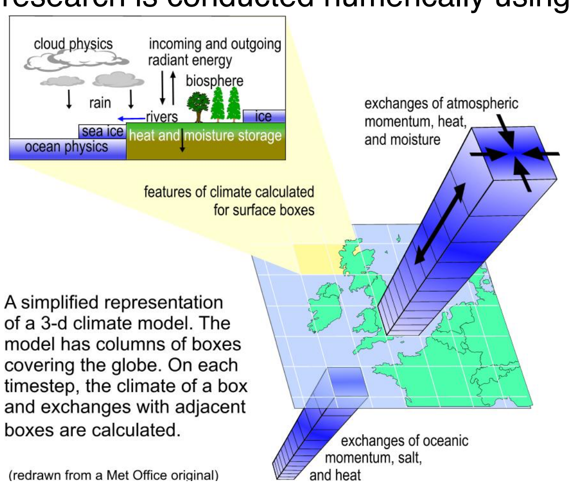
Fall 2021
Program in the Atmospheric Sciences

ATM SCI 480/480G (Class #20437/20438)
GENERAL CIRCULATION AND CLIMATE DYNAMICS

Class meets: MW 11:00–12:15, EMS W434
Instructor: Prof. S. Kravtsov

Will the Earth's polar ice caps melt within the next hundred years? Can this result, paradoxically, in the onset of a new ice age? Will there be an increase in the frequency or intensity of hurricanes in the near future? These questions lie within the scope of *Climate Dynamics*—a relatively novel field, which was born in the sixties and has developed rapidly thereafter. Currently, the Climate Dynamics research is conducted numerically using climate models (see the figure), in which processes (e.g., radiative transfer, convection, friction) that affect redistribution of climatic fields (such as temperature or wind speed) are parameterized and formalized in terms of exchange of properties between adjacent members of a three-dimensional array of boxes covering the region of interest (e.g., the globe). The purpose of this course is to provide a bird's eye view of General Circulation and Climate Dynamics.



A simplified representation of a 3-d climate model. The model has columns of boxes covering the globe. On each timestep, the climate of a box and exchanges with adjacent boxes are calculated.

(redrawn from a Met Office original)

The lecture/lab weekly sequences will be organized around construction of a suite of simple numerical (dynamical and statistical) climate models as prototypes of average climate, as well as climate variability on a range of spatial and temporal scales, from millennial global climate variations to (inter-)decadal variability associated with the thermohaline oceanic circulation and interannual El Niño/Southern Oscillation variability. These models — all to be coded in MATLAB during class — will introduce a set of original concepts that are at the heart of our understanding of climate system's inner workings, while graphically demonstrating the strengths and pitfalls of the numerical approach.

This course is designed for advanced undergraduate and beginning graduate student level. Knowledge of Calculus and/or MATLAB is a plus, but not required. For further information contact: Sergey Kravtsov, kravtsov@uwm.edu, EMS W441.

Format. Average of one lecture/one MATLAB-based lab per week.

Text. Not required: All necessary materials will be provided in class. The course presentation uses, to some extent, texts by A. E. Gill (1982) *Atmosphere–Ocean Dynamics* and M. Ghil & S. Childress (1987) *Topics in Geophysical Fluid Dynamics: Atmospheric Dynamics, Dynamo Theory, and Climate Dynamics,* as well as numerous research articles.

Course webpage can be found at https://people.uwm.edu/kravtsov/teaching/; it contains this syllabus, as well as lab assignment scripts (MATLAB). The same information will also be posted on Canvas.

Course requirements and evaluation:

- **Labs** — 70%. The completed Wed. labs will be due before the next lab.
- *Typed* (minimum 2 pages; single-spaced,12-pt font size) **term paper** (15%) and **in-class** conference-style (10+5 min.) **presentation** (15%). Some suggested topics for this project are attached below. Any other topic related to the subject of the class will also be fine. Ideally, the project should include a MATLAB-based toy modeling of a geophysical phenomenon. The deadline to finalize the topics is March 15 (please see me ASAP and certainly before that time to discuss your choice).
- *Grading*: A (91–100%), B (81–90%), C (71–80%), D (61–70%), F (<61%).

Office Hours (EMS W441)**:** MW 1:30–3:00PM. Please feel free to drop by at any other time — no appointment necessary. E-mail and phone conferences are also welcome.

Syllabus Addendum

To comply with a Higher Learning Commission requirement, we provide below information on the estimated amount of time an average student needs to invest in order to achieve the learning goals for this class:

- 34 hours in the classroom (including lectures and in-class portions of labs)
- 70 hours for study and lab completion
- 40 hours for term project (including presentation)

Total number of hours: 144

Tentative Schedule:

09/13 **Lecture 1.** *Climate dynamics nomenclature. Climate state variables. Sub-systems of a climate system and ways of their classification. Intrinsic, forced, and coupled variability. The concept of parameterization; example: Reynolds-stress-type turbulence closures.*
09/15 **Lab 1.** *MATLAB basics sampler: One-dimensional plotting, random numbers, probability distributions, auto-correlation function. White-noise and red-noise series. Mean, variance, and standard deviation of a time series.*

09/20 **Lecture 2.** *Concepts of signal and noise; climate predictability. Stochastic parameterizations and concept of feedbacks within climate system. Dynamical basis for stochastic climate modeling. Probability distributions. Gaussian distribution and its use in climate science.*
09/22 **Lab 2.** *(i) Spectrum of a time series and its connection to the autocorrelation function. (ii) Numerical demonstration of the Central Limit Theorem. Galton machine.*

09/27 **Lecture 3.** *Radiation balance of the Earth. Albedo. Greenhouse effect. The simplest coupled energy balance (EBM) model of the Earth climate.*
09/29 **Lab 3.** *Numerical formulation of the simplest coupled climate EBM*. *Stability of numerical schemes. Explicit and implicit time integration schemes. Asynchronous numerical integration.*

