EEPS1820: Geophysical Fluid Dynamics

Rotating, Stratified Turbulence Edition

Spring 2026

Course Information

- **Instructor:** Baylor Fox-Kemper

- **Email:** baylor@brown.edu

- **Office:** Lincoln Field 214 or Zoom office

- **Class Hours:** MWF 13:00 — 13:50, Lincoln Field 117, https://brown.zoom.us/j/97116531632

- **Office Hours:** MWRF 08:00 — 09:00, MT 17:00-18:00 (make appointment at fox-kemper.com/contact)

- **Website:** https://fox-kemper.com/1820

Course Description

Explores theories of the large-scale ocean and atmosphere, including quasigeostrophic, planetary geostrophic, and shallow water equations. Topics will vary to focus on features of the general circulation and climate system (e.g. thermocline, westward intensification, jet stream dynamics, polar vortex, meridional overturning circulations), instabilities and waves (e.g. gravity, Rossby, and Kelvin), or rotating stratified turbulence. May be repeated with permission of instructor. Pre-requisites: EEPS 0350 or PHYS 0720 or APMA 0340 and EEPS 1510 or EEPS 1520.

Learning Goals

By the end of this course, students will be able to:

1. Quantify physical processes of the Earth System.

2. Understand turbulence and different types of averaging (volume vs. time vs. ensemble).

3. Analyze the effects of rotation and stratification on turbulence.

4. Practice solving geophysical problems using analytical and numerical techniques.

5. Critique and refine scientific work through peer review.

Resources

Textbooks

1. [**Required Purchase**] Vallis, G. K. (2019). *Essentials of Atmospheric and Oceanic Dynamics.* Cambridge University Press.

2. Wyngaard, J. C. (2010). *Turbulence in the Atmosphere*. Cambridge University Press.
   Electronic Access: Brown University Library Link

3. Thorpe, S. A. (2007). *An Introduction to Ocean Turbulence*. Cambridge University Press.
   Electronic Access: Brown University Library Link

Simulation Software

- **Oceananigans.jl**: `https://clima.github.io/OceananigansDocumentation/stable/`

- **GeophysicalFlows.jl**: `https://fourierflows.github.io/GeophysicalFlowsDocumentation/stable/`

- **julia**: `https://julialang.org`

- **Jupyter Notebooks**: `https://jupyter.org/`

Grading Scheme

- **Attendance, Participation, & Discussion:** 20%

- **Problem Sets (10 Total):** 60%

- **Peer Reviews:** 20%

Course Policies

Time Allocation (Workload Statement)

Over 14 weeks, students will spend 3 hours per week in class (42 hours total). Required reading, review of lecture notes, and watching of short videos is expected to take up approximately 6 hours per week (78 hours total). The 10 problem sets are estimated to require roughly 5 hours each to complete (50 hours total). The peer reviews are estimated to take 1 hour each (10 hours). Total time commitment is approximately 180 hours.

Accessibility and Accommodations

Brown University is committed to providing an equitable, inclusive, and accessible environment for all students. If you have a disability or other condition that may require accommodations, please contact **Student Accessibility Services (SAS)** at 401-863-9588 or sas@brown.edu to discuss your needs and obtain the necessary documentation. Once you have your SAS accommodation letter, please meet with me as early in the semester as possible so we can discuss how to best support your learning.

Academic Integrity

Academic achievement is evaluated on the basis of work that a student produces independently. A student who obtains credit for work, words, or ideas that are not the products of their own effort is dishonest and in violation of Brown's Academic Code. All students are expected to be familiar with and adhere to the Academic Code. You are encouraged to discuss problem sets with classmates,

but the final code implementation and write-up must be your own work. [Read the full Academic Code here](). All work that you submit during the course must be primarily your own original work and represent your own thoughts and ideas. This is especially true if AI is used in some way: it is your responsibility to document the *use and/or prompts* that you chose as examples of how its use still reflects your own thinking. Therefore, the use of AI-powered tools (such as OpenAI's ChatGPT or GitHub's CoPilot code-completion tool or Google Gemini) to complete significant portions of course assignments is discouraged, although their use in limited ways is not. Learning to use these tools will empower you to more rapidly code effectively, and learning to spot the errors and bugs and hallucinations they induce is important for your development. However, use of AI-powered tools without proper citation will be considered academic misconduct. Brown's Academic Code for both undergraduate and graduate students states that:

> A student's name on any exercise (e.g., a theme, report, notebook, performance, computer program, course paper, quiz, or examination) is regarded as assurance that the exercise is the result of the student's own thoughts and study, stated in his or her own words, and produced without assistance, except as quotation marks, references, and footnotes acknowledge the use of printed sources or other outside help.

If you choose to use these tools for course assignments, they must acknowledge and thoroughly document your use of the tool. An add-on to the assignment, specifying:

1. the tool used, and a brief explanation of how the tool was used for the assignment, and

2. a full delineation of the student's own contribution as input to the tool vs. the contribution of the tool.

All assignments will be graded based primarily your original ideas – you risk losing credit if documentation provided is insufficient to determine your original contributions.

Diversity and Inclusion

It is my intent that students from all diverse backgrounds and perspectives be well-served by this course, that students' learning needs be addressed both in and out of class, and that the diversity that students bring to this class be viewed as a resource, strength, and benefit. I aim to present materials and activities that are respectful of diversity: gender, sexuality, disability, age, socioeconomic status, ethnicity, race, and culture.

I Identify with a Group/Gender/Culture/Religion/Sexuality that is Uncommon in Science. Is It for Me?

