Oceans in the Global Carbon Cycle
CAS NS 321 (4 credits)

Course Catalog Description (max. 40 words):
Ocean as carbon source and sink. Examine global-scale flux patterns and carbon storage mechanisms, from solubility/biological pumps to geo-engineering. Explore buffering capacity and mitigation strategies in the face of anthropogenic carbon cycle perturbations. Oral presentation and written research proposal required.

Instructor(s): Sea Education Association (SEA) Oceanography Faculty and guest scholars and experts.

Location: SEA campus in Woods Hole, MA.

Prerequisites: Admission to SEA Semester. Three lab science courses (one at the 300-level or higher) or consent of instructor.

Course Philosophy and Approach:

Oceans in the Global Carbon Cycle (OGCC) is a six-week course designed to provide you with the fundamentals of chemical, physical, biological and geological ocean systems as well as their cross-disciplinary interactions. Our core objectives will include 1) developing a comprehensive understanding of the role the oceans play in the global carbon cycle, the resulting implications for the global climate, and corresponding ecological changes occurring around the world, 2) surveying the existing and evolving (marine) renewable energy technologies as well as their respective challenges and potential environmental impacts, and 3) appreciating the central Pacific island ecosystems and cultures we'll interact with during the sea component. Oceanographic concepts will be presented through a series of assigned readings, class presentations and hands-on activities; additional talks by visiting Distinguished Lecturers who are experts in their field of ocean, climate or energy science will further broaden the scope of the course. By the end of the shore component you will be able to converse intelligently as oceanographers; you will also possess the essential background to begin asking your own questions in preparation for your independent research project.

Field research is central to the study of oceanography, and therefore throughout the shore component we will explore the scientific process as you learn to develop research inquiries, plan experiments and craft a thorough yet concise collaborative project proposal. As a class, we will determine the scientific agenda of our pending research cruise aboard the *SSV Robert C. Seamans*. *Oceans in the Global Carbon Cycle* thus serves as the precursor to *Advanced Oceanographic Field Methods* and *Directed Oceanographic Research* (both of which occur during the sea component); these two classes will introduce the practical aspects of research at sea, including equipment and instrument deployments, chemical analyses, sample processing, and data analysis and interpretation. Your collaborative research project will culminate in a final paper and presentation near the end of the sea component.

This course consists of 17 lecture/discussion sessions (1.5 hours each) and 11 laboratory sessions, research project work sessions or field trips (3 hours each).

Learning Outcomes:

1. Gain knowledge of the core concepts and methods in the disciplines of physical, chemical, and biological oceanography, and climate science.
2. Read, analyze and evaluate scientific literature and data sources in relevant disciplines.
3. Employ this knowledge to examine interactions between science and policy in particular topic areas and regional contexts.
4. Demonstrate the quantitative data analysis and visualization skills required to interpret and communicate scientific datasets.
5. Recognize, formulate, and employ the scientific method through the development of a collaborative research project and completion of a proposal.
6. Demonstrate the written and verbal communication skills required to convey contemporary scientific theories and research findings through a range of products and presentations for both technical and lay audiences.

Evaluation:

Atlas Entry and Energy Storage Assignments	20%
Data Analysis Exercises	15%
Problem Set	20%
Research Project Preparation Assignments	20%
Research Project Written Proposal	25%

Assignments:

- One **Atlas Entry assignment** requires work that merges both science and policy around a specific topic or case study in the area of our cruise track. Preliminary research is conducted onshore and complemented by first-hand observations or interviews during port stops.
- One brief **Energy Storage Technology Presentation** offers the opportunity to learn about strategies being developed and/or employed to capture energy generated by renewable means and better integrate it into the electrical grid.
- Two **Data Analysis (DA) exercises** familiarize you with typical oceanographic data types and prepare you to conduct analyses of your own data while at sea.
- One **Problem Set** will evaluate your understanding of the core oceanography concepts presented during the first half of the course, in lieu of an exam.
- The **Research Proposal Preparation** process will guide your development of an original collaborative research project to be conducted while at sea. Included will be gathering essential background information for your topic, crafting the hypotheses to be investigated, and writing an account of experimental and data analysis methods to be employed. Through a series of research-focused seminars, you will be given five **Research Assignments (RA)** – reading journal articles, writing summaries and rough drafts and giving

