Geophysical Fluid Dynamics – MATH-GA.3001-001

Description of Course

Geophysical fluid dynamics is the branch of fluid dynamics that investigates the large-scale flows in the atmosphere and oceans. These flows are characterized by the preponderant role of planetary rotation and stratification. This course serves as an introduction to the fundamentals of geophysical fluid dynamics. No prior knowledge of fluid dynamics will be assumed, but the course will move quickly into the subtopic of rapidly rotating, stratified flows. Topics to be covered include momentum conservation and continuity, the rotating Navier-Stokes equations and non-dimensional parameters, equations of state and thermodynamics of Newtonian fluids, atmospheric and oceanic basic states, the fundamental balances (thermal wind, geostrophic and hydrostatic), the rotating shallow water model, vorticity and potential vorticity, inertia-gravity waves, geostrophic adjustment, the quasi-geostrophic approximation and other small-Rossby number limits, Rossby waves, baroclinic and barotropic instabilities, Rayleigh and Charney-Stern theorems, wave-mean flow interaction, geostrophic turbulence.

Assessment will be based on completion of problem sets and a take-home final exam. Attendance and participation will not be part of the assessment.

Instructor
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Logistics
Class time: Tuesday and Thursday | 9:30-10:45 AM | WWH 517
Office hour: Tuesday and Thursday | 10:45-11:45 AM | WWH 909

Textbook
Atmospheric and Oceanic Fluid Dynamics, G. Vallis (Cambridge, any edition)

Additional resources
Lectures on Geophysical Fluid Dynamics, R. Salmon (Oxford, 1998)
Waves in the Ocean and Atmosphere, J. Pedlosky (Springer, 2003)
Atmosphere-Ocean Dynamics, A. Gill (Academic 1982)
Geophysical Fluid Dynamics, B. Cushman-Roisin (Academic 2011)

Lectures

Week	Topics
1 (9/2)	Introduction to idea of GFD. Continuum approximation. Label space and Lagrangian/Eulerian perspectives. Material derivatives. (Vallis 1.1)

2 (9/9)	Mass conservation. Momentum equation. Rotating reference frame. Spherical coordinate. Hydrostatic balance. Primitive equations. f-plane and beta-plane approximations.. Shallow water model. (Vallis 1.2-1.3, 2.1-2.3, 3.1) *Problem Set 1*
3 (9/16)	Shallow water system: Geostrophic balance. Potential vorticity. Shallow water gravity waves. Inertia-gravity waves. (Vallis 3.5, 3.7, 3.8; Pedlosky 13)
4 (9/23)	Shallow water system (continued): Kelvin waves. Geostrophic adjustment. Geostrophic scaling. Quasi-geostrophic equations. (Vallis 3.8, 3.9, 5.1, 5.3; Pedlosky 13, 14, 15)
5 (9/30)	Rossby waves in a single-layer shallow water model: Dispersion relation, propagation mechanism, group velocity, energy propagation diagram, energy flux equation (Vallis 6.2, 6.4; Pedlosky 16) *Problem Set 2*
6 (10/7)	Asymptotic derivation of the quasi-geostrophic equations. Two-layer shallow water model. Reduced-gravity model. Rigid-lid approximation. Thermal wind balance. (Vallis 3.3, 3.5, 5.3.1)
7 (10/14)	Two-layer QG equations. Rossby waves in the two-layer QG model. (Vallis 5.3.2, 6.4.4)
8 (10/21)	Barotropic instability: parallel shear flows; piecewise shear flows; Rayleigh's equation; jump conditions; edge waves; interaction of edge waves generating instability. (Vallis 9.1, 9.2) *Problem Set 3*
9 (10/28)	Necessary conditions for barotropic instability - Rayleigh's and Fjortoft's criteria; baroclinic instability in a two-layer QG model. (Vallis 9.3, 9.6)
10 (11/4)	Boussinesq and anelastic approximations; Continuously stratified QG PV equation; baroclinic instability in stratified fluids (Eady's model). (Vallis 2.4,2.5,5.4,9.5)
11 (11/11)	Charney-Stern-Pedlosky criterion; internal gravity waves: dispersion relation, parcel interpretation, reflection, topographic generated waves (Vallis 9.4,7.3) *Problem Set 4*
12 (11/18)	Vorticity equation; "frozen-in" property of vorticity; Ertel's PV; potential temperature; Kelvin's circulation theorem; shallow water PV from the "frozen-in" property (Vallis 4.1,4.2,4.3,4.5,4.6)
13 (11/25)	3D incompressible turbulence: triad interactions; Kolmogorov theory; inertial range; viscous scale (Vallis 11.1,11.2)
14 (12/2)	2D incompressible turbulence: conservation of enstrophy; inverse energy cascade; 2D turbulence with beta effect, mechanism of midlatitude atmospheric jet production: vorticity budget; Rossby Wave momentum flux; pseudomomentum budget (Vallis 11.3,15.1)
15 (12/9)	Take-home final exam