SYLLABUS for SIO178

Geophysical Fluid Dynamics

Winter 2025, TuTh 11:00am-12:20pm, SPIESS 330

Instructor:

Janet M. Becker, jmbecker@ucsd.edu

Course format: Lectures will be delivered in person and podcast. Podcasts will be posted to Canvas. Exams are in person only.

Office Hours:

Instructor problem session and office hours: TBD

Academic Prerequisites: Phys 2C, SIO 177 (or equivalent), Math 18 or Math 20F or Math 31AH or consent of instructor.

Prerequisites by Topic: elementary mechanics, fluid mechanics, differential and integral calculus, elementary ordinary differential equations, vector calculus, linear algebra.

Textbook:

B. Cushman-Roisin and J.M. Beckers (not me!), Introduction to Geophysical Fluid Dynamics, 2nd Edition. The e-book is available through the UCSD library:

http://www.sciencedirect.com/science/bookseries/00746142/101

We also may read parts of G.K. Vallis' (GKV) new text "Essentials of Atmospheric and Oceanic Dynamics" from Cambridge University Press (not in the bookstore, but available on Amazon as an e-book or paperback).

Canvas and Gradescope: Assignments will be posted on Canvas. You will upload your solutions to the assignments to Gradescope.

Course description: Geophysical Fluid Dynamics (GFD) is the fluid dynamics that describes the large scale motions of the atmosphere and oceans. This course will explore how the Earth's rotation and variations in density govern atmospheric and oceanic circulation. The class will develop a framework for understanding how winds drive ocean currents, why ocean currents are stronger on the western sides of ocean basins (e.g. think of the Gulf Stream), and how large-scale waves (called planetary waves) can influence sea level and climate.

Topics covered:

1. Introduction to GFD (Chapter 1)
2. Rotational effects: The Coriolis force, the centrifugal force and the geoid. (Chapter 2)
3. Conservation laws in a rotating reference frame (mass, momentum and energy, briefly, Chapter 3) and the equations governing geophysical flows. (Chapter 4).
4. Geostrophic flows. Conservation of potential vorticity for the shallow water equations. (Chapter 7)
5. The importance of friction: The Ekman Layer (Chapter 8)
6. Linear waves in a homogeneous ocean: Poincare, Kelvin and Rossby waves (Chapter 9)
7. Effects of Stratification: Froude number, layered models (Chapters 11, 12)
8. Internal waves (Briefly, Chapter 13)
9. Stratified Geostrophic Dynamics: Thermal wind, Geostrophic adjustment (Chapter 15)
10. Large scale ocean circulation (Chapter 20)
11. The Thermocline and Overturning Circulation (if time allows, GKV, Chapter 15).

Course grade:

The final course grade will be based on following:

Homework assignments (40%), mid-term exam (20%), and final exam (40%).

Homeworks: We will have weekly homework assignments.

Exams:

• Midterm exam: 13 February 2025, 9:30am-10:50am, (Thursday, in person).

• Final exam: 20 March 2025, 11:30am-2:30pm (Thursday, in person).

Course policy and Academic integrity:

1. Homework assignments and solutions are available on the Canvas website.
2. All students are expected to adhere to the UCSD Policy on Integrity of Scholarship. You may discuss homework problems, but you must prepare and submit homework reports on your own.
3. Homework must be written clearly and neatly. The homework is due at the time specified on the assignment.
4. No late homework will be accepted without a valid reason. If you anticipate needing a homework extension, please ask at least a few days in advance of the due date so an extension can be offered to all students. Homework extensions, however, are not given the week prior to a midterm as the posted solutions need to be available for exam preparation. For medical/family emergency issues that are documented, individual extensions/accommodations are provided.
5. There will be no make-up exams (midterm or final) without a valid reason.
6. No course credit will be given for homework assignments or the midterm after the solutions have been posted to Canvas,
7. Asking questions during the lectures is encouraged and appreciated.

Disability Resources: Students requesting accommodations for this course due to a disability must provide a current Authorization for Accommodation (AFA) letter issued by the Office for Students with Disabilities (OSD) which is located in University Center 202 behind Center Hall.

