Introduction to Observational Physical Oceanography 12.808

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Overview of this course

This course is an introduction to the results and the methods of observational physical oceanography, a very rapidly developing field. Rapid development is a response to the pressing societal need to understand how the physical state of the oceans might be changing as part of a changing Earth climate — Are the oceans warming? Is the ocean circulation slowing? Rapid development on these and other questions is made possible by new technology, e.g., satellite measurement systems and autonomous floats and gliders that enable more efficient and more comprehensive observation of the ocean.

Topics are organized around concepts and processes, rather then geography, and, like modern oceanography generally, our approach will be quantitative rather than merely descriptive. Emphasis will be on large-scale distributions and processes and especially those that are central to the ocean's role in Earth's climate and biosphere.

This course is available to all Joint Program and MIT students regardless of discipline. It is, as advertised, an introduction to physical oceanography that is intended for students who have had little or no experience in ocean science. If you have had quantitative courses in oceanography or Earth system science or climate, then you should check with your advisor or with Jim Price to decide whether this course will be the best use of your time.

What we aim to accomplish and how we will get there

The broad goal of this course is to understand how the oceans contribute to Earth's climate and biosphere by storing and transporting properties and materials, e.g., heat (energy) and nutrients. Four specific objectives are to: 1) Know (be able to interpret) the large-scale distributions of the ocean's physical properties, e.g., temperature, salinity and currents, and how these are observed. 2) Understand (be able to explain) the basic principles of ocean physics, e.g., equation of state of sea water, consequences of stratification, effects of Earth's rotation, transport by mean and fluctuating ocean currents. 3) Learn how to estimate ocean processes from the observations, e.g., meridional heat transport by geostrophic and Ekman layer currents. 4) Examine critically some of the modern observational evidence and arguments for a changing ocean as summarized in Ch. 5 of 'IPCC Climate Change 2007: The physical science basis'.

The class will have four main components:

(1) Class meetings are scheduled for Tuesdays and Thursdays, 1:00 - 2:30. Most classes will originate from WHOI, but, depending upon the distribution of students between WHOI and MIT, some classes may originate from MIT.

Because the class size is likely to be large and split between WHOI and MIT, the classes will be mainly lectures; we will be talking away and flipping through PowerPoint slides while you will be sitting, listening and scribbling in your notebook. Does that sound familiar? Does that sound distressing? It does to us.

Our class meetings will be a valuable use of your time and a pleasure for us and for you to the extent that communication goes in two directions. That requires preparation on our part and yours – We will strive to make the lectures as interesting and as useful as we can, and your part will be to come to class having done the assigned reading and intellectually engaged with the topic at hand. Ask questions! Ask for clarification when unfamiliar jargon shows up, or even 'Why is this important?', if it hasn't been made clear. Your classmates will appreciate your intervention, and we will appreciate that you care about the topic and about the time that you are spending in this class.

The visual medium will be PowerPoint. The slides for a given class are available online from links in this syllabus. The slides are intended for the use of the present class only and hence are on a password protected site. We will give you the password at the first class or contact J. Price at the email address on the cover page.

Several of our class meetings will include a guest speaker who will introduce an example of a modern observational method, e.g., autonomous gliders, satellite altimetry or cabled observatories.

(2) Reading assignments will be indicated for each major topic and are an essential complement to the lectures. Readings will come from two somewhat different sources, textbooks and from brief, recent journal articles, most often from Science or Nature.

Textbooks: There is no single, ideal textbook for this course. There are two texts, that, taken together, come close. 'Ocean Circulation, 2nd Ed.' (2001) by the Open University (hereafter OC01) is modern, and well-illustrated and a very good source for much of the descriptive (geographic) material we will encounter. However, it is also somewhat elementary, and not as useful for some quantitative topics (equation of state and basic fluid mechanics) as is 'Introduction to Physical Oceanography, 2nd Ed.' (2005) by John Knauss (hereafter K05). Another highly recommended source is 'Ocean Chemistry and Deep Sea Sediments' (1989), also by Open University (hereafter OC89) which has a very good introduction to geochemical cycles in Ch. 2. These and a few other texts will be on reserve in the Physical Oceanography reading room in Clark 3, WHOI.

