Geophysical Fluid Dynamics I

Spring 2022

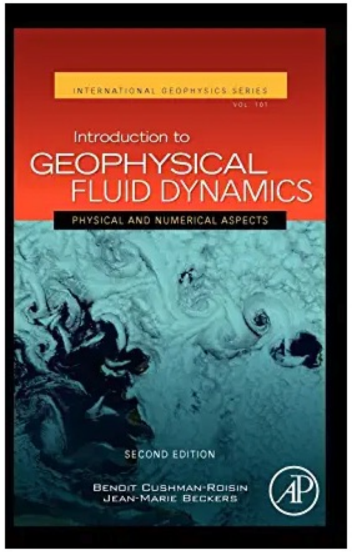
Instructor: Zhaoru Zhang

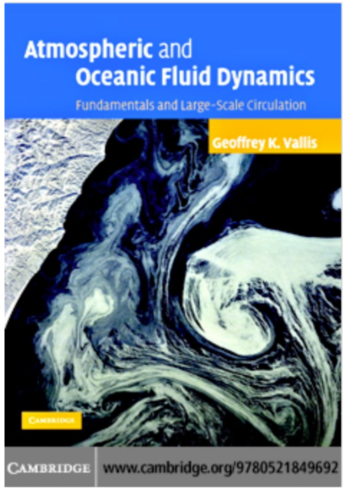
zrzhang@sjtu.edu.cn

Room 123, School of Oceanography

Textbooks

- **Benoit Cushman-Roisin and Jean-Marie Beckers. *Introduction to geophysical fluid dynamics: physical and numerical aspects*. Vol. 101. Academic Press, 2011.**
- Vallis, Geoffrey K. *Atmospheric and oceanic fluid dynamics*. Cambridge University Press, 2017.
- Pedlosky, Joseph. *Geophysical fluid dynamics*. Springer, 2013.
- Pedlosky, Joseph. *Waves in the Ocean and Atmosphere, Introduction to Wave Dynamics*. Springer, 2003.
- Gill, Adrian E. *Atmosphere—ocean dynamics*. Elsevier, 1982.
- Holton, James R., and Gregory J. Hakim. *An introduction to dynamic meteorology*. Vol. 88. Academic press, 2012.





Prerequisites

Course: Physical Oceanography

- Math

  All mathematical methods and tools
  Scalar, vector, tensor, ODE, PDE

  Elements of Geophysical Fluid Mechanics, Stephen M. Griffies, 2022

  Fluid Mechanics (Chapter 2), Pijush K. Kundu, Ira M. Cohen and David R. Dowling, 2012

- Physics

  Newton's Laws, Fluid dynamics, Thermodynamics

- Computer

  Matlab, Python, Fortran

Grading

- Class performance (10%)
- Homework (30%, including group presentation)
- Midterm exam (take-home, 30%)
- Final exam (project, 30%)

Distinguishing attributes of geophysical fluids

1. Rotation

Rotation rate of the Earth:

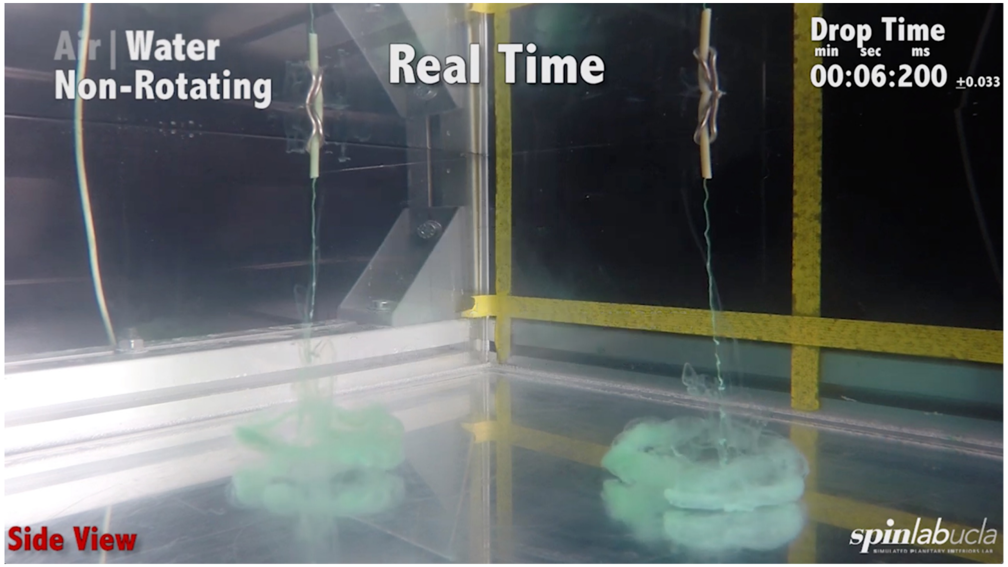
$$\Omega = \frac{2\pi \text{ radians}}{\text{time of one revolution}} \qquad \boxed{7.2921 \times 10^{-5}\ \text{s}^{-1}}$$

