ATOC 5060: Atmospheric dynamics

Project 1: Study of the baroclinic annulus
Due 4pm Friday 4 April

The atmospheric circulation in the midlatitude is characterized by wave activity in the form of synoptic scale eddies. These provide the all-important poleward transport of heat at these latitudes. But what determines their size? Why are eddies on earth the scale of 1000 km? An appropriate laboratory analog to study this system is the infamous baroclinic annulus. This experiment, first considered by Thompson to explain the Ferrell cell, consists of a rotating apparatus of concentric cylinders, with the annular gap between them filled with fluid. The fluid is heated at the outer boundary and cooled at the inner wall. This was the state of the art climate model until the advent of computers in the 1950s.

See an example of the apparatus at:
http://nimbus.colorado.edu/hart/pages/Demonstrations/RotatingAnnulus/rotating_annulus.htm

In this project, you will work in a group to devise mathematical model that predicts a) the onset of wave activity, and b) the dependence of the wave number on geometric aspects of the system. Once complete, you will test your prediction in the fluid dynamics lab by performing a critical test of your new theory.

Task 1

Visit Scott Kittleman in the GFD lab for an hour (to be scheduled the week 19-21 March). Make appropriate measurements of the apparatus and the experiment. You will use these data to “close” your calculations with any needed constants. Watch for temperature gradients, and the conditions needed for the onset of waves, and which wave numbers emerge.

Task 2

Develop a mathematical theory the predicts the onset of wave activity, and an analysis which predicts the most unstable baroclinic mode (i.e., a wave number or length) as a function of apparatus geometry (e.g., fluid depth, radius, rotation rate, viscosity, temperature difference between “equator” and “pole” or other relevant fixed quantities). You might consider starting with a two-layer quasi-geostrophic equations for an incompressible fluid, and performing a normal mode analysis. State which parameters are important and what assumptions you have made to get there. Test you mathematical prediction using the experiment data to see if you are correct, or otherwise. As is the scientific method, if the match is not good enough, you may need to modify your theory, or come up with a good explanation.

(Hint: See Holton Ch. 6 and 10. You might find it convenient to define buoyancy in terms of density variations, which can be related to temperature via a thermal expansion coefficient.)

Report

You will hand in one report per group, and it is left to your group to decide how to partition the tasks. Your report should take the form of a paper (I suggest styled after a Journal of Geophysical Research paper) with an introduction, methods and experiment design, results, and conclusions sections. It should contain citations to any relevant literature used in your study, give appropriate and referenced figures, state your experimental observations clearly and express relevance to the true atmosphere. Any mathematical derivations can be attached as an appendix, but key mathematical results should be given in the main text. The report should be no more than 2500 words (excluding appendices).

Your report should answer the following questions:

- Under what conditions can zonal waves exist in this system?
- Can one predict the threshold beyond which wave solutions should occur?
- What determines the wave length?
- What determines the propagation speed? (tough one)
- What are the appropriate quantities that determine the behaviour, and what are there analogs in the real atmosphere?

Your report should describe:

- the apparatus and how it is analogous to the Earth's atmosphere
- essential features of your mathematical analysis
- plots of change in wavenumber as a function of rotation rate, temperature difference, fluid depth, with your experimental results superimposed
- your experimental design and an explanation of why this is a critical test
- your experimental results and a conclusion describing the project outcome
- how the results are applicable (or otherwise) to the real atmosphere

Even the best experiments will not be perfect. Providing ample description of your experiment success and failure, with discussion of what you would do better next time, or where there was some imperfection in the experiment is very important. Reports that discuss this well but had a failed experiment will score better than those with a perfect experiment but have little discussion. Reports will score highly if they provide physically based explanation of the mathematics, discuss any relevant scaling, discuss the geostrophic balance and thermal wind, and establish if these are Rossby waves.

You are encouraged to consider published work on this topic for motivation and to aid in your interpretation. This is an open-ended project, so while you must address the aspects specifically requested you are free to do more. Carious detailed analysis of logged data is encouraged.

This assignment is to be completed in groups of about 4 or 5. We need to have no more than 6 groups for the class so we can to the lab work. Everybody must hand in a grade sheet that grades on a scale 0 (bad) to 5 (outstanding) each of your team members (including yourself) on a) intellectual input, b) work contribution and c) team work. This allows me to see who actually did the work!

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(*Everyone hands in this page*)

Grade your group members

Grade each of your groups' members (including yourself) by assigning a numeric score from 0 (no effort) to 5 (maximum effort) by filling in the table. (3 means "good enough", but not outstanding). Give grades for each of the three aspects.

Team member name	Intellectual input	Work contribution	Team work
1 (self)			
2			
3			
4			
5			

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Tips for getting full marks

The purpose of this project is to provide you the opportunity to study the problem of baroclinic instability in details. You should consider working through the relevant chapters in Holton in preparing your report. Your report should demonstrate that you (your group) has achieved a deep understanding of the problem and the main results of the linear stability analysis. The report will be graded on 3 criteria (below) approximately equally.

1) Theoretical basis of the project and your experiment

This aspect of your report should be quite mathematical. It should justify the use of any equations taken from elsewhere (e.g., Holton), and explain why they are appropriate for your case. A complete report should touch the following questions/suggestions, and refer to any pertinent equations you have derived:

- Is/how is your theory analogous to Holton's 2-layer system? How is it different?
- Explain how thermal wind is related to temperature difference
- How you define the Rossby radius (or wavenumber) for this system?
- How do you define the "stability"?
- How do you define beta? And what is the equivalent beta effect for this system?
- Write down and explain a mathematical expression for the amplification factor.
- Write down and explain a mathematic expression of the onset of instability.
- Create a graph of most unstable wave number as a function of rotation rate
- Create a graph of most unstable wave number as a function of temperature difference
- Explain how beta effect stabilizes the flow
- How do you define incorporate the thermal wind?
- Overlay you experiment results on the theoretical graphs. Why (why not) do they agree?
- Explain why you might expect to see the most unstable wave dominate the flow
- Explain how the depth of the fluid changes the results
- Explain how the stability changes the results

2) Discussion of experimental results

This aspect of the report can be considered the analysis of your results. Are you happy with your theory? What went right? What went wrong? You should consider the following in this regard:

- Comment on success and failure of experiment
- Comment on success and limitations of your mathematical treatment.
- Cite published literature on this topic
- Provide discussion of observational results. What features/behaviors were recorded?
- Comment how your experiment and theory differs from cited work
- Argue how your experiment results match or do not match with the predictions
- What are the appropriate quantities that determine the behavior, and what are there analogs in the real atmosphere?
- Explanation of any experimental limitations
- Compare your mathematic and experimental results with Figure 10.21 in Holton.
- How does your new theory explain this regime diagram

3) Presentation/clarity of the report

Well structured by sections, including a conclusions to the study and complete (cited) reference list. Include a description of theory, and experiment design and results. Adequate explanation of figures and tables. Free from spelling errors and grammar errors, and generally readable. Your report should be scientifically robust.