presentations, for example – and keeping up with each step of the process will prove essential to successful proposal creation. Thoughtful and well-prepared participation during research group meetings is expected of each student. All collaborative research projects will result in one **Final Research Proposal**; for joint work, all students earn the same grade.

Expectations and Requirements:

- Punctual attendance is required at every class meeting.
- Active participation in class discussion is expected.
- Late assignment submissions are not accepted.
- The policy on academic accuracy, quoted below, will be strictly followed in this class.

  The papers that you submit in this course are expected to be ***your original work.*** You must take care to distinguish your own ideas and knowledge from wording or substantive information that you derive from one of your sources. The term "sources" includes not only published primary and secondary material, but also information and opinions gained directly from other people and text that you cut and paste from any site on the Internet.

  The responsibility for learning the proper forms of citation lies with you. Quotations must be placed properly within quotation marks and must be cited fully. In addition, all paraphrased material must be acknowledged completely. Whenever ideas or facts are derived from your reading and research, the sources must be indicated. (Harvard *Handbook for Students,* 305)
- Considerations for use of internet sources:

  As you browse websites, assess their usefulness very critically. Who posted the information and why? Can you trust them to be correct? Authoritative? Unbiased? (It's okay to use a biased source as long as you incorporate it knowingly and transparently into your own work.) Keep track of good sources that might be useful for subsequent assignments, and annotate in your bibliography any sites you cite. Your annotation should include the name of the author or organization originating any material that you reference. If you can't identify the source, don't use it!

Readings:

Book Sections & Articles

Beaufort, L. et al. 2011. Sensitivity of coccolithophores to carbonate chemistry and ocean acidification. Nature. doi:10.1038/nature10295.

Buesseler, K. 2012. The great iron dump. Nature. 487:305-306.

Castelvecchi, D. 2012. Gather the wind. Scientific American. doi:10.1038/scientificamerican0312-48.

Dickinson, W. 2009. Pacific atoll living: How long already and until when? GSA Today. doi:10.1130/GSATG35A.1.

Doney, S. et al. 2009. Ocean acidification: The other CO_2 problem. Annual Reviews of Marine Science. doi:10.1146/annurev.marine.01908.163834.

Doney, S. et al. 2012. Climate change impacts on marine ecosystems. Annual Reviews of Marine Science. doi:10.1146/annurev.marine.041911.111611.

Donnelly, J.P. & J.D. Woodruff. 2007. Intense hurricane activity over the past 5,000 years controlled by El Nino and the West African monsoon. Nature. 447: 465-468.

Eglinton, T. & G. Eglinton. 2008. Molecular proxies for paleoclimatology. Earth and Planetary Science Letters. doi:10.1016/j.epsl2008.07.012.

Falkowski, P. et al. 1998. Biogeochemical controls and feedbacks on ocean primary production. Science. doi:10.1126/science.281.5374.200.

Hein, M. & K. Sand-Jensen. 1997. CO_2 increases oceanic primary production. Nature. 388:526-527.

Houghton, R. 2007. Balancing the global carbon budget. Annual Reviews of Earth and Planetary Sciences. doi:10.1146/annurev.earth.35.031306.140057.

Lemkau, K. 2011. Tracking toxic chemicals in oil spills. Oceanus Magazine. Accessed at http://www.whoi.edu/oceanus/feature/tracking-toxic-chemicals-in-oil-spills.

Longhurst, A. et al. 1995. An estimate of global primary production in the ocean from satellite radiometer data. Journal of Plankton Research. 17(6):1245-1271.

