EPS/ESE 131: Introduction to Physical Oceanography and Climate

Spring 2024

Canvas course web page for EPS/ESE 131

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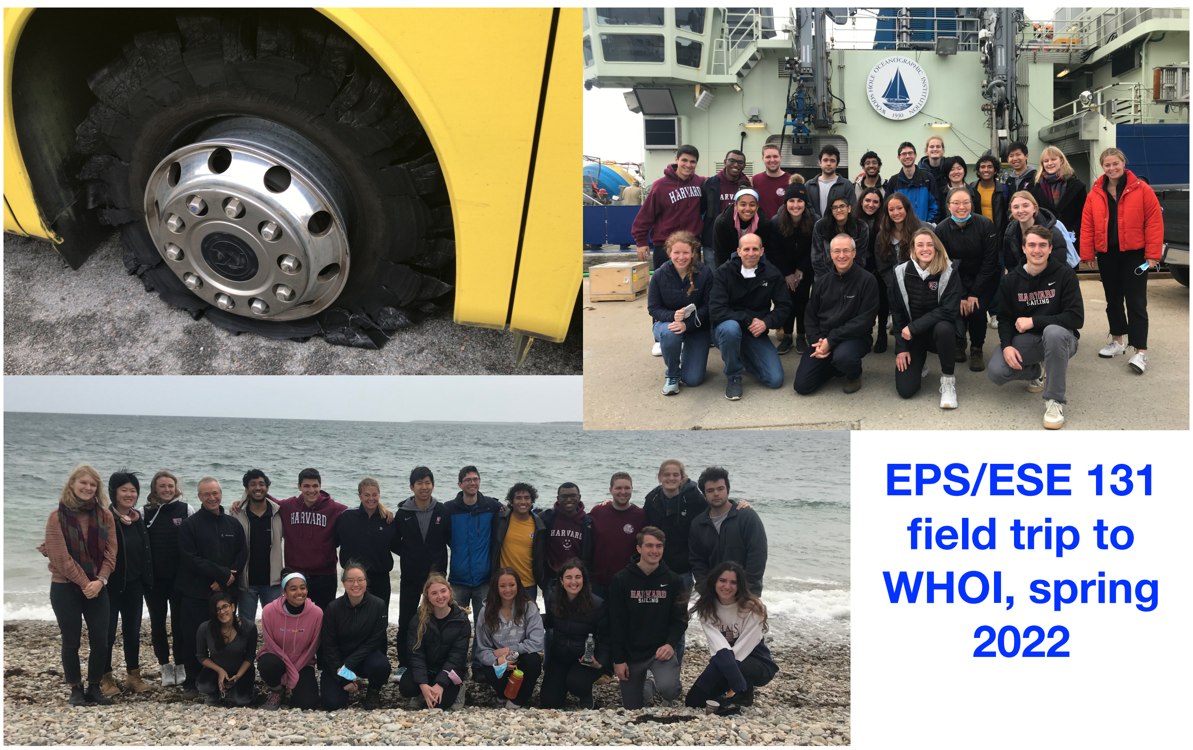

Field trip to the Woods Hole Oceanographic Institution, spring 2022.

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1 Logistics

This is: Earth and Planetary Sciences/ Environmental Science and Engineering 131: Introduction to Physical Oceanography and Climate.

Instructor: Eli Tziperman, office hours: please see Canvas course web page.

TF: Elle Weeks, elleweeks@g.harvard.edu. Office Hours: Canvas course webpage.

Day, time & location: Tuesday, Thursday, 10:30–11:45, Geological Museum, 24 Oxford St, third floor, room 375.

Field Trip! To the Woods Hole Oceanographic Institution/ WHOI, *obligatory & fun*; hosted by Dr. Bob Pickart; **date TBA**. Departing at 7:00 am, returning around 6 pm.

Section/HW help session: time and location: see Canvas course web page.

Sources directory: with all class notes, demos, code, and data! here, or DropBox link from Canvas page.

Important past events...:

- WHOI field trip. In previous trips we visited the R/V Atlantis, R/V Knorr, R/V Armstrong, the submersible Alvin, and we toured WHOI labs. Photos: 2005, 2008, 2010, 2012, 2014, 2016, 2018, 2020 no trip, Covid 🙁, 2022.
- EPS 131 Oscars (video project) events: 2005: surface waves; 2008: internal waves; 2010: great Pacific garbage patch; 2012: thermohaline circulation; 2014: surface waves; 2016: brine rejection; 2018: phase speed in 2d; 2020: sweet viscosity; 2022: sea level;
- zeta vs xi (ζ vs ξ) competition: 2008, 2010, 2012, 2014, 2016, 2018, 2020, 2022.
- The real stuff: Three 2022 EPS131 veterans on a cruise with Bob Pickart on the R/V Norseman II to the northern Bering/Chukchi/western Beaufort Seas!

