Global Warming Science 101 *(Spring 2024)*

Open course web-page
Harvard canvas course web page for EPS/ ESE 101:
https://canvas.harvard.edu/courses/129869
Last updated: Wednesday 24th April, 2024, 09:09.

Administrative

Instructor: Eli Tziperman (eli@eps.harvard.edu); **TFs:** TBA. Please feel free to email or visit us with any questions.

Day, time & location: Wednesday 3–5:45, HUCE room 440, 4th floor, 26 Oxford St.

Office hours: Each of the teaching staff will hold weekly office hours; see course web page for times & place. Eli's office: 24 Oxford, museum building, 4th floor, room 456.

Course resources: available under the course web-page,

1. Course notes
2. Python Jupyter-notebooks and corresponding pickle data sets
3. Slides

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Description: An introduction to the science of global warming/climate change, meant to assist students in processing issues that often appear in the news and public debates. The course is meant for any STEM student with basic math preparation, not assuming prior science courses. Topics include the greenhouse effect and consequences of the rise of greenhouse gasses, including sea level rise, ocean acidification, heat waves, droughts, glacier melting, forest fires, expected changes to hurricanes, and more. The scientific basis for each subject will be covered, and every class will involve a hands-on analysis of observations, climate models, and climate feedbacks, using guided work with python Jupyter notebooks. Throughout, an ability to critically evaluate observations, predictions, and risks will be developed.

Requirements: In-class participation required. Students are asked to complete two assignments for each class: (1) a Jupyter-notebook-based workshop, (2) a one-page report addressed to the president's science adviser, explaining the problem, motivation, methods, the science results based on the class and workshop outcome and the implications. You need to address all guiding questions while maintaining a coherent overall structure. Detailed guidelines here. Each student will serve as a *coach* in at least one workshop, helping other students after being prepared by the teaching staff the week before. Each group of coaches will also prepare a two-slide presentation for a special course session on critically reading popular press articles about climate change and another such presentation for the last class on the interface between climate change science and policy. **Grading:** HW, including workshop, essays, and group presentations: 75% (the lowest weekly grade will be dropped, the presentations cannot be dropped); coaching: 10%, participation: 15%. The course may be taken pass/fail only in unusual circumstances and with instructor approval during the first week of classes. Jupyter notebook and one-page report should be submitted via *Gradescope* as two separate PDFs by 2 pm on Wednesday a week after being assigned. You need to check the posted grades and come to Eli's office hours within seven days from the release of grades if you see a problem. Please approach (visit) Eli rather than the TFs with any issue related to grading.

Course forum: Please post questions regarding HW/lectures or other issues to the course forum on *Ed Discussions* (edstem.org) or come to office hours, rather than emailing the teaching staff. You are very welcome to respond to other students' questions.

Homework help session: a day before the HW is due, Tuesday 4–6, see location on Canvas. Come get your questions answered and help others!

Electronic homework submission: via www.gradescope.com: upload your submission, including code exported from Jupyter to pdf via LaTeX, and typeset essay; *tag your questions* as shown in the tutorial video. Late submissions would lead to a reduction of 2% per minute after the due time.

Optional extra credit HW problems: These will involve more challenging programming/ math/ independent work (teaching staff available to help, of course). Apart from the fun of doing these problems, they may bring the total HW score to up to 110%, counting against problems you may have missed in the same or other HW assignments…

Course meetings: 3-hour sessions, including short lecture segments mixed with guided hands-on programming. Group work is strongly encouraged during workshops.

Recommended Prep: Elementary calculus and ordinary differential equations, as covered, for example, by Math 19a or Math 21b. Previous exposure to programming in any programming language is sufficient. Python will be introduced as part of the course. The course will introduce the students to various science subjects, but no prior college-level science knowledge is assumed.

Programming in python, will be employed throughout the course. Basic exposure to programming (not necessarily Python) is assumed, and students will be provided with template code (in the form of easy-to-use **Jupyter notebooks**) to start from and be closely guided in the weekly course workshops. **Students are requested to bring their laptops to the first class**. We will be using the FAS OnDemand Jupyter server, which means that no software installation is needed, although students may also use Anacoanda python version 3.11.

Textbook: "Global Warming Science: A Quantitative Introduction to Climate Change and Its Consequences", Eli Tziperman, 2022.

Academic Integrity and Collaboration Policy: We strongly encourage you to discuss and work on homework problems with other students and with the teaching staff. However, after discussions with peers, you need to work through the problems yourself and ensure that any answers you submit for evaluation are the result of your own efforts, reflect your own understanding, and are written in your own words. In the case of assignments requiring programming, you need to write and use your own code; code sharing is not allowed. You must appropriately cite any books, articles, websites, lectures, etc. that have helped you with your work.

Lecture order

Lecture order this semester; see below for outlines of lectures:

1. Introduction
2. Hurricanes
3. The greenhouse effect
4. Sea level rise
5. Clouds
6. Temperature
7. Ocean acidification

Spring break

8. Critically reading popular press articles about climate change science
9. Floods [/Droughts/Heatwaves]
10. Sea ice
11. Ocean circulation [/Mountain glaciers/Greenland and Antarctica]
12. Forest fires
13. Last class! (mis)using climate science in setting policy

Lecture outline

1. Logistics, course requirements; overview of the course and an introductory Jupyter notebook with python basics.

2. **The greenhouse effect**
   (a) Energy balance, the greenhouse effect in a two-layer model.
   (b) Emission height, atmospheric lapse rate, response to greenhouse gas increase.
   (c) Black body radiation.
   (d) What are greenhouse gases, and how do they absorb radiation:
      - Vibrational and rotational modes.
      - Energy levels, absorption lines, absorption windows.
      - Pressure and Doppler broadening.
      - Different greenhouse gases compared via their Greenhouse Warming Potential.

