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Fall 2005

ESS/ATMOS/OCEAN 589: Paleoclimatology: Data, Modeling and Theory

Overview

In this course we will provide an introduction to the broad field of "Paleoclimatology" by focusing on the examination of three important and unsolved problems: the toggling between glacial and interglacial conditions over the past two million years; the remarkably abrupt, possibly global scale climate changes seen throughout the last glacial period; the relative stability of the climate of the past 10,000 years.

We will first examine the ice-age problem. The ice-age cycles are clearly paced by changes in insolation that occur because of changes in the properties of the Earth's orbit around the Sun: this is the so-called Milankovitch theory. There is a close relationship between insolation, ice volume and carbon dioxide. The processes that link these variables are still uncertain. Hence, it is not surprising that several theories for the ice ages exist, some of which are not complimentary. We will examine the climate proxy data, the theories and the modeling to determine what is known and what is uncertain about the ice-age cycles, and to illuminate the key questions that are being asked by investigators working on this problem today. [The state of affairs is such that one can seriously entertain two mutually exclusive theories: the ice-age cycles are fundamentally about interactions between atmosphere/ocean dynamics and the carbon cycle (with the ice being incidental), and the ice-age cycles are fundamentally about land ice (with carbon dioxide and atmosphere/ocean dynamics being incidental).]

The second problem we will examine is the causes for the remarkable abrupt climate changes seen during the last ice age, that have not been since: the so-called Dansgaard-Oescgher events and the Heinrich events (iceberg discharges) that may be associated with them. We will summarize and critiqued the observations that define theses events and the current ideas of the processes responsible for them.

In the final section of the course, we will turn to the Holocene. The Holocene starts about 10,000 years ago, at the end of the last ice age, when the amount of terrestrial ice is about the same as that today. It is widely believed that the climate during the Holocene is less variable in comparison to the climate during the ice-age climate. We will examine the proxy data and modeling evidence that challenges that paradigm. In particular, it appears the climate in the tropical regions during the early Holocene (5-10k yr BP) was much different than that during the late Holocene (5ky BP to present). Finally, we will examine the efficacy of the widely held assumption that the leading patterns of year-to-year climate variability observed in the instrumental record are useful in identifying and understanding the climate variability on interannual to centennial time scales throughout the Holocene.

Evaluation

An important feature of the class is discussion sessions, each one focusing on a key topic. These discussions will center on the results from key papers. Two or three students will be responsible for leading each focus discussion session, though everyone is expected to contribute to the discussion. The discussion leaders will also be responsible for additional papers that resolve issues raised in the key papers, and summarize the current issues/challenges in this area of research. At least 24 hours prior to the prior to each discussion section, all students who are not assigned to lead that discussion will submit to the discussion leaders and the instructors three questions that stem from reading the key papers. The leaders should address the most important questions during the discussion session.

In addition to the student-led discussion session, there will be several mandatory problem sets. There are no exams in this course.

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1. The Ice Ages

Thursday, September 29th (DSB)
Overview of course, Introduction to Milankovich Theory (DSB)

Tuesday, October 4th (EJS)
The stable isotope method: ice volume and sea level from ice and marine sediment cores

Thursday, October 6th (EJS)
Milankovich theory and the timing of ice age cycles; phase relationships between ice volume, temperature, CO_2 and insolation

Tuesday October 11th
Student-led discussion: Climate of the last glacial maximum: what do the data tell us?

1) CLIMAP Project. The surface of the ice-age earth. *Science*, 191:1131-1136, 1976.
2) Denton, G.H., Hughes, T.J., and Karlén, W., 1986. Global ice-sheet system interlocked by sea level. Quaternary Research, 26: 3-26.

Thursday, October 13th (DSB)
Paleo-general circulation modeling

Tuesday, October 18th (Camille)
Student-led discussion: How well do GCMs simulate the "Last Glacial Maximum" (LGM)? What variables are important for obtaining a picture that agrees with the data?
Key papers:

1) Manabe, S., and A. J. Broccoli, 1985: A comparison of climate model sensitivity with data from the last glacial maximum. *Journal of the Atmospheric Sciences*, 42(23), 2643-2651.

Thursday, October 20th (EJS)
Role of the ocean in glacial/interglacial cycles. (1) Evidence for changes in ocean circulation and poleward heat transport?

Tuesday, October 25th (with Gavin Schmidt)
Student-led discussion: What do general circulation models tell us about ocean circulation and heat transport changes in the climate of the LGM?
Key papers:

1) Webb, R.S. et al., Influence of ocean heat transport on the climate of the Last Glacial Maximum; *Nature* 385, 695-699 (20 Feb 1997).
2) Weaver, A.J. et al., Simulated influence of carbon dioxide, orbital forcing and ice sheets on the climate of the last glacial maximum. *Nature* 394, 847-853 (27 Aug 1998)

Thursday, October 27th (Emerson)
Role of the ocean in glacial/interglacial cycles. (2) The global carbon cycle.

Tuesday, November 1st (EJS)
Review of energy balance modeling and introduction to our own LGM simulations.

2. Rapid Climate Change

Thursday, November 3rd (EJS)
Ice core evidence of rapid climate change

Tuesday, Nov. 8th
Student-led discussion: How close can we get to the "right answer" for LGM climate with a simple EBM? What is missing?

1) North and Coakley, 1979: Differences between Seasonal and Mean Annual Energy Balance Model Calculations of Climate and Climate Sensitivity. Journal of the Atmospheric Sciences: Vol. 36, No. 7, pp. 1189-1204.

Thursday, November 10th (EJS)
Marine and other (non-ice-core) evidence of rapid climate change

Tuesday, November 15th
Student-led discussion: Is rapid climate change a global or a local phenomenon?

1) Alley, R.B. and P.U. Clark. 1999. The deglaciation of the Northern Hemisphere: a global perspective. Annual Reviews of Earth and Planetary Sciences 27, 149-182.
2) Roe GH & Steig EJ. Characterization of millennial-scale climate variability. *Journal of Climate* **17**: 1929-1944 (2004).

Thursday, November 17th (EJS)
Conceptual and numerical models of rapid climate change.

Tuesday, November 22nd
Student-led discussion: What processes can account for rapid climate change?

1) Ganoploski and Rahmstorf. 2001. Rapid changes of glacial climate simulated in a coupled climate model. *Nature* **409**: 153-158.
2) Chiang, J. C. H., M. Biasutti, and D. S. Battisti, 2003: Sensitivity of the Atlantic Intertropical Convergence Zone to Last Glacial Maximum boundary conditions. *Paleoceanography* **18**, 10.1029/2003PA000916.

Thursday, November 24th THANKSGIVING

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3. The Holocene

Tuesday, November 29th (DSB)
Holocene climate variability

Thursday, December 1st (DSB)
Patterns of variability, EOFs, and their dynamical basis.

Tuesday, December 6th (EJS)
The last 1000 years: data sets and statistical reconstructions

Thursday, December 8th
Student-led discussion: How variable is the climate of the last 1000 years? How does this compare with modern (anthropogenic) climate change?

1) Jones and Mann. 2004. Climate over past millennia, *Reviews of Geophysics*, 42, Paper number 2003RG000143