Two other notable textbooks on physical oceanography are available online: 'Introduction to Physical Oceanography', 2006, by Robert Stewart, which is modern and has several very good chapters, notably the chapter on geostrophy. Another is 'Regional Oceanography: an Introduction', 2003, by Matthias Tomczak and Stuart Godfrey (see the References section for links to these texts). This latter text is organized around geographic regions (Atlantic Ocean, Pacific Ocean .....) and can thus serve to make a useful cross-cut on the topics that we will address in this course, which is organized around concepts and processes.

Journal Articles: Reading assignments include also brief (usually three or four page) research articles from the modern scientific literature, most often Science or Nature. These have been selected so that the concepts will be familiar from material that we have discussed in the class or encountered in the textbooks. These are required reading (unless otherwise indicated in class) and will be available through active links to the password protected web page noted above. We will discuss this reading material toward the end of a given section. It is highly likely that there will be some revision of the reading list as we go along.

(3) Homework projects will be assigned about every other week during the class meetings, and will usually be due one week after assignment. An important, specific goal of this course is to learn to manipulate and analyze ocean data in a way that helps to reveal large scale processes and phenomenon, e.g., geostrophic currents and meridional heat transport. The simple plotting and analysis required for the homework can be done using Matlab, which is available on most PCs around WHOI and MIT and is available for installation on your computer (contact the WHOI CIS Helpdesk, x2439). Matlab is a highly versatile and powerful tool, and is well worth learning for your later research. It can also be exceedingly frustrating on first encounter, and so it is highly recommended that you start with an introductory tutorial and with a friend who knows the basics. Our Teaching Fellow, Nick Woods, is available by appointment to help with Matlab and with the homework generally.

Data files and Matlab scripts that you will need for the first several homework projects can be downloaded: http://www.whoi.edu/science/PO/people/jprice/class/Matlab-12808-2008.zip Unzip this in a way that preserves directory structure, and you will find one readme_IntroPO.txt file and four subdirectories. Open Matlab, go to the hydrography subdirectory and execute the Matlab script readme_hydrography. This provides documentation for the data files and also provides the Matlab code needed to load and plot some of the station data that you will encounter in the first several homework projects.

You may collaborate with one or two classmates while preparing a homework project, but each student must turn in the write-up individually. In the subject line indicate the HW assignment number and your name, e.g., HW# 3, M. F. Maury, would be the third homework assignment submitted by Matthew Fontaine Maury (a very distinguished oceanographer who never took this class).

(4) Exams/Quizzes and Grades

Exams will be given about half way through the semester and at the end. These will be during a regular class period, and will be closed book. The date for the mid-term is shown in the syllabus below; The final exam will be on the last day of regularly scheduled class, Dec 10 (not during the MIT final exam week). These exams will emphasize material covered in readings and in the class meetings.

Very brief (five minute) pop quizzes will be given on about five occasions throughout the semester. These will require that you be able to email your response during the class. We will discuss this more at the first class meeting.

The two exams taken together will account for about one half of the grade; homework will count for most of the rest and the pop-quizzes for a very small fraction, about 5%.

Topic outline and approximate schedule

1) An introduction to Physical Oceanography and to this course.

a. Ocean sciences, and the scope of physical oceanography.

b. A first look at large scale distributions and circulation, and the goals of this course. Part I; Temperature, salinity and other tracers in the deep ocean. Part II; Wind-driven circulation in the upper ocean.

c. Course administration.

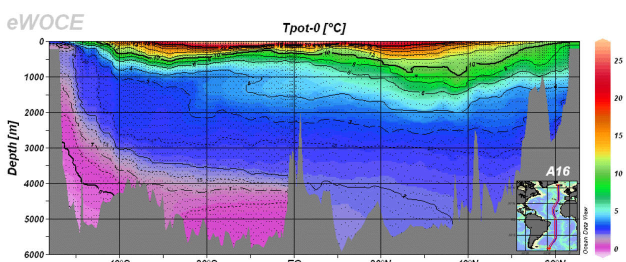
Class slides: http://www.whoi.edu/science/PO/people/jprice/class/miscart/Class1.ppt

