270.644: Physics of Climate Variability
Fall Semester 2005.

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This course is an advanced-level review of some key dynamic and thermodynamic processes causing climate fluctuations on timescales of seasons to decades. The focus is on phenomena that involve the ocean and topics will cover, depending on the class' interest: ocean circulation theories, large-scale ocean waves and eddies, thermohaline circulation, air/sea interaction, and modes of climate variability. Geophysical understanding and the links to fundamental mechanisms are emphasized.

Tools from dynamical systems theory and statistics are introduced where needed and the focus is on a geophysical understanding throughout.

Synopsis

I propose we discuss 3 or 4 of the following topics in detail:

1. **Mid-latitude climate variability.** Review of ocean mixed-layer and steady ocean circulation theory. The stochastic climate model of SST. Oceanic response to atmospheric fluctuations; atmospheric response to oceanic perturbations; coupled modes. Mechanisms of the North Atlantic Oscillation and Arctic Oscillation.

2. **Variability of the thermohaline circulation.** Review of abyssal ocean circulation. Stommel's box model. Multiple equilibria and hysteresis in simple coupled climate models. Paleo-evidence for North Atlantic thermohaline collapse. Predictions of future change.

3. **Tropical climate variability.** El–Niño Southern Oscillation (ENSO). Review of relevant equatorial dynamics; delayed oscillator model. ENSO in the Atlantic; tropical extra-tropical teleconnections. Seasonal predictability and phase-locking.

4. **Climate variability and global warming.** Predicted sea level, sea ice and ice sheet changes in the 21st century. Detection and attribution of climate change.

5. **Numerical models of the ocean climate system.** Formulation. Computational fluid mechanics and thermodynamics. Parametrizing unresolved processes. Coupled climate models.

6. **Fundamentals of climate variability**. Definitions of "climate," "climate variability," and "climate sensitivity." Mathematical approaches to finding climate sensitivity in chaotic dynamical systems. Feedback. Synchronization of weakly forced dynamical systems.

Suggestions for other possible topics are welcome!

We will meet twice a week (on average) for 60mins. I will review the background material in each topic and students will then take turns to present and discuss relevant studies from the research literature. This is a Pass/Fail course based on contributions to class presentations and discussions. The class is worth 2 credits and my permission is required to attend.

Textbooks

Peixoto and Oort [1992] is a good introduction to the major components of Earth's climate and provides good context for our more detailed discussion. The following books are also useful for background information: *Pedlosky* [1996] covers the physics of large-scale ocean circulation, but with little reference to variability or climate. *Salmon* [1998] is an alternative text on large-scale ocean circulation; it's physically motivated but doesn't discuss observations. *Houghton et al.* [2001] summarizes the scientific basis for climate change, and *Griffies* [2004] discusses the fundamentals of ocean circulation models. Finally, *Pikovsky et al.* [2001] covers synchronization in detail.

As an example of what we might cover, in previous years we have studied these topics:

Background

Background material: shallow-water and quasi-geostrophic theory; Rossby waves. Mixed layers, Ekman theory and Sverdrup balance. *Pedlosky* [1996], Chs. 1; 2.1–2.7, 2.15; 3.1–3.4, 3.11; 4.1

Mid-latitude climate variability

- Ventilation of the ocean interior: *Woods* [1985]; *Woods and Barkmann* [1986].
- The stochastic climate model: *Frankignoul* [1985]; *Halliwell and Mayer* [1996]; *James and James* [1989]; *Junge and Haine* [2001]; *Zhao and Haine* [2005].
- Effect of sea-surface temperature (SST) anomalies on the atmosphere: *Hoskins and Karoly* [1981]; *Palmer and Sun* [1985]; *Rodwell et al.* [1999]; *Venzke et al.* [1999]; *Lau* [1997].
- Effect of air/sea flux anomalies on the ocean: *Anderson et al.* [1979]
- Observations in the North Atlantic: *Dickson et al.* [1996, 2000]; *Sutton and Allen* [1997]; *Sturges and Hong* [1995]

- Mechanisms of coupled decadal variability: *Latif and Barnett* [1994, 1996]; *Grötzner et al.* [1998]; *Saravanan and McWilliams* [1998]; *Deser and Blackmon* [1993]; *Marshall et al.* [2001]

Variability of the thermohaline circulation (THC)

- Different stable regimes of thermohaline flow. (i) Concepts: *Stommel* [1961]; *Rahmstorf* [1996]; *Tzipermann* [1997]; *Griffies and Tzipermann* [1995].
- Different stable regimes of thermohaline flow. (ii) Coupled model results: *Manabe and Stouffer* [1988, 1999]; *Delworth et al.* [1993]; *Wood et al.* [1999]
- Paleoceanographic evidence of shutdown: Younger-Dryas/Alleröd oscillation:
- THC shutdown in past climates and in the greenhouse? *Stocker and Wright* [1991]; *Broecker et al.* [1985]; *Schmittner and Stocker* [1999]; *Rahmstorf* [1994]; *Rahmstorf and Ganopolski* [1999]

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