulation

In Part A, I suspect that you found that the cold front was frontogenetic along most of its length from Illinois to the south, while the warm front was less generally frontogenetic. We now look for evidence for a frontogenetic *circulation* in a vertical cross section across the cold front.

You will need to run **gdcross**. This program is similar to gdplot: it uses model output to generate a vertical transect. You will plot two cross sections. There is no need to include your WRF model top (100 mb): you can set the max height to 250 mb in the variable YAXIS. In gdcross CIRC is defined as a 2D vector (A,B) composed of A the projection of the horizontal wind in your transect (V_tangential) and B the vertical velocity (upward=positive). So if you plot CIRC(WND,W), you will see the actual flow projected into your transect.

Transect B1 → Plot isentropes [THTA], circulation vectors [please use arrows, not barbs] and 2D frontogenesis function [FRNT(THTA,WND)] in a cross section from 36.4°N, 97.9°W to 30.5° N, 84.3° W [CXSTNS= 36.4;-97.9>30.5;-84.3]. This is roughly from Enid OK to Talahassee FL, and roughly normal to the cold front. Time/date is 12 Z on 20 December 2012 as usual. You may want to move this transect a bit, depending on the region of best frontogenesis (map A1) in your model output. Whichever transect you choose, please <u>draw the location of this cross section</u> on the frontogenesis map A1. Also, in the cross section, <u>draw a curved sloping line</u> marking the location of the cold-frontal surface. The 2D frontogenesis function (color fill) can be positive or negative (frontolysis), so please use a color table that clearly contrasts positive from negative, leaving areas with weak | $\mathfrak{F}_{2D}$ | uncolored (transparent).

<u>Comments about gdcross</u>:

1. **gdcross** does not automatically conserve flow aspect ratio (as it does on maps). That is, the apparent vertical displacement inferred from trajectories may not be correct. Part of the challenge is that the (converted) model data vertical coordinate is pressure, and that vertical velocity has units of m/s. Please scale the vertical velocity such that the vertical exaggeration of the plot (height:width ratio) *approximately* corresponds with the vertical exaggeration of the flow (w:u). In the past we found a scale of 0.1 [MUL(W,-0.1)] to work well. Some trial & error may be needed.

2. Your WRF vertical velocity, when converted into a .gem file, actually is in vertical velocity units (upward=positive), as you recall from a previous lab assignment. But the function CIRC assumes that the 2nd parameter is omega and thus it changes the sign of the vertical component of the vectors. Also, CIRC assumes its 2nd parameter to be expressed in hPa/s, but w is in m/s. Thus you need to multiply 0.1, to convert m/s to hPa/s: omeg[hPa/s]=w[m/s]/10. In short, you should plot CIRC(WND, MUL(W,-0.1)), in the series of transects listed below.

3. Sometimes gdcross leaves some regions empty. This appears to be due to an interpolation error. For instance, you may want to plot θ_e (THTE(PRES,TMPC)). The interpolation in dry areas may yield negative relative humidities, which yields an error. You can get around this by GFUNC = thte(pres,tmpc,miss(dwpc,-50))

When you plot the circulation vectors, you will find that the flow is from the left (westerly) everywhere. In Lab 5 (and Lab 1) you estimated the speed of the cold front to be about 18 m/s, moving from the WNW (~280°), i.e. along the cross section you just plotted. You can you retain a more meaningful circulation if you remove the cold-frontal motion. In a front-relative framework, there may well be easterly flow over the front, and a closed circulation. Jim Moore emphasizes the usefulness of a storm-relative framework in his METED module on isentropic analysis.

Transect B2 → As B1, but subtract storm motion from the wind to obtain "front-relative" flow. That is, the flow arrows are computed as CIRC(VSUB(WND,VECR(17.7,-3.1)),MUL(W,-0.1)).

Transect B3 → As B2, but color fill vertical velocity (instead of frontogenesis), and add another field, relative humidity (e.g. dashed and/or red contours, contour interval 10%). Add a color key, and specify the units of vertical velocity in your figure caption. The reader needs to understand the range of vertical motions (e.g. in cm s^{-1}) displayed.

Transect B4 → As B2, but for a section further south across the cold front [CXSTNS= 35.2;-101.8> 26;-94], that is from Amarillo TX into the Gulf of Mexico. Make sure to plot front-relative flow. The cold front is oriented more SW-NE here, so use CIRC(VSUB(WND,VECR(14,-6)),MUL(W,-0.1)). Again, feel free to change the location of this southern transect somewhat based on Map A1, and please draw the location of this cross section on the frontogenesis map A1.

Transect B5 → As B3, but for this section further south across the cold front.

Transect B6 → As B2, but for a section across the warm front or double warm front [CXSTNS= 30.2;-87.8> 46.5;-84.4], that is from Gulf Shores AL to Sault St Marie MI. Use absolute wind, as the warm front (or stationary front) does not move significantly. Again, draw the location of this cross section on the frontogenesis map A1.

