Geology 111 – Glaciology, Ice Ages, & Climate Change **Spring 2013**

Steven Wojtal: Office: Carnegie 406
Office hours: Tues 9:00-11:00 a.m. & Wed 2:30-4:30 p.m.

Scheduled Meetings: : Mon - Wed - Fri 1:30 – 2:20 p.m.

Course Aims: To introduce you to scientific evidence for past changes in Earth's climate, to help you understand how Earth's climate system works, and to evaluate the prospects of future climate change.

Glaciers are neither static nor stable features. The ice in glaciers flows in response to gravitational forces. Moreover, glaciers grow or shrink in response to changes in climate. Geologic data document unequivocally that there were times when glacial ice covered 3x more of Earth's surface than it does at present and other times when there was little glacial ice on Earth. It is not just changes in ice volume that record changes in Earth's climate. Glacial ice itself holds important information on climate variability in the past and provides humans with data on changes in the concentrations of greenhouse gases in the atmosphere, changes in vegetation patterns on land, and changes in temperature and circulation patterns in the oceans. Glaciers are, then, a natural point of departure for anyone who is interested in understanding Earth's climate system and who endeavors to analyze critically the prospects for human-induced climate change.

We will use glaciers as a point of entry to study Earth's climate. We begin by examining the morphology, kinematics, and dynamics of glacier systems. As part of our examination of glaciers, we will (1) consider how glaciers sculpt the land surface and deposit rock debris, and (2) analyze the patterns and distribution of glacial erosional and depositional features to document the extent of glacial ice during the Pleistocene (the last ~2 million years of Earth's history). Studies of glacial erosion and deposition do not provide a detailed picture of global change throughout the Pleistocene, so we will turn to studies of the isotopic character of glacial ice and marine sediments for greater detail on and insight into past climate change. Faced with evidence for Earth's changing climate, we will analyze what causes climate changes. We start this section of the course by examining how Earth's climate system works, evaluating how Earth warms or cools and considering the causes of seasonal variations, the causes of rapid (short period) changes in climate during the Pleistocene, and causes of long-term changes in climate that took place over the hundreds million years. These 'natural' mechanisms for climate change are relevant to the climate system at the present time, for human activity changes the boundary conditions of the climate system in ways that are analogous to those prehistoric changes. We end the semester by examining what studies of Earth's climate system and climate history suggest regarding the prospect for human-induced, rapid climate change in the future.

Readings: For the first part of the semester, the required readings are PDFs you can download from the BlackBoard site for this course; the readings are a chapter from the first edition of the required text and chapters from two books that are no longer in print.

For the rest of the semester, assigned readings are from a required text:
Ruddiman, William F. 2008. *Earth's Climate: Past and Future (2nd Edition).* W. H. Freeman and Company. Print copies are available at the bookstore (and elsewhere), or you can purchase or rent electronic copies of this text from the publisher.

Additional readings relevant to material covered at the end of the semester are PDFs available from the BlackBoard site for the course; they include journal articles and documents published by the Intergovernmental Panel on Climate Change.

I also post to BlackBoard PDFs of the PowerPoint presentations I show in class.

Grading: I will determine grades from scores on (1) four brief exercises posted on BlackBoard and available to be completed between 5 p.m. one day and 12:00 noon two days later at different points during the semester (the dates are given below), (2) an in-class, hour-long 'mid-term' exam, (3) a longer exercise to be completed over a two day period in late April, and (4) an exam given at the regularly scheduled 'final exam' time of Wednesday, May 15 at 9:00 a.m. Each of the four short exercises will be worth up to 15 points, and I will score them as ✓+ = 15 points, ✓= 13 points, or ✓- = 11 points. The longer exercise will be worth up to 30 point, and I will score it as

✓+ = 30 points, ✓= 26 points, or ✓- = 22 points. The first exam will be worth 100 points, and the 'final' exam will be worth 110 points. Your grade will depend on the percentage of the 300 possible points you earn.

Quantitative Proficiency: It is possible to earn **Quantitative Proficiency – Half** certification in this course. The four short exercises and the one longer exercise will require you to reason quantitatively (there will not, however, be externsive or elaborate derivations or calculations to be done for these exercises). I will use your work on those exercises and selected exam questions that require quantitative reasoning to determine who earns certification.