Yes! You are just what is needed! Take a minute to think of all the ways your unique background will give you a different perspective and strengths as a scientist. These will help you to ask questions or find answers that no one else can!

Weekly Schedule & Readings

Dates conform to the Brown University Academic Calendar for Spring 2026. Classes begin Wednesday, Jan 21 and conclude by Wednesday, April 29.

Week 1: Jan 21–23

Foundations of Fluids

Short week (Classes start Wed).
Conservation laws, Reynolds Transport Theorem, Navier-Stokes.

- *Readings:* Read: Vallis Ch 1 & 2.
- *Readings:* Skim: Wyngaard Ch 1 & Thorpe Ch 1.
- **Problem Set 1 (Analytical), Due Jan 30:** Kinematics & Conservation.

Week 2: Jan 26–30

Averaging & Conservation

Boussinesq approximation, Reynolds decomposition, Averaging types, Navier-Stokes continued.

- *Readings:* Wyngaard Ch 2 & 3. Skim: Thorpe Ch 5.
- **Peer Review Problem Set 1, Due Feb 2**

Week 3: Feb 2–6

Computational Fluid Dynamics & Covariance

Grids, advection schemes, conservation in numerical models, Reynolds rules, tracer & momentum fluxes.

- *Readings:* Wyngaard Ch 3, 4 & 5.
- **Problem Set 2 (Computational), Due Feb 13:** Simulating tracer advection and conservation using `Oceananigans.jl`.

Week 4: Feb 9–13

Rotation & Stratification

Shallow Water Equations, Geostrophy, Thermal Wind, Static Stability.

- *Readings:* Vallis Ch 3; Thorpe Ch 4.
- **Problem Set 3 (Analytical), Due Feb 20:** Thermal wind balance & Static stability.
- **Peer Review Problem Set 2, Due Feb 18**

Week 5: Feb 18–20

Geostrophic Balance & Adjustment

Winter Long Weekend: No classes Mon Feb 16 or Tue Feb 17.
Initialization of baroclinic zones, Rossby adjustment problem, internal waves, super-inertial and sub-inertial.

- *Readings:* Vallis Ch 4 & 5.
- **Problem Set 4 (Computational), Due Mar 2:** Setting up a Thermal Wind balance and observing Geostrophic Adjustment, and (sub)mesoscale instability in `Oceananigans.jl`.
- **Peer Review Problem Set 3, Due Feb 23**

Week 6: Feb 23–27

Vorticity & Potential Vorticity

AGU Ocean Sciences Meeting: prerecorded classes all week.
Circulation, QG approximation, Rossby waves, Kelvin waves, mesoscale and synoptic scale defined.

- *Readings:* Vallis Ch 5, 6.

- **Problem Set 5 (Analytical), Due Mar 13:** Enstrophy conservation & QG Potential Vorticity budgets.
- **Peer Review Problem Set 4, Due Mar 9**

Week 7: Mar 2–6   **Waves & Instabilities**
Barotropic and baroclinic instability, hydrodynamic stability, finescale, sub-mesoscale, and mesoscale contrasted.

- *Readings:* Vallis Chp 8; Skim: Vallis Chp 7; Thorpe Ch 3.

Week 8: Mar 9–13   **Turbulence & Cascades**
Kolmogorov theory, Spectral analysis, 2D vs 3D turbulence.

- *Readings:* Vallis Ch 10; Skim: Wyngaard Ch 7, 8, 9.
- **Problem Set 6 (Computational), Due Mar 20:** Simulating instabilities and decaying and forced 2D/QG turbulence using `GeophysicalFlows.jl`.
- **Peer Review Problem Set 5, Due Mar 16**

Week 9: Mar 16–20   **Planetary Boundary Layers (PBL)**
Ekman layers, Surface layers, Monin-Obukhov similarity.

- *Readings:* Wyngaard Ch 5, 6, 8; Thorpe Ch 3
- **Problem Set 7 (Analytical), Due Apr 3:** Ekman transport & Vertical velocity pumping.
- **Peer Review Problem Set 6, Due Mar 30**

Spring Recess   **March 21 – March 29**
No University Exercises.

Week 10: Mar 30–Apr 3   **Wind-Driven Layers & Closures**
Surface stress, vertical resolution issues, second-order closure, Langmuir turbulence.

- *Readings:* Wyngaard Ch 9, 10.
- **Problem Set 8 (Computational), Due Apr 10:** LES of the turbulent Ekman spiral, Langmuir turbulence, and inertial oscillations under wind stress in `Oceananigans.jl`.
- **Peer Review Problem Set 7, Due Apr 6**

Week 11: Apr 6–10   **Convection & Langmuir Turbulence**
Convective boundary layers, surface fluxes, coherent structures.

- *Readings:* Wyngaard Ch 11, 12; Thorpe Ch 6
- **Problem Set 9 (Analytical), Due Apr 17:** Log-layers, Roughness lengths, and Stability functions.
- **Peer Review Problem Set 8, Due Apr 13**

Week 12: Apr 13–17   **Large Eddy Simulation (LES)**
Resolving turbulence, subgrid-scale closures.

- *Readings:* Wyngaard Ch 6;
- **Problem Set 10 (Computational), Due Apr 24:** LES of a convective and convective-shear boundary layer using `Oceananigans.jl`.
- **Peer Review Problem Set 9, Due Apr 20**

Week 13: Apr 20–24	**Synthesis & Review** Connecting the scales: from Boundary Layers to General Circulation.
Reading Period	**Starts April 24 (After Class), Ends May 5** **Peer Review Problem Set 10, Due May 1**