Introduction to Physical Oceanography
EARTH 421/CLIMATE 421/ENVIRON 426
Fall 2018

TuTh 10:00-11:30 PM, 2520 North University Building

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Office hours: By appointment

Course overview and what you will get out of the course

This course is an overview of physical oceanography, the field which strives to understand oceanic motions over a variety of time and space scales. We will seek a better understanding of these motions using both theoretical concepts and examination of actual oceanographic data from a wide variety of instruments. Wherever possible we will explain aspects of the observations using the theoretical concepts.

By the end of the course, you will understand oceanic distributions of temperatures and salinities, the importance of rotation and stratification for oceanic motions, the forces that drive oceanic motions, the types of waves occuring in the ocean, and the reasons that the ocean is important for Earth's climate. Specific topics covered include the physical properties of the ocean and water masses; the circulation of the atmosphere; wind- and buoyancy driven ocean circulation; tides; surface and internal waves; oceanic mesoscale eddies; and mixing.

To underline some specific knowledge and skills you will obtain in this course, you will learn to evaluate statements such as "the tsunami traveled at jetliner speeds" seen in the popular press. You will examine oceanic temperatures using the same archived datasets that practicing physical oceanographers use. You will learn how to use Matlab to manipulate scientific data, and you will practice your teamwork and public speaking skills.

Class makeup and level of mathematics assumed

As John Knauss states in the preface to his textbook, "some level of knowledge of physical oceanography is important to a wide variety of professionals, from meteorologists to fisheries biologists." This varied background is evident in the makeup of this class, which has included roughly equal numbers of upper-level undergraduates and graduate students every year. Throughout the years, students in this course have come from various departments in LSA, including Earth and Environmental Sciences, Ecology and Evolutionary Biology, Mathematics, Physics, Program in the Environment (PitE), and others, and various departments in the School of Engineering, including Aerospace Engineering, Climate and Space Science and Engineering, Chemical Engineering, Civil and Environmental Engineering, Computer Science, Electrical Engineering, Materials Science and Engineering, Mechanical Engineering, Naval Architecture and Marine Engineering (NAME), and Robotics. We have also had students from the School of Natural Resources and the Environment, the Business School, and the School of Education.

We have a diverse class again this year. Because of the varying levels of mathematical experience amongst us, we, like Knauss, will assume only a knowledge of introductory calculus. More advanced mathematical concepts will be taught as needed. A review of some important mathematical concepts will be sent to everyone after the first class. Those who feel that their math is a little "rusty" may want to look it over and consider coming in to my office hours (especially during the first three weeks–note by appointment) for some extra mathematical review. The homework sets will emphasize examination of oceanographic data and linkages to unifying concepts rather than mathematical derivations. Where mathematics is needed in the homework, it is kept at an introductory calculus level. The math required for the homeworks will be simpler than that shown in the lectures.

Use of class time

Much of the class time will be taken up by traditional lectures.

However, we will often break up into small groups for more active learning. During these group learning exercises we will discuss class material, develop questions, work on mathematical concepts, or examine oceanic data on websites.

We will also have brief presentations from each student, which will allow all of you to explore a "cutting-edge" topic in detail, and after which the audience of students is expected to provide feedback to the presenters in the form of anonymous online peer reviews. Part of your grade will depend on your own presentation, and part of it will depend on giving active feedback to other student presenters.

Do not be afraid to ask questions, during lectures or at any other time! If you do not understand something, chances are some of your classmates are in the same boat, and will appreciate your speaking up.

Readings will be suggested from the textbooks listed below. Obviously you will understand the material covered in the lectures better if you read the suggested textbook excerpts as a supplement to the time spent in class.

Textbooks

There are two optional texts which you may find helpful. "Introduction to physical oceanography, Second edition (2005)", by John Knauss, is the more mathematical of the two, and is hereafter referred to by "Knauss". "Ocean Circulation, second edition (2001)" by the Open University is more descriptive, and is hereafter referred to by "OC". Another nice textbook is the free online textbook "Introduction to Physical Oceanography" by Professor Bob Stewart at Texas A&M University. It can be found at
http://oceanworld.tamu.edu/resources/ocng_textbook/contents.html or at
http://oceanworld.tamu.edu/resources/ocng_textbook/PDF_files/book.pdf It is hereafter referred to as "Stewart".

