Comment on "Probability Distributions of Radiocarbon in Open Linear Compartmental Systems at Steady-State" by I. Chanca, S. Trumbore, K. Macario, and C. A. Sierra

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Key Points:

- The radiocarbon (^{14}C) distributions proposed by Chanca et al. (2022) are not measurable.
- The ^{14}C distributions proposed by Chanca et al. (2022) are not comparable to the distributions of ^{14}C measurements.
- The variability of ^{14}C measurements of soil respiration can not be captured with deterministic models with constant parameters.

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Abstract

Chanca et al. (2022) construct radiocarbon (^{14}C) distributions for compartmental ecosystem models and compare them to the variability of measured ^{14}C data for soil respiration. However, their ^{14}C distributions do not represent a measurable quantity and may not be used to draw any conclusions on the variability of ^{14}C measurements.

1 Measurability of the theoretical ^{14}C distributions

Chanca et al. (2022) construct radiocarbon (^{14}C) distributions based on the age distributions of linear compartmental ecosystem models at steady state, where the "age" of a carbon atom is the time elapsed since the atom entered the system. The ^{14}C distribution is created by associating each age in the age distribution to the decay-corrected $\Delta^{14}C$ (a normalized, standardized measure of ^{14}C content) of atmospheric CO_2 at the time when the carbon atom entered the simulated system from the atmosphere (e.g. through photosynthesis). By definition, the random variable associated with the age distribution is the age of a randomly sampled carbon atom. Therefore, by extension, the random variable associated with the ^{14}C distribution is the $\Delta^{14}C$ of a randomly sampled carbon atom, or alternatively, the decay-corrected atmospheric $\Delta^{14}C$ at the time when the randomly sampled carbon atom entered the system. However, it does not make sense to measure the $\Delta^{14}C$ for one single carbon atom, since $\Delta^{14}C$ can only be measured as the ratio between ^{14}C and the stable carbon isotopes, thus requiring a sample of many atoms. Therefore, the theoretical ^{14}C distributions are not measurable.

2 Comparing measured and theoretical ^{14}C distributions

Chanca et al. (2022) directly compare the means, modes, and standard deviations of their theoretical $\Delta^{14}C$ distribution and the distribution of $\Delta^{14}C$ measurements of CO_2 outflux from soils. They observe that the measured distribution looks quite different from their theoretical distribution: even though the two distributions generally have the same mean, the measured distribution looks more unimodal, and its standard deviation is around 10 times smaller than that of the theoretical $\Delta^{14}C$ distribution. Chanca et al. (2022) claim that the theoretical distribution in part explains the variability in the observations. However, we can not expect $\Delta^{14}C$ measurements to depend on anything but the mean of the theoretical distribution. Modern accelerator mass spectrometry (AMS) instruments require at least 10^{18} carbon atoms (or 20 µg of carbon) to perform precise $\Delta^{14}C$ measurements (Melchert et al., 2019). With such a large number of carbon atoms, we are bound to capture a wide range of ages in our sample, so we end up measuring a weighted average of past atmospheric $\Delta^{14}C$ values (corrected for radioactive decay), thus creating a new, distinct $\Delta^{14}C$ distribution. Furthermore, assuming the atoms in our carbon samples are random independent samples of the age distribution, the resulting measured $\Delta^{14}C$ distribution becomes independent of the spread and shape of the theoretical $\Delta^{14}C$ distribution. It is therefore inappropriate to compare the standard deviations and modes of the theoretical and measured $\Delta^{14}C$ distributions.

3 Causes for the variability in ^{14}C measurements

Besides errors introduced during sample processing and measurement, the most important sources of variability in $\Delta^{14}C$ measurements of pedogenic systems are small-scale spatial heterogeneity and temporal fluctuations (Hoffmann et al., 2017; Schöning et al., 2006; van der Voort et al., 2016), which cause the age distribution of the soil carbon outflux to be different for different samples. To correctly represent the variability of imperfect $\Delta^{14}C$ measurements of samples which are not taken at the exact same location and at the exact same time, we would need a stochastic model with spatial and temporal resolution. However, Chanca et al. (2022) only use deterministic models with constant parameters (Harvard Forest model, Porce model, Emmanuel model), which are incapable of capturing the variability of Δ^{14}C measurements.

4 Summary and conclusion

In this comment, we have shown that:

1. The random variable which defines the theoretical ^{14}C distribution proposed by Chanca et al. (2022) does not represent a measurable quantity.
2. The variability in Δ^{14}C measurements is not comparable to and does not depend on the shape and spread of the theoretical ^{14}C distribution.
3. The actual variability of measured Δ^{14}C cannot be captured with the models used as examples in Chanca et al. (2022).

We conclude that the theoretical Δ^{14}C distributions do not serve a practical purpose, and that the results and conclusions in Chanca et al. (2022) which relate the theoretical ^{14}C distributions to Δ^{14}C measurements are invalid.

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