Proposed Effects of Early Agriculture on Current Climate

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Abstract

In 2001, paleoclimatologist William Ruddiman proposed the Early Anthropogenic Hypothesis. This hypothesis contends that the Anthropocene the era in Earths geological history in which humans have affected the climate began about 8,000 years ago. The large collection of evidence that is available in support of this hypothesis is what makes the proposal worthy of further investigation. In order to explore Ruddimans theory, it was necessary to refer to ecological data that has been collected on the carbon and carbon 13 content of the atmosphere over time; Schmitt, et al. has published a large set of data gathered from Antarctic ice cores. This data can then be used to analyze a series of box models. First, how carbon 12 and carbon 13 flows in and out of the atmosphere is found. Then, using the first model's information, how carbon flows to and from organic and inorganic sources is found. In the future, a box representing the carbon from anthropogenic sources proposed by Ruddiman will be added to the in/organic box model to help determine the validity of the Early Anthropogenic Hypothesis.

1 Introduction

Over the last 8,000 years, life on Earth has been in a dynamical state of change civilizations have risen and fallen due to natural disasters and plagues, landscapes have been altered with newly discovered fire and increasingly advanced tools, and various living things have ceased to exist or have had to find alternative habitats and sources of food. Through all this change, one thing is certain, Homo sapiens have had a greater effect on the planet during the last few thousand years than in the millions of years before hand. These observations have led to the development of the Early Anthropogenic Hypothesis by paleoclimatologist William Ruddiman. In particular, this hypothesis is supported by the evidence of departure from regular Milankovitch cycle trends, as well as by the timeline of development of human agriculture. Milankovitch cycles show how the Earths movement through space affects the climate. In past interglacial states, there has not been a late deglacial CO2 max; the Holocene followed this trend up until 8,000 years BP (before present) when we see an anomalous rise in atmospheric carbon dioxide. Most models agree that new glaciers would be forming by now, if anthropogenic effects are ignored: The 23,000 year cycle (precession effects) predicts CO2 max 10,000 years BP with a decrease to the present. The 41,000 year cycle (obliquity effects) predicts CO2 decrease starting 3,500 years BP and the 100,000 year cycle (eccentricity effects) predicts CO2 max 13,500 years BP, with a following long term decrease. These predictions combined tell us that there must be an effect on the climate that is overpowering the cycles that have been consistent for millions of years. One possible source of this excess atmospheric carbon is the terrestrial biosphere specifically biomass losses related to the development of agriculture across the globe. As humanity began its transition from hunter/gatherer society to a farming society, areas that had long been fully forested were quickly being cleared and planted with edible crops meaning these areas, which were previously carbon sinks, have now become carbon sources. Therefore, the model designed for this exploration should show if the increasing amount of carbon seen in the atmosphere has its origin in the terrestrial biosphere.

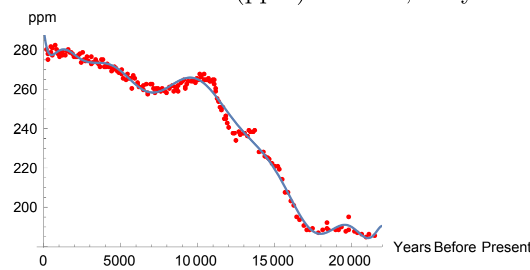
Most basically, a three box model can be set an atmosphere box, an inorganic carbon box, and an organic carbon box. This model will show the rates of change of amount of carbon in terrestrial biosphere (organic box) and ocean/crust/volcanoes (inorganic box). Before this model can be explored it is necessary to determine how the atmospheric concentration of carbon-12 and carbon-13 have changed over time. This can be found by using the experimentally measured carbon dioxide concentration and δ^{13}C of that carbon. These measurements can be obtained for tens thousands of years into the past from ice cores drilled from Antartic glaciers. A paper has been published by Schmitt, et al. with ice core reconstructions of δ^{13}C and CO_2 concentration over the past 24,000 years. This data was fit with a degree-13 polynomial in order to obtain a time series for the carbon dioxide concentration and for the isotopic signature of that carbon.

2 CO_2 and δ^{13}C from Schmitt

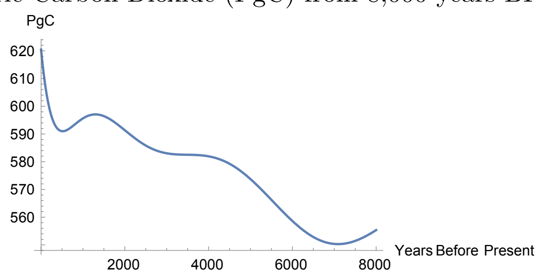
The CO_2 and δ^{13}C data was imported from the supplementary materials published by Schmitt et al. in Science, then fitted with a polynomial to obtain a time series using Mathematica. The data published for carbon dioxide concentration is measured in ppm; for our purposes PgC (GtC) is a more practical unit, so this conversion will be used going forward. One issue with this approach appears at the end points of the data fit - using a polynomial will not necessarily properly capture the data nearest to the time extremes. A refinement for future work on this data would be to correct for this inaccuracy. Besides this issue polynomials are sensible for use in the following models because it is easy to take derivatives. Graphical representations of CO_2(t), δ^{13}C(t), and $\frac{d}{dt}CO_2(t)$, and $\frac{d}{dt}\delta^{13}C(t)$ are shown below. It can be seen that the carbon dioxide concentration in the atmosphere has increased over the past 8,000 years. The most recent data point obtained from the ice cores was 173 years ago, therefore "Present" is pre-industrial. Keep in mind that the derivative is calculated as time goes backwards (from present to 8,000 years ago) so an increase to the present is shown as a decrease into the past.

