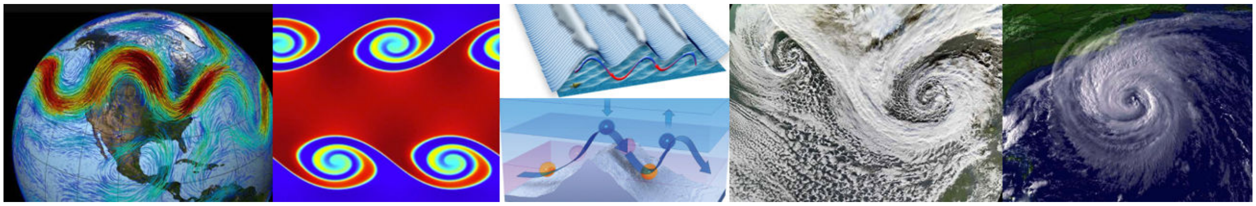
Syllabus for
CLIMATE 451 / EARTH457 / ENSCEN 451 **Fall 2021**

Atmospheric Dynamics I



Instructor:	Christiane Jablonowski (cjablono@umich.edu) CSRB 1541B, 734-763-6238
Location:	Climate and Space Research Building (CSRB)
Time and Room:	Tuesdays/Thursdays 1:30-3:20pm, room 2236
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Term:	Fall 2021, Aug/30 – Dec/10/2021 (28 2-hour classes) No class on Oct/19/2021 (Fall break) and 11/25/2021 (Thanksgiving break).
Credits:	4 credit hours
Office Hour:	Tuesdays after class from 3:30-4:30pm (can also be extended) in our classroom CSRB 2236

Textbook (highly recommended): available online

An Introduction to Dynamic Meteorology (5th edition), James R. Holton and Gregory J. Hakim, Elsevier Academic Press, 2012
or
An Introduction to Dynamic Meteorology (4th edition), James R. Holton, Elsevier Academic Press, 2004

Other Resources:

Atmospheric and Oceanic Fluid Dynamics: Fundamentals and Large-Scale Circulation, Geoffrey Vallis, Cambridge University Press, 2006, 745 pp.
More information on this book: http://www.vallisbook.org/
Available online

Mesoscale Dynamics, Yuh-Lang Lin, Cambridge University Press, 2007, 630 pp.
https://www.cambridge.org/core/books/mesoscale-dynamics/FBBF93FD4782DBE8CC30BDDB2AE53D56
Available online

An Introduction to the Global Circulation of the Atmosphere, David Randall, Princeton University Press, 2015, 456 pp. http://press.princeton.edu/titles/10520.html, see also http://saddleback.atmos.colostate.edu/group/dave/at605.html

Advisory Prerequisite:

An undergraduate-level course in fluid dynamics, ideally geophysical fluid dynamics, familiarity with calculus and partial differential equations

Course Outline:

This course for undergraduate seniors and graduate students provides an in-depth discussion of atmospheric fluid dynamics. It starts with a review of the equations of motion, the dominant balances in the atmosphere, and a brief reminder of the quasi-geostrophic theory to lay the foundation for more advanced topics. In particular, the course focuses on waves and instabilities in the atmosphere. This includes Rossby waves, gravity waves, inertial gravity waves, sound waves, mountain waves, thermal waves, and trapped tropical waves like Kelvin and mixed Rossby-gravity waves, and we will derive dispersion relations for these. In addition, we will discuss the principles behind static/convective, barotropic, baroclinic, symmetric, inertial, and Kelvin-Helmholtz instabilities. Waves and instabilities are the main drivers of weather systems and let us understand tropical phenomena (e.g., tropical cyclones or the Madden-Julian Oscillation), mid-latitudinal waves, stratospheric dynamics, and wave-mean flow interactions (e.g., the Quasi-Biennial Oscillation and Sudden Stratospheric Warmings in the stratosphere). A brief introduction to atmospheric modeling will be given. Furthermore, we will discuss how 'Atmospheric Dynamics' and 'The General Circulation of the Atmosphere' are connected.

