“Atmosphere-Ocean dynamics and Implications for future climate change”

EESC 4336 / PHYS 3314, Fall 2025 **EESC 6336** for graduate student credit

Syllabus

Lectures: Monday/Wd 3:30 – 4:59 pm, HAYD 360
First lecture only on zoom, Wd Aug 27, https://upenn.zoom.us/j/94111152346

Teacher: Associate Prof. Irina Marinov (research in oceans and climate modeling, carbon cycle)
Office Hayden 254B. Email: imarinov@sas.upenn.edun
webpage: https://web.sas.upenn.edu/oceans-and-climate/
All Class materials on the Class Canvas site
This class will next be taught in Fall 2027

This course covers the fundamentals of atmosphere and ocean dynamics and aims to put these in the context of 21st century climate change. The lectures will focus on the physical mechanisms responsible for the global energy balance and large-scale atmospheric and oceanic circulation. We will introduce fundamental concepts of fluid dynamics and we will apply these to the vertical and horizontal dynamics in the atmosphere and ocean. Concepts covered include hydrostatic law, buoyancy and convection, basic equations of fluid motions, Hadley and Ferrell cells in the atmosphere, thermohaline circulation, modes of climate variability (El-Nino, Southern Annular Mode), wind driven ocean circulation. We will discuss projections from the latest generation of global climate models as summarized in the UN Intergovernmental Panel on Climate Change (IPCC) 2022 reports. This is a general course, which spans many sub-disciplines (fluid mechanics, atmospheric science, oceanography, climate dynamics), and is a real-life application of fluid mechanics for engineering or physics students. The course will include sessions in which students will learn how to write and run simple Matlab or Python (your choice) programs to study the climate, as well as rotating tank experiments to simulate ocean/atmosphere flow in water labs. Computer related assignments will enhance the learning of the class material. No prior experience with Matlab or Python is needed.

Background in basic calculus needed (1st year calculus required, vector calculus ideal). Introductory physics (mechanics) recommended. This course is useful for anyone interested in entering a graduate program or pursuing research in climate sciences, fluid dynamics, fluid physics or engineering related fields. Prior knowledge of meteorology or oceanography not needed.

Graduate students should sign up for EESC6336.

General Goals:

- For you to learn basic atmosphere and ocean dynamics, in order to be able to understand fundamental climatic processes and future changes.
- To deepen your insights into methods of scientific inquiry. To improve your math and scientific skills, teach you basic modeling in MATLAB, a very useful computing language with a great visual interface and a solid online help manual.
- *To get you excited about the field of climate science. More researchers are needed in this field. Great graduate school and job opportunities out there waiting for you!*

Section Attributes:

- EASC Earth and Environmental Systems (AERE)
- ENVS Earth Systems Concentrations List (AESL)
- ENVS Geochemical Dynamics Concentration List (AESY)
- VIPER Energy Course (UNVE)
- Wharton UG Core Flex GenEd (WUFG)

Instructor and Office Hours: Dr. Irina Marinov, Office: Hayden Hall 254B. imarinov@sas.upenn.edu I can chat after class on Mondays and Wednesdays. Office hours with the teacher or TA will be arranged roughly every two weeks, before homework and labs are due. Group office hours will take place in DRL2W11, Irina's lab room.

Computer Labs:
Please install MATLAB on your computers, licenses are free for Penn students. For instructions, see:
For Arts and Sciences: https://computing.sas.upenn.edu/matlab-student
For engineering students: https://cets.seas.upenn.edu/software/matlab/student/
It is possible to run labs in Python rather than Matlab.

Extra Math or MATLAB/Python sessions:
If needed (and upon request), we will schedule math/physics review sessions, to cover the basic calculus and mechanics concepts needed in the class.

Readings:
Main textbook

- "Atmosphere, Ocean and Climate Dynamics: An Introductory Text" by John Marshall and Alan Plumb, Academic Press 2008.
  I recommend buying this book online for those interested to enter an ocean or atm dynamics related field of study. *Others do not need to buy it, as I will provide access to pdfs of the chapters covered.*

Additional/supplementary books you might like to look through (in Van Pelt library if you want to see the physical books, but I will provide pdfs for most relevant chapters):
"Global Physical Climatology" by Dennis Hartmann, Academic Press, 1994. I like Chapters 1-5. Older textbook, used broadly in Atmospheric science or Hydrological cycle classes.

- "Ocean Dynamics and the Carbon Cycle, principles and mechanisms", R.G. Williams and M.J. Follows, Cambridge Univ. Press 2011.
- "Introductory Dynamical Oceanography", 2nd ed., by Pond and Pickard, Pergamon Press. A classic.
- "Physics, Principles with applications" by D. Giancoli. Prentice Hall, 2005, general introductory physics text, particularly useful if you haven't had physics in a while or to brush up on basic concepts. Used in many of the intro physics classes at Penn.

Grading:
Computer labs, water labs and Homeworks: 65%. You are encouraged to work with others.
Final exam (cumulative, in the style of a long homework): 35%. Unlike your Homeworks and Labs, you cannot work with others on your Final exam.

