SIO 217a Atmospheric and Climate Sciences I:
Fall 2016 Atmospheric Thermodynamics

Course Introduction

Instructor: Lynn Russell, 343 Nierenberg Hall, 534-4852, lmrussell@ucsd.edu
Text: *Thermodynamics of Atmospheres and Oceans,* J. A. Curry & P. J. Webster (1999)

This course is part of an integrated 3-quarter series (SIO 217 A, B, C). Although it is formally a lecture course, we will incorporate student participation and student projects as integral parts of class. This form of teaching recognizes that students come to class with prior knowledge on the topics to be studied. Sometimes this knowledge is profound and accurate. Sometimes it isn't. Learning involves first confronting our prior knowledge. This form of teaching also stresses the similarity between the learning experience and the research experience. We learn by actively engaging in formulating questions and discovering the answers to them. This is very different from rote memorization of facts, lecture notes and pages of text.

For these reasons, this class will involve intensive student participation in in-class learning exercise and the group term project to be presented in class and in reports. Here are my expectations:

> Come to every class. Read the text. Always bring it to class. Take your own notes in addition to the posted slides. Study the assigned material in advance, especially by viewing the podcasts before the "Flipped" classes. I will generally not simply repeat the material in the text. Be an active participant in class; do not just sit and listen. There are 10 weeks in the quarter, and we will try to cover 10 chapters of the text, thus about a chapter per week. The ten chapters we will study are 1, 2, 3, 4, 5, 6, 7, 8, 12, and 13. In several chapters, I will specify some of the material to skip. The homework provides practice in key concepts; you are encouraged to get help from me or other students, but the answers you turn in must be in your words with answers that you can explain and defend.

Expect frequent questions about the readings and in-class assignments that test or document your understanding. I will give guidance in advance on which material is most important. Be prepared to discuss the material you have studied. In particular, always know the meaning of every word in the assigned portions of the text because learning the "jargon" of the atmosphere is an important part of this class. Quizzes and the mid-term and final exams will include definitions.

The textbook web site is http://curry.eas.gatech.edu/Courses/5225/index.html. Download the errata file and the answers to homework file. Check out the links for each of the topics as we take them up. Formulate questions as you study, and bring them to class for us all to discuss.

Old lecture notes and exams from previous years are posted at http://aerosol.ucsd.edu. Lecture notes from this year are posted after lectures. Quizzes are not announced in advance and cannot be made up. Exams are announced in advance and cannot be rescheduled (except with a letter from a "dean, divinity, doctor, or DoD"). Grading will be approximately as follows:

> Homework and in-class assignments, including projects: 40%.
> Mid-term exam, optional re-grade, surprise quizzes: 30%.
> Final exam: 30%.

IMPORTANT: In this course, you must not remain silent. You must speak as well as listen. If English is not your first language, make use of this opportunity to practice your English.

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Course Objectives

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The course goal is to provide knowledge of atmospheric structure, composition and processes. This course is designed to provide an enduring understanding of: energy content and transfers, water saturation, and climate forcings and feedbacks. The essential questions that will focus, guide, and sustain learning during the course are:

- What does energy content and transfer reveal about the Earth's temperature?
- How does water saturation link clouds, temperature, and stability in the atmosphere?
- How do forcings and feedbacks shape my views of human role in the Earth system?

This course is designed to provide first-year graduate students with climate-relevant knowledge of the atmosphere; some students are focused on this area specifically for future research and others just want some introductory knowledge. The course is designed to address both of these interests.

After completing this course, students will know how to apply thermodynamic principles to understanding atmospheric processes and students will be able to explain the role of thermodynamic relationships in atmospheric processes.

Specific objectives of this course are to learn to:

1 Identify fundamental thermodynamic concepts.
1.1 Relate pressure, temperature and energy to define the state of a fluid.
1.2 Quantify the kinetic theory of gases using the ideal gas equation of state.
1.3 Apply the hydrostatic balance to idealized conditions.
2 Describe heat-work cycles, including the Carnot cycle.
2.1 Evaluate the heat and work associated with specific adiabatic or isothermal state changes.
2.2 Distinguish between states and pathways.
2.3 Use the first and second laws of thermodynamics to quantify energy, heat, and work.
2.4 Distinguish between enthalpy, entropy, and Gibbs free energy.
2.5 Evaluate hurricanes as Carnot cycles.
3 Describe optical properties and radiative balance of the atmosphere.
3.1 Define optical properties of the atmosphere and use them to describe radiative transfer.
3.2 Distinguish between diffuse and direct, irradiance and radiance, absorption and reflection.
3.3 Define radiative transfer laws: Kirchoff, Wien, Stefan-Boltzman, Planck
3.4 Use the principles of blackbody radiation to describe Earth's radiative balance (Ch. 12).
4 Identify what controls water phase transition.
4.1 Sketch the phase diagram of water and explain the meaning of its lines and spaces.
4.2 Apply the Clausius-Clapeyron equation to calculate the change in saturation pressure.
4.3 Define the variables used to track atmospheric water and energy.
4.4 Identify and explain the unique properties of water and its role in cloud formation.
5 Learn aerosol-cloud transition processes.