Learning Outcomes:

Students that take CLIMATE 451

- Have an in-depth understanding of basic atmospheric dynamics concepts and terminology (e.g. geopotential, hypsometric equation, potential temperature, forces, vorticity, dominant balances in the atmosphere)
- Understand the atmospheric equations of motion and how to approximate the equations in various ways
- Know how to use advanced mathematical tools (like complex numbers, vector identities, vector calculus, differential equations, eigenvalues, derivatives, integrals, separation of variables) to gain insight into the physical meaning of the equations and manipulate them
- Are able to visualize the dynamics equations with the help of a programming language and plotting tools
- Are able to use their base knowledge to draw new conclusions about atmospheric motions
- Understand wave dynamics and are able to describe atmospheric waves via physical assumptions and mathematical tools (linearization, complex theory)
- Know the mechanisms that lead to atmospheric instabilities (like barotropic, baroclinic, static, inertial, symmetric, Kelvin-Helmholtz) and growing/decaying waves
- Gain a basic understanding of the general circulation of the atmosphere
- Understand the fundamental differences between tropical and mid-latitudinal flow phenomena
- Gain insights into upper atmospheric motions in the stratosphere

- Are able to formulate a dynamics-related research question, pursue a short research project and present their results in class

Overview of the Topics:

Reminder of the key atmospheric dynamics concepts (approx. 6 lectures):

- Equations of motion in z- and p-coordinates
- Dominant balances and scale analysis:
    - Hydrostatic equation
    - Geostrophic balance
    - Static stability and potential temperature
- Geostrophic wind
- Gradient wind
- Thermal wind
- Hypsometric equation
- Vertical velocity
- Vorticity equation
- Potential vorticity
- Quasi-geostrophic theory and motions

Atmospheric waves (approx. 7 lectures)

- Reynolds averaging
- Linear perturbation theory
- Wave kinematics
- Types of waves:
    - Sound waves
    - Shallow water gravity waves
    - Internal gravity waves without rotation
    - Inertia-gravity waves (gravity waves with rotation)
    - Orographically-forced flow: mountain waves
    - Thermally-forced flow and waves
    - Rossby waves
    - Trapped waves:
        - Equatorial and coastal Kelvin waves
        - Equatorial Rossby and mixed Rossby-Gravity waves

Instabilities in the atmosphere (approx. 5-6 lectures)

- Dry and moist static (convective) instability
- Rayleigh-Benard instability and convection
- Barotropic instability
- Kelvin-Helmholtz instability
- Symmetric instability
- Baroclinic instability:
    - 2-layer model
    - Rayleigh theorem

- The Eady stability problem

Example connections between 'Atmospheric Dynamics' and the 'General Circulation' of the Atmosphere (approx. 1-2 lectures)

- Zonally averaged circulation
  - Conventional Eulerian Mean Equations
  - Hadley circulation

Middle atmosphere dynamics (approx. 2-3 lectures)

- Transformed Eulerian mean (TEM) equations
- Wave-mean flow interaction
- Vertically propagating waves, Rossby-wave breaking, Kelvin and Mixed Rossby-Gravity waves
- Quasi-Biennial Oscillation (QBO) and Sudden Stratospheric Warmings (SSW)
- Brewer-Dobson circulation

Overview of Tropical Dynamics (approx. 2 lectures)

- African Easterly Waves (AEW)
- Madden-Julian Oscillation (MJO)
- Hurricane dynamics

Project discussions & in-class presentations (1 lecture)

Expectations and grading policy:

Students will be evaluated based on their homework assignments, two midterm exams (on 10/14/2021 and 11/23/2021) and a short project (with a presentation on 12/9/2021). There is no final exam during the exam week. Unless otherwise specified, homework assignments will be due one week from the day they are assigned. Late assignments will not be accepted without prior approval from the instructor.

Your final grade will be determined by your performance on the homework assignments, exam and project. The grade break down is:

Homework:	40%
Exam1:	20%
Exam2:	20%
Term project:	20%

There are 8 graded homework assignments, each assignment has equal weight (despite a varying number of points for each homework assignment) and contributes 5% to your final grade.

You are encouraged to form study groups to work on homework problems and to study in other ways. You are allowed to consult with other students during the conceptualization of a problem. However, all written work, whether in scrap or final form, is to be generated by you alone.
The College of Engineering Honor Code is enforced:
http://www.engin.umich.edu/students/honorcode/code/index.html