Transect B7 → As B3, but for the warm front transect.

<u>Questions</u>:

Q1. Are the flow vectors close to the sloping isentropes near the cold frontal surface in transect B2 (front-relative frame)? Is the flow over this surface upslope and front-to-rear (“anafront”), or rather downslope and rear-to-front (“katafront”)?

Q2. Describe and compare the 2D frontogenesis function $\mathfrak{F}_{2D}$ in transects B2 and B4 (sign, strength, depth …). Hint: recall that gempak’s frontogenesis function only captures 2D frontogenesis, i.e. due to horizontal wind.

Q3. The most important term <u>offsetting</u> this 2D frontogenesis is the thermally-direct vertical circulation, which opposes the tilt of the isentropes. Does the vertical velocity field (transect B3) reveal a low-level thermally-direct circulation. Is this circulation separate from the larger-scale updraft associated with upper-level jet dynamics. In your answer, you may refer to your isentropic analysis maps you produced for Lab 5.

Q4. Is the <u>circulation</u> in the three cross sections (B2, B4, B6) consistent with the frontogenesis? In other words, is there a secondary circulation across the front that opposes the 2D frontogenesis, thermally direct if $\mathfrak{F}_{2D}>0$ and thermally indirect if $\mathfrak{F}_{2D}<0$?

Q5. Compare the depth of the front (humidity, vertical velocity, circulation) in the three transects.

C. Upper-level and low-level PV anomalies

Examine a cross section from Albuquerque NM (35.1° N, 106.6° W) to Ft Wayne IN (41.1° N, 85.1° W) 12 Z on 20 December 2012, from the surface up to 200 mb. Plot isentropes THTA (solid contours), isotachs of wind normal to the transect, not total wind NORM (WND) (dashed negative or out of the page, solid positive or into page), and potential vorticity PVOR (THTA, WND).

In your report, please include your 310K IPV map from Lab #5, and show the location of this transect. This transect is chosen to reproduce the cross section from A to A’ in the image to the right, from Martin (2006)

Q1. Briefly discuss the upper-level PV anomaly, and the low-level PV anomaly in this transect.

Q2. Compare this transect to the one from Martin (2006). Identify the trowel, and the “PV notch” in your own transect

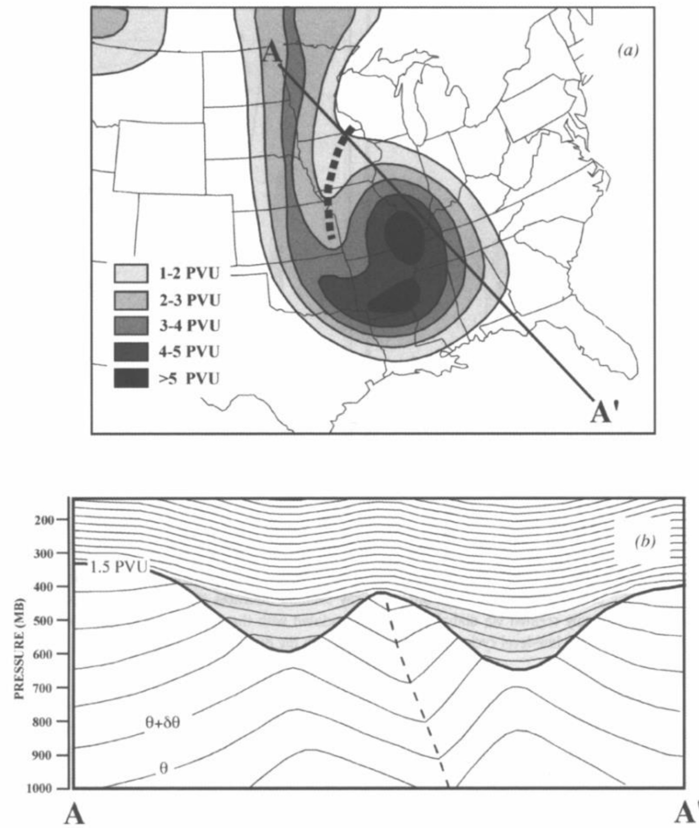

Figure 9.15 (a) Schematic of treble-clef-shaped upper tropospheric PV structure described in the text. Solid lines are isopleths of PV on an isobaric surface contoured and shaded in PVU (1 PVU = 10^{-6} m^2 K kg^{-1}s^{-1}). The thick dashed line identifies the PV ‘notch’ described in the text. (b) Schematic cross-section of potential temperature (θ) in the vicinity of a treble-clef-shaped upper tropospheric PV signature. The dashed axis denotes the sloping axis of warm air in the troposphere characteristic of an occluded cyclone