SIO 209 (Spring 2014)

Introduction to numerical modeling of the climate system

Course description

Instructor: Ian Eisenman, (office) Nierenberg Hall 223, (email) eisenman@ucsd.edu, (phone) 858-822-5176.

Date, time, location: Tuesdays, 12:30-1:50pm, Spiess Hall 330.

Synopsis: This course will provide an introduction to the methods used in numerical models of the ocean and atmosphere. The course is aimed at a broad range of SIO graduate students, and no background in dynamics or modeling will be assumed. A range of numerical methods will be introduced in the context of a series of example problems: a large-amplitude pendulum, dye flowing in a pipe, a simple diffusive energy balance model of the atmosphere and climate, and a wind-driven homogenous ocean basin model. This will be followed by an overview of the equations represented in general circulation models (GCMs) of the atmosphere and ocean, along with the additional numerical methods that are used in these models. The course will include lectures, homework exercises, and a short final project.

Prerequisites: Basic familiarity with calculus and Matlab.

Office Hours: I will informally hold office hours immediately after each class. Students are also welcome to stop by my office anytime (knock if door is shut), but I recommend checking beforehand to make sure I am in.

Grading: 50% homework, 50% final project. Course can be taken for letter grade or pass/not pass.

Homework: There will be 3 homework assignments. Homework assignments may be turned in one class later than they are due (grace period), but will be accepted later than this only in exceptional circumstances. Homework will be graded on a ✓+, ✓, ✓- basis. Students are encouraged to work together on homework exercises as long as each student turns in only his or her own work.

Final project: Each student will be asked to do a short project at the end of the course in which they numerically solve a system of equations describing a geophysical problem of their choice (some problems are suggested below). Each student will give a brief (~15 minutes) presentation of their project to the rest of the class and submit a written report (several pages).

Textbook: Readings will include sections from *Introduction to Geophysical Fluid Dynamics* by Benoit Cushman-Roisin and Jean-Marie Beckers (2011, listed as "CRB" in schedule below), online here. All readings will be available for download from the course website.

Schedule and assignments

Course schedule (tentative and evolving):

- 4/01: Intro & Pendulum I (finite differencing, explicit & implicit Euler method, higher order methods). Reading: CRB 1.9-1.11, 2.6.
- 4/08: Pendulum II (leapfrog, Robert filter, Runge-Kutta, truncation error, numerical convergence). Reading: CRB 2.7, 2.9, 4.8.
- 4/15: Dye in pipe I (finite differencing with PDEs, boundary conditions, ghost points, numerical

stability). Reading: CRB 4.7, 5.3, 5.4-5.6.

- 4/22: Dye in pipe II (advection schemes, method of characteristics, CFL instability). Reading: CRB 6.4-6.5.
- 4/29: Energy Balance Models *(guest lecture: Till Wagner)*. Reading: North (1981).
- 5/06: Wind-driven ocean circulation (elliptic equations, staggered grids, discretized Jacobian). Reading: CRB 7.6-7.8, 16.7.
- 5/13: Atmospheric and oceanic GCMs (governing equations, spectral methods, convective adjustment, Arakawa grids). Reading: CRB 19.4, 19.7, 20.6, 9.7.
- 5/20: Ocean GCM simulations *(guest lecture: Rebecca Dell)*.
- 5/27: High-resolution coupled GCM simulations *(guest lecture: Julie McClean)*.
- 6/03: Student project presentations.

Homework assignments:

- HW-1 *(due 4/15)*
- HW-2 *(due 4/29)*
- HW-3 *(due 5/13)*

Suggested course project topics:

- Using the numerical model for wind-driven ocean circulation from the homework, find the ocean flow when several islands are added at various locations in the ocean basin.
- Using the numerical model for wind-driven ocean circulation from the homework, add a discrete jump in the wind forcing at a particular latitude, which could be due for example to the presence of sea ice. How does the solution depend on the time and space resolution? Does it converge more quickly if you smooth the jump in wind forcing (for example using a tanh function)?
- Adjust the numerical energy balance model from the homework such that the diffusivity can vary with latitude. Find an observational estimate of the annual-mean zonal-mean surface temperature, and determine the diffusivity as a function of latitude in the energy balance model that yields the result that best matches the observations. Read Lindzen and Farrell (1980) and discuss how your results compare with their discussion.
- Numerically solve the Lorenz system (3 coupled ODEs used to investigate inherent limits in weather predictability associated with chaotic dynamics). How does the rate at which errors in the initial conditions grow depend on the time step size? Numerically find the parameter value at which the pitchfork bifurcation occurs; how quickly does this converge on the theoretical value as the time step is reduced?
- Other possible topics: Reproduce aspects of the results of (i) Frierson et al. (2007) who used an energy balance model that diffused moist static energy rather than temperature, (ii) Peter Lynch's Matlab recreation of the original Charney weather prediction model, or (iii) the meridional overturning circulation 2-box model from Huang et al. (1992).