PHY 2504S: Advanced Atmospheric Dynamics, Winter 2019

Instructor: Nicolas Grisouard (https://sites.physics.utoronto.ca/nicolasgrisouard)
Office: MP703
Office Hours: if my door is open, please come in. I will also open a Slack channel (https://slack.com/), which is like a professional chatting service. It will be optional, but I found that people tend to be less afraid to ask questions via this medium, for whatever reason.
Voice Landline: +1-416-978-6824
Email: nicolas.grisouard@physics.utoronto.ca

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

Course description

In all other institutions that I know of, this class is called "Geophysical Fluid Dynamics (I)", or 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. Following up on last year, I will use a table-top rotating tank, in order to illustrate some of the lectures. I would like to turn this experiment into graded labs eventually, but this year I will simply take some time during lectures for 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.
- GFD processes in the 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 12-1 MP408 (backup slot)
Monday 3-4 MP606 (regular slot)
Thursday 12-1 MP408 (regular slot)
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. I will attend a conference during reading week, and my tentative plan is to use two hours/week before that, and three/week after, until we reach 24 hours. This is negotiable, but if you agree with it, it should have us be done with lectures well before the official end of classes. The final project presentations will take place over one day during final exams period, and the project report will be due one week later.

As of 13 January, the tentative schedule breakdown is:

Lec #	Date	Organizational item	Lecture topic
1	13 Jan #2	Organizational mtng	Scales of motion
2	16 Jan		Equations of motion

3	20 Jan #2		Thermodynamics
4	23 Jan		Rotation in the equations of motion
5	27 Jan #2		Geostrophic balance, Ekman layer
6	30 Jan		Density stratification
7	3 Feb #2		Internal waves; Pressure coordinates.
8	6 Feb		Single-layer shallow-water (1LSW) equations
9	10 Feb #2	PS1 due	1LSW: waves
10	13 Feb		1LSW: geostrophic adjustment and normal modes
	17-21 Feb		Reading week
	24 Feb	Project abstract due	No lecture
11	27 Feb		n-layer shallow-water equations
12	2 Mar #1		nLSW equations, continued
13	2 Mar #2		Vorticity in GFD
14	5 Mar	PS2 due	Potential Vorticity
15	9 Mar #1		1LSW quasi-geostrophic (QG) equations
16	9 Mar #2		1LSWQG, continued
17	12 Mar		2LSWQG equations
18	16 Mar #1		Baroclinic instability (BCI): informal presentation
19	16 Mar #2		BCI: the Phillips problem
20	19 Mar	PS3 due	Continuously stratified QG equations
21	23 Mar #1		Continuously stratified QG, continued
22	23 Mar #2		Transformed Eulerian Mean equations
23	26 Mar		GFD processes in the atmospheric and oceanic general circulations
24	30 Mar #2		Ageostrophic instabilities
	6 Apr	PS4 due	
	Mid-Apr?	Project presentations	
	End Apr?	Project reports due	

Evaluation

Problem Sets (4, due every 2-3 weeks)	48% (12% each)
Project (8-10-page paper + 20-minute presentation)	40% (20% each)
Quercus quizzes	8%
Class participation	4%

Notes on Assignments

- The problem sets involve mathematical and numerical exercises. You can hand in hard copies or upload them onto Quercus. If you choose to upload a scan of a handwritten copy, make sure it is legible: 400 dpi mini, and no pictures taken from a phone! I will count it as late until I receive a legible copy.

- 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). **Do not use Matlab! I do not have a licence and cannot check your code.**
- I encourage you to discuss questions on the problem sets and to check that you got the same answer with other students, and to exchange ideas about final projects. However, what you hand in must be your own work. **Do not copy any part of someone else's assignment**. **Do not copy solutions found from any source (e.g. websites).** This is plagiarism and is a serious academic offense.
- The projects should cover a chosen topic in atmospheric or ocean dynamics (e.g., topics in the list of suggestions below or one of your own) and can include a literature review and some numerical investigation or mathematical analysis. I will provide you with a detailed rubric as the date gets closer, but I can already say that **I will mostly judge formal skills** (quality of presentation and writing, etc.). Indeed, in academia as in all other high-skilled professions, the transition from undergraduate to graduate studies means that you will be evaluated increasingly on how you deliver your work, and less exclusively on the quality of the work itself. It is typical of creative and leadership positions, and it is what graduate school is meant to prepare you for. It might sound harsh at first, but it actually becomes even more important during the course of a Ph.D.
- **Please send me a project plan (1 paragraph) by February 24** (first Monday after reading week). You can propose a project involving a collaboration between you and another student if you wish.
- Late penalty: you lose 1/3 of your original mark per day of lateness, **starting when the first lecture of the day begins** (zero if more than 2 days late).
- Quercus quizzes will happen approximately every 2-3 lectures. They are meant for me to ensure that you are keeping up with the lectures.
- Class participation: try to ask questions, either in class or on Quercus… This is a more flexible item.

