CLIMATE/SPACE/EARTH 321: Earth and Space System Dynamics

Earth and Space System Dynamics (Winter 2020 term):

Introduction to the dynamics of the atmosphere, oceans, space & planets

Instructors: Christiane Jablonowski (cjablono@umich.edu)
CSRB 1541B, 734-763-6238
Guest lecturers:
Jamie Ward (1/14/2020)
Steve Bougher (4/7 and 4/9/2020)

Location: CSRB 2246 (auditorium)
Time: 12pm-1:20pm, TTh
Credits: 3 credit hours
Office Hour: **before 3/12/2020 in-person office hours**

- Tuesdays after class 1:25-2:30pm, CSRB 2236
- Wednesdays 9:30-10:30am, CSRB 2236

Starting on 3/17/2020 online office hours, I suggest keeping our regular times

- Tuesdays 1:30-2:30pm ET, https://meet.google.com/kxp-mwxe-zpf
- Wednesdays 9:30-10:30am ET, https://meet.google.com/keg-dxct-njz

We will use the Google Hangout telecon connections listed above. Google Hangout provides audio, video (optional), and an option to share the screen

Virtual classroom (after 3/12/2020):

Reference Textbooks:

An Introduction to Dynamic Meteorology (5th edition), chapters 1-3, James R. Holton and Gregory J. Hakim, Elsevier Academic Press, 2012
recommended, pdfs of all chapters are freely available online via the UM library page: https://www-sciencedirect-com.proxy.lib.umich.edu/book/9780123848666/an-introduction-to-dynamic-meteorology

Atmosphere, Ocean, and Climate Dynamics, chapters 9 & 10, John Marshall & R. Alan Plumb, Academic Press, 2008 (**recommended**, **available online via the UM library, see lecture 1)**

Course Outline:

The course is roughly divided between atmospheric dynamics (part 1) and ocean, space and planetary dynamics (part 2). In the first part, topics will cover fundamental dynamical concepts (forces and dominant balances of the neutral atmosphere) and how these concepts shape motions, weather systems and climate phenomena on Earth. In the second part, we will build on these dynamical concepts and apply them to the oceans and the space environment. In particular, we focus on space objects with atmospheres like the planets Venus and Mars as well as Saturn's moon Titan. The course highlights what the most important dynamical processes for these dynamical systems are. Mathematical tools will be used to describe and explain the motions.

The course includes in-class discussions and exercises that address both the mathematical aspects of the course as well as the physical systems. The latter includes the interpretation of maps (e.g. surface pressure, temperature, geopotential height and vorticity) and how to derive information about the dynamical state from such maps. The in-class exercises take up about 15% of the class time. All lecture slides and some additional handouts will be provided via the Canvas class page.

Learning Outcomes:

Students that take CLIMATE/SPACE 321

- are able to quantitatively and qualitatively describe the basic characteristics of atmospheric, oceanic and planetary-atmosphere motions, and their typical spatial and temporal scales
- can apply mathematical tools (like derivatives, integrals, trigonometric functions, spherical coordinates) and vector calculus concepts (like divergence and rotation) to provide insights into physical flow phenomena
- are trained to sketch the characteristics of flow fields
- understand transport processes in the atmosphere and their mathematical description
- understand the forces and partial differential equations (the equations of motion) that drive the fluid motions on rotating planets
- understand the concept of a conservation law
- are able to rewrite the equations sets in various forms and convert physical units
- can use scaling arguments to simplify the equation set and expose fundamental balances like the hydrostatic balance, geostrophic balance and its vertical variation (thermal wind), and static stability
- are able to interpret weather and ocean maps, and draw conclusions about the flow fields
- are able to apply the atmospheric dynamics concepts and slightly modify them to make them applicable to the motions of the oceans and planetary atmospheres
- understand the dynamical interactions between the atmosphere and the ocean (e.g. how do the wind and friction drive the ocean flow)

Schedule:

1/9	Introduction, overview of the course and logistics (HW0 out: math review, not graded)
1/14	Introduction to the Earth's atmosphere (descriptive characterization), physical units and scales

Part 1: Atmospheric Dynamics

1/16	Ideal gas law, hydrostatic equation, mass, pressure (HW0 due, HW1 out)
1/21	Integration of the hydrostatic equation, geopotential and hypsometric equation
1/23	Geopotential thickness, layer-mean temperature, gradients (HW 1 due)
1/28	Review of all equations so far and mathematical tools (vectors, operators), divergence and vorticity, material derivative
1/30	Advection from an Eulerian and Lagrangian viewpoint, pressure gradient force (HW 2 due)
2/04	Analyzing weather maps, viscous force, gravitational force
2/06	Non-inertial rotating coordinate systems, centrifugal force, definition of gravity

(HW 3 due)
2/11 Coriolis force
2/13 Review of the momentum equations, scale analysis, geostrophic & hydrostatic balance (HW 4 due)
2/18 Ageostrophic wind, continuity equation, thermodynamic equation
2/20 Vertical pressure coordinates, thermal wind (HW5 due)
2/25 Potential temperature
2/27 Review for exam 1 (HW 6 due)
3/03 Spring Break, no class
3/05 Spring Break, no class
3/10 First Exam, in class 12-1:20pm (atmospheric dynamics, material covered in HW 1-5)

Part 2: Ocean and Space/Planetary Dynamics

3/12 class cancelled (due to the transition to virtual lectures)
3/17 dry adiabatic lapse rate, Brunt-Väisälä frequency, stability.
Transition to ocean dynamics: Differences between the ocean and atmosphere, introduction to the ocean
3/19 Ocean momentum equation, salt water equation of state, ocean layering, incompressibility and mass conservation law for the ocean, hydrostatic pressure (HW 7 due)
3/24 Pressure gradients in the ocean, Boussinesq approximation, scale analysis of open ocean flow, geostrophic flows at the ocean surface and at depth
3/26 'Thermal wind' in the ocean, ageostrophic flow (HW 8 due)
3/31 Wind stress, viscosity, Ekman spiral, Ekman mass transport, Ekman pumping
4/02 Ocean gyres and interior flow, stability and gravity waves in the ocean (HW 9 due)
4/07 Space/Planetary dynamics: Mars
4/09 Space/Planetary dynamics: Venus
4/14 Discussion of alternative dominant balances (gradient wind, cyclostrophic wind) on other planets, review of the motions on Mars, Venus, Titan
4/16 Review for exam 2 (HW 10 due)
4/21 Fun lecture: Tropical Cyclones
4/23 Exam 2 (atmospheric, oceanic and planetary dynamics, material covered in HW 6-10). Exam 2 will be an open-book take-home exam that you turn in via Canvas. I will distribute exam 2 on Thursday 4/23 at 9am ET via Canvas (labeled as Exam 2 in the Assignments directory) and ask you to turn it in on Friday (4/24/2020) before 5pm ET.

Expectations and grading policy:

Students will be evaluated based on weekly homework assignments and two exams. 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 an instructor.

Your final grade will be determined by your performance on the two midterm exams and the homework. There is no comprehensive final exam. The grade breakdown is:

Homework	33.33 %
First exam	33.33 %

Second exam   33.33 %

There are 10 graded homework assignments, each assignment has equal weight (despite a varying number of points for each homework assignment) and contributes 3.3% 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