10/04 **Lecture 4.** *A null hypothesis for low-frequency climate variability (Hasselman 1976; Barsugli and Battisti 1998. Statistical diagnostics of the system's behavior: Variance and Fourier spectrum of the model time series, autocorrelation function. Comparison of coupled and uncoupled climate simulations. The concept of reduced thermal damping.*
10/06 **Lab 4.** *Ensemble integrations of atmospheric models forced by observed sea-surface temperature anomalies: Interpretation using a coupled EBM.*

10/11 **Lecture 5.** *Nonlinear processes affecting radiation budget of the Earth. Re-examination of greenhouse effect. Land-ice–albedo feedback. Multiple equilibria of the Earth's climate: Paleoclimatic perspective.*
10/13 **Lab 5.** *Linear and nonlinear stability analysis of EBM's steady states. Structural stability. Stochastic resonance as a possible explanation of the periodicity of the Earth's ice ages.*

10/18 **Lecture 6.** *Linear oscillations. Classical linear resonance. Delayed action oscillators. Classification of potential predictability.*
10/20 **Lab 6.** *Latitudinal variations in the Earth heat budget. Atmospheric heat transport. Approximation of the observed annual-mean radiative fluxes by Legendre polynomials. One-dimensional climate EBM (North et al. 1982).*

10/25 **Lecture 7.** *Spectral representation of one-dimensional EBM. Land-ice–albedo effect in one-dimensional model. Steady solutions and their linear/nonlinear stability: Generalization of 0-D results.*
10/27 **Lab 7.** *(i) Delayed action oscillator; (ii) Steady solutions of one-, two-, and three-mode spectral truncations to the 1-D climate EBM.*

11/01 **Lecture 8.** *How do we "observe" climates of the past? Isotope fractionation and its application to documenting the Earth's climate variability. Proxy-data evidence for the glacial cycles. Main characteristics of glacial cycles. Conceptual explanations in terms of the kinematics and thermodynamics of glaciers. Solar forcing and nonlinear resonance. Modified and alternative explanations of glacial cycles.*
11/03 **Lecture 9.** *General circulation of the atmosphere: Hadley circulation, Mid-latitude jet stream. Baroclinic instability. Synoptic-eddy feedback onto low-frequency variability of the jet stream.*

NB! Deadline for choosing the subject of the term paper.

11/08 **Lecture 10.** *General circulation of the ocean. Physical differences between atmosphere and ocean. Buoyancy-driven circulation and climate. Wind-driven circulation. Poleward heat transport by ocean currents. Deep convection in the ocean.*
11/10 **Lab 8.** *Stommel's box model and halocline. "Freshwater pulse" experiments in Stommel's box model (numerical nonlinear stability analysis). Interpretation of Younger Dryas event (~11,000 yr BP). Why can global warming result in the onset of a new ice age?*

11/15 **Lecture 11.** *Interannual-to-interdecadal variability in the NH's middle latitudes: Observations and theories.*
11/17 **Lab 9.** *Freshwater pulse experiments in mass-conserving and coupled modifications of the Stommel's model: Do ocean–atmosphere feedbacks stabilize or destabilize climate system?*

11/22 – 11/24 NO CLASSES (THANKSGIVING)

11/29 **Lecture 12.** *Delay mechanisms in the atmosphere and ocean. Gravity waves and Rossby waves. Kelvin waves. Equatorially trapped waves. Effects of stratification on wave speeds. Other types of adjustment mechanisms: Diffusive, advective, and eddy-driven adjustment.*
12/01 **Lecture 13.** *ENSO ingredients and delayed-oscillator models of ENSO (Schopf and Suarez 1987; Battisti and Hirst 1988).*

12/06 **Lab 10.** *Delayed-oscillator models of ENSO.*
12/08 **Lab 11.** *Effects of seasonal forcing in Battisti and Hirst's model of ENSO.*

12/13 **Lecture 14.** *Introduction to atmospheric low-frequency variability in the Northern Hemisphere (NH LFV): Persistent anomalies and blocking.Three-spectral-mode approximation of Charney & DeVore (1979).*
12/15 **Lab 12.** *Theory of NH LFV: Topographic instability/parametric resonance*. *Alternative theories of NH LFV.*

12/20 **Students' in-class presentations (typed reports are due).**

EXAMPLES OF TOPICS/TIPS FOR TERM PAPER/PRESENTATION

One strategy to choose a topic for the term paper and presentation would be to use textbooks (and papers) provided and select a section of a book (or a paper) that expands somewhat on the material covered in class (don't try to cover too much new material: your presentation/paper should illustrate a conclusion that can be stated in one, at most two sentences). Another one is to think of a topic of interest (in climate) and we can narrow it down together to something that can be presented in terms of a simple model and simple result. Some possible topics are:

Glacial Cycles and Global Climate Change

Decadal Climate Variability and Stochastic Climate Models

Role of Ocean in Climate

Atmospheric Low-Frequency Variability/Multiple Planetary Flow Regimes

Models of Tropical Climate and ENSO

General circulation of Ocean and Atmosphere

Any other topic related to the course subject will also be fine…

The ten-minute conference-type presentation (five minutes for questions) should, in general, consist of four parts: (i) statement of the problem and context; (ii) methodology; (iii) result answering the question stated in (i); (iv) broader implications. The maximum number of slides should be 10 (plus maybe a couple of slides on the side to answer possible questions – it's a good idea to make a presentation in a way that conditions certain questions you anticipate: at the conference, it gives you a chance to present more of your work). You can present other people's work entirely, but it would be more fun for all if you could actually reproduce some of the authors' results (if the topic allows).