PHY 2504S: Advanced Atmospheric Dynamics, Winter 2019

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Class Website: available through Quercus. If you are not registered to take the course, I can provide guest access using your UTorID.

Summary and Syllabus: In all other institutions that I know of, this class is called "Geophysical Fluid Dynamics (I)", or GFD. I will call this class GFD.

For latitudes outside the Earth's tropics, the general circulation of the atmosphere and oceans is dominated by "quasi-geostrophic" (QG) fluid motions that are controlled by planetary rotation and fluid stratification, while faster processes are dominated by waves. In this course, we develop an understanding of this class of dynamics using scaling and analysis of simplified models. In particular, we will focus as much as possible on dynamics that are common to the atmosphere and oceans. These are the synoptic dynamics in the atmosphere (~1000 km, i.e. weather and large-scale circulation patterns), and the mesoscale dynamics in the ocean (~100 km, contains ~90% of the ocean's kinetic energy). The course includes analytic and numerical exercises, and a class project and presentation.

As a new addition this year (2019), I will introduce a table-top rotating tank, in order to illustrate some of the lectures. Because this year is the first time I will test this device, and because not everything is in place yet, I will simply replace some lectures by in-class experiments.

I will assume that you already have some background in fluid mechanics and atmospheric science, but interested students without this background will be able to keep up if they do some additional reading and homework.

I will break down this class into the following chapters:
- Relevant scales and quantities.
- Equations of motion.
- Effects of rotation and stratification.
- One-layer shallow water theory: wave and geostrophic modes.
- Multi-layer shallow-water theory: towards a comprehensive description of the dynamics.
- Potential Vorticity.
- QG theory and Rossby waves.
- Two-layer baroclinic instability.
- Extra topics, time permitting. For example, atmospheric and oceanic general circulations.

Objectives

Concepts to learn (in a somewhat random order):
- Some basic sets of equations of motions, and their ranges of validity.
- Effects of rotation (Coriolis effect) and differential rotation (beta effect).

- Effects of stratification (or baroclinicity): static stability, internal waves, vertical coupling.
- Circulation, vorticity, potential vorticity and their relevance to extratropical dynamics.
- Geostrophic adjustment, and how inertia-gravity waves and vortices are the two fundamental modes of motion in GFD.
- Quasi-geostrophic scaling.
- Properties of Rossby waves and other waves relevant to atmosphere-ocean circulation.
- Two-layer QG theory and baroclinic instability theory.
- QG theory for continuously stratified flow.
- Applications: baroclinic instability (continued), stationary waves, baroclinic adjustment.

Skills to learn and develop (in a somewhat random order):

- Lagrangian and Eulerian viewpoints.
- Analysis of wave dynamics in simplified fluid systems.
- Hydrodynamic stability and instability
- Scale analysis for fluid dynamics (truncation, perturbation expansion).
- Research report writing and presentation.
- Simple numerical analysis and data analysis.

Course schedule:

Monday	11-noon	MP606
Tuesday	3-4	MP606
Friday	11-noon	MP606

Note that this course will have 24 hours of lectures in total. Therefore, I will not use three hours a week every week. Stay up-to-date with the Quercus calendar and announcements for specific lecture hours.

Evaluation:

Problem Sets (3 or 4)	48% (equal weights for each)
Project (8-10 page paper + 20 minute presentation)	42% (21% each)
Class participation and topic leadership	10%

Notes on Assignments:

- The problem sets involve mathematical and numerical exercises.
- Current numerical exercises are based on the Python programming language and software packages. This is free open source software which we are using in undergraduate courses as well. Please see https://computation.physics.utoronto.ca/ to get started. A standard distribution, and the one recommended for UofT students, is Anaconda (https://www.anaconda.com/; choose the option to install Python 3).
- The projects should cover a chosen topic in atmospheric or ocean dynamics (e.g, topics in the list of suggestions below) and can include a literature review and some numerical investigation or mathematical analysis.

- **Please submit a project plan (1 paragraph) by the beginning of Reading Week.** You can propose a project involving a collaboration between you and another student if you wish.
- Late penalty: you loose 1/3 of your original mark per day of lateness (zero if more than 3 days late).