Schedule of class topics		
Date	***Topic***	***Assigned Reading†***
Feb 4	1. Introduction: Weather, climate & glaciers	Ruddiman, ch. 1
Feb 6	2. Ice, water, & water vapor	Hambrey & Alean, ch. 1 & 2
Feb 8	3. Water & ice in glacial systems	
Feb 11	4. Glacier ice & glacier systems	
Feb 13	5. Macroscopic morphology of glaciers	Hambrey & Alean, ch. 3
Feb 13-15	First short exercise	
Feb 15	6. Glacier surface features	
Feb 18	7. Features within glaciers	
Feb 20	8. Glacier dynamics – why & how glaciers move	Hambrey & Alean, ch. 4 & ch. 5
Feb 22	9. Glacier dynamics II – ice distortion	Sharp, ch. 3
Feb 25	***No class*** – SFW at conference	
Feb 25-27	Second short exercise	
Feb 27	10. Defining glacier mass balance	Sharp, ch. 5
Mar 1	11. Measurements of glacier mass balance	
Mar 4	12. Glacier erosion - processes	Sharp, ch. 6
Mar 6	13. Products of glacial erosion - landforms	Sharp, ch. 7
Mar 8	***FIRST EXAM*** - on lectures and reading through 3/8	Sharp, ch. 7
Mar 11	14. Erosional landscapes; Depositional processes	Sharp, ch. 8, pp. 132-145
Mar 13	15. Depositional processes, landforms, & landscapes	Sharp, ch. 8, pp. 145-159
Mar 15	16. Glacial deposition	
Mar 18	17. Glacial deposition; Melt water in glacial systems	
Mar 20	18. Melt water erosion & deposition	Sharp, ch. 8, pp. 159-169
Mar 22	19. Melt water deposition	Sharp, ch. 8, pp. 159-169
	Spring Break	
Apr 1	20. Melt water deposition & large glacial floods	
Apr 3	21. Historical context of Ice Ages	Ruddiman, ch. 2, 12, & 13*
Apr 5	22. Problems with geologic record of Ice Ages – introduction to isotopic data on climate	Ruddiman, Appendices 1 & 2
Apr 8	23. More on isotopes & Introduction to Earth's climate system; the global picture	Ruddiman (1st Edition), ch.2 (PDF on BlackBoard), IPCC TAR WG1, ch. 1, pp. 87-92
Apr 10	24. Latitudinal variations in heat balance	IPCC TAR WG1, ch. 1, pp. 87-92
Apr 10-12	Third short exercise	
Apr 12-15	25. Latitudinal variations; atmospheric & oceanic circulation	Ruddiman (1st Edition), ch.2

Apr 15	26. Seasonal variations	Ruddiman (1st Edition), ch.2
Apr 17	27. Astronomical factors that alter Earth's heat balance	Ruddiman, ch. 7, 8*, & 9*
Apr 19	28. Tectonically driven climate variations	Ruddiman, ch. 3 & 4
Apr 22	29. Plate tectonics & climate history	Ruddiman, ch. 4; Fischer (1984)
Apr 24	*No class* – SFW at conference	
Apr 22-24	Exercise on Earth's climate system	
Apr 26	30. Plate tectonics & greenhouse gases	Ruddiman, ch. 5 & 6
Apr 29	31. The carbon cycle on land	Ruddiman, ch. 10 & 11
May 1	32. The carbon cycle in the oceans	Ruddiman, ch. 10 & 11
May 1-3	Fourth short exercise	
May 3	33. How humans alter the carbon cycle & the impact of anthropogenic carbon in the atmosphere	Ruddiman, ch. 14, 15, & 16
May 6	34. Climate change – observations & predictions	Ruddiman, ch. 17 & 18; IPCC TAR WG1, ch. 1, pp. 92-98
May 8	35. A critical examination of GCMs	Ruddiman, ch. 19; IPCC AR4 WG1 Summary for Policy Makers; IPCC AR4 WG1 Technical Summary
May 10	36. Evaluating contrarian positions & determining where to go from here	Oppenheimer et al. (2007); IPCC TAR WG 1 ch. 8*; IPCC AR4 WG 1, ch 8*
Wednesday, May 15, 9:00-11:00 a.m. - ***SECOND EXAM***		

† An asterisk indicates that a particular reading is recommended and not required. Unless otherwise noted, PDF versions of readings other than the assigned text are available on the course BlackBoard site.

