Dynamical Systems and Statistical Mechanics applied to Atmosphere and Oceans

ATS 78X, Department of Atmospheric Science
09:00-09:50 AM Tuesday and Thursday, 2020 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. We will also derive and work with equations for information flow, and discuss cause and effect relations in the Earth System.

We start with an introduction to Dynamical Systems, followed by applications to atmospheric and oceanic flows. The emphasis is what we can learn from Dynamical Systems Theory beyond standard techniques like potential vorticity conservation, and on how to apply these methods in your own research. Then we recap elements of Statistical Mechanics and move to powerful concepts such as maximum entropy and maximum entropy production, large deviation theory and information flows. This then leads on to cause and effect relations and causal discovery. 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 and review article provide basic and advanced material that relate to the course:
Henk A. Dijkstra (2000) Nonlinear Physical Oceanography, Kluwer,
Bouchet F., and A. Venaille (2012) Statistical Mechanics of two-dimensional and geophysical flows, Physics Reports 515, doi: 10,1026/j.physrep.2012.02.001.

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, statistical mechanics and causal discovery
2) Dynamical systems theory I: fixed points, bifurcation theory
3) Dynamical systems theory II: Poincare sections and maps, Floquet Theory, bifurcations of periodic orbits, route to chaos
4) Dynamical systems theory III: physics of bifurcation behavior
5) Dynamical systems applied to ENSO
6) Dynamical systems applied to ocean problems
7) Dynamical systems applied to atmospheric problems n/a
8) Basics of statistical mechanics applied to geophysical flows
9) Large deviation theory
10) Maximum entropy and maximum entropy production
11) Lyapunov theory and instability, chaotic systems, strange attractors
12) Applications of statistical mechanics to large-scale oceanic and atmospheric problems
13) Dynamical systems, statistical mechanics and information theory
14) Modern causal discovery theory
15) Applications of causal discovery for atmosphere and ocean
16) 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 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.

Disclaimer

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