Note 1: Homeworks and Labs have a lot of weight, so pay close attention to them. You are encouraged to discuss the assignments and labs with each other, but you need to do (and turn in) the writeups individually.

Note 2: Late HWs and labs will result in a lowering of the grade by 15% for each day late.

Academic dishonesty and plagiarism: You are encouraged to work together and with your TA on your Labs and Homeworks (except for the Final) in this class but turn in your own work. While you are welcome to use ChatGPT for studying purposes, you are not allowed to use ChatGPT/OpenAI for Homeworks/Labs/exam. Honesty is fundamental to science and academia. For details, see the student handbook or go to http://www.vpul.upenn.edu/osl/acadint.html. You will be required to sign your homeworks and exam and your signature will signify your acceptance of the class rules.

Breakdown of the course:

This course covers **Equations of Fluid Motion, basics of Atmospheric Dynamics and basics of Ocean Dynamics.** You will also do some coding in either MATLAB or Python (your choice), and apply it to idealized climate models. Additionally, we will have 2 or 3 fun "Water Labs" which will take place in DRL2W11. In these labs we will get to play with water and see some rotating (and non-rotating) tank experiments. I will announce beforehand the days we will have computer labs, so you can bring your laptops.

Approximate order (might change slightly):

L1: Intro to the Class. The greenhouse effect.

L2: Global Energy balance. Intro to the box model concept.

Intro to MATLAB.

Computer Lab1: Box model of global energy balance

L3: The vertical structure of the atmosphere and ocean.

L4: Buoyancy and Convection in the atmosphere

L5: Intro to the Atmosphere and Energy Cycle

Computer Lab2: another box model of global energy balance

L6: Horizontal Motion in the Atmosphere.

L7: The Continuity Equation (using the concept of total derivatives)

L8. Tracers and Deriving the Tracers equations. Examples of tracers: T, S, density, CFCs, radiocarbon.

Computer Lab 3: How diffusion drives the temperature, salinity and radiocarbon vertical distributions in the ocean (1D advection-diffusion models with no time dependence).

Computer Lab 4: 1D advection-diffusion models with time dependence to explain temperature and oxygen profiles in the ocean

L9: Sea-Water Properties

L10: Ocean Circulation - descriptive

L11: Equations of fluid motion: deriving the Momentum Equations

L12: Equations of fluid motion: - continued

L13: Scaling the Equations of motion: dimensional analysis. Geostrophy in the atmosphere

Water Lab 1: (meets in DRL 2W11)

L14: Thermal wind and Geostrophy in the ocean. Sea surface height. Deep ocean circulation.

L15: Wind driven ocean circulation: response of the ocean surface. Ekman pumping.

L16: Wind driven ocean circulation: response of the ocean interior. Why are there gyres in the ocean? Sverdrup, Stommel and Western Boundary Currents: Why is there a Gulf Stream?
Computer Lab 5: Simulating the Wind driven ocean circulation (a simple model with and without time dependence).
Water Lab 2: (meets in DRL 2W11)
L17: Vorticity
Water Lab 3: (meets in DRL 2W11)
L18: Future climate change. Where do we go from here?
Final Exam

ONLINE RESOURCES FOR CLIMATE SCIENCE WE MIGHT USE:

The IPCC AR6 Climate Change 2021 and 2022 reports:
https://www.ipcc.ch/report/sixth-assessment-report-cycle/
The IPCC WGI: The physical science basis
The IPCC WGII: Impacts, Adaptation and Vulnerability
The IPCC WGIII: Mitigation of Climate Change

IPCC, 2019: IPCC Special Report on the Ocean and Cryosphere in a Changing Climate [H.-O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, N.M. Weyer (eds.)]. Especially the Technical Summary and Summary for Policymakers https://www.ipcc.ch/srocc/

Fourth National Climate Assessment, 2018. Washington, D.C.: U.S. Global Change Research Program.https://nca2018.globalchange.govhttps://nca2018.globalchange.gov/chapter/front-matter-about. The National Climate Assessment (NCA) assesses the science of climate change and variability and its impacts across the United States (regional breakdown also), now and throughout this century. The NCA was mandated by the Global Change Research Act of. 1990 and it has been produced about every 4 years or so. The latest*:* Vol I: the Science (2017)*,* Vol II: Impacts, Risks and Adaptation in the US (Nov 2018).

IPCC Special Report 2018: Summary for Policymakers. ***Global Warming of 1.5°C***, a United Nations, IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [Masson-Delmotte, V., P. Zhai et al. (eds.)]. *https://www.ipcc.ch/sr15/*

Climate Change Evidence & Causes*.* ***An overview from the Royal Society and the US National Academy of Sciences, 2015****. Washington, DC: The National Academies Press. https://doi.org/10.17226/18730.*

Cook J, Oreskes N, Doran PT et al. **Consensus on consensus: a synthesis of consensus estimates on human-caused global warming**. Environmental Research Letters. 2016; 11(4):048002.