Syllabus for Planetary Climate

Units:	3
Offered:	Spring 2020, Tuesday and Thursday 11:00–12:15 p.m.
Location:	Kuiper Space Sciences Room 312
Instructor:	Adam Showman, Space Sciences 432
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Office hours:	After class or by appointment

Note that I will be out of town during a few weeks of the semester, so I will arrange a time to do some make-up lectures.

Course description (for catalog): Physical and chemical processes governing the climate of planets. Climate feedbacks and stability; greenhouse effect, ice-albedo feedback, cloud feedbacks. Effect of atmospheric circulation on climate. Milankovitch cycles and ice ages. Long-term atmospheric evolution; runaway greenhouse, Snowball Earth, atmospheric loss/collapse, faint young Sun problem. Interaction of climate with geology/biology. Observable signatures. Habitable zones. Application to Earth, Mars, Venus, Titan, and habitability of extrasolar planets.

Course objectives: This is a graduate-level course that will provide an overview of the physics and dynamics of the climate of planets. The target audience is graduate students in planetary sciences, atmospheric sciences, and astronomy. Students from hydrology and geosciences may also be interested. In addition to students primarily focusing on atmospheric studies, I hope to attract students whose research involves (for example) Mars/Titan geomorphology or exoplanets.

Text: The required text is *Principles of Planetary Climate* by Ray Pierrehumbert, published in 2010. I also recommend (but do not require) *Planetary Climates* by Andrew P. Ingersoll, which is one of the Princeton Primers in Climate (an excellent series covering many aspects of climate at a level intermediate between a popular treatment and a textbook). I will also hand out detailed lecture notes, which will serve as an informal textbook for the course.

Tentative List of Topics Covered:

<u>Overview of climate on planets</u>: Observational survey of the climates on Earth, Venus, Mars, and Titan. Paleoclimate history from geologic records. Paleoclimate proxies. Brief discussion of what's ahead for exoplanets.

<u>Atmospheric Statics and Thermodynamics</u>: Description of air; ideal-gas law; hydrostatic balance. Introductory thermodynamics, including adiabatic relationships between thermodynamic variables. Adiabatic lapse rates for the atmosphere. Implications for atmospheric vertical structure. Criterion for atmospheric (in)stability to convection. Moist adiabats and the role of condensation in affecting the atmospheric theral structure.

Simple models of planetary energy balance: Blackbody radiation, Planck functions. Simple, globally-averaged energy balance models to determine mean surface temperature of a planet, considering greenhouse effect. Ice-albedo feedback; multiple equilibria. Faint-young sun problem. Climate sensitivity to perturbations; feedbacks.

Radiative transfer: Basics of radiative transfer. Two-stream approximation. We will develop and solve the radiative transfer equations for a variety of simplified problems to determine temperature profile and surface temperature, first for grey gas and then for nongray gases such as CO_2 and H_2O. Greenhouse effect. Runaway greenhouse. Effect of clouds on radiative transfer and the resulting atmospheric temperature structure.

Atmospheric circulation regimes and effect of atmospheric circulation on climate: Qualitative mechanisms controlling an atmospheric circulation; governing laws of atmospheric circulation; scaling analysis to demonstrate dynamical regimes; the importance of rotation; thermal wind. Interaction of an atmosphere with buoyancy (gravity waves) and rotation (Rossby waves) and how this helps control the circulation and atmospheric structure. Basic modes of atmospheric circulation (Hadley cells vs baroclinic zones vs day-night advection), and their dependence on planetary parameters. Latitudinally varying energy balance models with diffusive heat transport; what determines the equator-to-pole or day-night temperature variations. Effect of circulation on feedbacks (e.g., transition to a Snowball state). Hydrological cycle, clouds, and cloud feedbacks.

Atmospheric evolution over planetary timescales: Faint young sun problem. Interaction of climate with geology/biology. Carbonate/silicate weathering cycle and other long-term feedbacks. Chemical evolution of atmosphere/ocean generally, and implications for climate. Snowball Earth episodes. Mechanisms for atmospheric loss and the resulting climate evolution (e.g., loss of water from Venus, loss of CO_2 from Mars, etc); atmospheric evolution, lakes/seas, and the origin of methane on Titan. Divergent evolution of Venus, Earth, Mars.

Prerequisite: The course is intended for introductory planetary science, astronomy, and atmospheric science graduate students. Basic vector calculus and differential equations will be used, and basic familiarity with physics will be needed (some of this will be developed as we go along). There are no specific course prerequisites.

Grades: The grades will be on an A, B, C, D, E scale and will be based on two components:

60% Homework
40% Term Project

Given the grades for the homeworks and term paper, the assignment of the final grade will be based on a curve.

The term project is an important aspect of this course — my aim is to get your creative juices flowing and get you excited about being at the cutting edge of this field. The term project will require a short written paper as well as a presentation at the end of the semester (perhaps during the final exam slot).

There are no exams in this course. However, we may use the final exam slot for presentations, so please reserve it in your schedules for this course.

Course policies:

Feedback: Please let me know how you think the course is going. Suggestions for improvements and ideas for things to try (e.g., topics or activities you'd like to see) are both welcome.

Late work: If an assignment is due, you are responsible for turning it in, even if you are absent. All assignments are due at the beginning of class on the due date. Any assignments turned in after that time will be considered late. I will try to be understanding, but I reserve the right to enforce the following policy: Late assignments turned in within one week of the due date will receive one-half credit, after which they will receive zero credit. Please talk to me if you think you can't finish an assignment on time.

Special needs: Students with disabilities who require reasonable accommodations to fully participate in course activities or meet course requirements must register with the Disability Resource Center. If you qualify for services through DRC, bring your letter of accommodations to me as soon as possible.

Academic Integrity: It is strongly recommended that all students read the *University of Arizona's Code of Academic Integrity.* All students in this course are expected to abide by this code, which will be strictly enforced. Cheating will not be tolerated in any form. Submission of any written work that partially or fully duplicates material from the web, your fellow students, or any other source constitutes plagiarism. Students are encouraged to work together on the homework sets, but unique written responses must be handed in by each student. Instances of plagiarism will lead to a zero on that assignment, with harsher penalties for repeat offenses or extreme cases. Plagiarism on the term project will lead to a failing grade for the course.