Seasonality of carbon-14 in atmospheric carbon dioxide at Point Barrow, Alaska: Observations and modeling

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Introduction

- $\Delta^{14}C$ of atmospheric CO_2 has been measured regularly at few stations, despite its value in tracing fossil fuel emissions, biosphere respiration, and air-sea gas exchange.
- Here, we present two years of $\Delta^{14}C$ measurements (July 2003-August 2005) of flask samples at Point Barrow, Alaska, collected weekly to monthly at the same place and times as flasks for NOAA gas measurements.
- Measurement precision, confirmed by running replicate samples, is about 2 permil.
- We compare the seasonal cycle in these observations with that predicted using the atmospheric transport model MATCH (*1*) and estimated fields of fossil emissions, land photosynthesis and respiration, air-sea CO_2 exchange, and exchange with the stratosphere.

Data Reduction

- Using least squares, we fit a long-term trend (at annual resolution) and a superimposed seasonal cycle (at monthly resolution) to the measurements.
- The long-term trend was constrained to be close to linear (small second derivative) and the seasonal cycle, with zero mean, was constrained to be close to constant (small first derivative); the smoothing weights were chosen through generalized cross validation (*2*).

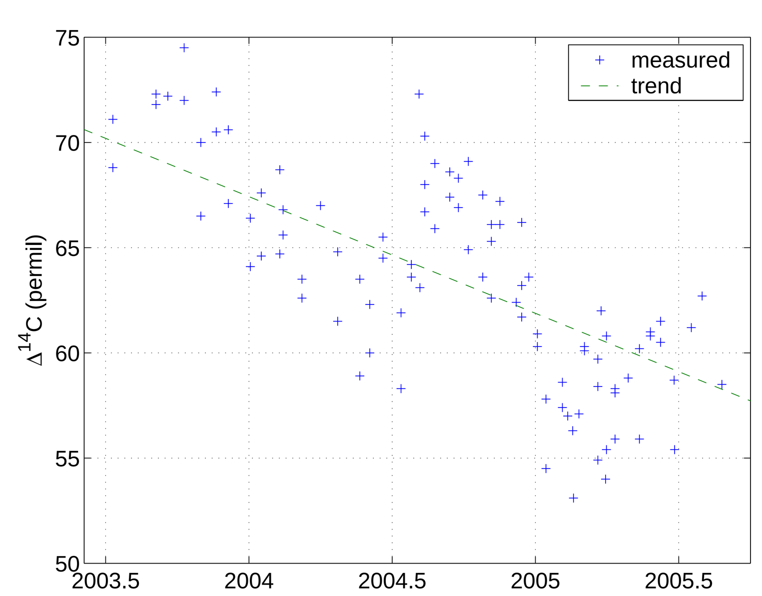

Figure 1. Point Barrow $\Delta^{14}C$ measurements and the derived long-term trend, showing a decline rate of 5.5 permil / year.

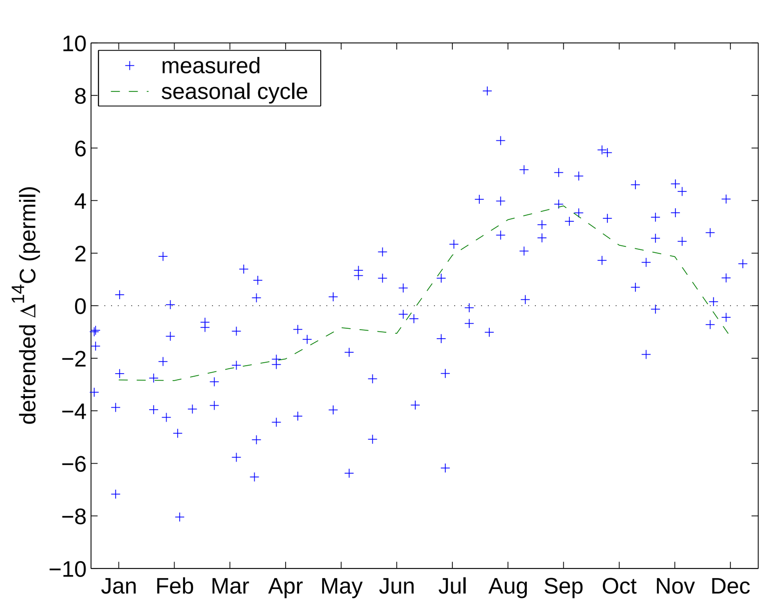

Figure 2. Point Barrow $\Delta^{14}C$ measurements with the long-term trend removed, showing the derived mean seasonal cycle, with a minimum around February, a maximum around September and an amplitude of 7 permil.