Requirements: Homework will be assigned every 9–10 days (40% of course grade, lowest HW grade dropped). Each student will give one to two short (10 min) presentation(s) (details), which, together with a small-group video project (examples above) and/or a Wikipedia entry-writing project, will constitute another 30%. The final exam will be an open-book take-home (30%).

Course forum: Please post questions regarding HW or other issues to the course forum (edstem.org). You are very welcome to respond to other students' questions.

Electronic homework submission: Your submission, via www.gradescope.com, may be typeset or scanned but must be clear, easily legible, and correctly rotated. A scan using a phone app (e.g., this) may be acceptable if done carefully. Upload different files for the different questions, or upload a single pdf and mark which pages contain answers to which question; see tutorial video. Unacceptable scans could lead to a rejection of the submission or to a grade reduction of 15%.

Recommended Prep: Mathematics 21a, 21b; Physical Sciences 12a, Physics 15a or Applied Physics 50a; or equivalents/ permission of instructor. Basic programming for scientific computation and graphics will be introduced (students may choose either Matlab or Python) and will be used for some homework assignments; no prior programming experience is assumed.

Academic Integrity and Collaboration policy. We strongly encourage you to discuss and work on homework problems with other students and the teaching staff. However, after discussions with peers, you need to work through the problems yourself and ensure that any answers you submit for evaluation are the result of your own efforts, reflect your own understanding, and are written in your own words. In the case of assignments requiring programming, you need to write and use your own code; code sharing is not allowed. You must appropriately cite any books, articles, websites, lectures, etc. that have helped you with your work.

Course materials are the property of the instructional staff or other copyright holders and are provided for your personal use. You may not distribute them or post them on websites without the permission of the course instructor.

Contents

2 Outline

Observations and fundamentals of ocean dynamics, from the role of the oceans in climate change to beach waves. Topics include the greenhouse effect and the role of the oceans in global warming; El Niño events in the equatorial Pacific Ocean; the wind-driven ocean circulation and the Gulf Stream; coastal upwelling and fisheries; temperature, salinity, the overturning ocean circulation and its effect on global climate stability and variability; wave motions: surface ocean waves, internal waves, tsunamis, and tides; ocean observations by ships, satellites, moorings, floats and more.

A field trip to the Woods Hole Oceanographic Institution on Cape Cod will be an opportunity to learn about sea-going oceanography. Students will be doing a group video project and group in-class presentations. Scientific computation and visualization methods will be introduced (students may choose either Matlab or Python) and will be used for some homework assignments.

3 Detailed syllabus

Here is a link to the pdf of the detailed syllabus, and to the directory with all source materials and lecture notes.

1. **Outline and motivation,** downloads.

2. **Temperature and salinity,** downloads.

   (a) *Greenhouse effect:* Calculating the expected globally averaged temperature given the solar radiation and the atmospheric greenhouse effect. Atmospheric lapse rate and the mechanism of anthropogenic global warming.

   (b) Sea level rise

   (c) *North-south and vertical temperature profiles:* Why is the deep ocean so cold? What's setting the near-exponential vertical ocean temperature profile? Munk's "abyssal recipes".

   (d) Salinity and water masses:

   (e) *Water masses:* T–S diagrams, mixing of two and three water masses.

   (f) *Potential density:* Stability and σ_θ vs σ_4, why stratification seems unstable on σ_θ but is clearly stable when plotted using σ_4. Explanation via nonlinearity of equation of state.

3. **Horizontal circulation I: currents, Coriolis force,** downloads.

   (a) The Great Ocean Gyres and the Gulf Stream.

(b) INTRODUCTION TO THE MOMENTUM BALANCE, $F = ma$, FOR FLUIDS: density×acceleration = pressure gradient force + Coriolis force + friction + gravity + wind forcing;

(c) The Coriolis force and the geostrophic balance in the ocean and atmosphere: wind around highs and lows on a weather map, currents around the subtropical gyre in the North Atlantic.

(d) Hydrostatic equation: the vertical momentum balance.

(e) Boussinesq approximation: water as a nearly incompressible fluid.

(f) Competing effects of sea level and density gradients in driving the vertical structure of the Gulf Stream.

(g) The thermal wind balance: calculating ocean currents from temperature and salinity observations, monitoring the ocean circulation to observe early signs of AMOC collapse.

4. **Waves,** downloads.

   (a) INERTIAL MOTIONS: circular water motion at the inertial period after a passing storm explained by the Coriolis force.

   (b) Wave basics: wavelength, period, wave number frequency, dispersion relation, phase and group velocities; phase velocity in 2d.

   (c) Surface shallow-water gravity waves (beach waves, tides, and Tsunamis!)

   (d) Deep water surface gravity waves/ scaling.

