PHYS-575/CSI-655
Introduction to Physics and Chemistry of the Atmosphere
Mondays, 4:30-7:10pm, Innovation Hall 203
Spring Semester, 2010
Michael E. Summers
PHYS-575/CSI-655
Introduction to Physics and Chemistry of the Atmosphere

Catalog description: Introduction to basic physical and chemical processes that operate in the Earth’s atmosphere. Emphasis on those concepts that provide a global description of the current atmospheric state and those processes that relate to global change and atmospheric evolution. Topics include equilibrium structure, radiative transfer models, thermodynamics of various atmospheric layers, and the various processes defining these layers.

Prerequisites: MATH 213 and PHYS 160
This course will focus on the physical and chemical processes that control the state, variability, and long-term evolution of the atmosphere.

Prerequisites: MATH 213 and PHYS 160
PHYS 575/CSI 655
Introduction to Physics and Chemistry of the Atmosphere

Specific Course Goals:

To provide the student with:

1) an overview of the physical and chemical processes which control the state and evolution of planetary atmospheres.
2) an understanding of the key scientific discoveries and remaining unanswered questions in atmospheric science.
3) an overview of the primary scientific principles and analytical tools used in atmospheric science studies, including both remote and in-situ techniques.
Topics will include an overview of the **history of the Earth’s atmosphere**, and the Earth’s atmosphere in the context of **comparative planetary atmospheres**.

**Topics Include:**
- Atmospheric thermodynamics
- Hydrostatics
- Phase transformations of water
- Radiation transfer
- Spectroscopy
- Cloud physics
- Atmospheric chemistry
- Atmospheric motions
- Climate Change
An overview of the long-term evolution of the atmosphere, including forcing by natural and anthropogenic effects, will be considered.
Class **format** will consist of:

1. lectures covering material in the required text,
2. homework assignments designed to illustrate various aspects of topics encountered in the lectures and readings,
3. reading assignments both from the text and supplemental material,
4. group discussion,
5. and a term paper which focuses on a topic in atmospheric science chosen by the student in consultation with the instructor.

**There are no stupid questions!!**
Required Text:

- *Atmospheric Science, An Introductory Survey*
  - John M. Wallace
  - Peter V. Hobbs
  - Academic Press, 2006
  - ISBN 0-12-732951-X
Grading Policy:

- *Homework = 30%,
- **Two in-semester exams = 30%
- **Term Paper = 30%
- ***Class participation = 10%

*Homework mainly from end-of-chapter questions.

**You are responsible for all material from text, and any additional assigned readings.

***There will be material discussed in the lectures that is not included in the on-line lecture notes. You are responsible for this material.
PHYS-575/CSI-655 Exams

Tentative Exam Schedule:
- March 1 – Exam #1
- March 8-12 Spring Break
- April 19 – Exam #2

Term Paper Presentations:
- Monday, May 10, 4:30pm-7:15pm
Instructor and Contact info:

Michael E. Summers  
Science and Tech I, Room 301C  
Email: msummers@gmu.edu, msummers@physics.gmu.edu  
Phone: (703) 993-3971  
FAX: (703) 993-1269  
Office Hours (with appointment)  
Tues, Thurs: 3:00-4:00pm  

Spring, 2010: Tentative Travel  
January 7-8, NYC  
January 20-21, New Horizons STM, APL  
February 15-19, NSRC, Boulder, CO  
March 8-12 Spring Break  
May 24-27 AGU, Toronto CA  

A picture on its way to Pluto
Term Paper

- A term paper (or project) is required in this course. The topic is chosen by the student with close consultation with the instructor.

- Generally, the term paper topic will be related to topics discussed in the lectures, but a fair degree of latitude will be allowed in the students’ choice.

- I will be glad to help students pick a topic, to narrow its focus, and to help find reference materials.

- Students are encouraged to choose a topic that fascinates them and to begin working on their paper within the first few weeks of the semester, and to give the class a brief update every 2-3 weeks.

- Term papers are almost always the highlight of the course.
Term Paper Format

The term paper must follow standard guides for research papers, and have the following sections:

- **Title**
- **Abstract**
- **Introduction & background**
- **Body of paper** - with a significant number (10-15) references to primary literature and/or review articles. This may include discussion of scientific theories, observations, and/or methods.
- **Conclusions**
- **Figures (& captions) are important in the body of the paper.**
- **Primary References (not Wikipedia)**

The paper must be typed, double spaced, and have ~ 15-25 pages of text, not including figures, and at least 3 figures (may have more, include captions). Please number all pages.
Term Paper Themes, Spring 2009

- Climate Change
- Severe Weather
- Planetary Atmospheres

Term paper/project – important dates:

**March 1** – Tentative title/topic due
**March 29** – Abstract (1 paragraph), outline, and key references due
**May 10** – Final paper due, and a 10-15 minute oral presentation
Tutorials

Tutorials serve as a brief review and/or refresher of focused topics that the students have likely encountered previously in their education, but usually in a different context. For example, most physics students have taken a course in Thermodynamics or at least have covered the key thermodynamic concepts in their Freshman Intro to Physics course. Yet I’ve found that almost all physics students remember very little in this area.