Textbooks:

- Geoffrey Vallis, "Atmospheric and Oceanic Fluid Dynamics" (required). I will closely follow this book. It is not a fun read, but it is THE book about GFD anyone should have on their desk. Fortunately, the 2nd edition is available for free via the library website (http://go.utlib.ca/cat/11621853). The companion website contains figures, code, etc.: http://empslocal.ex.ac.uk/people/staff/gv219/aofd/
  Because the 2nd edition is relatively recent, I might refer to chapters of the 1st edition, though I will try to correct it as lectures progress.
- Geoffrey Vallis, "Essentials of Atmospheric and Oceanic Dynamics". A shorter version of the textbook above. I did not look into it carefully, but I believe that it covers the sub-set of the full book that I will address in the lectures.
- Cushman-Roisin and Beckers, "Introduction to Geophysical Fluid Dynamics" (recommended). This book does not cover enough topics, and does not show how GFD "gets done" by professionals. However, I strongly recommend that you download the individual chapters on the UofT library website at http://go.utlib.ca/cat/8203627. They insist on building intuition rather than diving into math, and therefore, it is a much more pleasant and understandable read than Vallis. A bit sloppier too, but for the purpose of this class, no need to be fussy.
- Rick Salmon, "Lectures on Geophysical Fluid Dynamics". A short book with an approach that is decidedly Physics-oriented: symmetries, dynamical systems and analogies with quantum mechanics galore.
- John Marshall and Alan Plumb, "Atmosphere, Ocean and Climate Dynamics: An Introductory Text". This book's target audience is at the undergraduate level, but it has descriptions of lab experiments that may be useful, depending on how the rotating tank works out.

Project Topics:

The following is a list of past projects (plus a handful of my own suggestions) rather than **the** list of topics you have to choose from. You can pick one in these, or suggest one. For example, you might have a reason in mind as to why you registered in this class, can serve as inspiration. Of course, I am here to help you design your project.

1. Quasi-Biennial Oscillation: theory and models
2. Dynamics of the North Atlantic Oscillation and the Annular Modes
3. Baroclinic wave packets and downstream development
4. Baroclinic adjustment
5. The Gill model and related models of tropical wave dynamics
6. Simmonds-Wallace-Branstator and other simple models of atmospheric low frequency variability

7. Simple models of the Hadley Circulation
8. Wave activity fluxes, theory and application
9. Linear and nonlinear stability theory, and/or GFD applications
10. Oceanic mesoscale eddy parameterization
11. Geostrophic Turbulence
12. Computational methods in atmosphere/ocean dynamics
13. Comparing tracer advection schemes
14. Statistical mechanics in geophysical fluid dynamics
15. Stationary wave theory and modeling
16. Stratospheric sudden warmings theory and modeling
17. Dynamics of the Brewer Dobson Circulation and related circulations in the atmosphere and ocean.
18. Role of mixing in the ocean
19. Submesoscale dynamics
20. Non-linear waves
21. Applications of GFD to lakes (to be specified).

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In particular, you will submit your end-of-term project reports, and perhaps more, to Turnitin.com, which is a plagiarism detection software used at UofT. In such cases, the following paragraph applies:

"Normally, students will be required to submit their course essays to Turnitin.com for a review of textual similarity and detection of possible plagiarism. In doing so, students will allow their essays to be included as source documents in the Turnitin.com reference database, where they will be used solely for the purpose of detecting plagiarism. The terms that apply to the University's use of the Turnitin.com service are described on the Turnitin.com web site."

You have the option to opt out of Turnitin. If you wish to opt out, let me know, and we will work together to find alternative arrangements.

Familiarize yourself with the University of Toronto's *Code of Behaviour on Academic Matters* (http://www.governingcouncil.utoronto.ca/policies/behaveac.htm). It is the rule book for academic behaviour at the U of T, and you are expected to know the rules. Potential offences include, but are not limited to:

In papers and assignments:

- Using someone else's ideas or words without appropriate acknowledgement.

- Copying material word-for-word from a source (including lecture and study group notes) and not placing the words within quotation marks.
- Submitting your own work in more than one course without the permission of the instructor.
- Making up sources or facts.
- Including references to sources that you did not use.
- Obtaining or providing unauthorized assistance on any assignment including:
  - working in groups on assignments that are supposed to be individual work (note: it is OK, sometimes encouraged, to work together on homework assignments, as long as each copy is individual);
  - having someone rewrite or add material to your work while "editing".
- Lending your work to a classmate who submits it as his/her own without your permission.

Misrepresentation:
- Falsifying or altering any documentation required by the University, including doctor's notes.
- Falsifying institutional documents or grades.

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