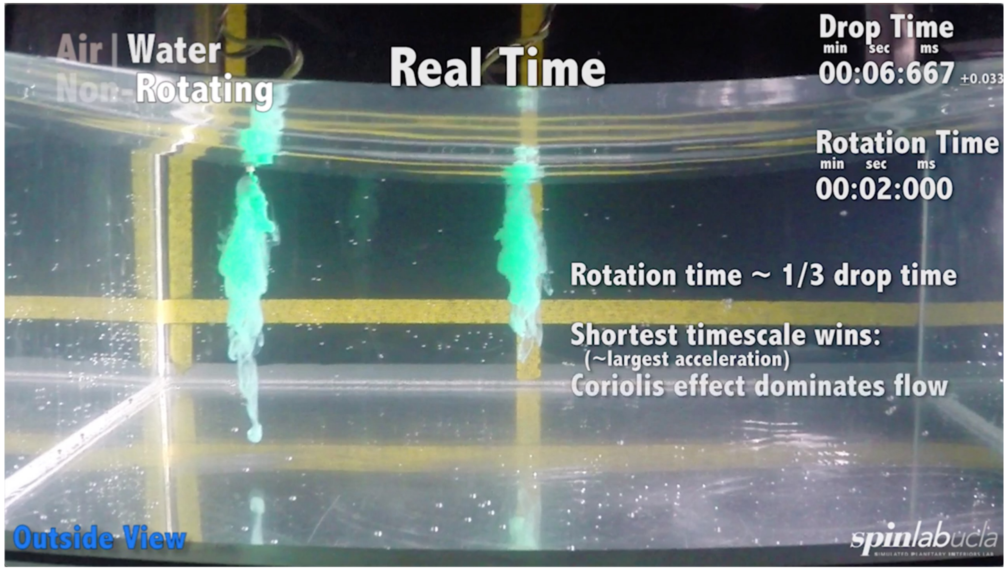
If fluid motions evolve on a **time scale comparable to or longer than the time of one rotation**, then the fluid can feel the effect of ambient rotation:

$$\omega = \frac{\text{time of one revolution}}{\text{motion time scale}} = \frac{2\pi/\Omega}{T} = \frac{2\pi}{\Omega T} = \frac{2\pi U}{\Omega L} \qquad R_0 = \frac{U}{fL}\,(f = 2\Omega sin\varphi)$$

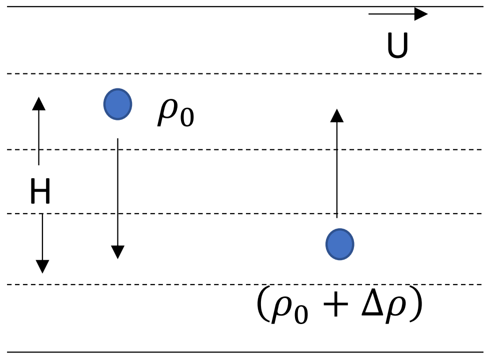
$\omega \lesssim 1$, rotation effect is important

The effect of rotation on fluid motions – imparting rigidity





2. Stratification – break vertical rigidity



For per unit volume,

Potential energy change:

$$\Delta PE = (\rho_0 + \Delta\rho) gH - \rho_0 gH = \Delta\rho gH$$

Kinetic energy:

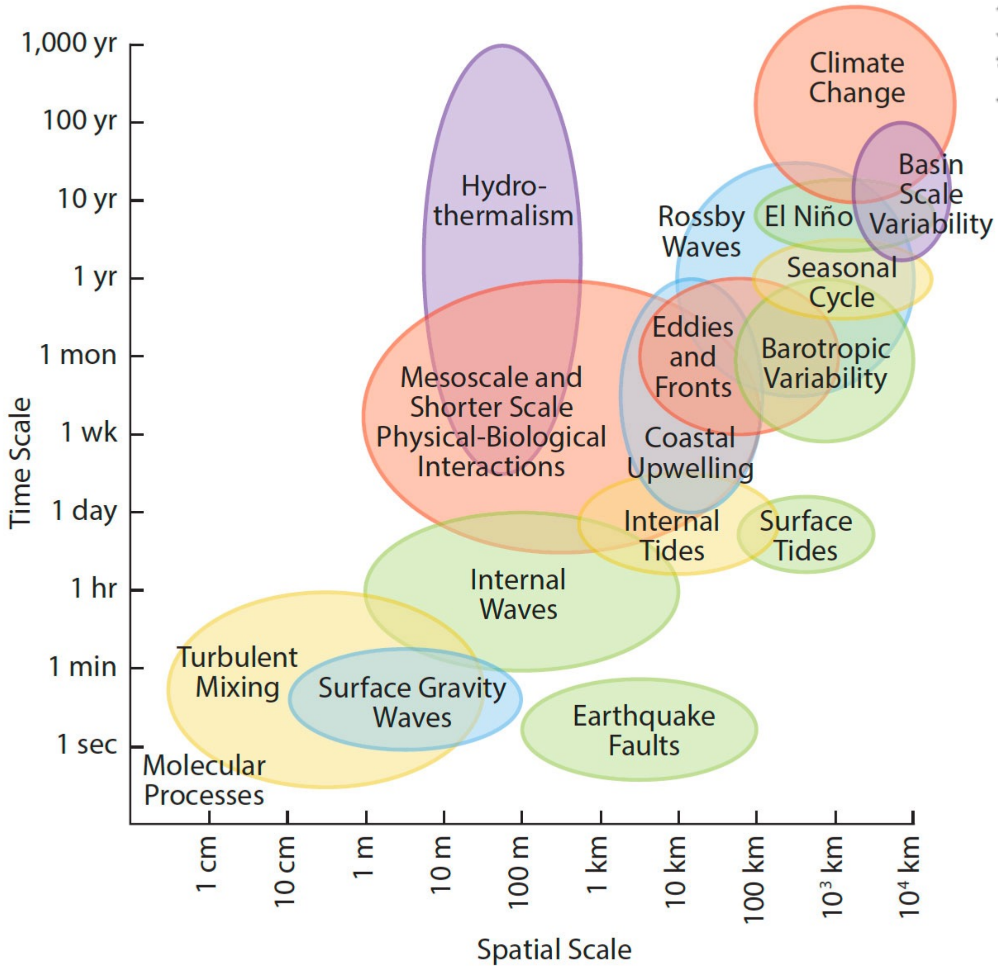
$$KE = \frac{1}{2}\rho_0 U^2 + \frac{1}{2}(\rho_0 + \Delta\rho)\, U^2 \approx \rho_0 U^2$$