   (e) Water vapor feedback to increased CO_2.

3. **Temperature**
   (a) Equilibrium climate sensitivity.
   (b) Transient climate sensitivity and the role of the ocean.
   (c) Polar amplification.
   (d) Natural variability and “hiatus” periods.
   (e) Stratospheric cooling.

4. **Sea level rise**
   (a) The historical record and future projections:

- Exiting from the Little Ice Age vs. anthropogenic global warming.
- Decadal variability.
- Global vs. regional.
- Future projections.

(b) Global mean sea level change:
- Thermal expansion.
- Glacier and ice sheet mass balance.
- Land water storage.

(c) Regional sea level change:
- Wind stress.
- Atmospheric sea level pressure.
- Ocean circulation.
- Land erosion.
- Gravitational effects.

5. **Clouds**
   (a) Cloud types: high/ low, water/ ice.
   (b) Shortwave (SW) and longwave (LW) cloud radiative forcing (CRF).
   (c) How clouds form, atmospheric convection.
   (d) Cloud microphysics: fall speed of cloud droplets, cloud dissipation, droplet size distribution, hygrometer types, aerosols.
   (e) Cloud feedbacks and warming uncertainty.

6. **Ocean acidification**
   (a) The ocean carbonate system.
   (b) Alkalinity, total CO_2, pH.
   (c) The effect of increasing atmospheric CO_2 on ocean acidity and on calcium carbonate dissolution.
   (d) Long-term decline of anthropogenic CO_2

7. **Ocean circulation collapse**
   (a) The Atlantic Meridional Overturning Circulation.
   (b) Ocean temperature, salinity, density.
   (c) Multiple equilibria, stability, tipping points, hysteresis.
   (d) Consequences of meridional circulation collapse
   (e) Observations, has the ocean's circulation started collapsing? Projections.

8. **Hurricanes**
   (a) The big factors: Sea Surface Temperature (SST), wind shear.
   (b) Have hurricanes become stronger already: correlation with SST.
   (c) Potential intensity: Clausius-Clapeyron relation, hurricane energetics, and future intensification.

9. A special course session on **critically reading popular press articles about climate change**, first class after spring break: The individual and group

assignments, in this case, are due before class; see reading material and guidelines here.

10. **Arctic sea ice**
    (a) Recent changes to Arctic ice extent, area, volume, and age.
    (b) Why do these changes occur, and what is the impact?
    (c) sea-ice feedbacks: albedo, age and melt ponds, thickness and insulation, thickness and mobility due to storms.
    (d) Detection of climate change.
    (e) Future projections.
11. **Greenland and Antarctica**
    (a) Observed changes to Greenland and Antarctica.
    (b) Surface Mass balance (SMB): Ablation vs accumulation, positive degree days (PDD).
    (c) SMB as a function of height: elevation-desert effect; lapse rate and reduced ablation; temperature precipitation feedback.
    (d) Calving: yield stress, floating criteria, hydro-fracturing in ice shelves.
    (e) Marine Ice Sheet Instability (MISI).
    (f) Basal heat budget and meltwater production.
    (g) Ice stream acceleration, lubrication by basal water, melt ponds, and Moulins.
    (h) Ice ages
    (i) Observations of current trends and future projections.
12. **Mountain glaciers**
    (a) Observed retreat over the past 150 years, acceleration in recent decades.
    (b) Surface mass balance, equilibrium line, accumulation, and ablation zones.
    (c) Glaciers as climate proxies: ice cores and glacier length records.
    (d) Glacier ice flow and retreat due to warming and changes in surface mass balance.
    (e) Retreat due to exit from Little Ice Age vs. anthropogenic climate change.
13. **Droughts and precipitation**
    (a) Precipitation, evaporation, and soil moisture.
    (b) Droughts driven by remote SST changes due to natural variability modes such as El Niño or the Indian Ocean dipole.
    (c) Reconstructing past droughts, tree rings, and the detection of anthropogenic climate change.
    (d) Future projections: two case studies, Sahel and South-West US.
    (e) Understanding precipitation projections:
        i. The "wet getting wetter, dry getting drier" global-scale projection.
        ii. Expansion of the Hadley cell and shift of desert bands.
        iii. Strengthening of extreme precipitation events.
    (f) Bucket model for soil moisture.
14. **Heatwaves**

(a) Heat waves as weather events, location-specific threshold temperature, and duration.
(b) Processes: high pressure aloft, subsidence, surface winds, clear sky and enhanced shortwave radiation, dry soil, heat stress.
(c) Heat stress and human health effects
(d) Projections: anticipated changes to amplitude, frequency, duration, and the total number of heatwave days.
(e) Understanding the projected shift in heatwave statistics.

15. **Forest fires**
    (a) Fuel aridity and fire weather indices.
    (b) Non-climate human influences: ignition, fuel, and fire suppression management, population increases.
    (c) Climate factors: drought, temperature, prior-year cold season precipitation, winds, vapor pressure deficit.
    (d) Fires enhanced by climate variability modes and teleconnections vs by climate change.
    (e) Test cases: southwestern US and Australia.

16. Last class! **Using climate science in setting policy.** The individual and group assignments, in this case, are due before class; see guidelines and reading material here.