CLIMATE 473: Climate Physics
Fall 2024

Instructor: Mark Flanner (flanner@umich.edu)
Pronouns: he/him/his

Credits: 3

Lecture: Mon., Wed., Fri. 1:30-2:20 in 136 EWRE

Office Hours: Monday, Wednesday 2:20-3:00 in 136 EWRE, or by appointment.

Pre-requisites: Basic physics and calculus

Course website: (via canvas)

Required Text: *Global Physical Climatology, Second Edition*, by Dennis Hartmann
(Elsevier, 2016, ISBN-13: 978-0123285317)
* Errata published at: http://www.atmos.washington.edu/~dennis/gpc.
*** pdfs are available free through UM Library / ScienceDirect**
* Hardcover available through multiple retailers

Supplemental Texts:

1) *Atmospheric Science: An Introductory Survey (2nd Edition)* by Wallace and Hobbs (Academic Press, 2006, ISBN: 978-0127329512). This book provides excellent introductory descriptions of important atmospheric processes and has clear figures, but its focus is restricted to the atmosphere.
2) *Physics of Climate* by Peixoto and Oort (Springer Press, 1992, ISBN: 978-0883187128). This book provides excellent theoretical bases of climate-relevant processes. Some of the theory is more in-depth than needed for this course, but we will draw on this text occasionally throughout the course.
3) *Principles of Planetary Climate* by Raymond Pierrehumbert (Cambridge University Press, 2010, ISBN: 978-0521865562)
4) *Climate Change 2021: The Physical Science Basis*, report produced by the Intergovernmental Panel on Climate Change (IPCC) Working Group 1. This report provides summaries of relevant science (as of ~2020) and is a useful source of references to peer-reviewed literature on many different topics. **pdfs are available for free** at: https://www.ipcc.ch/report/ar6/wg1/

Course Description:

This course will explore processes that determine Earth's climate. We will apply descriptive and quantitative techniques to understand how radiative, thermodynamic, and dynamic processes distribute energy throughout the Earth System, drive climate feedbacks, and determine the sensitivity of Earth's climate to external perturbations. We will apply these concepts to explore how atmospheric, hydrologic, cryospheric, solar/orbital, land surface, volcanic, and human processes influence past, present, and future climate. We will also study inherent modes of climate variability, including the El Niño-Southern Oscillation (ENSO).

Course Structure and Policy:

Readings: All required readings will come from Hartmann's text, or will be provided as pdfs. Supplemental readings are also listed in green on the schedule below. These readings are optional, and are provided as references for more in-depth knowledge on particular topics.

Homework: There will be about 8 homework sets, posted on canvas, that will draw on problems from Hartmann's text and elsewhere. Some assignments will require programming in a high-level language such as Matlab or Python. You may (and are encouraged to) form study groups to discuss homework problems and approaches, **but your homework responses must be prepared and completed individually, using your own formulations and wording.** You may complete these assignments in (legible) written or typed form. For assignments requiring programming, please also upload your source code to canvas. Unless prior arrangements have been made with the instructor, assignments turned in late will be docked 10% per weekday.

Exams: There will be one midterm exam, administered in-class. If you have a conflict with this time, you must make arrangements to take the exam at an earlier date.

We will apply the College of Engineering honor code in this course: https://bulletin.engin.umich.edu/rules/. You are responsible for understanding these terms. The basic theme of the honor code is that *unfair advantage cannot be sought.*

Course Project:

The purpose of this project is to explore in greater detail an agent or mechanism that induces climate change, via either natural or anthropogenic means. The project will be conducted individually and will culminate in a ~5-page written paper and a 10-15 minute oral presentation to class. Topic suggestions are listed below, but your choice is not limited to these suggestions.

It is intended that you research the topic and address relevant questions primarily through literature review ("Option A", see below). *However*, you may instead choose to adopt a numerical approach to this project, through (e.g.,) model development or data analysis ("Option B"). The definition of this option is intentionally vague because of the huge variety of processes, and hence approaches to research, involved with climate change agents and mechanisms. With this flexibility comes opportunity, but also need for a well thought-out plan so the project is manageable and useful to you. Hence, if you choose this approach, you must meet with Prof. Flanner by October 16 to discuss your proposed plan and finalize an approach that will lead to successful completion of the project.

Option A:

Prepare a written report, **in your own words,** that addresses questions such as: How does this mechanism or agent alter climate? What feedback mechanisms are involved with the radiative forcing caused by this agent or mechanism? What climate processes are most affected and how? What types of models and observations are needed to understand its importance, and what are the key uncertainties associated with our current understanding? Where in the Earth System and during which seasons is the mechanism most influential, and why? Over what timescales does the mechanism operate? If dealing with an agent, what are the sources and sinks of the agent, and what controls its lifetime of influence? Is the mechanism or agent influenced by human activity, and if so, how? During which time periods in Earth's or humans' past has this mechanism or agent likely been most influential, and what may cause its strength to change in the future? Your report is not restricted to these questions, but the focus must be on physical processes, with some deviations into chemical and biogeochemical processes as needed.