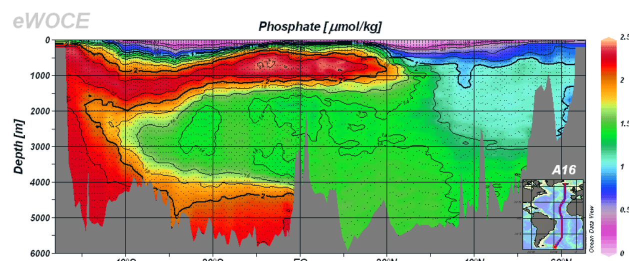
Reading:

(1) K05 Ch. 1.

(2) IPCC 2007, Exec. Summary of Ch. 5 and 5.1 (See References for download link).

Additional Resources: A comprehensive collection of (beautiful) modern hydrographic sections that span the world ocean are available from the eWOCE gallery at http://www.ewoce.org (Linking to this and most other web pages is often better done through your web browser rather than through Acrobat Reader.)





Part I; Temperarture, salinity and other tracers in the deep ocean.

2) Temperature, salinity and density.

a. Temperature and salinity in the oceans; vertical profiles and sections.

b. Density, and the equation of state of sea water.

c. Stratification, and storage on seasonal and long time scales.

d. The geography of T and S; water types and water masses.

e. Measurement techniques: observing T/S and more from ARGO floats and gliders.

Class slides: http://www.whoi.edu/science/PO/people/jprice/class/miscart/Class2-5.zip

Reading:

(1) OC01, Ch. 6.3, 6.4.

(2) K05, Ch. 2, 8(pp 163-183).

(3) Levitus, Anthropogenic warming, Science, 2001.
http://www.whoi.edu/science/PO/people/jprice/class/miscart/LevitusScience2001.pdf

(4) Levitus, Warming the world ocean, Geophys Res Lett, 2005.
http://www.whoi.edu/science/PO/people/jprice/class/miscart/LevitusGRL2005.pdf

(5) Curry, Change in freshwater balance, Science, 2003.
http://www.whoi.edu/science/PO/people/jprice/class/miscart/CurryNature2003.pdf

Additional Resources:
http://ingrid.ldgo.columbia.edu/SOURCES/.LEVITUS94/oceanviews2.html is a terrific web site that allows exploration of a world ocean climatology. Check your homework against this web page. ARGO

float data from the world ocean is online at http://www.argo.ucsd.edu

3) Anthropogenic and biologically active tracers.

a. Conservative and nonconservative tracers; age.

b. The geography of productivity and biologically active tracers.

c. Tracking the abyssal circulation with preformed phosphate.

Class slides: http://www.whoi.edu/science/PO/people/jprice/class/miscart/Class6-7.zip

Reading:

(1) OC01, Ch. 6.5.

(2) OC89, Ch. 2.1 - 2.4.

(3) Gruber, N and J. Sarmiento, 2002, 'Large Scale Biogeochemical-Physical Interactions', Sections 1 and 2. http://www.whoi.edu/science/PO/people/jprice/class/miscart/GruberTheSea2002.pdf

(4) Willey, Global chlorfluorocarbon inventory, 2004 Geophys Res Lett, http://www.whoi.edu/science/PO/people/jprice/class/miscart/WilleyGRL2004.pdf

(5) Barnett, Penetration of human-induced warming, 2005 Science, http://www.whoi.edu/science/PO/people/jprice/class/miscart/BarnettScience2005.pdf

4) Air-Sea interaction.

a. Turbulent and radiative heat fluxes through the sea surface.

b. Phase changes of water.

c. Continuity and heat and salt budgets for control volumes; Mediterranean Sea.

d. Meridional energy transport by the ocean and the atmosphere.

e. Measurement techniques: observing on both sides of the air/sea interface; a visit to the WHOI Upper Ocean Processes Group.

Class slides: http://www.whoi.edu/science/PO/people/jprice/class/miscart/Class8-12.zip

Reading:

(1) OC01, Ch. 1, 2.1, 2.2, 6.1, 6.2, 6.6.

(2) K05, Ch. 3.

