

Tropical Meteorology – Homework #7

Due Date: 10 May 2018

Learning Objectives: In this assignment, you will use a secondary circulation numerical model based upon the Sawyer-Eliassen equation to *analyze* a tropical cyclone's response to specific heat and momentum forcing and quantify sensitivity therein to vortex structure (baroclinicity, inertial stability) and static stability.

To begin, log on to a Mac in EMS W434 (although you may use any computer on which you can compile Fortran code using gfortran). Use the Application Launcher to open a Terminal window. Next, issue the following command:

```
wget http://derecho.math.uwm.edu/classes/TropMet/assignments/hw7/semodel.tar
```

This will download a file named semodel.tar to this directory. Expand the archive by issuing the following command in the Terminal:

```
tar -xvf semodel.tar
```

This will result in sixteen new files being created within this directory. You may list them by typing 'ls' (without the quotes). Together, the .f90 files represent a Fortran program to diagnose the secondary circulation response to specified heat and momentum flux forcing for an idealized tropical cyclone vortex. The model domain extends out to 1500 km from the cyclone's center ($\Delta r = 15$ km) and up to 10 km from the sea surface ($\Delta z = 0.5$ km).

Parameters controlling the heat flux, momentum flux, and horizontal idealized vortex structures are set in lines 19-21 of the common.f90 file. Specifically,

- Idealized vortex (line 19)...
 - rmw = radius of maximum winds (in m; default: 50,000 m)
 - vmax = maximum sustained 10-m winds (in m s^{-1} ; default: 42.5 m s^{-1})
- Idealized heat source forcing (line 20)...
 - fluxmax = magnitude of the maximum heat flux forcing (in K s^{-1} ; default: $1 \times 10^{-3} \text{ K s}^{-1}$); positive values denote warming
 - r_o = radius from the center of the vortex at which the maximum heating is located (in m; default: 50,000 m)
 - z_o = altitude at which the maximum heating is located (in m; default: 5,000 m)

- r_d = radial distance from r_o over which the heating decays to zero (in m; default: 25,000 m)
- z_d = vertical distance from z_o over which the heating decays to zero (in m; default: 2,000 m)
- Idealized momentum source forcing (line 21)...
 - $momfluxmax$ = magnitude of the maximum momentum flux forcing (in $m\ s^{-2}$; default: $1 \times 10^{-3}\ m\ s^{-2}$); positive values denote cyclone momentum flux forcing
 - ro = radius from the center of the vortex at which the maximum momentum forcing is located (in m; default: 500,000 m)
 - zo = altitude at which the maximum momentum forcing is located (in m; default: 7,000 m)
 - rd = radial distance from r_o over which the momentum forcing decays to zero (in m; default: 250,000 m)
 - zd = vertical distance from z_o over which the momentum forcing decays to zero (in m; default: 1,000 m)

Parameters controlling the static stability and vertical idealized vortex structure are set in the vortex.f90 file. Specifically,

- Static stability (Nsq; line 95): default $1.44 \times 10^{-4}\ s^{-2}$
- Vertical vortex structure (lines 39, 41)...
 - Barotropic vortex (constant intensity with height): uncomment (remove leading !) in line 39, comment out (add leading !) in line 41
 - Baroclinic vortex (decreasing intensity with height): uncomment (remove leading !) in line 41, comment out (add leading !) in line 39. This is the default setting.

Note, however, that the baroclinic vortex is only very weakly baroclinic; there is no outward tilt of the radius of maximum winds with increasing height, for instance.

Use your favorite text editor to edit any desired parameters within these files. I recommend using nano within the Terminal window, i.e.,

```
nano common.f90
```

In nano, the arrow keys are used to move from one line to the next, or to the left or right on one line. To save, use Ctrl-O, then hit Enter. To exit, use Ctrl-X.

Once `common.f90` and `vortex.f90` have been edited to reflect the desired values of the above variables, issue the following command (all on one line) to compile and run the model:

```
rm *.o ; make ; ./a.out
```

This will remove any old model code that may exist, re-compile all of the model code, and then execute it. Successful execution should only take a few seconds. If they did not exist already, a series of `.dat` files will be created by this program.

To view model output, the output data must first be converted from text format to binary format. To do so, issue the following command:

```
gfortran -o binaryconvert binaryconvert.f ; ./binaryconvert
```

Next, to display the data, simply run the provided `seplot.gs` script:

```
grads -clb seplot.gs
```

This script will create six PNG images...

