Global Warming Science 101 *(Spring 2020)*

Administrative

Instructor: Eli Tziperman (eli@eps.harvard.edu); **TFs:** Please see course web page. 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 stuff 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: Notes, slides and python Jupyter-notebooks for each class are available under the canvas webpage.
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Description: An introduction to the science of global warming, meant to assist students to process issues that often appear in the news and public debates. Topics include: the greenhouse effect and consequences of the rise of greenhouse gasses, including sea level rise, ocean acidification, heat waves, droughts, glacier melting, 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 python Jupyter notebooks. Throughout, an ability to critically evaluate observations, predictions and risk will be encouraged.

Requirements: Students must attend all classes. Students are asked to complete the weekly Jupyter-notebook based workshop and write a one-page report addressed to the president science adviser, explaining the problem, motivation, methods, the science results based on the workshop outcome and the implications (together 70%, lowest grade dropped). Each student will serve as a *coach* in at least one workshop, helping other students after being prepared by the teaching stuff. Each group of coaches will also prepare two slides for the special course session on critically reading popular press articles about climate change (together, 15%). Participation (15%). Jupyter notebook and one-page report should be submitted via Canvas as a single pdf by 2pm on Wednesday the week after being assigned. Homework grades are posted to canvas, you need to check the posted grades and let Eli know within 7 days from the release of grades if you see a problem. Please approach Eli rather than the TFs with any issue related to grading.

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

Recommended Prep: Basic calculus and ordinary differential equations, as covered for example by Math 1b, Math 19a, Math 21b. Basic programming experience is assumed. 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 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**, and to *try* to install Anacoanda python version 3.7 before class.

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.

Course outline

(In green: hands-on activities using python Jupyter notebooks)

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

2. **Hurricanes**
   (a) Stages of hurricane development
   (b) Analyzing the observed hurricane record
   (c) Hurricane energetics and "potential intensity": estimating hurricane strength from sea surface temperature
   (d) Calculating projected future hurricane strength
   (e) Role of wind shear and El Nino

3. **The greenhouse effect**
   (a) Black body radiation, short wave vs long wave radiation
   (b) Estimating the Earth temperature with and without the greenhouse effect
   (c) Role of the vertical temperature profile of the atmosphere, lapse rate
   (d) How greenhouse gasses work, estimating the CO_2 greenhouse effect strength

4. **Sea level rise**
   (a) Analyzing the observed sea-level record and future projections, decadal variability vs long-term trend
   (b) Global mean sea level change: estimating the effect of thermal expansion, glacier and ice sheet mass balance, land water storage
   (c) Regional sea level change: estimating the effect of wind, ocean circulation, land erosion, gravitational effects

5. **Clouds**

(a) How clouds form: modeling atmospheric convection and cloud formation

(b) Suspension of cloud droplets, Stokes terminal velocity

(c) Cloud types: high/ low, water/ ice

(d) Cloud cooling effects due to shortwave (SW) radiation, and warming effects due to longwave (LW) radiation; cloud radiative forcing (CRF)

(e) Estimating global warming uncertainty due to cloud feedbacks

6. **Temperature**

(a) Analyzing the instrumental record of last 100/1000 years, the "hockey stick" curve and future projections

(b) Natural variability and "hiatus" period(s)

(c) Radiative forcing, equilibrium climate sensitivity, estimating future warming from present-day observations

(d) Transient climate sensitivity, modeling and understanding the role of the ocean

(e) Polar amplification: why is the Arctic warming much faster?

7. **Ocean circulation collapse**

(a) Ocean temperature, salinity, density,

(b) Circulation collapse due to warming: tipping points and abrupt collapse

(c) Estimating the response of the meridional overturning circulation to global warming using the Stommel model

(d) Has the ocean circulation started collapsing? Future projections.

8. A special course session on **critically reading popular press articles about climate change**, first class after spring break: You need to read the full annotated version of the article "The Uninhabitable Earth" from the New York Magazine.
Your assignments: (1) Write a 1-page (single space, 12pt) recommendation to the chief editors of major papers such as the New York Times, based on your reading of **the entire article**, about how they should deal with articles about global warming, with a focus on how they should consider scientific accuracy vs other factors. **(2)** Each group of coaches will be assigned one section from this article for further analysis. Follow the provided links in your assigned section to the scientific literature, carefully evaluate what you find, and prepare **exactly two** carefully reasoned **slides** using a **24pt font or larger, maximum two images and 50 words per slide**: one summarizing points you agree with and another summarizing those that you feel are not supported by the science. During class, we will examine the slides and discuss what is the best way for the press to cover global climate change. The TFs will email your assigned section before spring break. You need to submit your slides and writing via Canvas by 4pm, Monday, two days before class, to allow us to provide feedback on the slides and revise if neede.

9. **Ocean acidification**

(a) Acidity (pH), Alkalinity, the ocean carbonate system

(b) Calculating ocean acidity (pH) from atmospheric CO_2 using the ocean carbonate system equations for historical observations and future projections.

(c) Effects of acidification on biological calcification

10. **Arctic sea ice**

    (a) Characterize recent changes to Arctic sea ice extent, area, volume and age.
    (b) Sea ice albedo feedback, effects of ice area, age and melt ponds
    (c) Attribution in the presence of positive feedbacks.

11. **Droughts**

    (a) Connecting Precipitation and evaporation to soil moisture via a "bucket model"
    (b) Climate effects: natural variability vs anthropogenic change, role of El Nino
    (c) Shifts of climate zones due to climate change, rich getting richer and poor getting poorer
    (d) Analyzing past droughts using tree ring data
    (e) Examining future precipitation and soil moisture projections: two case studies, the Sahel and South-West US.
    (f) Using non-parametric statistics to evaluate how unusual is a given drought event

12. **Greenland and Antarctica**

    (a) Surface mass balance, response to warming
    (b) Marine ice sheet instability
    (c) "cliff instability" leading to ice calving
    (d) Basal hydrology and ice stream acceleration

13. Last class! **Using climate science in setting policy.** Read the "Green New Deal" law posted to canvas, we are focusing only on the parts that are not highlighted in blue. **Your assignments: (1)** Each group of coaches will be assigned three short sections from this law for further analysis. Prepare one carefully reasoned slide for each of your three sections, using a **24pt font or larger, with a maximum of one image and 30 words per slide**, addressing: are scientific claims about climate change correct? Are policy goals feasible? Other comments? During class, we will examine the slides, and discuss what is the best way for policymakers to use climate (and other) science. To research these issues, use the IPCC 2018 global-warming 1.5degree report, and the US 4th national assessment science and mitigation reports posted to canvas, as well as other sources, as needed. Be prepared to explain your further detailed and reasoned opinion in class. The TFs will email your assigned sections before the final week. You need to submit your slides via Canvas by 4pm, Monday, two days before class, to allow us to provide feedback on the slides and revise if needed. **(2)** Write a 1-page final paper (single space, 12pt) with a recommendation to your representative in congress, based on your reading of **the entire law** (blue parts excluded again), about how they should deal with the issue of climate change in setting new policies/ laws, with a focus on how they should consider scientific accuracy vs other factors. Submit your writing via Canvas by 4pm, Wednesday, one week after the last class.