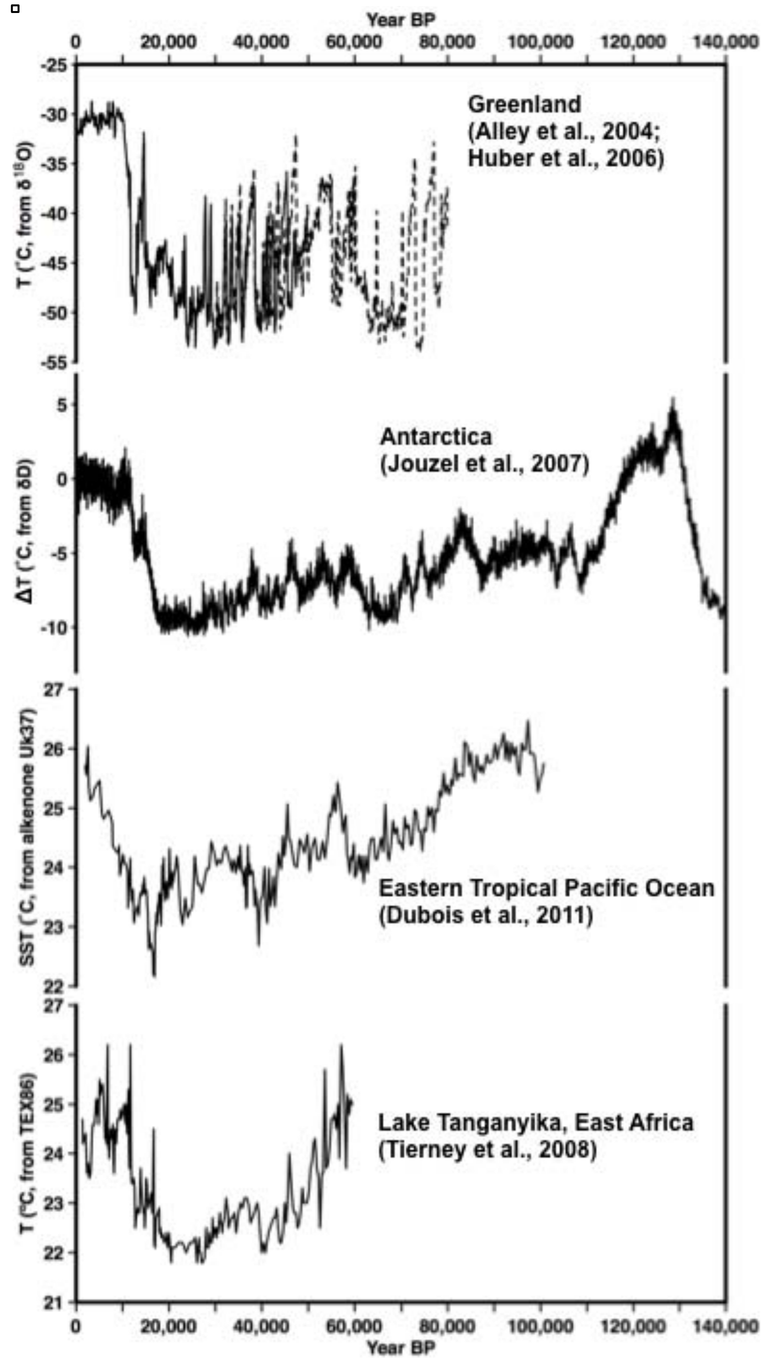
12.340: Global Warming Science
Problem Set #1: Paleoclimate
Date assigned: Thursday, 16 Feb 2012
Date due: Thursday, 23 Feb 2012

Question 1: Space- and time-scales in climate

Please use the following time-series of the local mean temperature [°C] estimated from time-series of isotope ratios in ice/sediment cores. (Note: Antarctica core shows temperature difference relative to present; x-axis = "Years Before Present").



a) Were there any times in the past 150,000 years in which temperatures were warmer than today? If so, when?

b) Based upon the paleoclimate temperature time-series:
   i) Do you think climate can change rapidly (consider how "rapid" might be defined)? Give an example to support your answer.
   ii) What can we say about changes in climate on the timescale of a human lifetime?

c) Which cores have time series that are generally similar or different? Based upon these observations, what conclusions might you draw about changes in climate at a regional vs. global scale? Do you think one core alone can provide good paleoclimate data?

d) Would you feel fairly confident predicting climate for the next 10 years? 100 years? 1,000 years? 100,000 years? Why or why not?

Question 2: Understanding the PETM using carbon isotopes

Around 55 Myr ago, global temperatures increased by 5-9˚C over 1-10 thousand years, and the $\delta^{13}C$ of the ocean's carbon (as recorded by benthic foraminifera) decreased by 3‰. The cause of the Paleocene-Eocene Thermal Maximum (PETM) was initially thought to be a sudden increase in volcanic activity. Some scientists now believe that it was caused by a massive injection of methane to the atmosphere from methane hydrates in marine sediments (the methane was subsequently oxidized to CO_2). Carbon isotope data offer a way to test these hypotheses, since volcanic CO_2 has a very different $\delta^{13}C$ than methane.

In the problems below, we'll consider only the carbon in the ocean and atmosphere. Assume that just prior to the PETM, the atmosphere held 2,000 GtC, and the ocean held 38,000 GtC. Because there's so much more carbon in the ocean than in the atmosphere, and because most of the ocean's carbon is in the deep ocean, the $\delta^{13}C$ of deep waters (again, recorded by benthic foraminifera) can be taken as the $\delta^{13}C$ of the combined ocean-atmosphere carbon reservoir.

a) Volcanic carbon dioxide $\delta^{13}C$ is –5‰. The average $\delta^{13}C$ of the climate system before the PETM was –1.45‰. The magnitude of change during the PETM was $\delta^{13}C$ was –3‰. Use the following isotopic mass balance equation to calculate how much volcanic carbon would have to be added to the climate system at the start of the PETM in order to produce the isotopic change observed. M_X is the mass of carbon at time X, $(\delta^{13}C)_X$ is the $\delta^{13}C$ at time X.

$$^{13}C \text{ during PETM (F)} = {}^{13}C \text{ before PETM (0)} + {}^{13}C \text{ added (A)}$$

$$(\delta^{13}C)_F M_F = (\delta^{13}C)_0 M_0 + (\delta^{13}C)_A M_A$$

b) Modern volcanic CO_2 fluxes are ~80 MtC per year (Morner and Etiope, 2002). Assume that the PETM carbon release occurred over 10,000 years. Using your answer from #1, by what factor would volcanic emissions have to increase to reach the implied fluxes for the PETM if volcanic CO_2 was the sole source of the additional carbon?

c) The average $\delta^{13}C$ of methane is –60‰. What mass of carbon from marine methane hydrates would have to be added to the climate system to cause the observed isotopic change? The estimated mass of carbon stored as marine methane hydrates today is 500 to 2,500 Gt. Do you think that dissociation of methane hydrates is a reasonable explanation for the PETM?

Question 3: Interpreting oxygen isotopes

The two plots below show glacial-interglacial variations in the $\delta^{18}O$ of deep-sea foraminifera and of Antarctic ice over the past 900,000 years.

a) Why does $\delta^{18}O$ change in opposite directions in the two records? Explain the main factor(s) affecting glacial-interglacial $\delta^{18}O$ changes in each record.

b) The records seem quite similar, but there are a few important differences. Identify one difference that seems fairly consistent and suggest a possible explanation for this difference.