Climate Changes GEOS 215

Spring, 2009

Problems due Wednesday, 18 March. Show all your work.

1. The Sun is about 4.6 billion years old, and its luminosity is increasing through time. The luminosity can be approximated by:

$$L = L_0\left(1 + \frac{0.4t}{4.6\text{Ga}}\right)^{-1}$$

where L is the luminosity at time t (in billions of years ago, Ga), and L_0 is the luminosity of the Sun today ($t = 0$).

a) Make a graph showing the luminosity of the Sun from the time of its formation to today.

For each of the following questions, derive an equation that describes the answer and plot the equation on a graph. You can put the answers to parts b to e on the same graph. In addition, for each question, write a paragraph discussing the implications of your calculation on the fate of the early Earth.

b) Assuming a constant albedo at the modern value ($\alpha = 0.3$), and no greenhouse gases in the atmosphere ($\beta = 0$), what is the evolution of the average temperature of the surface of Earth (T_G) from the time of its formation 4.5 Ga to today?

c) What would T_G be if β were at its modern value?

d) Could a change in albedo (and with modern β) bring T_G above freezing?

e) With a modern albedo, what β is required for T_G to be consistent with geological evidence for liquid water on Earth since 4.3 Ga?

2. The half life of ^{14}C ($t_{1/2}$) is 5780 years.

a) What is the decay constant (λ) of ^{14}C?

b) Carbon-14 is a very rare isotope. The ratio of ^{14}C to ^{12}C in the atmosphere today is 1.18×10^{-12}. During photosynthesis, a tree living takes up carbon isotopes in a ratio that is 95% that of the atmosphere (discriminating against ^{14}C). What is the $^{14}C/^{12}C$ of the wood?

c) In 1000 years, what will the $^{14}C/^{12}C$ of that wood be?

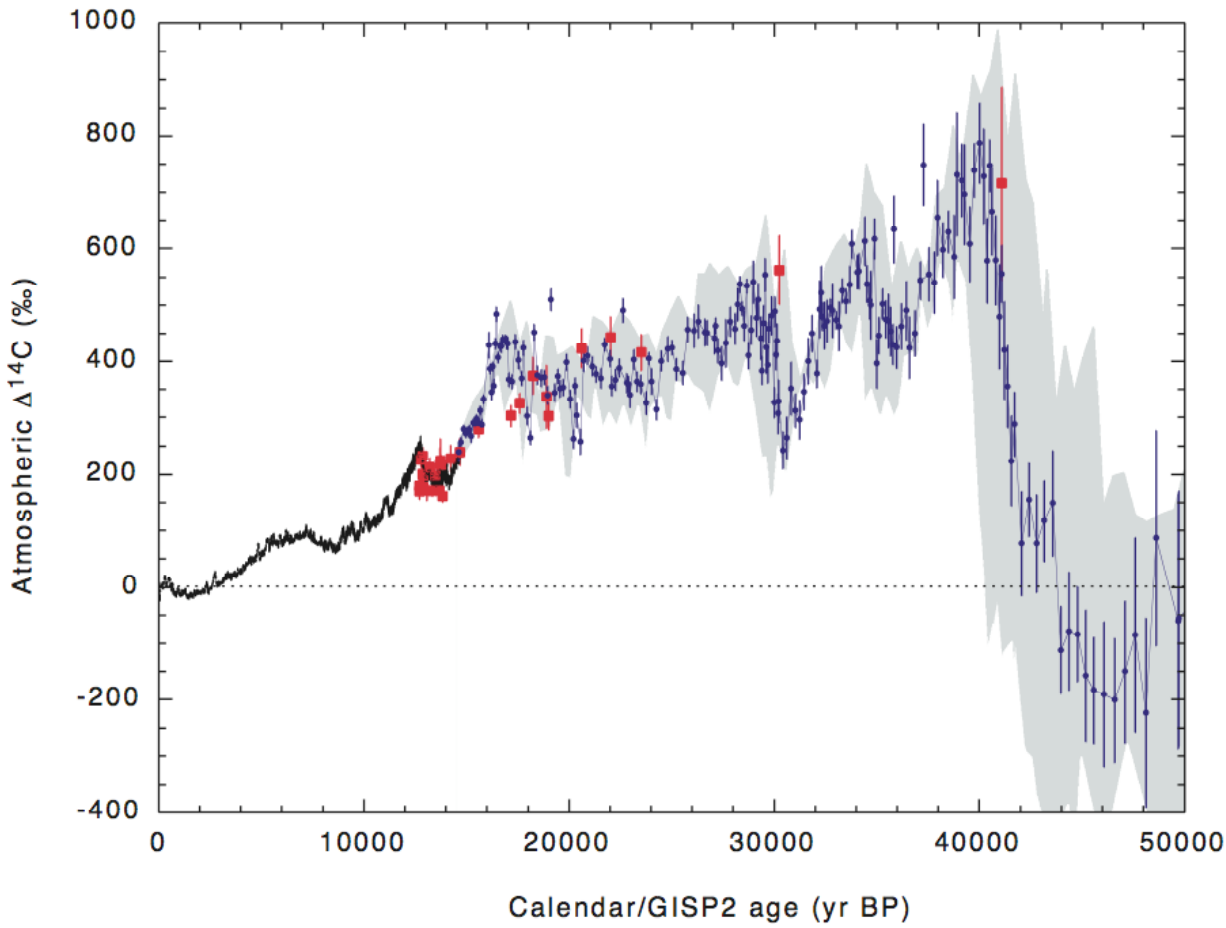
d) The delta notation is often used to describe the ratio of rare isotopes to the most common isotope of an element. The definition of $\Delta^{14}C$ is

$$\Delta^{14}\text{C} = 1000\left(\frac{r_{sample}}{r_{standard}} - 1\right)$$

where $r_{standard}$ is the $^{14}C/^{12}C$ of the modern atmosphere and r_{sample} is the $^{14}C/^{12}C$ of a sample. The units of $\Delta^{14}C$ are ‰ (permil, or parts per thousand anomaly from a standard). What is the $\Delta^{14}C$ of the sample of wood in part c?

e) If you found a sample of wood that had $\Delta^{14}C$ of –564‰, what is the age of the sample?

f) It turns out that the $\Delta^{14}C$ in the atmosphere is not constant through time (see the figure below). It has been decreasing pretty steadily since about 40 ka. So the amount of ^{14}C a sample starts out with (N_0) depends on when a sample formed. Is the actual age of the sample from part e larger or smaller than the radiometric age you calculated? Why?



Hughen et al., 2004