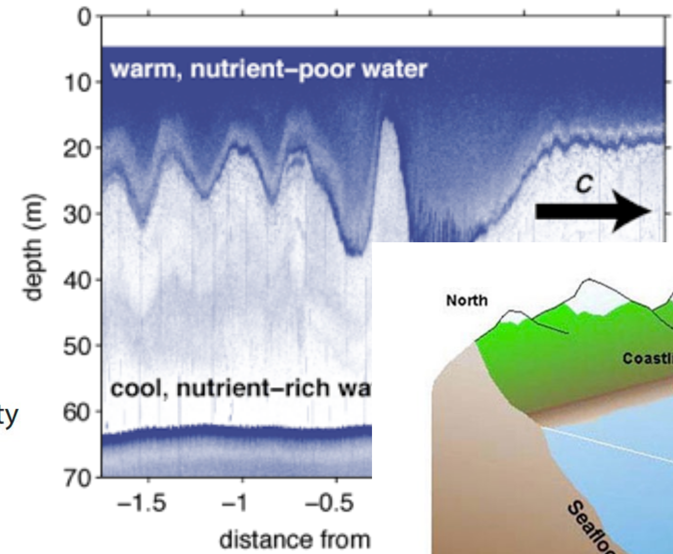
$$\sigma = \frac{KE}{\Delta PE} = \frac{\rho_0 U^2}{\Delta\rho gH} \sim \frac{U^2}{N^2 H^2}$$ Froude number

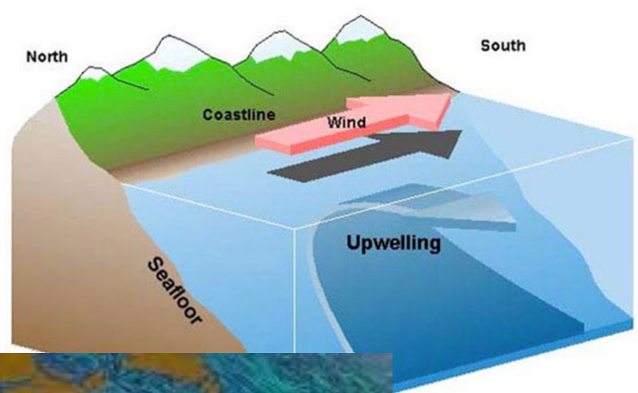
$\sigma > 1$, PE change consumes a small portion of the KE of the system, so it takes little cost to break stratification, stratification is unimportant

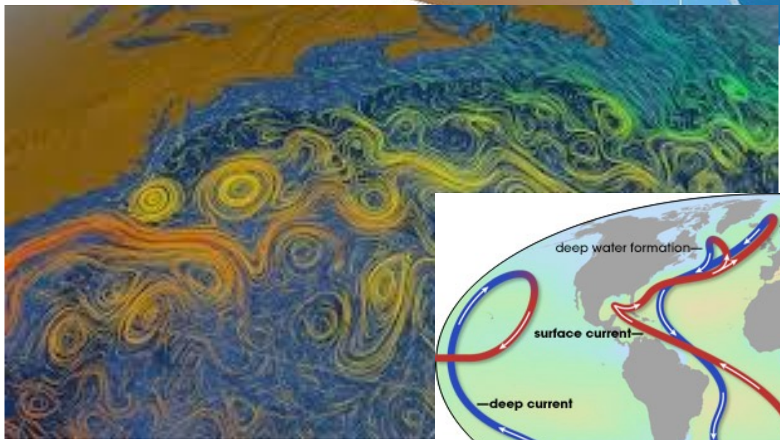
$\sigma \leq 1$, PE change consumes all KE of the system, or KE is not sufficient to supply ΔPE , stratification cannot be broken and is important

