EART 124 Modeling Earth's Climate

This course is a hands-on investigation of the climate system using numerical and mathematical models. We will collectively work with a range of models, including comprehensive climate models and assorted simpler process models. Our objectives are the following:

- To use climate models to build an understanding of the physical laws governing climate and climate change.
- To learn principles of climate modeling, such as complexity, parametrization, and the difference between prediction and understanding.
- To gain substantial experience using the Python programming language to generate, analyze, and interpret geophysical data.

This is a modeling course not a programing course. We will be developing coding skills but always in service of asking interesting questions in climate science. This course does not currently have advanced prerequisites in Earth sciences or computer programming, though courses like EART 121 and EART 119 would be good preparation. Some coding experience in a high-level programming language (Python, Matlab, R, NCL, etc.) is helpful. If you enjoy "learning by doing," then you should find the class challenging but rewarding. If you are seeking a solid foundation in computer programming, I would recommend that you first take EART 119 or another programming course.

Meets: TuTh 9:50AM - 11:25AM, Zoom: https://ucsc.zoom.us/meeting/register/uJMsf-6prTsu8BzW-0-DAPV6fcSQRr9P7Q

Discussion Section: We 11:00AM - 12:00PM, Zoom: https://ucsc.zoom.us/meeting/register/u5YqfuCtpjkqdsCT8SzRncFkSszABSYZog

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Office Hours: Tuesday 1:30PM - 3:30PM

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Office Hours: Thursday 3:00PM - 4:00PM

Course website(s): https://canvas.ucsc.edu/, http://earth124.ucsc.edu/

Grading: Assignments (70%), Final Project (written report 25%, oral presentation 5%)

Course requirements: A computer with internet access.

Reading and textbooks: The principal source will be my own lecture notes, which I will distribute to the class electronically. I will sometimes assign readings from papers and books. You may find this book useful: K. McGuffie and A. Henderson-Sellers (2014), *The Climate Modelling Primer* (4th edition), Wiley Blackwell. A copy of the book will be on reserve at the Science & Engineering Library. It is also available online through the UCSC library: http://cruzcat.ucsc.edu/record=b4376142~S5

Strategies for Success:

Work together. Active collaboration with your classmates on the lecture material and homework assignments is encouraged. However, you must always submit your own work and your own thoughts in your own words. This is very important when writing computer code! There is nothing wrong with borrowing useful pieces of code from classmates or online sources—that is in fact the central principle of open-source software. However, you must always acknowledge the original author(s). You must also, wherever practical, understand the code you are borrowing and be able to explain what it does. This is important for academic integrity as well as for your own learning: students who do not learn how to complete the earlier assignments are at a substantial disadvantage on the later assignments.

Think physically. Sometimes it is easy to get lost in the mechanics of code or math, but you should always have in mind that you are solving a physical problem. This is especially important when you arrive at a solution. It should make sense to you given what you know about the world around you.

Academic integrity: The cornerstone of intellectual life at UC Santa Cruz is a commitment to integrity in all forms of teaching, learning, and research. Cheating, plagiarism, and all other forms of academic misconduct will not be tolerated. Suspected or admitted cases will be reported to your college provost, which will result in a permanent record, and possible additional consequences such as suspension or dismissal from the University. Students are responsible for becoming familiar with Sections 102.01–102.016 and 105.15 of the UC Santa Cruz Student Policies and Regulations Handbook.

Disability accommodation: UC Santa Cruz is committed to creating an academic environment that supports its diverse student body. If you are a student with a disability who requires accommodations to achieve equal access in this course, please submit your Accommodation Authorization Letter from the Disability Resource Center (DRC) to me by email, preferably within the first two weeks of the quarter. I would also like us to discuss ways we can ensure your full participation in the course. I encourage all students who may benefit from learning more about DRC services to contact DRC by phone at 831-459-2089 or by email at drc@ucsc.edu.

A note on COVID-19: All instruction will be online for the entire Spring Quarter 2020. Modifications to the course include:

- All lectures, discussion sections, office hours, and final project presentations will all occur via Zoom meetings. Links are on the first page of this syllabus and on Canvas.

- Due to the potential for related disruptions, I will waive penalties on late assignments. Otherwise, the homework policy remains the same (i.e., no late submissions after the solution has been discussed in section).
- While attendance and active participation in class meetings is expected, I will provide recordings of the lectures at https://webcast.ucsc.edu/ in the event that you experience internet connectivity or other technical difficulties.

If you have any concerns about your ability to participate fully in the course, please discuss them with your professor as soon as possible. The university has also put together a new website with resources for students embarking on remote learning: https://keeplearning.ucsc.edu/

Assignments

Much of the course will consist of hands-on computing exercises, including both in-class exercises and homework. We will use the computer language Python for our exercises and calculations. We recommend software called Anaconda Python, which in completely free and provides everything we need. The instructor will provide additional Python code files for each exercise as necessary. The goal of the exercises is to carry out scientifically meaningful calculations. We will therefore view our efforts in learning to work with Python code as a means to an end, not an end in itself. Grading of homework will be based more on scientific content and understanding than on programming skill. The TA is available for computing assistance.