$$CO_2(t) \tag{1}$$

Atmospheric Carbon Dioxide (ppm) from 22,000 yr BP to Present

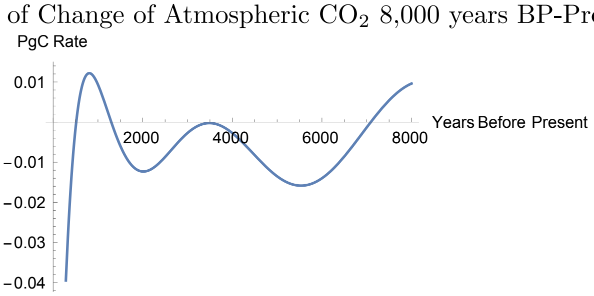


Atmospheric Carbon Dioxide (PgC) from 8,000 years BP to Present



$$\frac{d}{dt}CO_2(t) \tag{2}$$

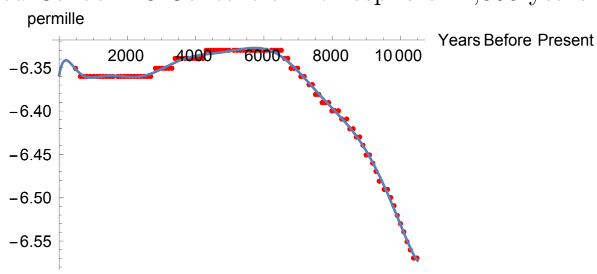
Rate of Change of Atmospheric CO_2 8,000 years BP-Present



When plotted, the data from Schmitt, et al. shows that atmospheric carbon dioxide has been on an upward trend over the last 22,000 years. As this paper is concerned with activity in the last 8,000 years, only the plots for the data obtained from Schmitt are shown beyond that time period. The plot of Atmospheric Carbon Dioxide (PgC) from 8,000 years BP to today shows there has been an increase of over 100 PgC in the atmosphere since the dawn of agriculture. Ruddiman claims that, including the industrial revolution, up to 320 PgC have been released from anthropogenic sources. According to the NOAA, the current concentration of atmospheric carbon dioxide is approximately 858 PgC, over 200 PgC more than our last data point. Thus is appears our model supports Ruddiman's claim that about 320 PgC have been added to the atmosphere in the last 8,000 years. Therefore the next step is to check if the source of this excess carbon appears to be an anthropogenic source.

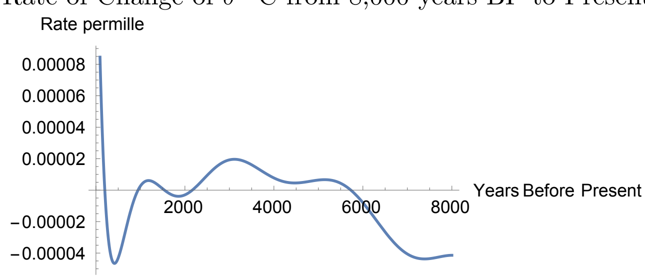
$$\delta^{13}C(t) \tag{3}$$

Standardized Carbon-13 Content of Atmosphere 11,000 years BP-Present



$$\frac{d}{dt}\delta^{13}C(t) \tag{4}$$

Rate of Change of δ^{13}C from 8,000 years BP to Present



These plots show that δ^{13}C increased rapidly up to 6,000 years BP then stayed approximately constant. δ^{13}C is standardized to the VPDB standard and reported in permille. It can be seen that the δ^{13}C changed about .2‰, meaning that the change in this value over the target time period is very small.

3 ^{12}C and ^{13}C

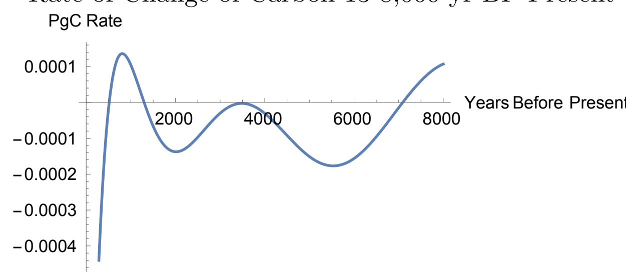
How ^{12}C and ^{13}C vary over time is determined here; these functions can be used to explore how carbon of a specific isotopic content varies, as is done in the final section. To obtain a time series for the ^{12}C and ^{13}C, it is necessary to use CO_2(t) and δ^{13}C(t) together with the standard VPDB $\frac{^{12}C}{^{12}C}$ which is .0112372, call this s. The standard is used to determine the ratio of carbon 12 to carbon 13 in the data, and ^{13}C(t) is obtained by taking that ratio of the total atmospheric carbon dioxide. Further, ^{12}C(t) is simply the total atmospheric carbon less the ^{13}C concentration.