The textbook readings are meant to expose you to important material in ways that supplement the lectures (and homeworks). The lectures are not based on the textbooks, but many of the topics covered in class lectures can be found in these textbooks. Lecture notes will be posted online.

Homework

Seven homework assignments will be given over the term. Thus on average, homeworks will be given every other week. They will be assigned during class and will generally be due one week later. Since homework sets are given frequently, they will generally not contain a large number of problems. Homework will often emphasize manipulation of actual oceanographic data, and interpretation of the data using concepts derived in class. Where mathematical derivations are required, the level will be kept to that of introductory calculus, and guidance will be given. The data manipulations will be performed in MATLAB.

Therefore, as a side-benefit of this class, you will learn MATLAB (for those who already have experience with it, you will hone your MATLAB skills). MATLAB is a very nice data analysis package to learn and many of you will likely find it a useful tool throughout your careers. I use it constantly in the analysis of oceanographic data and ocean model output. Prior knowledge of MATLAB is not assumed. Students are encouraged to drop by during office hours (by appointment) for help with MATLAB, especially during the first few weeks. Also, some of the third class meeting will be used to help you get started on your first homework, which is MATLAB-based. Furthermore, example MATLAB codes will frequently be given. However, the best way for you to use MATLAB is by using it, and by learning from your peers. You will be expected to try MATLAB on your own, and to learn from/with your peers, especially as the semester develops.

Homework can be done in collaboration with other students.

Student presentations

Each student will deliver a brief presentation to the class. In the previous versions of this class, these presentations were definitely one of the highlights of the course. Approximately 50 topics for student presentations are given in this syllabus, along with estimated presentation dates. It is emphasized that the presentation dates are *estimates*. Due to the difficulty in estimating the exact speed with which syllabus material will be covered, students are asked to be flexible. You will never be asked to go earlier than the original schedule indicates, but you might be asked to go 1-2 periods later, depending on syllabus coverage speed. The presentations are spread throughout the semester in order to roughly correspond to material presented in lectures. The presentation topics will prod you to explore material beyond the "classic textbook" material that will take up much of the class lectures. This is your chance to learn about something close to the "cutting edge" and then to practice your public speaking skills while sharing your newfound knowledge with the rest of the class. The presentation topics cover a wide variety of material, suitable for a class of students with wide-ranging backgrounds.

Graduate students will give solo performances. Undergraduate students can either go solo or team up with one partner. All presentations whether solo or team efforts should be around 12 minutes long (excluding questions). This length is chosen because it is a typical length of a conference talk at an actual research conference.

All presenters should be prepared to take questions on the material they present from the instructor and from fellow students. Keeping in mind that some students may be unaccustomed to giving oral presentations, questions should only be asked after the student has had a chance to complete their presentation (this rule does not apply to the instructor–interrupt me as appropriate!).

After each student presentation, we will open the floor for questions. The audience discussion, and audience participation in general, is expected to be courteous and constructive. Each student will provide an anonymous peer review of other student presentations, and the peer reviews will be considered by the instructor in the presentation grading. More details on this are given below. After each student presentation, each student should email the instructor their presentation slides, to be used as part of this evaluation. We will not begin the student presentations until week 4, to allow the first few presenters time to organize their work.

If student(s) come up with a topic on your/their own which is related to the course material, I will be happy to have it presented as long as it fits naturally into one of the class periods and you run it past me. Regardless of whether you choose one of my suggestions or develop one of your own, I will be available to work with you during the one or two weeks prior to your presentation, to help you define, develop, and hone it. And of course I will be available to help you choose a topic. Choosing a topic early will help you plan your semester more easily.

What are the advantages to you, the students, of having student presentations in class? Aside from the opportunity to explore a cutting-edge topic in depth, there is also the opportunity to practice public speaking (and listening) skills. A 5-10 minute presentation with questions at the end is standard fare at scientific conferences, and at company meetings in the private sector. Most of you will have to prepare and deliver short technical talks in front of an audience during your careers. Of course this also means that most of you will have to listen to others deliver presentations, and provide useful feedback. This provides practical training for such experiences.