<u>Project summary</u>

Group size:	Individual
Written report:	**4+ pages of text, excluding figures and references, with 1.5-line spacing, 12 point font, and 1" margins. You are encouraged to include figures, but they do not contribute to the page total. The figures do not need to be produced by you, and proper credit must be given to the original source of the figures if you did not produce them.**
Due date:	December 9
Oral presentation:	In-class, 15 minutes in length, media of your choice.
Grading:	60% weighting on written report, 40% on presentation
Selection:	Topics and presentation times will be selected in class on Friday September 27. Please have preferred topics in mind at the beginning of this class. Each topic can only be selected by one person, and the selection order will be determined randomly ahead of time.
Format:	Typed and submitted in paper and electronic format. If "Option B" is chosen, plots that supplement the analysis should be included, and source code provided.

<u>Topics</u>

Suggestions for project topics are listed below. You are welcome to choose a different topic, but it must be approved. (Anthropogenic carbon dioxide is excluded). The mechanism or agent can be natural or anthropogenic.
*If you have written previously on this topic, the content of your report must be unique.

1) methane
2) nitrous oxide
3) stratospheric ozone
4) tropospheric ozone

5) CFC's and HCFC's (or total halocarbon effect)
6) halocarbons
7) water vapor
8) sulfate aerosols from fossil fuel use
9) sulfate aerosols from volcanoes
10) carbon dioxide from volcanoes
11) black carbon aerosols in the atmosphere
12) black carbon aerosols deposited to snow
13) mineral dust aerosols
14) organic aerosols
15) nitrate aerosols
16) aerosol-cloud indirect effects
17) contrails from airplanes
18) “waste heat” or “anthropogenic heat flux” from energy use
19) altered surface albedo from land use change
20) changes in solar irradiance
21) changes in Earth's orbit
22) asteroid or comet impacts with Earth
23) cloud feedback
24) albedo feedback
25) lapse-rate feedback
26) geoengineering with sulfate aerosols
27) geoengineering with stratocumulus seeding
28) geoengineering with iron fertilization
29) geoengineering with space mirrors

Grading: Homework: 50%, Midterm: 25%, Course Project: 25%.

Grade assignment will be based on absolute performance, so that the grading is non-competitive. We will start with the following fixed-scale, but will loosen it as needed, based on course performance:

A+	97%	A	93%	A-	90%
B+	87%	B	83%	B-	80%
C+	77%	C	73%	C-	70%
D+	67%	D	63%	D-	60%

Course Schedule (tentative):

Date	Class #	Lec #	Topics (timing will change)	Reading (optional)	Homework
M 8/26	1	1	**Introduction to climate**	Hartmann, Ch.1	
W	2			IPCC AR4, FAQ1.1 & 1.2	
F	3	2	**Global energy balance**	Hartmann, Ch.2	HW1 assigned
M 9/2	**U-M HOLIDAY, NO CLASS**				
W 9/4	4				
F	5				
M 9/9	6	3	**CERES observations**	IPCC AR5, FAQ8.1	HW1 due, HW2
W	7		**Radiative forcing definitions**		
F	8	4	**Radiative transfer**	Hartmann, Ch. 3	
				Wallace and Hobbs, Ch.4	
M 9/16	9				HW2 due, HW3
W	10				
F	11	5,6	**Surface Energy and Hydrology**	Hartmann, Ch. 4 & 5	
M 9/23	12				
W	13				HW3 due, HW4
F	14		**(Course project selection)**		
M 9/30	15	7	**Climate sensitivity and feedback**	Hartmann, Ch. 10	
W	16			Pierrehumbert, Ch. 3	
F	17				
M 10/7	18				HW4 due
W	19		(remote lecture)		
F	20				
M 10/14	**U-M HOLIDAY, NO CLASS**				
W 10/16	21		**Midterm Review**		
F	22	**MIDTERM EXAM**			
M 10/21	23				
W	24	8	**Transient climate response**	Hartmann, Ch. 13	HW5
F	25			Wallace and Hobbs, Ch. 10	
M 10/28	26				
W	27				
F	28	9	**Atmospheric circulation & climate**	Hartmann, Ch.6	
				Wallace and Hobbs, Ch.7	HW5 due, HW6
M 11/4	29				
W	30				
F	31				HW6 due, HW7
M 11/11	32	10	**El Nino Southern Oscillation**		
W	33				
F	34				HW7 due, HW8
M 11/18	35	11	**Ocean circulation and climate**	Hartmann, Ch.7	
W	36				
F	37				HW8 due
M 11/25	38				
W	**U-M HOLIDAY, NO CLASS**				
F	**U-M HOLIDAY, NO CLASS**				
M 12/2	39	12	**Volcanoes and Climate**		
W	40				
F	41		**Course project presentations**		
M 12/9	42		**Course project presentations**		**Project due**