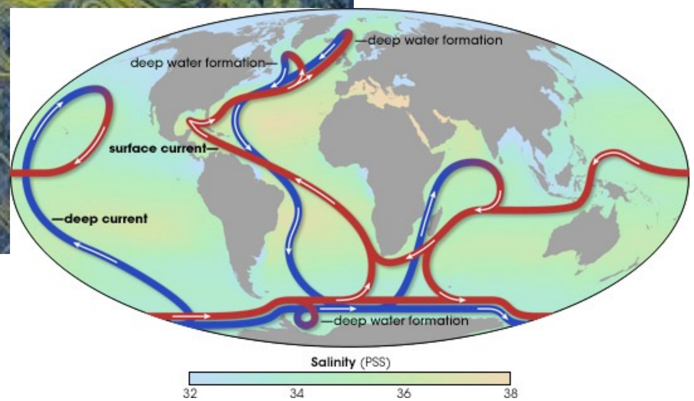
Scale of motions in the ocean



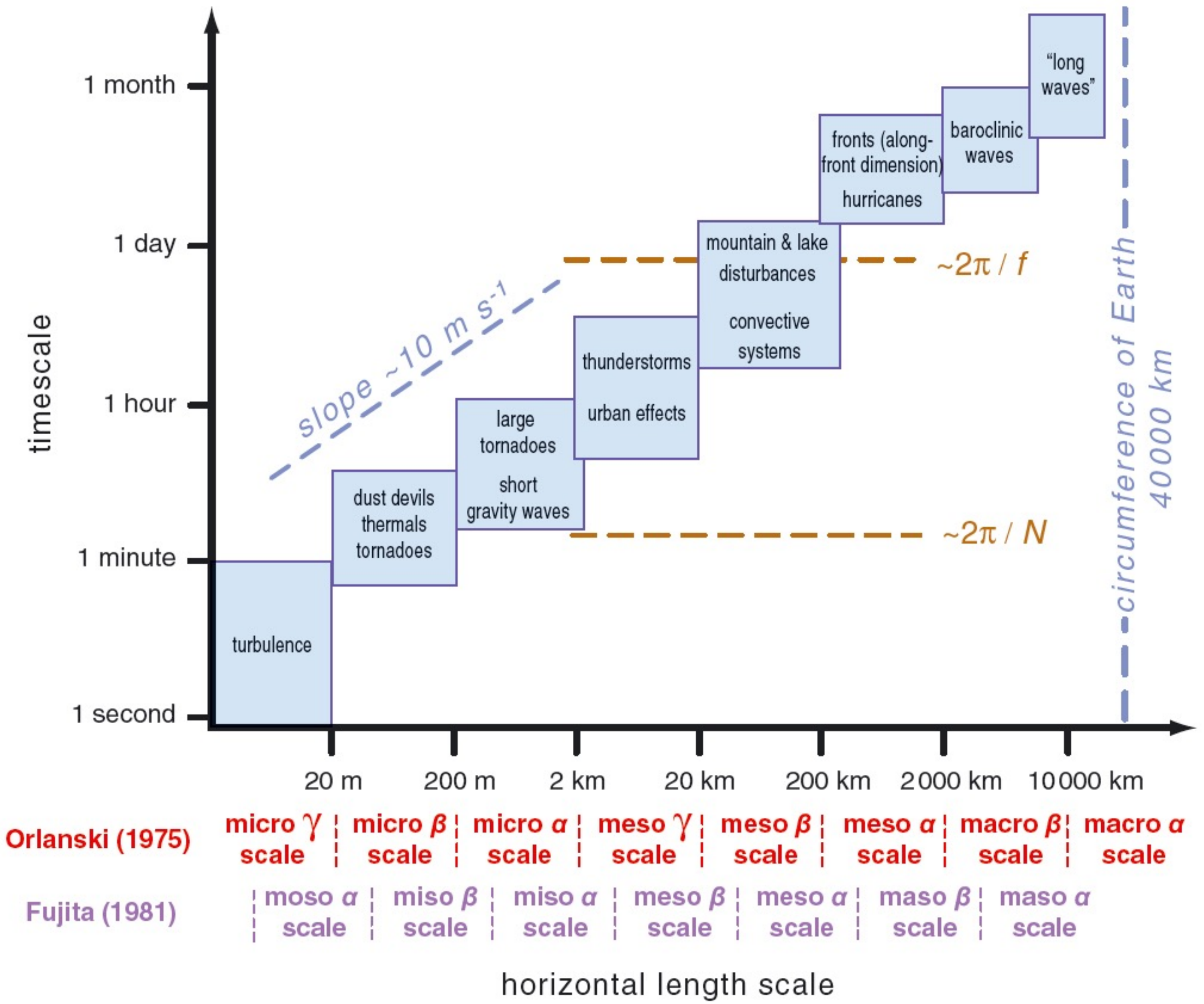






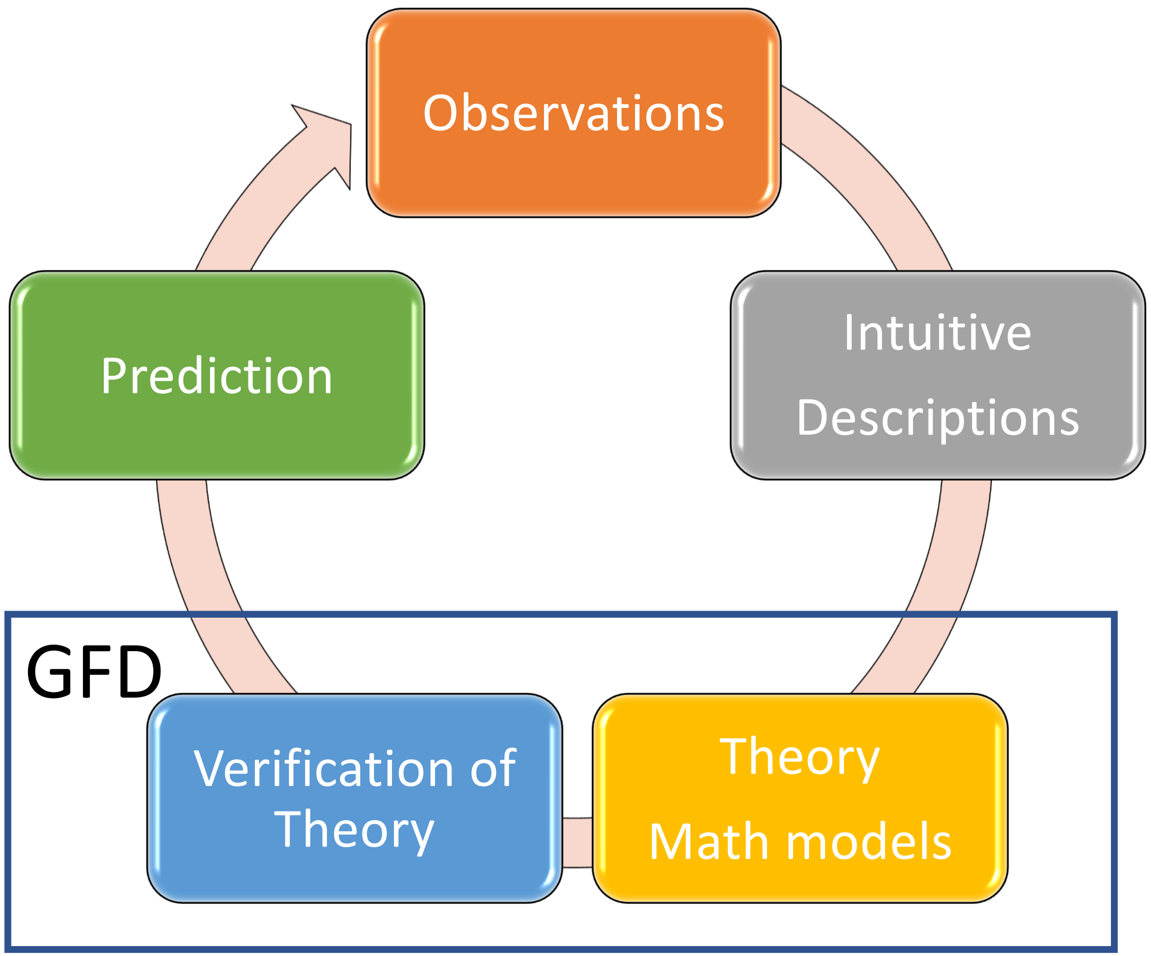


Scale of motions in the atmosphere



Oceanic motions are generally **slower and more confined** than their atmospheric counterparts

Principle of GFD



Syllabus

Part I: Governing equations

1. Primitive equations
2. Approximation and simplication

Part II: Rotation effects

1. Intertial motions
2. Geostrophic flows
3. Shallow-water model and shallow-water waves
4. Geostrophic adjustment
5. Batrotropic instability
6. Ekman layer dynamics

Part III: Statification effects

1. Basic concepts
2. Internal waves
3. Normal modes of internal waves
4. Kelvin-Helmholtz instability
5. Layered models
6. Baroclinic geostrophic adjustment
7. Baroclinic instability