$$^{13}C(t) = ((\delta^{13}C(t)/1000) * s + s)CO_2(t)$$

$$^{12}C(t) = CO_2(t) -^{13} C(t)$$

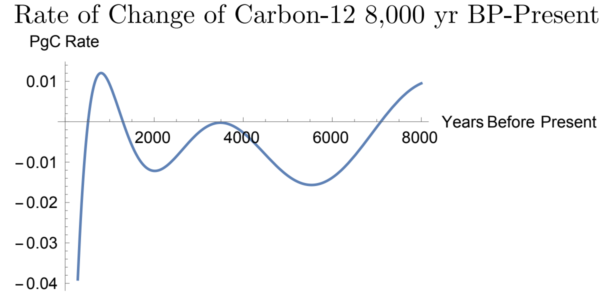
$$\frac{d}{dt}^{13}C(t) \tag{5}$$

Rate of Change of Carbon-13 8,000 yr BP-Present



$$\frac{d}{dt}^{12}C(t) \tag{6}$$

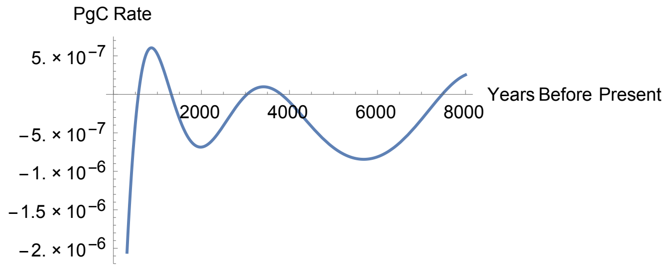
Rate of Change of Carbon-12 8,000 yr BP-Present



It is difficult to see how the change in carbon-13 and change in carbon-12 differ over time as the carbon-12 is the dominating term. Therefore, we would like to standardize the carbon-12 to VPDB and compare that to the carbon-13.

$$\frac{d}{dt}{}^{13}C(t) - s * \frac{d}{dt}{}^{12}C(t) \tag{7}$$

Difference of ^{12}C and ^{13}C Rate of Change 8,000 yr BP-Present



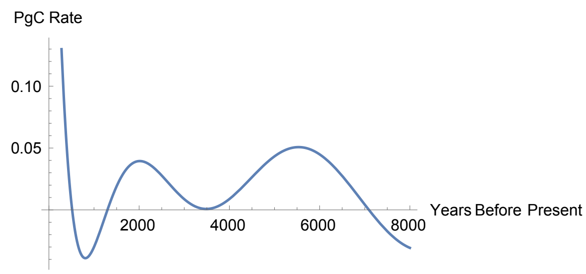
This plot shows that the amounts of carbon-12 and carbon-13 in the atmosphere are changing at different rates, as needed. Further, it can indeed be seen that the difference in rate of change at any given time is small, which is to be expected as the δ^{13}C at any given time is on the order of thousandths.

4 Organic and Inorganic ^{12}C

After determining how ^{12}C and ^{13}C changed over time, these functions can be used to set up a system of equations to observe how organic and inorganic ^{12}C changed over that same period of time. This system will depend on two parameters r_1 and r_2, which represent the δ^{13}C of the two pools of carbon, allowing for a future sensitivity analysis to show how the system behaves with small changes to these estimated values. The system defined below can be described as the sum of inorganic and organic carbon 12 leaving or entering the atmosphere is at each time equal to the total amount of carbon 12 in the atmosphere, while the same is true for carbon 13. For the given plots of the rates of Organic and Inorganic ^{12}C, it is assumed organic is carbon in the biosphere so r_1 is -27‰ and inorganic carbon is mostly ocean so r_2 is 6‰.

$$\begin{aligned} \tfrac{d}{dt}{}^{12}C_O(t) + \tfrac{d}{dt}{}^{12}C_I(t) &= \tfrac{d}{dt}{}^{12}C(t) \\ r_1 \tfrac{d}{dt}{}^{12}C_O(t) + r_2 \tfrac{d}{dt}{}^{12}C_I(t) &= \tfrac{d}{dt}{}^{13}C(t) \end{aligned}$$

$$\frac{d}{dt}{}^{12}C_O(t, r_1, r_2) = \frac{\begin{vmatrix} \tfrac{d}{dt}{}^{12}C(t) & 1 \\ \tfrac{d}{dt}{}^{13}C(t) & r_2 \end{vmatrix}}{r_2 - r_1} \tag{8}$$



$$\frac{d}{dt}^{12}C_I(t) = \frac{\begin{vmatrix} 1 & \frac{d}{dt}^{12}C(t) \\ r_1 & \frac{d}{dt}^{13}C(t) \end{vmatrix}}{r_2 - r_1} \tag{9}$$