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/
- 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. Vallis was our Noble lecturer last year, and donated a copy to the library.
- 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 (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. Wave-flow interactions
10. Linear and nonlinear stability theory, and/or GFD applications
11. Oceanic mesoscale eddy parameterization
12. Geostrophic Turbulence
13. Other types of turbulence
14. Computational methods in atmosphere/ocean dynamics
15. Comparing tracer advection schemes
16. Statistical mechanics in geophysical fluid dynamics
17. Stationary wave theory and modeling
18. Stratospheric sudden warmings theory and modeling
19. Dynamics of the Brewer Dobson Circulation and related circulations in the atmosphere and ocean.
20. Role of mixing in the ocean
21. Submesoscale dynamics
22. Non-linear waves
23. Applications of GFD to lakes (to be specified)
24. Convection

Academic integrity

See this official statement:

> *The University of Toronto is deeply committed to the free and open exchange of ideas, and to the values of independent inquiry. As such, academic integrity is also fundamental to the University's intellectual life. What does it mean to act with academic integrity? U of T supports the International Center for Academic Integrity's definition of academic integrity as acting in all academic matters with honesty, trust, fairness, respect, responsibility, and courage.*
>
> *In our Code of Behaviour on Academic Matters, the University has identified academic offences that run counter to these values, and that are in opposition to our mission to create internationally significant research and excellent academic programs. This mission can only be realized if all members of the University appropriately acknowledge sources of information and ideas, present independent work on assignments and examinations, and complete and submit group projects in accordance with the standards of the discipline being studied.*
>
> *The University offers many resources to help you if you're feeling stuck or confused by an assignment or in a course. The first place to start is always your instructor, who can also tell you about further resources available within your faculty and department.*
>
> *Please visit academicintegrity.utoronto.ca for smart strategies and information on academic integrity processes and procedures at the University of Toronto. The website includes a link to decisions of the University Tribunal in student cases involving academic integrity. You can review the Code of Behaviour on Academic Matters in its entirety here.*
>
> *With best wishes for the academic year,*
>
> *Professor Cheryl Regehr*
>
> *Vice-President & Provost*

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.

If you have any questions about what is or is not permitted in this course, please do not hesitate to contact me. If you have questions about appropriate research and citation methods, seek out additional information from me, or from other available campus resources like the U of T Writing Website. If you are experiencing personal challenges that are having an impact on your academic work, please speak to me or seek the advice of your college registrar.

Accommodations

If you have a learning need requiring an accommodation the University of Toronto recommends that students immediately register at Accessibility Services at http://www.studentlife.utoronto.ca/as.

Location: 4th floor of 455 Spadina Avenue, Suite 400
Voice: 416-978-8060
Fax: 416-978-5729
Email: accessibility.services@utoronto.ca

The University of Toronto supports accommodations of students with special learning needs, which may be associated with learning disabilities, mobility impairments, functional/fine motor disabilities, acquired brain injuries, blindness and low vision, chronic health conditions, addictions, deafness and hearing loss, psychiatric disabilities, communication disorders and/or temporary disabilities, such as fractures and severe sprains, recovery from an operation, serious infections or pregnancy complications.

As the instructor of this course, you are also invited to communicate with me at any time about your learning needs. Confidentiality of learning needs is respectfully and strictly maintained.

Equity, Diversity and Excellence

At the University of Toronto, we strive to be an equitable and inclusive community, rich with diversity, protecting the human rights of all persons, and based upon understanding and mutual respect for the dignity and worth of every person. We seek to ensure to the greatest extent possible that all students enjoy the opportunity to participate as they see fit in the full range of activities that the University offers, and to achieve their full potential as members of the University community.

Our support for equity is grounded in an institution-wide commitment to achieving a working, teaching, and learning environment that is free of discrimination and harassment as defined in the Ontario Human Rights Code. In striving to become an equitable community, we will also work to eliminate, reduce or mitigate the adverse effects of any barriers to full participation in University life that we find, including physical, environmental, attitudinal, communication or technological.

Our teaching, scholarship and other activities take place in the context of a highly diverse society. Reflecting this diversity in our own community is uniquely valuable to the University as it contributes to the diversification of ideas and perspectives and thereby enriches our scholarship, teaching and other activities. We will proactively seek to increase diversity among our community members, and it is our aim to have a student body and teaching and administrative staffs that mirror the diversity of the pool of potential qualified applicants for those positions.

We believe that excellence flourishes in an environment that embraces the broadest range of people, that helps them to achieve their full potential, that facilitates the free expression of their diverse perspectives through respectful discourse, and in which high standards are maintained for students and staff alike. An equitable and inclusive learning environment creates the conditions for our student body to maximize their creativity and their contributions, thereby supporting excellence in all dimensions of the institution. For more information please see http://about.hrandequity.utoronto.ca/.