Modeled seasonal cycle: CO_2 and $\delta^{13}C$

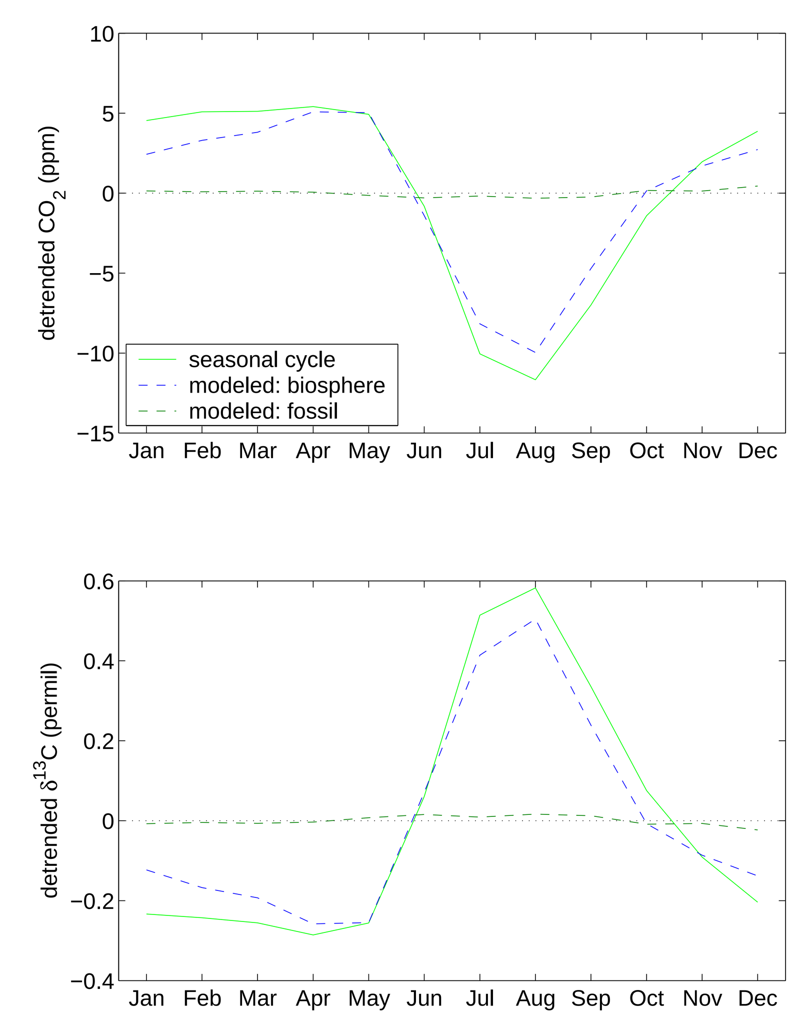

Figure 3. The seasonal cycle in CO_2 and its $\delta^{13}C$ at Point Barrow, derived from NOAA flask measurements (*3*-*4*) for 2001-2004, compared with model simulations.

- The observed amplitudes are 17 ppm and 0.9 permil respectively, and the cycles in CO_2 and $\delta^{13}C$ are almost perfectly anticorrelated, suggesting that biosphere exchange and/or fossil emissions with $\delta^{13}C$ of -25 to -30 permil are the primary contributors.
- The dashed lines show the modeled seasonal cycles, assuming seasonally constant fossil emissions from *Andres et al.* (*5*) (We scaled up their 1995 map by 10%.) and land biosphere seasonality and age structure from the CASA model (*6*). To model ^{13}C fluxes, fossil fuel carbon was assumed to have a uniform $\delta^{13}C$ of -28 permil and photosynthesis to have a uniform discrimination of 19 permil against ^{13}C, typical of C_3 vegetation.
- The modeled seasonal cycle due to biosphere emissions matches the observed shape well. An increase in its amplitude of 20%, either due to higher plant productivity than in CASA or to more air from forest areas being transported to Barrow than our model predicts, would better match the observed amplitude.
- The modeled seasonal cycle due to fossil fuel burning is small (with an amplitude of 0.7 ppm CO_2).
- The modeled seasonal cycle due to CO_2 exchange with the ocean as estimated from air-sea disequilibria (*7*) is even smaller (amplitude of 0.2 ppm CO_2) and not plotted.

Modeled seasonal cycle: $\Delta^{14}C$

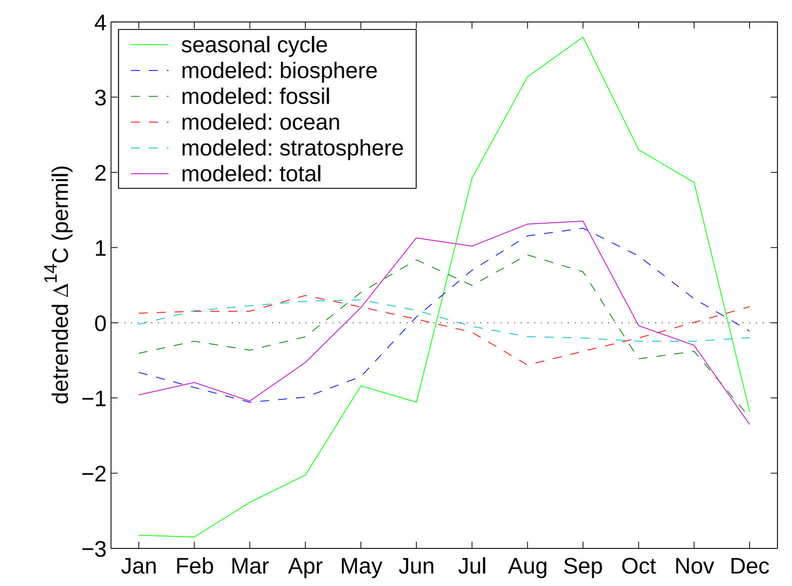

Figure 4. The modeled vs. observed seasonal cycle of $\Delta^{14}C$ at Point Barrow.

