Synoptic Meteorology Lab 4 score: _____/100
Due Tue 8 March, 2016

Quasi-geostrophic omega and its forcing terms

In the previous lab you created a map showing the 500-mb vertical velocity values, together with the 1000-mb height field to pinpoint the surface cyclone. You will need this map. We now compare this vertical velocity field to the QG forcing terms, to see how important the QG forcing is in the synoptic-scale vertical motion. From the lectures you recall:

$$\left(\sigma\nabla^2 + f_o^2\frac{\partial^2}{\partial p^2}\right)\omega = \qquad f_o\frac{\partial}{\partial p}[\mathbf{V}_g\cdot\nabla(\zeta_g + f)] \qquad - \nabla^2\left[\mathbf{V}_g\cdot\nabla\left(\frac{\partial\phi}{\partial p}\right)\right]$$

>0 implies a local maximum in vertical velocity (-ω)	positive vorticity advection increasing with height	local maximum in warm-air advection
(synoptic-scale updraft)	(differential PVA)	(WAA)

A. Temperature advection patterns

Open **gdplot2**. Typing 'help gparm' will again get a listing of possible grid diagnostic functions and operations in GEMPAK. Of interest is 'ADV(S,V)'. This is a built-in function to calculate advection. Note that two parameters are required. The 'S' refers to the scalar variable to be advected. In our case this will be 'TMPK' or 'TMPC' (they will give the same answer). The next parameter is the vector wind quantity that we will use for advection. QG theory assumes that the geostrophic wind is as approximation to the actual wind. In the previous lab we found that the non-divergent wind is less sensitive to local perturbations in the GPH field, and, being non-divergent, it is a close approximation to the geostrophic wind. Thus we use your WRF wind vector 'ND' [that is VECN(UND,VND)] as the second parameter in 'ADV'. The units for this are K s^{-1}. Thus it will be necessary to properly scale advection. There are two ways to do this. One is to simply set 'SCALE' to 4 for the 'ADV(TMPC,ND)' parameter. Perhaps a more useful means is to multiply the 'ADV' function by 3600 to get the temperature advection in terms of K hr^{-1} :

GDPF= MUL(ADV(TMPC,ND),3600)

(I suggest you set CONTUR=2/2 for fields to be plotted more smoothly without loss of intensity, here and in the rest of this assignment)

We will again examine your WRF output for the **12 Z on 22 Jan 2016** time. Horizontal temperature advection will be computed on the 1000-, 850- 500- 300- and 200 mb levels. Again, you should have *.nts files for the isobaric maps of interest to help you get going. It is easiest to simply add the advection parameter after your height and temperature fields in 'GDPF'. To answer questions, have windows open for all five levels. Remember that you can specify a new xwindow in the DEVICE command. Set 'dev = xw | xname' where 'xname' refers to the name of the xwindow (your choice). You can name your xwindow anything you want, but it may be helpful to give names such as '1000', '850', etc. so you can refer to them when answering questions. Remember to keep the *.nts files for your temperature advection maps.

Answer the following questions below:

A1. At what level do you see the strongest cold air advection patterns? What are the values (as always, state the units)? Why would you think the strongest T advection is found here? (these questions are worth 5%)

A2. How do the patterns of low-level horizontal temperature advection compare to patterns discussed in class regarding the idealized cyclone (e.g., Fig. 5.13a in Lackmann)?

A3. Pinpoint the area of strongest CAA (cold air advection). Does this region change with height?

A4. Explain the 200 mb level temperature and temperature advection pattern. [hint: think about tropopause undulations and warm stratospheric air)

A5. How is the real 500 mb vertical velocity field (w) spatially related to the 500 mb temperature advection pattern? Look both at areas of sinking motion and rising motion. Is the relationship consistent with the QG omega equation?