One last thing about presentations: you can either use your own laptop or the professors' laptop. In past years some students were not able to get animations working on the instructors' laptop. This can be avoided by using your own laptop. Learning how to connect your laptop to a projector is a useful skill! On the other hand some students find dealing with technology to be an unwelcome distraction and prefer to use the instructors' laptop. It is up to you.

Quizzes

There will be nine short quizzes, after each of the topics covered in the "Anticipated Class Schedule" at the end of this document. Note that some of the quizzes will be on two short topics; to be exact, there will be quizzes on Topic 2, Topic 3, Topic 4, Topics 5 and 6, Topic 7, Topic 8, Topic 9, Topic 10, and Topics 11 and 12. For each topic, several key questions will be put at the end of the "Course Summary" for you to study. On the lecture after each topic has been completed, there will be a short quiz on one or more of these key questions. The purpose of the quizzes is to practice with some of the material learned in class, and to supplement the homework sets with another tool for exam preparation.

Midterm and final exams

There will be one midterm and one final exam for the class. The midterm will be during class, on October 25. The time and date for the final exam is set by the Registrar's Office to be Monday December 17 from 1:30 to 3:30 PM. Midterm and final exam questions will be drawn from lectures, student presentations, and (especially) homeworks and quizzes– so pay attention to all of them! In contrast to the homeworks, MATLAB will not be accessible during the midterm and final exam–however the concepts learned during the MATLAB exercises will be used on exams.

Student evaluations and course grades

Student evaluations of the course are strongly encouraged and have been used by the instructor in the past to improve the course. As described below, substantial participation by students in course evaluations will also lead to higher grades for everyone.

Grade determination

15% of your grade will be based on the topical quizzes.

15% of your grade will be based on the homework sets. Homework sets will generally be due one week after being assigned, and before lecture begins. Late homework sets will not be accepted unless there is a very good excuse due to illness or other good reason.

15% of your grade will be based on the midterm exam.

25% of your grade will be based on the final exam.

20% of your grade will be based on your in-class presentation.

10% of your grade will be based on giving feedback to your fellow students during their presentations. Shortly after each presentation you should log on to give anonymous feedback to the student presenter. Your feedback should be submitted before the start of Tuesday's class of the week following the presentations. Your feedback should include explanations for the grades you give. For each presentation you give feedback on, you will receive one point. To receive the point, you must include reasons for the grades you gave. Your point will not be affected by the grades you assign. In the case of undergraduate pairs you should not grade your collaborator. In order to receive the one point evaluation score for your own presentation you should give an assessment of your own performance including what you thought went well and what you thought could use improvement. The average over the zeroes and ones obtained in grading other students will then constitute your feedback grade. Your feedback will be anonymous to the student presenters, but will be seen by the instructor. The student feedback will be collected and sent as a package, with no names attached, to the student presenter. This feedback will be useful to student presenters as they consider how to improve their public speaking skills. The instructor alone will assign grades to the student presenters, but will give serious consideration to the student evaluations/peer reviews when so doing.

To encourage student evaluations of the course, if at least 80% of you evaluate the course by 10:30 PM on the last night that evaluations are accepted by Canvas, then both the lowest homework grade and the lowest quiz grade will be dropped, for every student.

This class is meant to be accessible to students from a wide variety of backgrounds. My goal is to help all of you successfully learn the material. As in previous versions of the class, I expect that most of you will do well. The course grading scale is already posted on Canvas.

Absences due to illness or other good reasons

The expectation is that you will attend every class unless you have a good reason not to. Of course illnesses, family emergencies, etc., can arise. In order to avoid losing out on the attendance parts of the grade (i.e. peer reviewing other student presentations, quizzes), you need to email me ahead of classes you will not be able to make, with stated reasons for the non-attendance. Great skepticism can be expected if this becomes a habit.

