ATS620
Thermodynamics and Cloud Physics
Fall 2021

Drs. Jeff Pierce and Sonia Kreidenweis
jeffrey.pierce@colostate.edu, SoniaK@colostate.edu
Jeff: Room 220 ATS Main Bld. 491-8572
Sonia: 19 Atmos. Chem. Bld. 491-8350
Office hours by appointment or Slack

Course time and location: 9:00 – 9:50 AM Tues/Thurs, ATS 101

Class Website: https://colostate.instructure.com/courses/127871
Slack workspace: https://ats620thermoc-os07550.slack.com

Lectures and discussions will be recorded and live-streamed (Zoom) this semester. Recordings will be available on the Canvas site. The live stream is:
https://zoom.us/j/92502384222?pwd=aG5uOVdsbElNKzdPVTgyR214eVliZz09

Graduate Teaching Assistant: Nicole June (Nicole.June@colostate.edu)
Office: Room 222 ATS Main Bld.
Office hours: Mondays 2-3 PM in Room 209 of ATS Main Bld.

Please contact the instructors if you have special learning needs that should be accommodated in this class, and refer to http://rds.colostate.edu/accommodation-process for more information.

Course Objectives

The intent of this course is to introduce graduate students to key concepts in thermodynamics and cloud physics as applied to the atmosphere. These concepts include energy variables and energy calculations, thermodynamic diagrams, phase changes, and cloud microphysical properties and processes. A particular emphasis is placed on the formation of precipitation in warm and cold clouds.

Course Structure, Expectations and Grading Criteria

Course Material:
Class material will be delivered in lecture and discussion format, meeting for two 50-minute periods each week. Lectures are posted to the class website. At least 4 hours of effort (2 hours per each hour of class time) outside of class each week are expected to complete homework assignments and any outside reading needed to support learning.

Course Grading:
This class is graded on a letter basis, using the +/- options. Students are expected to notify the instructors of any planned absences from class and should make arrangements to make up missed assignments. Homework will be posted on Canvas and will submitted there as well (please take clear photos of or scan written work, do on your computer). The

homework due dates, as well as exam dates will be listed on the class calendar online when the dates are known. Regarding late assignments, for every weekday that an assignment is late, 10% will be taken off that assignment. *Your course grade will be based on your performance on one midterm exam, one comprehensive final exam and a number (~7) of homework assignments. The midterm exam will be weighted 25%, the final 25%, and the homework assignments 50% of your final grade.*

Course Texts:

There are no required texts for this class. In addition to the class notes that will be available on Canvas, the following resources may be useful:

- Cotton, ATS620 past notes, available on Canvas. *Please do not distribute these notes outside of CSU.*
- Schroeder, An Introduction to Thermal Physics, Pearson, 1999.
- Rogers and Yau, A Short Course in Cloud Physics, Pergamon Press, 1989, Third Edition.
- Lohmann, Luond and Mahrt, An Introduction to Clouds from the Microscale to Climate, Cambridge University Press, 2016.
- Lamb and Verlinde, Physics and Chemistry of Clouds, Cambridge University Press, 2011.
- Cotton, Bryan and van den Heever, Storm and Cloud Dynamics, Academic Press, 2011, Second Edition.
- Pruppacher and Klett, Microphysics of Clouds and Precipitation, Kluwer Academic Publishers, 1997.
- Young, Microphysical Processes in Clouds, Oxford, 1993.
- Fletcher, The Physics of Rainclouds, Cambridge University Press, 1962.

Academic Integrity

All students are subject to the policies regarding academic integrity found in the 2021 – 2022 General Catalog, found at http://catalog.colostate.edu/general-catalog/policies/, and the student conduct code (http://resolutioncenter.colostate.edu/conduct-code). Other information on academic integrity can be found on the Learning@CSU website (http://learning.colostate.edu/integrity/index.cfm). Examples of academic dishonesty can be found in these sources. At a minimum, violations will result in a grading penalty in this course and a report to the Office of Conflict Resolution and Student Conduct Services.