Contact the OSD for further information:

T: 858.534.4382

E: osd@ucsd.edu

W: http://disabilities.ucsd.edu

Disability Resources, Triton Testing Center: Exams requiring accommodation will be administered by the Triton Testing Center (TTC). Students authorized for accommodation must register with the TTC by completing the student registration form. Once the form is completed (they need only do this once), TTC will review their request and create or update the their RegisterBlast/TTC account. Then, TTC will send the students the RegisterBlast log-in information. If they are a student with accommodations and received their AFA letter(s) for the course(s) they have at the TTC, they can copy and paste their accommodations into the registration form.

How to access your TTC account:

To log into your account for the first time please visit this website, enter your UCSD email address, and select a new password:

https://www.registerblast.com/ucsd/ResetRequest/Password/4

Once you have your password, you can access your account at this link:

https://www.registerblast.com/ucsd/User/Authenticate

Answers to frequently asked questions and information on how to schedule a test may be found at the TTC webpage.

Students must schedule their test with TTC at least 3 days in advance.

Learning outcomes (may be updated):
Students will be able to:

1. describe the conditions under which rotation and stratification are important for geophysical fluid dynamics (GFD).
2. describe the laws governing GFD using vector calculus, and solve ordinary differential equations for the physical fields that describe geophysical fluid motions.
3. derive the expression for the acceleration of a fluid in a noninertial (rotating) reference frame that includes the Coriolis and centrifugal accelerations.
4. explain why the centrifugal force is unimportant in GFD and what is meant by the geoid.
5. solve for the fluid velocities of free oscillations on a rotating plane and interpret the solution in terms of oceanographic observations of inertial oscillations.
6. understand the formulation of the full equations that describe the mass budget, momentum budget, energy budget, salinity or moisture budgets, and the equation of state.
7. apply approximations to reduce the full equations to the primitive equations of GFD
   (a) understand and apply the Boussinesq approximation to simplify the full governing equations.
   (b) understand how turbulent dissipation is modeled and incorporated into the momentum equations
   (c) understand the scaling arguments for large scale horizontal motions that simplify the full governing equations
   (d) understand how the effects of Earth's spherical geometry may be approximated by formulating the primitive equations in a plane tangent to the earth (f-plane and β-plane) in which both horizontal components of the Earth's rotation have been neglected (traditional approximation).

(e) define the Coriolis parameter as a function of the Earth's rotation rate and the latitude.

8. understand and identify the physical meaning of each term in the primitive equations of GFD for a homogeneous fluid.
9. define the Rossby number, the temporal Rossby number and the Ekman number and understand how the dynamic balances described in the primitive equations for a homogeneous fluid are simplified in specific parameter regimes.
10. evaluate the dynamical balance of geostrophy and show that geostrophic motions are steady and isobaric.
11. understand the derivation of the shallow-water equations from the primitive equations for a homogeneous fluid and the associated conservation law for potential vorticity.
12. apply and evaluate the conservation law for potential vorticity to realistic ocean flows.
13. identify the dynamical balance and boundary conditions in Ekman layers, derive the velocity field and associated transport in surface and bottom Ekman layers, and apply the solutions to realistic oceanic conditions.
14. derive expressions for Ekman pumping and apply these to realistic oceanic flows.
15. derive dispersion relationships and associated velocity fields and surface elevations for planetary (Poincare, Rossby and Kelvin) waves from the shallow water equations with rotation (and boundary conditions for Kelvin waves) and apply these solutions to realistic oceanic conditions.
16. derive and evaluate wave energy expressions for planetary waves.
17. evaluate the characteristics of short and long Rossby waves in terms of approximate forms of conservation of potential vorticity.

18. derive the dispersion relationship and phase and group velocities for short internal waves in a continuously stratified fluid.

19. understand and apply how the Froude number may be used to determine the importance of stratification in GFD and realistic atmospheric flows.

20. understand how the effects of stratification on fluid motions maybe modeled using the dynamics of two-layer and 1.5-layer reduced gravity models

21. define and evaluate the thermal-wind balance and the geostrophic adjustment problem to model horizontal density fronts

22. analyze an idealized problem of coastal upwelling

23. derive the solution for the interior wind-driven Sverdrup transport from the primitive equations on the β-plane for a homogeneous fluid and boundary conditions and apply the solution to realistic ocean conditions.

24. use potential vorticity conservation to show that the wind-driven circulation in a closed basin consists of an intensified western boundary current that returns the interior Sverdrup flow.