   (e) BUOYANCY OSCILLATIONS: due to the effects of ocean stratification and gravity.

   (f) INTERNAL WAVES: wave-like motions of deep constant temperature surfaces below the ocean surface.

   (g) Waves in the presence of rotation: Coastal Kelvin waves and Poincare waves

5. **Sea-going physical oceanography**

   Finally, the real stuff: a field trip to Woods Hole Oceanographic Institution to learn more about sea-going oceanography.

6. **Friction, Ekman,** downloads.

   (a) Motivation: Why don't Icebergs move with the wind direction (Ekman 1905). Coastal upwelling regions that are responsible for a significant part of fisheries exist due to friction effects and are driven by coastal winds.

   (b) Damped inertial oscillations

   (c) Ekman transport and coastal upwelling: the combined effect of the Coriolis force and vertical friction.

(d) Scale-selective friction.

(e) The Ekman spiral.

7. **The meridional overturning circulation,** downloads.

   - *Motivation:* The day after tomorrow... Can the ocean meridional overturning circulation collapse due to global warming?
   - The RAPID observing system in the North Atlantic Ocean.
   - The Stommel box model, multiple equilibria, tipping points, and catastrophes.

8. **Horizontal circulation II: vorticity, Gulf Stream and other western boundary currents, Rossby waves, abyssal circulation,** downloads.

   (a) The critical effect of latitudinal changes in the Coriolis force, beta plane

   (b) Vorticity

   (c) Ekman pumping

   (d) Vorticity equation

   (e) Rossby waves

   (f) Wind driving of currents away from western boundary current: the Sverdrup balance

   (g) Western boundary currents (Gulf Stream, Kuroshio, and more)

   (h) Abyssal circulation and deep western boundary currents

9. **El Nino,** downloads.

   (a) El Niño and La Niña: observations and global weather effects

   (b) Equatorial Kelvin and Rossby waves

   (c) Delayed oscillator mechanism

10. (Time permitting) **Abrupt climate change,** downloads.

   (a) Introduction to paleo climate variability; proxies, ice cores and sediment cores; ice ages, abrupt events (Heinrich and D/O events).

   (b) Ocean-related abrupt climate change mechanisms:

      i. MOC variability (Welander flip-flop) & sea ice amplification,

      ii. Ice shelf collapse via hydrofracturing,

      iii. Ice sheet collapse via the Marine Ice Sheet Instability or via basal melting (binge-purge).

4 Homework assignments

Assignments from a previous occurrence of the course are available here; please email if you are teaching a similar course and are interested in the solutions.

5 Additional readings

Beginning texts:

- John A. Knauss, *Introduction to Physical Oceanography*, 320 pages (2nd edition), 2005.
- J. Marshall and R. A. Plumb, *Atmosphere, ocean, and climate dynamics*, 319pp, 2008.
- Lynne D. Talley, George L. Pickard, William J. Emery, and James H. Swift, *Descriptive Physical Oceanography — An Introduction* (6th edition), online, 2011.
- Stephen Pond and George L. Pickard, *Introductory dynamical Oceanography* (3rd edition), 1993.
- Evelyn Brown, Angela Colling, Dave Park, John Phillips, Dave Rothery, and John Wright, *Open university: Ocean Circulation* (2nd Edition), 2001.
- Wright, John, Angela Colling, and Dave Park, *Open university: Waves, Tides, and Shallow-Water Processes* (2nd Edition), 1999.
- Robert H. Stewart, *Physical Oceanography*, online, 2008.
- Matthias Tomczak and J. Stuart Godfrey, *Regional oceanography*, online, 1994.
- Eli Tziperman, *Global Warming Science: A Quantitative Introduction to Climate Change and Its Consequences*, details, 2022.

Intermediate texts:

- Philander, S. G. H., *El Niño, La Niña, and the Southern Oscillation*, 1990.
- Kundo P.K. and Cohen I.M., *Fluid mechanics* (2nd edition) 2002.

Advanced texts:

- Vallis, G., *Atmospheric and oceanic fluid dynamics, fundamentals and large-scale circulation* (2nd edition), 2017.
- Pedlosky, J., *Geophysical Fluid Dynamics* (2nd edition), 1987.
- Pedlosky, J., *Ocean circulation theory*, 1996.
- Pedlosky, J., *Waves in the ocean and atmosphere*, 2003.
- Gill, A. E, *Atmosphere-ocean dynamics*, 1982.

6 Misc links

- Greenpeace bottom trawling and protect the oceans.
- Shifting baselines: "pristine".
- NOVA documentary about the Sumatra Tsunami of 2004, with more here.
- Ocean acidification NRDC video
- Orca hunting video
- The great Pacific garbage patch.
- Ocean data sources: Marine Explorer, Ocean Data Viewer, and the IRI/LDEO Climate Data Library.
- A day in the life of a fluid dynamicist