5.1 Explain the role of nucleation (activation) in forming new phases.
5.2 Describe what controls the role of particles in forming clouds using the Kohler equation.
5.3 Review the history of advances in our understanding of cloud formation processes.
6 Quantify processes associated with cloud formation.
6.1 Identify the causes of cloud formation and the processes that are relevant.
6.2 Evaluate the amount of water that will condense when a cloud forms.
6.3 Use dew point temperatures as a metric of relative humidity.
7 Evaluate atmospheric stability and describe its role in vertical circulation.
7.1 Describe how water vapor and liquid affect the degree (and sign) of stability.
7.2 Define convective available potential energy and apply it to describing changes in clouds.
8 Describe cloud characteristics for types of low, middle, and high clouds.
8.1 Distinguish optical properties for different cloud types.
8.2 Distinguish likelihood for precipitation for different cloud types.
12 Relate Earth's radiation budget to large-scale circulation.
12.1 Use simple climate model to evaluate the components that affect global mean temperature.
12.2 Describe the different energy streams that affect the Earth's radiative balance.
12.3 Identify the consequences of radiation for driving circulation poleward and longitudinally.
13 Explain three examples of climate feedbacks.
13.1 Distinguish between climate forcings and feedbacks.
13.2 Explain three important feedback loops in the Earth system.

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Course Syllabus and Lecture Schedule

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Text: ***Thermodynamics of Atmospheres and Oceans,*** **J. A. Curry & P. J. Webster (1999)**

Date	Dy	Ch	Skip:	Hmwk	Lectures and Topics
23-Sep	F				Flipped: Hydrostatic Balance Example Derivations.
26-Sep	M	1	1.2, 1.8-9		Flipped: What is thermodynamics? What do thermodynamics do in the atmosphere? What parts of thermodynamics are covered in this class?
28-Sep	W	2	2.11		Lecture: First and Second Laws of Thermodynamics (Work, Heat, First Law, Second Law, Heat Capacity, Adiabatic Processes)
30-Sep	F				Flipped: Hurricanes; Homework 2.
3-Oct	M	2	2.11		Lecture: More on Ch. 2.
5-Oct	W	3	3.4-6	**1+2**	Flipped: Transfer Processes (Time-dependent Thermodynamics. Radiant Energy. Radiative Transfer. Transport); Homework 3.
7-Oct	F	12			Flipped: Radiative Balance Model.
10-Oct	M	4	4.5-6		Lecture: Thermodynamics of Water (Molecular Structure, Properties of Water. Phase Equilibria. Atmospheric Humidity Variables); Homework 4.
12-Oct	W	4		**3+4**	Lecture: More on Ch. 4.
14-Oct	F				Flipped: Review for Midterm (Ch. 1-4 plus 12 Energy Balance).
17-Oct	M				Rescheduled to 9/30/16. Graded homework available for pickup Keck 223.
19-Oct	W			**EXAM**	**Midterm (Ch. 1-4 plus Ch. 12 Energy Balance)**
21-Oct	F				No class scheduled.
24-Oct	M	5	5.5-7		Lecture: Nucleation (Surface Tension. Droplet Nucleation. Droplet Growth. Ice Formation); **Project Assignments.**
26-Oct	W	5			Lecture: More on Ch. 5, Cloud Nucleation Demo.
28-Oct	F				Flipped: Homework 5 + Projects.
31-Oct	M	8		**Figure**	Flipped: Cloud Characteristics and Processes (Cloud Classification and Characteristics. Precipitation Processes. Radiative Transfer in Cloudy Atmosphere. Fogs and Stratocumulus Clouds. Cumuliform Clouds).
2-Nov	W	8			Flipped: Cloud Formation.
4-Nov	F				Flipped: Homework 8 + Projects.
7-Nov	M	6			Lecture: Moist Thermodynamic Processes in the Atmosphere (Isobaric Cooling. Evaporation of Water. Adiabatic, Isobaric Mixing. Saturated).
9-Nov	W	7		**5+8**	Lecture: Introduction to Stability: Application and Limitations of Dry Theory (pp. 191-194 ONLY).
11-Nov	F				**Holiday: Veteran's Day.**
14-Nov	M	7		**Subm**	Flipped: Stability
16-Nov	W	12			Flipped: Global Energy and Entropy Balances (Planetary Radiation Balance. Global Heat Engine. Entropy and Climate. Global Hydrologic Cycle).
18-Nov	F			**Rvw**	Flipped: Homework 6+7 + Projects.
21-Nov	M	13	13.6-7		Lecture: Thermodynamic Feedbacks in the Climate System (Water Vapor Feedback. Cloud-Radiation Feedback. Snow/Ice-Albedo Feedback).
23-Nov	W			**6+7**	Rescheduled to 10/7/16.
25-Nov	**F**				**Holiday: Thanksgiving.**
28-Nov	M				**Project Presentations (submit presentations by noon on 11/28).**
30-Nov	**W**				**Project Presentations (submit presentations by noon on 11/28).**
2-Dec	F			**Rpt**	Flipped: Final Exam Review.
8-Dec	Th			EXAM	**Final Exam (Ch. 1-8, 12, 13, ROAST) at 11:30-2:30, Location TBA.**