The Thermo tutorial reviews the Ideal Gas Law, State Variables (like Temperature, Pressure, Internal Energy, Entropy, Enthalpy, Gibbs energy) the First and Second Laws, Adiabatic and Diabatic processes, the concept of a heat engine, heat capacities and their relationship to atomic/molecular properties, and phase changes.

Tutorials usually takes about half an hour or so and provides enough refresher to then tackle the applications to the atmosphere.
Noctilucent Clouds:
- Earth’s highest clouds (82 km!)
- Clouds at the “edge of space”
- Indicators of climate change?

Launched: April 25, 2007
New Horizons Pluto Mission
Southwest Research Institute (Lead)
JHU-APL, Ball, Boeing, DoE, Lockheed-Martin, JPL, GMU, Stanford U, U. of Colorado-LASP

Launched: 17 January 2006
Pluto Flyby: 14 July 2015
Mission Website: [http://marsairplane.larc.nasa.gov/](http://marsairplane.larc.nasa.gov/)
Corresponds to Chapters in Wallace & Hobbs

(1) Introduction and Overview of the Atmosphere
(2) The Earth System
(5) Atmospheric Thermodynamics
(6) Atmospheric Radiation
(7) Atmospheric Chemistry
(8) Clouds
(9) Atmospheric Dynamics
(15) Weather – brief coverage
(16) The Boundary Layer – brief coverage
(17) Climate Dynamics
(1) Overview of the Atmosphere

- The atmosphere as a complex physical system
- Survey of major & minor gases (biology, chemistry, geochemistry)
- Vertical T, P, N structure;
- Atmospheric layers: Troposphere, Stratosphere, Mesosphere, Thermosphere/ionosphere
- Survey of planetary atmospheres
(2) The Earth System

- Atmospheric Structure & Composition
- External Influences
- Weather and climate
- Atmospheric development and co-evolution of life.
Biogeochemical Cycles

- Life and the atmosphere
- Biogeochemical cycles
- Climate forcing
- Ice ages
(3) Atmospheric Thermodynamics

- Ideal gas law
- Hydrostatic balance
- Parcel concepts
- The dry lapse rate
- Entropy, potential temperature, and available energy

The Influence of Water

- Moisture in the atmosphere
- Saturated lapse rate
- Clouds
- The life of a raindrop

Wet Adiabatic Lapse Rate

- Once air condenses it cools more slowly
- Why?
- Latent heat is released
- The wet adiabatic lapse rate varies. About 6 °C per 1000 meters (3 °F per 1000 feet)
(4) Atmospheric Radiation

- Basic concepts, flux, intensity of radiation
- Blackbody radiation
- Radiative transfer equation
- The greenhouse equation
Spectroscopy

- Absorption and Emission by molecules
- Heating rates
- Greenhouse effect
- Scattering by gases and aerosols
(5) Atmospheric Chemistry

- Intro to chemical reactions
- Thermodynamics of reactions
- Equilibrium versus non-equilibrium chemistry
- The sun and atmospheric chemistry

http://www.nature.com/nature/journal/v442/n7099/images/442145a-f1.2.jpg
Stratospheric Ozone

- Ozone chemistry
- Catalytic cycles
- Chemistry and dynamics
- Ozone Hole
(6) Cloud Microphysics

- Average rain drop size: 2 millimeters
- Average cloud droplet size: 0.02 millimeters
- Average condensation nucleus size: 0.0002 millimeters

- vapor pressure = saturation vapor pressure
- condensation
- evaporation

- Deep Cold Layer
- Temperature of the atmosphere: 25°F to 32°F
- Surface Elevation: 25°F and 32°F
(7) Atmospheric Dynamics

- Conservation of mass
- Material derivative
- Conservation of momentum (fundamental forces)
- Equation of motion
Non-inertial Reference Frames

- Effects of rotation (apparent forces)
- Coordinate systems
- Geostrophy and balanced flow (diagnostic equations)
- Pressure coordinates
- Thermodynamic energy equation

Coriolis Force deflects winds to the right in the Northern Hemisphere.

Coriolis Force deflects winds to the left in the Southern Hemisphere.

