EAS 6140 - Thermodynamics of Earth Systems

Time & Place:
3:05-4:25 M W, ES&T L1125

Instructor:
Dr. Athanasios Nenes (nenes@eas.gatech.edu, ES&T 3258, 4-9225)
Office hours: TBA

Teaching Assistant:
None

Class Website:
http://nenes.eas.gatech.edu/EAS6140

Text:
Thermodynamics of Atmospheres and Oceans, by Curry and Webster

Grading:
Homework: 25%
Exam I, II: 25% each.
Final exam: 25%

Class material usage:
The instructor and students in this class, as members of the Georgia Tech community, are bound by the Georgia Tech Academic Honor Code. The instructor will make available copies of previous examinations and/or other appropriate assignments, samples, and readings. Unauthorized use of any previous semester course materials, such as tests, quizzes, homework, projects, and any other coursework, is prohibited in this course. Using these materials will be considered a direct violation of academic policy and will be dealt with according to the GT Academic Honor Code. Students will be asked to acknowledge their acceptance of this stipulation and their willingness to abide by all terms of the Academic Honor Code by signing a copy of the "Honor Agreement" attached to all quizzes and exams. The complete text of the Academic Honor Code may be found at http://www.deanofstudents.gatech.edu/integrity/policies/honor_code.html

Course Objectives and Teaching Philosophy:
The objective of this course is to apply thermodynamic principles to understand the role of water in the Earth System. The aim is to provide a broad conceptual framework for understanding the thermodynamics of oceans and atmospheres, so material can be integrated into other study disciplines. The matter will closely follow that of the textbook, and additional readings will be provided on the course web page from a variety of sources.

Students are expected to read the assigned material before class. A fraction of the class time will be used for lecturing, with the purpose of emphasizing points of the material, or, going through other aspects not directly covered by the textbook. A "collaborative learning" approach to teaching will be often used, that integrates conceptual and operational knowledge, where students working in teams use class time for worksheets that include quizzes, problem-solving and discussions. Students are expected to work in teams on the worksheets (both in class and homework).

Homework (problem sets) will be given out periodically throughout the course. Problem sets will be due one week later. Late homework sets are not accepted without prior approval of the instructor. Collaboration on the homework is allowed, although each student must return their own solutions. At least 80% of the homework sets must be handed in to count in the grade.

COURSE MATERIAL OVERVIEW

Part 1: Introduction

Introduction

- Thermodynamic systems: composition and state; system vs the environment; open or closed or isolated; boundaries of a system and the environment,
- Thermodynamic state and properties of a system: state variables (intensive and extensive). thermodynamic properties

Composition, structure of components of the earth system

- Composition: atmosphere, ocean, solid earth
- Pressure, Density, Temperature; variations in the atmosphere, ocean, solid earth;
- Hydrostatic equation: application to ocean and hypothetical constant density atmosphere; solid earth

Equation of state

- Ideal gas law
- Kinetic-molecular model of the ideal gas
- Equation of state for air: Dalton's law of partial pressures; virtual temperature
- Hypsometric equation (atmosphere)
- Equation of state for real gases, liquids, and solids
- Equation of state for seawater

Part 2: Framework

First Law of thermodynamics

- Basic concepts & review
- Work; expansion work
- Heat: heat capacity, basics of heat transfer mechanisms
- First law: internal energy, enthalpy, specific heats, heat capacity.
- Applications of first law to ideal gases: Poisson's relations

Entropy and the 2nd law

- Entropy: reversible and irreversible processes; Clausius inequality; Boltzmann-Gibbs statistical picture of entropy

- 2^{nd} Law of thermodynamics
- First and second laws combined: Legendre transformations: Gibbs and Helmholtz functions; thermodynamic equilibrium
- Thermodynamic relations: Maxwell relations; relations involving specific heats
- Adiabatic processes in the dry atmosphere, and ocean
- Static stability
- Entropy and diffusive processes (heat conduction, viscosity, etc)
- Entropy, heat, and the 3^{rd} law

Phase Equilibria

- Gibbs phase rule: thermodynamic degrees of freedom, phases and components
- Energy in phase changes and chemical reactions
- Phase equilibria: chemical potential and multicomponent systems (Gibbs-Duhem); latent heat; Clapeyron equation (first latent heat law) and Kirchoff's equation (second latent heat law)
- Application to water (single component system): phase diagram; Clausius-Clapeyron equation;
- Binary phase diagrams (water solution): simple eutectics, lever rule
- Crystallization in binary systems: equilibrium crystallization, fractional crystallization, melting

Part 3: Applications

Moist thermodynamic processes in the atmosphere

- Humidity variables
- Isobaric cooling: dew point and frost point; radiation fog
- Cooling and moistening by evaporation of water: wetbulb temperature; prefrontal rain fog
- Saturation by adiabatic, isobaric mixing: steam fog and jet contrails
- Saturated adiabatic cooling: equivalent potential temperature; saturated adiabatic lapse rate, adiabatic liquid water content; convective cloud formation
- Aerological diagrams

Physical chemistry of water solutions – solution thermodynamics

- Activity and chemical potential
- Ideal solutions – Real solutions
- (Real solutions: variation of activities)
- Aerosols (deliquescence-efflourescence; applications using ISORROPIA)

Nucleation and Diffusional Growth

- Surface energy, surface tension - Kelvin effect
- Nucleation of the liquid and ice phase
- Diffusional growth of cloud droplets and ice.