Suggested Topics for Student Presentations, and Approximate Dates

1) Plate tectonics and the shape of ocean basins (October 2)

2) Construction of state-of-the-art maps of the seafloor (October 2)

3) Modern methods (e.g., CTD, ARGO floats, gliders) versus historical methods (e.g,

reversing thermometer, titration) for measuring ocean temperatures and salinities (October 2)

4) The ARGO Float array (October 2)

5) TEOS-10, the new thermodynamic equation of state of seawater (October 2)

6) Measuring ocean winds from satellites (October 2)

7) Milankovich cycles (orbital forcing of the ice ages) (October 2)

8) Exchange of carbon dioxide and other gases at the air/sea interface (October 2)

9) TRMM–NASA's tropical rainfall measuring mission (October 2)

10) NASA's Aquarius mission to measure sea surface salinity (October 2)

11) Acoustic (sound) waves (October 2)

12) Theory of surface wind waves (October 18)

13) Satellite measurements of surface wind waves (October 18)

14) The physics of breaking waves (October 18)

15) Current meters: how they work and how they are used to identify near-inertial peaks in frequency spectra (October 18)

16) The geological causes of tsunamis (November 6)

17) An overview of the technology behind satellite altimetry (November 6)

18) The 2004 Boxing Day Indian Ocean tsunami and its aftermath (November 6)

19) The 2011 Tohoku tsunami and its aftermath (November 6)

20) Solid earth body and load tides (November 6)

21) Tidal energy dissipation over very long (geological) time scales (November 6)

22) Measuring tidal energy dissipation using lunar laser-ranging (November 6)

23) Tide gauges and how they work (November 6)

24) Early history of numerical weather prediction (November 15)

25) The importance of physical oceanography to national security (November 15)

26) Observed propagation of oceanic eddies (November 15)

27) Geographical distribution of eddy energy as measured by satellite altimeters (November 15)

28) Impact of eddies on biology (November 15)

29) Effects of coastal upwelling on ocean biology (November 22)

30) Oceanic dead zones/hypoxia (November 22)

31) Oceanic motions forced by atmospheric pressure loading (November 22)

32) Ocean heat transport and climate (November 29)

33) Paleoceanography (November 29)

34) Possible contributions of ocean biology to ocean mixing (November 29)

35) Contributions of double diffusion (salt finger formation) to mixing (November 29)

36) Geothermal forcing of oceanic motions (November 29)

37) Generation of internal waves over rough topography (December 4)

38) Sea ice (December 4)

39) Floating ice shelves (December 4)

40) The global carbon cycle (December 4)

41) Archaeological oceanography (December 4)

42) The computer science behind numerical ocean modeling (December 6)

43) Hurricanes and hurricane prediction (December 6)

44) BP oil spill and oil spill prediction (December 6)

45) Ocean optics (December 11)

46) The potential for extraterrestrial oceans (Europa, ancient Mars, even other solar systems) (December 11)

47) Dynamics and prediction El Nino (December 11)

48) Impact of El Nino on climate, fisheries, agriculture, etc. (December 11)

Anticipated Class Schedule (may evolve)

1) Introduction to course–September 4
a) Overview of physical oceanography
b) Course goals and administration.
c) Brief review of MATLAB
d) Demonstration of the usefulness of MATLAB: plotting maps of the seafloor shape
e) What you can expect to gain from the course
Suggested reading: Knauss Chapter 1; Stewart Chapters 1 and 3; Mathematics and MATLAB reviews for those who need them

2) The physical properties of seawater–September 6 and 11
a) Temperature and salinity distributions
b) Seawater density and stratification
c) Water masses
d) Steric heights and thermal expansion
e) Compressibility of seawater versus air
f) Practice with MATLAB–helping you to get started on the first homework set
Suggested reading: Knauss Chapter 2 and 8 (pp 163-183); OC Chapters 6.3 and 6.4; Stewart Chapter 6

3) Air/sea interaction and atmospheric circulation–September 13 and 18
a) Solar forcing
b) Atmospheric wind patterns
c) Air/sea heat exchange
d) Rainfall and evaporation
e) Momentum exchange and wind stress
f) Oceanic mixed layer
g) Atmospheric and oceanic heat transports
Suggested reading: Knauss Chapters 3 and 4; OC Chapters 1, 2, 6.1, and 6.2; Stewart Chapters 4 and 5.1-5.6