The convergence at the Equator is called the InterTropical Convergence Zone, or ITCZ.
(8) Weather Systems

- Quantifying effects of rotation
- Linearized equations
- Quasi-geostrophy
- Atmospheric waves
- Boundary layers, friction and stresses
- Turbulence and mixing
- The planetary boundary layer
- Instabilities and wave breaking
(9) The Atmospheric Boundary Layer

- Turbulence
- The Surface Energy Balance
- Vertical Structure and Evolution
- Special Effects
- The Planetary Boundary Layer

Stably stratified flow over a ridge (side view)
(10) Climate Dynamics

- The Present Day Climate
- Climate Variability
- Climate Equilibria, Sensitivity, and Feedbacks
- Greenhouse Warming
- Climate Monitoring and Prediction
Climate Change

- History of the Atmosphere
- Future Changes
- Global warming (short term, buildup of greenhouse gases)
- Global warming (long-term, runaway greenhouse)
- Climate forcing (solar, orbital, internal)
- Ozone depletion and human activity
Term Paper Suggestions

I. Related to the current Earth

Atmospheric Phenomena:

- Weather systems
- Hurricanes, Tornadoes
- Optics, Aurora, airglow
- Atmosphere – ocean effects
- El Nino
Term Paper Suggestions

I. Related to the current Earth

Global Atmospheric Change:
- Causes of climate change (e.g. solar forcing, industrial emissions)
- Ozone depletion and consequent biological effects
- Greenhouse models and long-term prediction
- Regional effects of climate change

Global Atmospheric Stability:
- Ice ages
- The “runaway greenhouse”
- Chaos in the climate system
- DMS thermostat
- Gaia hypothesis (homeostatic control)
Term Paper Suggestions

II. Related to the origin and evolution of the Earth’s Atmosphere:

Earth’s early atmosphere:
- Source(s) of the early atmosphere (e.g. volcanoes, comets)
- Greenhouse effect, i.e., role of CO$_2$, H$_2$O, CH$_4$ on surface temperature
- Faint Sun Paradox

Asteroid and comet impacts:
- Effects of asteroid impacts on atmosphere and climate
- Escape of light gasses from top of atmosphere
- Formation of oxygen atmosphere from water
- Photosynthesis and oxygen; Ozone layer with low O$_2$ abundances
- Stromatolites and atmospheric gasses
Term Paper Suggestions

II. Related to the origin and evolution of the Earth’s Atmosphere:

**Ice ages**
- Iceline problem, unstable to both + and – solar changes.
- Runaway ice age and sensitivity to solar output.

**Snowball Earth and the effects on the Atmosphere**
- How fast can ocean and atmosphere freeze? Will thawing overshoot and create a hot and violent atmosphere?

**Greenhouse effect**
- Greenhouse effect at several points in Earth’s history and future

**Atmospheric shielding**
- Early Earth and hot sun
- Supernova, cosmic rays, effects and frequency
- Induced mutations and effects on surface life

**Biogeochemical cycles (oxygen, carbon, nitrogen, sulfur)**
Term Paper Suggestions

III. Mars and Venus

Venus:
- Runaway greenhouse
- Volcanoes
- Surface chemistry & thermal chemistry
- Cloud physics and chemistry

Mars:
- Stability of water on the surface, e.g. source of “gullies”
- Evolution of the atmosphere
- Where’s all the water?
- Atmospheric dynamics
- Atmospheric chemistry
- Dust storms
Term Paper Suggestions

IV. Outer solar system atmospheres

Jupiter:

- Atmospheric dynamics of bands and zones, spots
- **Colors of clouds: role of chemistry and cloud physics**

Europa’s Atmosphere:

- State of transient atmosphere. Subsurface liquid water?
- Stability over long time periods

Io: supersonic winds:

- Atmosphere/plasma torus interactions
- Surface colors from atmospheric gases
Term Paper Suggestions

IV. Outer solar system atmospheres

**Titan:**
- Analog of early Earth’s atmosphere
- Source of clouds
- Surface/atmosphere/seas interaction

**Pluto and Charon**
- Stability of atmosphere on Pluto, Charon (& KBO’s)
- Hydrodynamic escape of atmospheres
- Low temperature atmospheric chemistry
- Radiative/convective models.
Assignments (Monday, Jan. 25, 2009)

Read: Wallace & Hobbs, Chapters 1 & 2
Read: D. Bodanis article “It’s in the air…”

Chapter 1 problems:
1.6, 1.7, 1.8, 1.9, 1.17, 1.18

Due: Monday, February 8

For Problem 1.6, write 1-2 sentence explanation

Please look at the problems before next class meeting (2/2) to see if you have any questions.
Suggested Readings


Useful Websites:

American Meteorological Society:
http://www.ametsoc.org/

National Aeronautics and Space Administration:
http://www.nasa.gov

National Oceanic and Atmospheric Administration:
http://www.noaa.gov

The Weather Channel:
http://www.weather.com

The NASA Astrobiology Institute:
http://nai.nasa.gov/
Important Dates:

**February 2 – Enrollment Deadline.** This is the last day to add into a course. Students may not register into any section after this date. No exceptions. This is also the last day to drop a course without losing tuition money.

**February 9 – Drop Deadline.** This is the last day a student may drop a course. Students will receive a 33% tuition refund. After this date, students may withdraw from a course, but only according to strict guidelines.
Students with Disabilities

If you are a student with a disability and you need academic accommodations, please see me and contact the Office of Disability Resources at 703/993-2474.

All academic accommodations must be arranged through that office.