(3) Kortzinger, The ocean takes a breath, Science, 2004. http://www.whoi.edu/science/PO/people/jprice/class/miscart/KortzingerScience2004.pdf

(4) Doney, Plankton in a warmer world, Nature, 2006. http://www.whoi.edu/science/PO/people/jprice/class/miscart/DoneyNature2006.pdf

(5) Behrenfeld, Climate-driven trends in productivity, Nature, 2006. http://www.whoi.edu/science/PO/people/jprice/class/miscart/BehrenfeldNature2006.pdf

5) Mid-term Exam
http://www.whoi.edu/science/PO/people/jprice/class/miscart/Midterm-exam.ppt

Part II; Wind-driven circulation in the upper ocean.

6) Conservation equations and transport processes of the ocean circulation.

a. Eulerian and Lagrangian measurements of ocean currents.

b. Scales of motion: advection by mean flow and diffusion by turbulent flow.

c. Abyssal recipes - a steady balance of advection and diffusion.

d. Measurement techniques: Long range float tracking.

Class slides: http://www.whoi.edu/science/PO/people/jprice/class/miscart/Class13-16.zip

Reading:

(1) OC01, 6.1, 6.2.

(2) K05, Ch. 4.

(3) Lavender, Subpolar gyre by direct mesurements, Nature, 2001.
http://www.whoi.edu/science/PO/people/jprice/class/miscart/LavenderNature2001.pdf

7) Momentum balances, geostrophy and the large scale circulation of the upper ocean.

a. F = ma on a rotating planet; the Coriolis force.

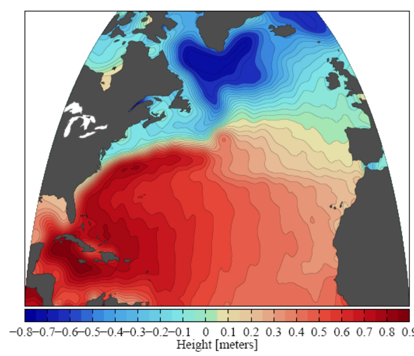
b. The hydrostatic pressure field.

c. Geostrophy and thermal wind.

d. Barotropic and baroclinic phenomenon and reference level evaluation.

e. Dynamic height and circulation patterns inferred from geostrophy and hydrography.

f. Measurement techniques: observing the sea surface from space, the Grace mission.



Class slides: http://www.whoi.edu/science/PO/people/jprice/class/miscart/Class17-19.zip

Reading:

(1) OC01, 3.3.

(2) K05, Ch. 5 and 6 (pp 108-122).

Additional Resources:

(1) Price, A Coriolis tutorial, 2006. For those who are obsessed with the Coriolis force, online at http://ocw.mit.edu/ans7870/resources/price/index.htm

(2) For more on Topex altimetry: http://puddle.mit.edu/∼detlef/altimetry/altimetry.html

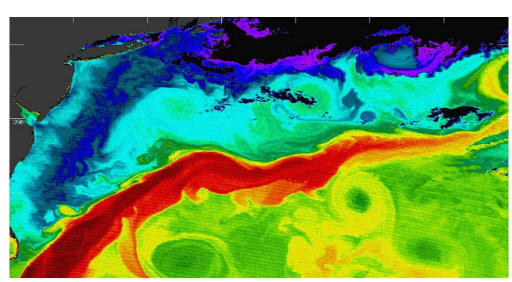
8) Wind-driven circulation. 4 classes, Nov 24 - Dec 8.

a. Large scale patterns of wind and wind stress.

b. Diffusive and Ekman boundary layers.

c. Ekman divergence and Sverdrup transport.

d. Wind-driven gyres and their boundary currents; the Gulf Stream.



e. The Southern Ocean.

f. Measurement and analysis techniques: the HydroBase ocean climatology.

Class slides: http://www.whoi.edu/science/PO/people/jprice/class/miscart/Class20-24.zip

Reading:

(1) OC01, Ch. 2.1, 3.1, 4.

(2) K05, Ch. 6(122-135), Ch. 7.