4) Development of fluid dynamical equations including shallow water equations–September 20, 25, 27, October 2, 4, 9
a) Conservation equations
b) Nonlinear advection, viscosity, and turbulence
c) Diffusivity
d) Mass conservation
e) Pressure gradients
f) The Coriolis force

g) The geoid
h) General equations of fluid flow
i) Widely used approximations: hydrostatic, Boussinesq, incompressibility
j) Deep-water versus shallow-water limits of surface waves
k) Surface wind waves and breaking waves
l) Langmuir cells
m) Development of shallow water equations
n) Reminder of what is missing from shallow water equations
Suggested reading: Knauss Chapter 5; Stewart Chapters 7 and 8

5) Near-inertial motions–October 11 and 18
a) Wind forcing of near-inertial motions
b) Slab model of near-inertial motions
c) Theoretical construction of near-inertial peak in frequency spectrum
Suggested reading: OC Chapter 3.2; Stewart Chapter 9.1

6) Shallow-water gravity waves–October 23
a) Gravity waves in an unbounded domain with no rotation
b) Gravity waves in an unbounded domain with rotation
c) Gravity waves in the presence of boundaries (Kelvin waves)
d) The Rossby deformation radius: a natural length scale for fluids in a rotating frame
Suggested reading: Knauss Chapter 10 (pages 223-228); OC Chapter 5.3.1

Midterm exam October 25

7) Tides–October 30 and November 1
a) Astronomical forcing–Newton's astronomical potential
b) Laplace's equations–dynamic theory of tides
c) Solar versus lunar tides
d) Causes of diurnal tides
e) Solar vs lunar vs sidereal day, tidal frequencies, spring-neap cycle
f) Tidal resonance
g) Tidal energy dissipation
Suggested reading: Knauss Chapter 10 (pages 234-244); Stewart Chapters 17.4 and 17.5

8) Geostrophy and thermal wind–November 6, 8, 13
a) Requirements for geostrophic balance
b) Geostrophic balance
c) Circulation patterns of high and low pressure systems
d) Derivation of shallow-water potential vorticity
e) Derivation of quasi-geostrophic equations
f) Rossby waves and westward propagation
g) Barotropic versus baroclinic motions
h) Thermal wind
i) Vertical distribution of kinetic energy in eddies and western boundary currents
j) Mass and heat transport
Suggested reading: Knauss Chapter 6 (pages 108-122) and 8 (pages 183-186); OC Chap-

ters 3.3, 3.5.2, and 5.3.2; Stewart Chapters 5.7-5.8, 10, 12.1, and 12.2

9) Ekman flows and wind-driven oceanic general circulation–November 15 and 20
a) Turbulent eddy viscosity
b) Ekman flows
c) Sverdrup interior flow
d) Western intensification
Suggested reading: Knauss Chapter 6 (122-135) and Chapter 7 (136-143); OC Chapters 3.1, 3.4, and 4; Stewart Chapters 9.2, 9.3, 9.4, and 11

10) Meridional overturning circulation and energy sources for mixing–November 27
a) Deep-water formation
b) Overturning circulation
c) Importance of mixing
d) Wind work on general circulation
e) Wind work on near-inertial waves
f) Tidal energy dissipation
Suggested reading: Knauss Chapter 8; OC Chapter 6; Stewart Chapter 13

11) Stratification dynamics and internal waves–November 29
a) Internal gravity waves
b) Internal Rossby waves
c) Internal Rossby deformation radius
Suggested reading: Knauss Chapter 10 (pages 229-234)

12) Equatorial waves and El Nino–December 4
a) Equatorial waves
b) Equatorial currents
c) El Nino
Suggested reading: Knauss Chapter 7 (pages 146-156); OC Chapter 5; Stewart Chapter 14

Course wrapup and final presentations–December 6 and 11

13) Final exam–Monday December 17, 1:30-3:30 PM