Dynamical Systems and Statistical Mechanics applied to Atmosphere and Oceans

ATS 781A3, Department of Atmospheric Science
11:00-11:50 AM Monday and Wednesday, 2022 Fall Term
Room to be decided

Instructor Contact Information

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Office hours: By appointment, just send me an email

Course Description

This course describes what can be learned about atmosphere and ocean (thermo-)dynamics when viewed as dynamical systems, and when viewed from the angle of Statistical Mechanics. Dynamical systems is a tool to understand the overall behavior of a system and is especially useful when trying to understand regime shifts, Recently there has been an explosion of applications of dynamical system theory to atmosphere, ocean, and climate, allowing much better understanding of regime shifts such as blocking events in the atmosphere, local weather regimes, changes in the thermohaline circulation in the ocean, and ENSO. Statistical Mechanics offers another set of tools help us understand the structure of the climate system. For instance, it can be used to explain the buoyancy structure of the ocean just based on energy and potential enstrophy conservation, the temperature structure of the atmosphere, and land-atmosphere interactions.

We start with an introduction to Dynamical Systems and show that regime shifts are related to bifurcations of the system, followed by applications to atmospheric and oceanic flows. Then Statistical Mechanics is introduced and we discuss powerful concepts such as maximum entropy and maximum entropy production, and large deviation theory. The focus is on applications to the Earth system and its components, and providing the necessary ideas and tools to apply these techniques for your own research.

Since this is a graduate level course the emphasis is strongly on understanding and less so on derivations. Discussions are the central element of the course, facilitated by questions from teacher and students, student presentations, past and recent papers that either were the first to present important new ideas or contain in-depth discussions.

Course goals

Students who complete this course successfully will be able to:
- describe and explain applications of Dynamical Systems and Statistical Mechanics applied to the Earth System and its components,
- have a critical understanding of when these methods might add useful results to existing knowledge, and know how to apply them,
- critically evaluate the literature on this subject

Course materials

Detailed lecture notes will be available on Canvas in due course. The instructor does not use a specific textbook. The following textbook provides basic and advanced material that relates to the dynamical systems part of the course (and does not only treat the ocean):
Henk A. Dijkstra (2000) Nonlinear Physical Oceanography, Kluwer,

Grading

The grading will be based on a small number of assignments, including running simplified toy models to study the application of Dynamical Systems and Statistical Mechanics to our field, student presentations and participation in discussions.

Overall structure

The following subjects will be covered:

1) Introduction to dynamical systems theory and statistical mechanics for Earth-system applications
2) Dynamical systems theory I: fixed points, bifurcation theory
3) Dynamical systems theory II: Poincare sections and maps, bifurcations of periodic orbits, routes to chaos
4) Dynamical systems applied to atmosphere, ocean, and climate
5) Basics of statistical mechanics applied to geophysical flows
6) Large deviation theory, maximum entropy and maximum entropy production
7) Applications of statistical mechanics to atmosphere, ocean, and climate
8) Bringing it all together

This schedule is flexible and there is possibility to discuss one or two subjects that the students bring up, for instance related to their own research, or e.g. applications to other planets.

Statement on Academic Integrity

This course will adhere to the CSU Academic Integrity Policy as found in the General Catalog (http://www.catalog.colostate.e and the Student Conduct Code (http://www.conflictresolution.colostate.edu/conduct-code). 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.

COVID information for students

Masks are optional. You must meet university vaccine or exemption requirements. All students are expected and required to report to the COVID Reporter (https://covid.colostate.edu/reporter/) when:

- You suspect you have symptoms of COVID, regardless of whether or not you are vaccinated and even if your symptoms are mild
- You have tested positive for COVID through a non-CSU testing site, such as home test or test at a pharmacy
- You believe you may have been exposed to COVID go to the COVID Reporter and follow the guidance under "I believe I have been in close contact with someone who has COVID-19." This guidance will depend upon your individual circumstances

You will not be penalized in any way for reporting symptoms or concerns.

Do not ask me as your instructor to report for you. It is your responsibility to report through the COVID Reporter promptly. As your instructor I may not ask you about vaccination status or if you have COVID but you may freely volunteer to send me information from a public health official if you have been asked to isolate or quarantine.

When you complete the COVID Reporter, 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. If you do not have internet access to fill out the online COVID-19 Reporter, please call (970) 491-4600.

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

Disclaimer

The instructor reserves the right to make modifications to this information throughout the semester.