- The modeled seasonal cycle due to land biosphere respiration, which releases previously fixed bomb ^{14}C, has an amplitude of 2.2 permil, peaking in the summer when there's more respiration.
- The modeled seasonal cycle due to fossil fuel burning has an amplitude of 1.8 permil and dips in the winter when emissions stay closer to the ground.
- The modeled seasonal cycle due to ocean ^{14}C uptake has an amplitude of 0.9 permil, with a dip in the late summer, mostly because the model has more air coming in then from the North Atlantic/ Arctic Ocean, where the ocean takes up ^{14}C.
- The modeled seasonal cycle due to exchange with the upper atmosphere, where cosmogenic ^{14}C is produced and where there is higher residual bomb $\Delta^{14}C$, has an amplitude of 0.5 permil, with a peak in April-May when the most air from the northern stratosphere is modeled to reach the surface.

Conclusions: *Can we explain the observed $\Delta^{14}C$ seasonal cycle?*

The amplitude of the observed seasonal cycle at Barrow is underestimated by our model, and its phase is not fully explained either. Possible resolutions include:

Fossil fuels

- The observed seasonal cycle could be due to different seasonality of fossil fuel emissions and transport from what our model predicts, with larger amplitude and a trough in July-October instead of June-August. This seems quite possible for realistic seasonality in the fossil emissions. The level of fossil fuel carbon required would be small relative to the magnitude of the seasonal cycle in CO_2 (adding 1 ppm fossil CO_2 reduces $\Delta^{14}C$ by some 2.8 permil).
- This could be tested by comparing the seasonality of other gases that correlate with fossil fuel emissions, such at CO and SF_6.

Stratosphere

- The observed peak in the late summer could also due to more stratospheric air, with high $\Delta^{14}C$, reaching Barrow then, contrary to our model predictions.
- This could be tested by looking at the phase of the $\Delta^{14}C$ seasonal cycle in the Arctic during the 1960s, when transport from the stratosphere clearly dominated (*8*).
- Looking at transport from the stratosphere in other models may also help.

Biosphere

- The modeled biosphere seasonality has the right shape to account for the observed summer peak, but the amplitude is too small by over a factor of 2.
- The overall biosphere flux cannot be a factor of 2 larger than modeled because the CO_2 and $\delta^{13}C$ seasonal cycles would then be too large.
- Possibly, the seasonality of respiration in CASA or the residence time of carbon in organic matter (which affects the mean bomb $\Delta^{14}C$ enrichment of respired carbon) are wrong. However, uniformly changing the residence time of carbon in organic matter does not lead to a better match with observations (Figure 5).

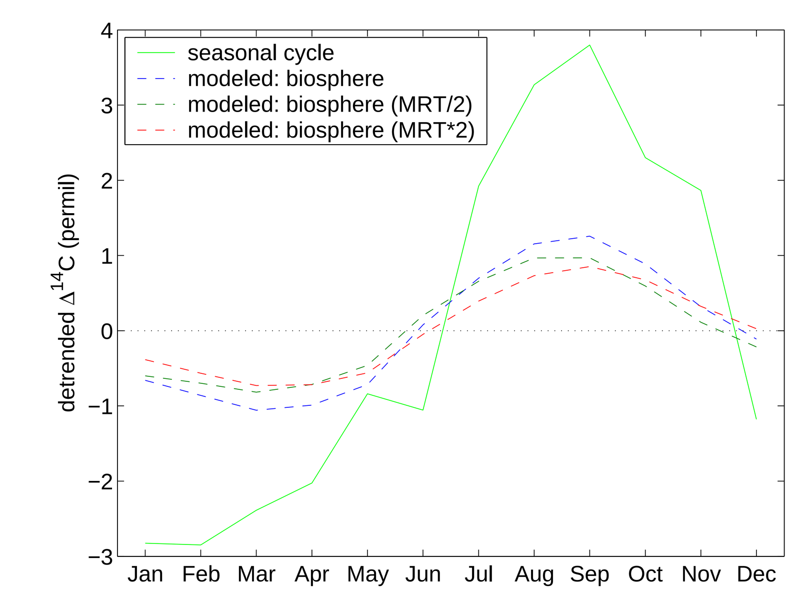

Figure 5. The modeled seasonal cycle in $\Delta^{14}C$ due to seasonality in biosphere respiration if we uniformly halve or double the mean residence time (MRT) of carbon in each of the organic pools in CASA. Because of the way in which the mean residence time distribution in CASA convolves with the history of bomb ^{14}C, whose decay time is about the same as the $\sim$18 year mean residence time found in CASA, uniformly changing MRT does not increase the seasonal cycle amplitude as required to match observations.

References

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