(3) Quadfasel, Nature, 2005,
http://www.whoi.edu/science/PO/people/jprice/class/miscart/QuadfaselNature2005.pdf

(4) Bryden, Changing THC, Nature, 2005,
http://www.whoi.edu/science/PO/people/jprice/class/miscart/BrydenNature2005.pdf

(5) Cunningham, Temporal variability of the MOC, Science, 2007,
http://www.whoi.edu/science/PO/people/jprice/class/miscart/CunninghamScience2007.pdf

Additional Resources: the HydroBase project is at http://www.whoi.edu/science/PO/hydrobase/

9) End of Term Exam

http://www.whoi.edu/science/PO/people/jprice/class/miscart/Endterm-exam.ppt

References

Our primary reference texts:

OC01, 'Ocean Circulation', 2nd Ed., by the Open University Press. Butterworth-Heineman. Modern, well-illustrated, and a bit elementary. Very good for descriptive material. It is highly recommended that you have a personal copy; about $40.

K05, Knauss, John, 'Introduction to Physical Oceanography', 2nd Edition, 2005. Waveland Press Inc. This is a clearly written and well-rounded introductory survey of physical oceanography that covers many of the topics of interest to this course. Sections on equation of state of sea water, the conservation equations and the Gulf Stream are especially good. It is recommended (but not required) that you have a personal copy; available for about $50 from the Waveland Press website: http://www.waveland.com/Titles/Knauss.htm

OC89, 'Ocean Chemistry and Deep-Sea Sediments', 1989. Open University and Pergamon Press. This is a basic description of sea water chemistry that makes a valuable supplement to physical oceanography texts. Chapter 2 on Geochemical cycles is highly recommended.

Also highly relevant and appropriate for this course:

Baum, S., 2004. 'A glossary of Physical Oceanography'. All of the oceanography jargon that you will run into: http://www.whoi.edu/science/PO/people/jprice/class/miscart/Glossary.pdf

'Encyclopedia of Ocean Sciences, 2002'. Ed. by J. Steele, S. Thorpe and K. Turekian. Elsevier Press. An up-to-date collection of accessible articles on many of the topics that you will encounter in this class and in oceanography, generally. If you are using a WHOI computer, you have access to an electronic copy at this link: http://www.sciencedirect.com/science/referenceworks/012227430X If you outside of the WHOI IP address range, then take a look at http://www.mblwhoilibrary.org/services/remote/proxy.html

IPCC, 2007: 'Climate Change 2007: The physical science basis. Contribution of Working Group I to the Fourth Assessment'. Ed. by Solomon, S., D. Qin, M. Manning, D. Chen, M. Marquis, K. B.

Avryt, M. Tignor and H. R. Miller. Cambridge Univ. Press. This remarkable document summarizes our present knowledge of of Earth's climate, including a detailed report on the world ocean, Ch. 5. Available online from http://ipcc-wg1.ucar.edu/ This is too condensed to make an ideal, primary reference for an introductory course. However, it does make an ideal target — at the end of this course you will have read crtically some of its most important primary references and you should understand much of the content of Ch. 5.

Stewart, R. H., 2004. 'Introduction to Physical Oceanography'. Is modern and well-illustrated. Available online at
http://www.whoi.edu/science/PO/people/jprice/class/miscart/Stewart2006.pdf

Summerhayes, C. P. and S. A. Thorpe, 1996, 'Oceanography, An Illustrated Guide'. Wiley and Sons, New York. A look at a wide range of topics in ocean science including: Large scale tracer distributions, Ch. 11; Air-sea interaction, Ch. 2; Oceans and climate change, and measurement methods.

Tomczak, M., and J. S. Godfrey, 2003, 'Regional Oceanography: an Introduction'. This useful text takes a geographic perspective on the ocean. Available online,
http://gyre.umeoce.maine.edu/physicalocean/Tomczak/regoc/pdfversion.html

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http://www.ibiblio.org/lenhart/gallery/slideshow.php?set_albumName=arctic, the North Atlantic sea surface topography in Section 6 is thanks to Steve Jayne and the Grace mission, the Gulf Stream image in Section 7 is from US Navy, FNMOC MODIS, and the beach image of of Section 8 is from http://www.powerfloe.com/Photo%20Gallery.html

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