Special Statement on COVID-19 for Fall 2021

Throughout the semester, we will follow all CSU guidelines regarding COVID-19 as described on https://covid.colostate.edu/. Note that these guidelines may be updated during the semester. Providing that these guidelines continue to allow in-person instruction and the instructors are healthy, we will provide in-person lectures for the course. All healthy students should attend in person to aid in discussions, group questions, and community building. Anyone experiencing cold/flu-like symptoms should stay home and join the Zoom live stream and Slack discussions.

Important information for students: All students are expected and required to report any COVID-19 symptoms to the university immediately, as well as exposures or positive tests from a non-CSU testing location.

If you suspect you have symptoms, or if you know you have been exposed to a positive person or have tested positive for COVID, you are required to fill out the COVID Reporter (https://covid.colostate.edu/reporter/). If you know or believe you have been exposed, including living with someone known to be COVID positive, or are symptomatic, it is important for the health of yourself and others that you complete the online COVID Reporter. Do not ask your instructor to report for you. If you do not have internet access to fill out the online COVID-19 Reporter, please call (970) 491-4600. You may also report concerns in your academic or living spaces regarding COVID exposures through the COVID Reporter. You will not be penalized in any way for reporting. When you complete the COVID Reporter for any reason, the CSU Public Health office is notified. Once notified, that office will contact you and, depending upon each situation, will conduct contact tracing, initiate any necessary public health requirements and notify you if you need to take any steps.

For the latest information about the University's COVID resources and information, please visit the **CSU COVID-19 site**: https://covid.colostate.edu/.

ATS620 THERMODYNAMICS AND CLOUD PHYSICS			
Topics	**Subtopics**	**HW**	**#Class**
	INTRODUCTION [1 Class]		
Introduction	• The importance of thermo / cloud physics		1
	THERMODYNAMICS [10 Classes + 1 Midterm Exam]		
The First Law	• Classical thermodynamics • Thermodynamic definitions • Dalton's Law of Partial Pressures • First Law of Thermodynamics • Joule's Law • Specific heats • Potential temperature • Enthalpy • Latent heating	HW1	2
The Second and Third Laws	• Entropy • Second Law of Thermodynamics • Carnot cycle • Third Law of Thermodynamics		2
Free Energy Functions and Thermodynamic Potentials	• Introduction • Helmholtz and Gibbs Functions • Thermodynamic Potentials • Chemical Potential		2
Equilibrium	• Introduction to equilibrium • Non-equilibrium conditions • Equilibrium in chem. reactions • Equilibrium vapor P vs. T • Equilibrium for mixtures Gibbs phase rule	HW2	3
Thermodynamics of the Moist Atmosphere	• Phase changes • Clausius-Clapeyron equation • Properties of water • Phase diagrams		1
	CLOUD PHYSICS [17 Classes + 1 Midterm Exam]		
Nucleation and Activation	• Introduction to nucleation and activation • Homogeneous nucleation of water drops	HW3	4

	• Heterogeneous nucleation of liquid water • Activation of water-solute mixtures • Liquid cloud formation		
Condensation	• Fick's law of diffusion • Energy balance at drop surface • Complete diffusional growth equation • Evaporation of drops • Impacts on DSDs • Supersaturation	HW4	2
Warm Rain Formation	• Collision-coalescence • Continuous collection equation • Collection kernels • Stochastic collection equation • Factors impacting the evolution of the droplet spectrum	HW5	3
Ice Crystal Nucleation and Growth	• Structure of ice • Homogeneous nucleation of ice by freezing and deposition • Heterogeneous nucleation of ice on flat and curved surfaces	HW6	2
Ice Particle Growth	• Growth mechanisms • Deposition • Capacitance • Habit theory • Fall speeds • Aggregation • Riming • Ice multiplication	HW7	3
Graupel and Hail Formation	• Energy balance at the surface • Dry and wet growth regimes • Hail growth models • Melting		1