There will be regular homework assignments throughout the quarter. Homework will be due on the stated due date. All homework will be returned, and solutions discussed, in discussion section. Late assignments will not be accepted after the solution has been discussed (typically, the Wednesday following the deadline).

DEADLINES

Assignment 1 - April 10, 11:59PM

Assignment 2 - April 17, 11:59PM

Assignment 3 - April 28, 11:59PM

Assignment 4 - May 8, 11:59PM

Assignment 5 - May 15, 11:59PM

Final Project

There will be no final exam. Each student will complete a small independent project, submit a written report in Jupyter notebook format, and give a brief oral presentation to the class. You will choose your own topic exploring an issue in climate science and climate modeling. The project must include some original calculations described and carried out by you. These may be extensions of homework exercises or something entirely different than we covered in the course, subject to approval by the instructor.

You will submit your written report electronically as a Jupyter notebook. We will use these notebooks frequently throughout the course so all students will become well acquainted with them. The notebook is a document combining formatted text with executable computer code for self-describing calculations.

Your final report will:

- Describe the scientific problem you are studying
- Provide necessary details for the methods you are using
- Include all the code necessary to generate your results
- Clearly communicate results as well-labeled graphs and tables as appropriate
- Conclude with a brief summary of what you learned.
- Be completely reproducible (i.e. the instructor must be able to run your notebook cleanly from start to finish).

The instructor and TA will assist you meeting all these goals.

The grade for the written papers will be determined by both scientific content and clarity of presentation.

The purpose of the oral presentations is to share your work with your classmates and practice your presentation skills. Each student will give a brief presentation (about 10 minutes), followed by a brief class discussion. Grades for the oral presentation will be based primarily on clarity.

You will work independently on your own project. However we strongly encourage you to discuss with your classmates and give each other feedback along the way.

DEADLINES

Final Project Proposal - May 22, 5:00PM - Describe the scientific problem you wish to investigate and the methods you will use to do so (length: 1 page)

Final Project Oral Presentations - June 10, 12:00-3:00PM (Final Exam block)

Final Project Written Paper - June 10, 5:00PM

Python

In this course we will be working extensively with a computer programming language called Python. Python is a general-purpose high-level interpreted language that is now being used by many people in the geosciences. Benefits of Python include:

- It's easy to learn.
- The code tends to be simple and easy to read.
- It can run on just about any computer, maybe even your smartphone.
- You can run your code interactively, so it's great for exploring and learning about your data.
- Lots of packages are available for powerful scientific computing and graphics.
- It's completely free and open-source.

Most of our interactive Python work will happen inside of the Jupyter notebook. The notebook lets you write and execute Python scripts inside a web browser, in a document that combines

Python code, graphics, and nicely formatted text. It is a very useful tool for organizing a scientific workflow because the code remains tied to the text descriptions and the actual results.

You will not need to install any software on your own computer. Instead, we will run Python code on a server called a JupyterHub. This allows you to log in through a web browser and run Jupyter notebooks on a remote server.

To access the JupyterHub for this course go to: http://earth124.ucsc.edu/.

You will need your UC Santa Cruz *blue* credentials.

Interacting with notebooks on JupyterHub

When you log in to the JupyterHub you will see a file browser containing the material for this course. You will be interacting with the Assignments and Lectures folders.

- The files in Assignments and Lectures are local copies that are owned by you. You can freely edit these files without affecting anyone else's work.
- To submit a completed homework assignment, go to File > Save as … In the box, type Submissions/[your username]/[some sensible filename]

For instance, I might type Submissions/nfeldl/Assignment1.ipynb to save a copy of the notebook into the Submissions folder for grading by the instructors. If you do not complete this step, your homework is not submitted!

Alternatives to JupyterHub: We will not be providing support for alternative installations, however, it is also possible to reproduce all the work you will do in this course if you have Anaconda Python (version 3) and climlab (a climate modeling toolkit) installed on your own computer.

https://www.anaconda.com/

https://climlab.readthedocs.io/

Tentative Schedule of Topics

1. Climate models, the global energy budget, and fun with python
2. Modeling the global energy budget
3. The climate system and climate models
4. Introducing the Community Earth System Model (CESM)
5. Building simple climate models using climlab
6. Physics of radiation
7. Elementary greenhouse models
8. Grey radiation modeling with climlab
9. Radiative equilibrium
10. Radiative-convective equilibrium
11. Climate sensitivity and feedback
12. Transient and equilibrium CO2 response in the CESM
13. Toy models of transient warming
14. Clouds and cloud feedback
15. Insolation
16. Orbital variations, insolation, and the ice ages
17. Heat transport
18. The one-dimensional energy balance model
19. Modeling the seasonal cycle of surface temperature
20. Ice albedo feedback in the EBM
21. Snowball Earth and large ice cap instability in the EBM

Stretch goals:

22. The surface energy balance
23. Land-ocean contrasts under climate change
24. Water, water everywhere!