Geophysical Fluid Dynamics – MATH-GA.3001-001

Fall 2025

Course Description

Geophysical fluid dynamics, or "GFD", takes fluid dynamics and gives it a planetary *spin*. On a rotating planet, the rules of fluid motion change. Rotation and stratification shape the atmosphere and ocean, producing the jet stream, hurricanes, the Gulf Stream, and even the bands on Jupiter (check out the course flyer).

In this course we will study the equations describing these motions, but just as importantly, we will build the physical intuition that makes GFD one of the most fascinating areas of fluid dynamics. Among these ideas are the shallow water model, which captures the essence of large-scale motion; potential vorticity, a conserved quantity that guides our intuition; and baroclinic instability, a uniquely geophysical process that drives ocean eddies and atmospheric storms. See the schedule on the second page for more details.

Instructor

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Logistics

- **Class time:** Tuesday and Thursday, 2:00–3:15 PM, Warren Weaver Hall 517
- **Office hours:** Tuesday and Thursday, 3:15–4:15 PM, Warren Weaver Hall 909

Assessment

Completion of four problem sets and a take-home final exam.

Textbook

- *Atmospheric and Oceanic Fluid Dynamics*, G. Vallis (Cambridge, any edition)
- *Waves in the Ocean and Atmosphere*, J. Pedlosky (Springer, 2003)

Both available online for NYU students.

Additional Resources

- *Lectures on Geophysical Fluid Dynamics*, R. Salmon (Oxford, 1998)
- *Atmosphere-Ocean Dynamics*, A. Gill (Academic 1982)
- *Geophysical Fluid Dynamics*, B. Cushman-Roisin (Academic 2011)

Lecture Schedule

Week	Dates	Topics / Notes
1	9/2, 9/4	Introduction to fluid dynamics and the idea of GFD: continuum approximation, label space and Lagrangian/Eulerian perspectives, material derivatives. (Vallis 1.1)
2	9/9, 9/11	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, 9/18	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, 9/25	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, 10/2	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, 10/9	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	10/16	Two-layer QG equations, Rossby waves in the two-layer QG model. (Vallis 5.3.2, 6.4.4)
8	10/21, 10/23	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, 10/30	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, 11/6	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, 11/13	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, 11/20	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, 12/4	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. (Vallis 11.3, 15.1)
15	12/5–12/12	**Take-home final exam**