MacKay, D. 2009. Sustainable energy without the hot air. Accessed at http://www.withouthotair.com/.

Mahadevan, A. 2014. Eddy effects on biogeochemistry. Nature. doi:10.1038/nature13048.

McPhaden, M. et al. 2006. ENSO as an integrating concept in earth science. Science. doi:10.1126/science.1132588.

Sarmiento, J.L. & N. Gruber, 2002. Sinks for anthropogenic carbon. Physics Today. : 30-36.

Schiermeier, Q. 2010. The real holes in climate science. Nature. doi:10.1038/46328a.

Segar, D. 2012. Introduction to Ocean Sciences, 3rd edition. Accessed at http://www.reefimages.com/oceans/oceans.html.

Smetacek, V. et al. 2012. Deep carbon export from a Southern Ocean iron-fertilized diatom bloom. Nature. doi:10.1038/nature11229.

Tomczak, M & J. Godfrey. 2005. Regional Oceanography: an Introduction. Chapters 8 & 9. Accessed at http://gyre.umeoce.maine.edu/physicalocean/Tomczak/regoc/pdfversion.html.

Toomey, M.R. et al. 2013. Reconstructing mid-late Holocene cyclone variability in the Central Pacific using sedimentary records from Tahaa, French Polynesia. Quaternary Science Reviews. 77: 181-189.

Online Resources

An Energy Primer for the AP Environmental Science Student. Undated. Accessed at http://apcentral.collegeboard.com/apc/members/courses/teachers_corner/49184.html.

Bloomberg Sustainable Energy Factbook. 2013. Accessed at http://www.bcse.org/sustainableenergyfactbook.html

British Petroleum's Statistical Review of World Energy. 2013. Accessed at http://www.bp.com/en/global/corporate/about-bp/energy-economics/statistical-review-of-world-energy-2013.html.

Department of Energy's Energy Literacy Principles. 2013. Accessed at http://www1.eere.energy.gov/education/pdfs/energy_literacy_2.0_low_res.pdf.

NASA's Earth Observatory Paleoclimate Overview. 2005. Accessed at http://earthobservatory.nasa.gov/Features/Paleoclimatology/paleoclimatology-_intro.php.

NOAA Earth System Research Laboratory, Global Monitoring Division, Global Greenhouse Gas Reference Network website. 2014. Accessed at http://www.esrl.noaa.gov/gmd/ccgg/trends/index.html.

Southeastern Massachusetts Resource Recovery Facility (SEMASS) website, operated by Covanta Energy. 2014. Accessed at http://www.covantaenergy.com/facilities/facility-by-location/semass.aspx.

Union of Concerned Scientists Summary of Renewable Energy Technologies. 2012. Accessed at http://www.ucsusa.org/clean_energy/clean_energy_101/

U.S. Energy Information Administration's International Energy Outlook & Renewable Energy Summary. 2013. Accessed at http://www.eia.gov/forecasts/ieo/ & http://www.eia.gov/renewable/.

Woods Hole Oceanographic Institution, Science in a Time of Crisis: Deepwater Horizon Oil Spill website. 2011. Accessed at http://www.whoi.edu/deepwaterhorizon/.

Videos

"How Much Oil?". https://www.youtube.com/watch?v=Wl6jOVyFWL8

"Sampling the Source". https://www.youtube.com/watch?v=FAAaMKnsPOs

Course Calendar:

<table>
<tr><th>Topic</th><th>Required Readings/Assignment(s) Due</th></tr>
<tr><td colspan="2">Week 1 (7.5 hours) – on shore at SEA campus in Woods Hole</td></tr>
<tr><td>Introduction to O&C Program and OGCC
Lecture/Discussion Topics:
• Heat Budgets
• Ocean/Atmosphere Dynamics
• Surface & Deep Ocean Circulation
• The Global Carbon Cycle
• Geological History of the Ocean Basins
• RCS Research Capabilities & Program
MBL Library & Woods Hole Tour</td><td>Readings:
Doney et al. (2012)
Segar (2012): Chpts. 4, 6, 7, & 8 (selections)
Tomczak & Godfrey (2005): Chpt. 8 selections
Cruise Prospectus & Equipment List</td></tr>
<tr><td colspan="2">Week 2 (10.5 hours) – on shore at SEA campus in Woods Hole</td></tr>
<tr><td>Lecture/Discussion Topics:
• Natural Long-term Climate Variability
• Climate Dynamics & the Equatorial Pacific Ocean
• Climate Change & Extreme Weather Events
• Chemical Oceanography
• Nutrient Dynamics & Biogeochemical Provinces in the Ocean
Research Project Work Sessions (2)</td><td>Readings:
Donnelly and Woodruff (2007)
Eglinton and Eglinton (2008)
Longhurst et al. (1995)
Mahadevan (2014)
McPhaden et al. (2006)
Segar (2012): Chpts. 5 & 12 (selections)
Toomey et al. (2013)
Online Resources:
NASA’s Paleoclimate Overview (2005).
Two Research Assignments (RA1 & RA2) due.
First Data Assignment (DA1) due.</td></tr>
<tr><td colspan="2">Week 3 (12 hours) – on shore at SEA campus in Woods Hole</td></tr>
<tr><td>Lecture/Discussion Topics:
• Diversity, Distribution & Biogeochemical Activity of Phytoplankton
• Pacific Island Ecosystems; Coral Reefs and Atoll Islands
• Secondary Production
• Ocean Acidification
Research Project Work Session
Ocean Data View (ODV) Lab</td><td>Readings:
Beaufort et al. (2011)
Dickinson (2009)
Doney (2009)
Falkowski et al. (1998)
Segar (2012): Chpts. 4, 6, 12, 15 (selections)
Third Research Assignment (RA3) due.
Problem Set due.</td></tr>
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Week 4 (13.5 hours) – on shore at SEA campus in Woods Hole	
Lecture/Discussion Topics: • CO_2: Sources, Sinks, Status, Questions • U.S. Energy Industry; Grid & Management • Introduction to Renewable Energy Technologies • Deepwater Horizon Oil Spill Research Project Work Session Field Trip to SEMASS (joint w/ OSPP)	***Readings:*** Hein and Sand-Jensen (1997) Houghton (2007) Lemkau (2011) MacKay (2009) Sarmiento and Gruber (2002) Schiermeier (2010) ***Online Resources:*** An Energy Primer for the AP Environmental Science Student BP's Statistical Review of World Energy History of Energy Use NOAA ESRL CO_2 Monitoring Site Union of Concerned Scientists Summary of Renewable Technologies SEMASS Site Bloomberg Sustainable Energy Factbook (2013) US Energy Forecast highlights WHOI, Science in a Time of Crisis: Deepwater Horizon Oil Spill – Watch "How Much Oil?" and "Sampling the Source" ***Second Data Assignment (DA2) & Draft Atlas Entry due.*** ***Last Research Assignments (RA4 & RA5) due.***
Week 5 (7.5 hours) – on shore at SEA campus in Woods Hole	
Lecture/Discussion Topics: • Energy Storage • Ship's Energy Systems • Engineering Earth's Climate Zooplankton Lab I Research Project Work Session	***Readings:*** Buesseler (2012) Castelvecchi (2012) MacKay (2009) Smetacek (2012) ***Energy Storage Technology Presentations*** ***Draft Research Proposals due***
Week 6 (7.5 hours) – on shore at SEA campus in Woods Hole	
Lecture/Discussion Topics: • Tropical Pacific Review • Cruise Research Planning Zooplankton Lab II Research Project Proposal Presentations	***Readings:*** Doney et al. (2012) ***Atlas Revisions & Fieldwork Plan due*** ***Final Research Proposals due***