Full citations for readings posted to BlackBoard

Fischer, A. G. 1984. The Two Phanerozoic Supercycles. In: *Catastrophes and Earth History - The New Uniformitarianism* (edited by Berggren, W. A. & Van Couverling, J.E.). Princeton University Press, Princeton, 129-150.

Hambrey, M. J. & Alean, J. 2004. *Glaciers*. Cambridge University Press.

IPCC AR4 WG1 = Intergovernmental Panel on Climate Change Fourth Assessment Report by Working Group 1, *Climate Change 2007 - The Physical Scientific Basis*. The *Summary for Policy Makers*, *Technical Summary*, *FAQ* document, 11 numbered chapters, *Annexes*, etc. that constitute the latest publication by Working Group 1 are available in PDF format from the World Meteorological Organization web site. You can reach that using a link from the BlackBoard site for this course. Reports from other Working Groups are also available.

IPCC TAR WG1 = Intergovernmental Panel on Climate Change Third Assessment Report by Working Group 1, *Climate Change 2001 - The Scientific Basis*. You can download full Working Group 1 document, which includes a *Summary for Policy Makers*, a *Technical Summary*, 14 separate chapters, and *Appendices*, or publications by other Working Groups from the WMO web site. You need to follow the left side-bar link entitled *IPCC Reports*.

Oppenheimer, M., O'Neill, B. C., Webster, M.,& Agrawala, S. 2007. The limits of consensus. *Science* **317**, 1505-1506.

Ruddiman, William F. 2001. *Earth's Climate: Past and Future*. W. H. Freeman and Company.

General References (not posted)

Alverson, K. D., Bradley, R. S. & Pedersen, T. F. (editors). 2003. *Paleoclimate, Global Change, and the Future*. Springer.

Barry, R. G. & Chorley, R. J. 1992. *Atmosphere, weather, and climate, 6th Edition*. Routledge.

Bigg, G. R., 1996. *The Oceans and Climate*. Cambridge University Press.

Bradley, R. S. 1985. *Quaternary Paleoclimatology: Methods of Paleoclimatic Reconstruction*. Allen & Unwin.

Bryant, E. 1997. *Climate Processes & Change*. Cambridge University Press.

Eichenlaub, V. 1979. *Weather and Climate of the Great Lakes Region*. University of Notre Dame Press.

Houghton, J. T. 1997. *Global Warming: The Complete Briefing (2nd Edition)*. Cambridge Press.

Houghton, J. T., Jenkins, J. G. & Ephraums, J. J. 1990. *Climate Change: The IPCC Scientific Assessment*, Cambridge Press.

Houghton, J. T., Meira Filho, L.G. , Callander, B. A., Harris, N., Kattenberg, A., & Maskell, K. (1995) *Climate Change: The Science of Climate Change* (The Second Assessment Report), Cambridge Press.

Jäger, J. & Ferguson, H, L. 1991. *Climate Change: Science, Impacts, and Policy*. Cambridge Press.

Lamb, H.H. 1977. *Climate: Past, present, and future*. Methuen, v. I & II.

Moore, P. D., Chaloner, B., & Scott, P. 1996. *Global Environmental Change*. Blackwell Science.

Neelin, J. D. 2011. *Climate change and climate modeling*. Cambridge University Press.

Nesje, A. & Dahl, S. O. 2000. *Glaciers and Environmental Change*. Arnold Press.

Open University Team. 1989. *Ocean Circulation*. Pergamon Press, Oxford.

Paterson, W. S. B. 1994. *Physics of Glaciers, 3rd Edition*. Pergamon Press.

Skinner, B.J. & Porter, S.C. 1987. *Physical Geology*. John Wiley & Sons, New York.