ESE-136: Climate and Climate Engineering

Term:	Spring 2020
Class hours:	Tuesday and Thursday 9:00-10:15 AM
Room:	Pierce 209
Instructor:	David Keith
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	Note: This is my cell number. I don't use an office number. I prefer that you contact me by email, but if you do need to call please use my cell only between 7 AM and 7 PM. Better text first and I will call you.
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Faculty assistant:	Selena Wallace, (617) 998-5561, swallace@g.harvard.edu
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Textbook:	*Atmospheric Science: An Introductory Survey*, Wallace and Hobbs, 2nd Edition, Academic Press. Available as e-book for ~50 to 75$ depending on distributor.

Description: An introduction to the physics that determine our planet's climate motivated by concerns about human-driven climate change. From highly simplified models of radiation and convection in a column to state-of-the art models of the general circulation, the course provides a hands-on introduction to modeling tools as a basis for understanding predictions of climate change and assessing their uncertainty. Solar geoengineering, the possibility of deliberate large-scale intervention in the climate, is covered as a potentially important new application of atmospheric science and as a tool to motivate analysis of aerosol radiative forcing, feedbacks, and uncertainty.

Audience: This course adopts an engineer's viewpoint not just in the obvious sense that it covers climate engineering, but also in the general sense, that it's motivated by practical application rather than theoretical understanding. I hope to serve students interested in energy technology, environmental science, or environmental policy, for whom climate science is a vital background. Students with strong science or engineering interests who want to be smart consumers of results from the atmospheric sciences. Finally, I hope to course will be useful for anyone who wants to understand solar geoengineering, a controversial and risky emerging technology that may enable a substantial reduction the human and environmental risks of climate change.

Recommended preparation: One freshman-level math or applied math course, one freshman-level science course, and physics at either the freshman or high-school level; or, permission of instructor.

Learning objectives:

- Understand the physics behind some of the most important atmospheric processes that determine the climate response to anthropogenic forcing
- Develop a critical understanding of the strengths and limitations of climate models
- Be familiar with standard predictions of climate change
- Understand the basics of solar geoengineering, methods, risks, and predicted climate response

Assignments & Grading

Activity/Assignment	*%*
Class participation • Comments and responses in class. • Quality of peer evaluation commentary.	10%
Problem sets • 5 p-sets, roughly one p-set assigned every two weeks. • The best 3 of the 5 p-sets will count toward the final grade. • You may elect to do p-sets with one other person by permission of instructor. Permission must be requested one week before due date.	30%
Analysis µ-essays • Short informal essays analyzing readings or arguments arising from the class materials. • 2 essays will be assigned, one on some aspect of climate change other than geoengineering, and the other on a geoengineering topic. • Maximum 750 words in length. Informal reference style. • Essays will be evaluated by instructor and by two randomly assigned peers.	15%
Quizzes • 3 quizzes of 45 min duration to test knowledge and ability to solve problems like those on the p-sets. • The best 2 of 3 quizzes will count toward the final grade. • Dates: Thursday 28th February, Thursday 28th March, and Tuesday 23th April	30%
Oral exam • There will be a 20 min oral exam during finals week.	15%

Assignments must be posted to the class page by midnight on the day they are due. Late assignments will be marked down one grade for each day they are late, unless an exception is requested and granted *in advance*.

The class participation grade is evaluated on each student's engagement with the class as a whole. Effective class participation requires that students read and review the assigned readings before coming to class. The class participation grade is not a measure of the quantity of a student's interventions, but rather on the quality of verbal participation in class discussions. I am looking for interventions that (a) bring in evidence/ideas from the readings, (b) build on comments from others, and (c) link professional experience to the material being discussed.

Topic outline

1. Setting the stage
    a. An overview of the climate-energy challenge
    b. Solar geoengineering: history, prospect, and controversy
2. A short incomplete introduction to atmospheric science
    a. Column World
        i. How does our atmosphere hold itself up? Physics of a dry atmospheric column
        ii. Observed vertical structure of the atmosphere
        iii. Latent heat, moist lapse rate
        iv. Radiative-convective equilibrium
        v. Thermal radiation, a simple model of radiative transport through N-grey bodies
        vi. Runaways, Venus, and Simpson's paradox
    b. A tour through the general circulation
        i. What's a trade wind? What explains the locations of deserts?
        ii. The general circulation
        iii. Geostrophic balance
        iv. Clouds
        v. A brief mention of fronts and instabilities
    c. Simple climate models
        i. Climate sensitivity
        ii. Climate for Column World
        iii. A 1-D model with ice-albedo feedback
    d. A tour through the earth system
        i. Carbon cycle
        ii. Oceans
        iii. Cryosphere
        iv. Earth's history
    e. Atmospheric General Circulation Models (GCMs)
        i. Descriptive tour: Gridding and numerical schemes, 'physics' vs 'dynamics'…
        ii. Numerical weather prediction
3. Predictions of anthropogenic climate change and it's impacts
    a. How might the climate where grew up change over your lifetime?
    b. Economy → Emissions → Concentrations → Climatic Changes → Impacts
    c. Scenarios (RCP's, SSPs, narratives and other nonsense)
    d. Uncertainties
    e. Impacts
4. Solar geoengineering
    a. An overview of methods
        i. Stratospheric aerosols
        ii. Cirrus thinning
        iii. Marine cloud brightening
        iv. Space based methods
    b. Climate response to solar geoengineering
        i. Applying simple models

        ii. Results from GCMs
        iii. Insights from natural analogs
    c. Risks
        i. Risk, side-effects, and uncertainties of individual methods
        ii. Risk and efficacy of solar geoengineering
    d. Feedback and control
        i. Controlling radiative forcing
        ii. Controlling climate
    e. Technology
5. Discussion and debate: What does it all mean? Reflections on the evolution of climate science and politics.