- `hflux.png`: displays the vertical and radial structure of the specified heat forcing
- `mflux.png`: displays the vertical and radial structure of the specified momentum forcing
- `psi.png`: displays the streamfunction resulting from the heat and momentum forcing
- `u.png`: displays the radial wind (positive outward) resulting from the streamfunction
- `vbar.png`: displays the vertical and radial structure of the vortex's tangential wind
- `w.png`: displays the vertical velocity (positive upward) resulting from the streamfunction

These can be displayed using any image viewer on the Macs. After each run of the model code, create a new directory in which to store these images, then move the images to that directory:

```
mkdir <name>
```

```
mv *.png <name>
```

where `<name>` is replaced by the name of the new directory. Do not include `<` or `>` at the end of this name. Naturally, you will probably want to choose some descriptive name. If you do not save the images after each run of the model code, they will be overwritten!

If you run into any technical issues in running the code, please let me know as soon as possible. Please include the relevant figures with your answers to the questions below.

1. (30 pts) In this question, you will examine the basic streamfunction response to idealized heat and momentum flux forcing.
 - a. (10 pts) Edit `common.f90` and set `momfluxmax` to `0.0d-3`. Compile the model and visualize the output. Describe the secondary circulation (u , w – signs, magnitudes, and locations) resulting from this forcing. If the specified forcing destroys thermal wind balance, physically describe how the resulting secondary circulation attempts to restore thermal wind balance.
 - b. (10 pts) Edit `common.f90` and set `momfluxmax` back to the default `1.0d-3`. Set `fluxmax` to `0.0d-3`. Compile the model and visualize the output. Describe the secondary circulation (u , w – signs, magnitudes, and locations) resulting from this forcing. If the specified forcing destroys thermal wind balance, physically describe how the resulting secondary circulation attempts to restore thermal wind balance.
 - c. (10 pts) Edit `common.f90` and set `fluxmax` back to the default `1.0d-3`. Compile the model and visualize the output. How does the secondary circulation response (u , w – signs, magnitudes, and locations) to the specified forcing compare to (a) and (b)?
2. (20 pts) In this question, you will explore the sensitivity in the secondary circulation response to the magnitude of the heat and momentum flux forcing.
 - a. (10 pts) Repeat Question 1a, except with `fluxmax` set to `2.5d-3`. Describe the secondary circulation (u , w – signs, magnitudes, and locations) resulting from this forcing. In the context of the destruction and restoration of thermal wind balance, physically describe why this response differs from Question 1a.
 - b. (10 pts) Repeat Question 1b, except with `momfluxmax` set to `2.5d-3`. Describe the secondary circulation (u , w – signs, magnitudes, and locations) resulting from this forcing. In the context of the destruction and restoration of thermal wind balance, physically describe why this response differs from Question 1b.
3. (20 pts) In this question, you will explore the sensitivity in the secondary circulation response to the radii at which the heat and momentum flux forcing are applied.
 - a. (20 pts) Repeat Question 1c, except with `r_o` (the heat flux forcing radius) set to `500.0d3`. Describe the secondary circulation (u , w – signs, magnitudes, and locations) resulting from this forcing and how it differs from Question 1c.
 - b. (20 pts) Repeat Question 1c, except with `ro` (the momentum flux forcing radius) set to `50.0d3`. Describe the secondary circulation (u , w – signs, magnitudes, and locations) resulting from this forcing and how it differs from Question 1c.

4. (10 pts) In the preceding questions, an idealized, weakly baroclinic vortex has been used. Repeat Question 1c, except for the Gaussian barotropic vortex. Describe the secondary circulation (u , w – signs, magnitudes, and locations) and how it differs from Question 1c. How does this difference compare to theoretical expectations (Slide 20 of the TC Structure slide deck)? Briefly speculate as to why.
5. (10 pts) In this question, you will explore the sensitivity in the secondary circulation response to the inertial stability, as manifest by the idealized vortex's horizontal structure. Repeat Question 1c, except with a large radius of maximum winds and weak maximum sustained wind ($rmw = 200.0d3$, $vmax = 12.5d0$). Describe the secondary circulation (u , w – signs, magnitudes, and locations) and how it differs from Question 1c. How does this difference compare to theoretical expectations (Slide 20 of the TC Structure slide deck)?
6. (10 pts) In this question, you will explore the sensitivity in the secondary circulation response to the static stability. Note that in this model, static stability is constant over the entire domain, rather than varying with height as is seen in the real atmosphere. Repeat Question 1c, except with a reduced value of static stability (0.14d-4; e.g., as might result from sustained diabatic warming over a deep vertical layer by deep, moist convection). Describe the secondary circulation (u , w – signs, magnitudes, and locations) and how it differs from Question 1c. How does this difference compare to theoretical expectations (Slide 21 of the TC Structure slide deck)?