A6. **Create two maps** (worth 10% in total), one at at 850 mb and one at 500 mb, at **12 Z on 22 Jan 2016**. Your map should have height contours (black – solid, bold – please use 30 m interval at both 850 mb and 500 mb), temperature contours (dashed, red, 3K interval) and temperature advection by the non-divergent wind (color fill, cold colors: CAA, warm colors: WAA). You can save it as a ps or PDF file and print it out and hand it in, or include it in your Word document with all the answers, and print or email that. *Please make sure all your maps are labeled, using the parameter TITLE*. In this case, the title can be labeled "A6: 850 mb height, T (fill), geo T adv (lines) red=WAA" and "A6: 500 mb height, T (fill), geo T adv (lines) red=WAA"

Note: to save a color postscript, set **dev=psc|filename.ps**. Note that the computers in the 6th floor lab have Adobe Illustrator, which allows you to import postscript files, edit them (e.g., you can add some extra text, change the color or thickness of lines, etc), and then export as a jpg image. Give it a try.

A7. Qualitatively check the validity of the **"solenoid" rule** for the two maps in A6, that is that advection is largest where the area contained by two adjacent height contours and two isotherms is smallest.

B. Vorticity advection patterns

We now examine vorticity advection and its relationship to the vertical velocity field from your WRF model for the **12 Z on 22 Jan 2016** time. Start by restoring the gdplot2 *.nts file for temperature advection. It is easiest if we simply modify those settings. In 'GDPF' we need to specify heights as before but instead of temperatures, let's insert vorticity. If you type 'help gparm' you will see listed under 'SCALAR OUTPUT GRID' the 'VOR(V)' parameter. We examine the non-divergent wind vorticity, because as you saw in the previous lab, the geostrophic vorticity is dominated by small-scale perturbations in the height field. Set 'SCALE' for the appropriate value for vorticity. Quasi-geostrophic dynamics assumes the use of vorticity of any wind that is non-divergent. This can be the ND wind or the GEO wind (e.g., Cunningham et al. 2006, in the QJRMS). To start, examine the 300-mb non-divergent wind (ND) vorticity VOR(ND) patterns from your WRF model for **12 Z on 22 Jan 2016**. You should be familiar with finding the relevant parameters and 'GDPF' format based on previous exercises. Create contour plots of vorticity (and heights) at the 850, 500 and 300 mb levels at **12 Z on 22 Jan 2016** to answer the following questions (these questions are worth 5% each):

B1. At what level do you see the largest ND vorticity values?

B2. Are the vorticity patterns at the various levels "stacked" (in phase)? Explain.

B3. From the quasi-geostrophic equations, the vorticity advection terms are of the form:

$$\vec{v}_g \bullet \nabla_P \left(\zeta_g + f\right),$$

implying advection of absolute geostrophic vorticity by the geostrophic wind. Using the ND wind instead of the GEO wind, what is the 'GDPF' command to calculate the above term?

B4. What SCALE factor should you use to produce contours of the advection of absolute ND vorticity?

B5. **Create two maps**, 10% of the grade

(a) showing 500 mb heights (black solid contours, 60 m interval), the 500 mb absolute ND vorticity (blue contours for negative values, red contours for positive ones) and 500 mb advection of absolute ND vorticity by the non-divergent wind (color fill). Please have such a color scheme that it easy to contrast NVA against PVA regions. TITLE= 1/-1/^ ~ @ B5: 500 mb height, avor(nd) (lines) red=cycl, avor(nd) adv (fill)

(b) showing 500 mb heights (black solid contours, 60 m interval), the 500 mb absolute ND vorticity (blue contours for negative values, red contours for positive ones), and the difference in advection of absolute ND vorticity by the non-divergent wind between 525 and 475 mb (color fill, again clearly distinguishing between positive and negative regions). TITLE= 1/-1/^ ~ @ B5: 500 mb height, avor(nd) (lines) red=cycl, differential avor(nd) adv (fill)[1]

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[1] note: 525 and 475 mb are the first level below and above the 500 mb level. If your model output (wrf2gem) vertical resolution is 50 mb instead of 25 mb, you 'll have to use 550 and 450 mb

Note that the difference field in (b) is an approximation to the first term on the right in the omega equation:

$$\left[-\vec{v}_g \bullet \nabla_P\left(\zeta_g + f\right)\right]_{300} - \left[-\vec{v}_g \bullet \nabla_P\left(\zeta_g + f\right)\right]_{700} \approx \Delta p \left\{ \frac{\partial\left[\vec{v}_g \bullet \nabla_P\left(\zeta_g + f\right)\right]}{\partial p} \right\}_{500}$$

B6. Compare map (a) with the actual 500 mb vertical velocity field (plotted in Lab 3, also in map C2 below). Is the vertical velocity field in phase with the 500 mb vorticity advection pattern?

B7. Compare map (b) with the 500 mb vertical velocity field plotted in Lab 3. Is the 500 mb vertical velocity field in phase with the *differential* PVA (increase in PVA with height) pattern centered at 500 mb, as expected from the QG omega equation?

B8. How does the 500 mb temperature advection pattern (see map created in #6 in Part A) compare to the 500 mb differential vorticity advection pattern (map b)? Do [WAA and differential PVA] overlap, both driving rising motion? Do [CAA and NVA] overlap, both driving sinking motion? Or do you see some cancellation between the two terms on the right of the QG omega equation? I am asking for a simple qualitative assessment.

C. Q-vectors

In the previous sections we examined the two QG "forcing" terms in the Omega Equation. Specifically, we looked at the vertical structure of temperature advection and non-divergent absolute vorticity advection. We did not, however, try to compute the full RHS of the Omega Equation and evaluate the accuracy of this equation. We will do just that in this lab, by examining Q vector convergence.

This is how gempak computes the Q-vector:
QVEC Q-vector at a level (K / m / s)
QVEC (S, V) = [- (DOT (DVDX (V), GRAD (S))), - (DOT (DVDY (V), GRAD (S)))]

Please choose V=ND (consistent with the QG assumptions) and S= THTASM (from Lab #3), and smoothen:
SM5V(QVEC(THTASM,ND))

Please **generate the following maps**, for **12 Z on 22 Jan 2016** (3 maps, 10% of the grade).

C1. Map height (thick solid contour), Q-vector (arrows), and Q-vector divergence DIV (negative should imply rising motion: use warm color fill; positive should imply sinking motion: use cold color fill) at 500 mb. TITLE= 1/-1/^ ~ @ C1: 500 mb height, Q vectors, div Q (fill) red=up
C2. Map height (thick solid contour), and vertical velocity (w) (>0 rising motion: warm color fill; <0 sinking motion: cold color fill) at 500 mb. TITLE= 1/-1/^ ~ @ C2: 500 mb height, actual vertical velocity (fill) red=up
C3. Map height (thick solid contour), and the Poisson solver of Q-vector divergence POIS(DIV(SM5V(QVEC(THTASM,ND))),0), at 500 mb. A Poisson solver is an inverse Laplacian operation, subject to lateral boundary conditions, which we set to zero. Note that we could change the sign SUB (0, S1) = -S1, in order to obtain convergence. But then we want to change the sign a 2nd time, to go from omega to vertical velocity w. A positive value of POIS(DIV(QVEC(THTASM,ND)),0) should imply rising motion: use warm color fill; a negative value should imply sinking motion: cold color fill. TITLE= 1/-1/^ ~ @ C3: 500 mb height, QG vertical velocity (fill) red=up

Questions (worth 5% each)
C4. Explain why the red contours in Maps C1 and C3 are expected to correspond with rising motion (hint: refer to the Q vector form of the omega equation).
C5. Compare the (approximate) QG vertical velocity to the actual one (C3 vs C2). Discuss possible causes of the discrepancies.

Hint: we did not include the vertical derivative in the full Q-vector equation: $\left(\nabla^2 + \frac{f^2}{\sigma}\frac{\partial^2}{\partial p^2}\right)\omega$. But at 500 mb, I expect that the vertical derivative term is generally small compared to the (horizontal) Laplacian term. In short, Map C3 shows the QG vertical velocity, with two simplifications (w=0 at the lateral boundaries; and vertical derivative ignored).

Total score: 14 questions (70%) and 7 maps (30%)