ESS 461: Calibration of Radiocarbon Ages

Variations in the atmospheric ^{14}C activity through time, and error in the half-life used to calculate radiocarbon ages cause ^{14}C ages to deviate from the "calendrical" timescale.

Calendrical ages can be recovered from radiocarbon dates by use of a "calibration curve", a plot of ^{14}C age measured on tree rings *vs* calendar age. The presently accepted calibration curve has been painstakingly produced by ^{14}C dating successive 1-, 10-, and 20-year tree ring segments in a sequence extending back to ~11,500 years BP. Carbon-14 ages from corals and speleothems dated by the ^{238}U-^{234}U-^{230}Th method, and from annually-layered lake and marine sediments extend the curve back further, to 50,000 cal BP (which is the effective limit of radiocarbon dating). You can download both the data on which the calibration is based, and plots of the calibration curve from: http://www.radiocarbon.org/IntCal13.htm. Take a look at the pdf plots of the curve and compare the tree-ring-based part of the curve (0-11,500 yr) with the subsequent section. Notice how the precision of the later curve is quite a bit lower, and that some of the calibration data sets disagree significantly. Other calibration curves (for marine, and southern hemisphere samples), plus reference information for the papers describing the construction of the curve are also at: http://www.radiocarbon.org/IntCal13.htm.

The ^{14}C age plotted in the calibration curve is the formally defined value:

$$\mathbf{t = -\ln(R/R_0) / \lambda_{Libby} = -\ln(pmC) / \lambda_{Libby}}$$

where: R is the measured $^{14}C/C$ ratio of the sample.

R_0 is the $^{14}C/C$ ratio of a standard intended to represent the hypothetical $^{14}C/C$ ratio of the 1950 atmosphere without industrial CO_2 additions.

$\lambda_{Libby} = \ln 2 / 5568\ \text{yr} = 1.2449 \times 10^{-4}\ \text{yr}^{-1}$, *i.e.* the decay constant derived from the half-life assumed in Libby's original measurements.

The calibrated (or "cal" or "dendrochronological" or "calendar" age) is the mid-point age of the tree-ring segment dated with ^{14}C. The tree ring samples used in the calibration span 1-20 years of growth, with individual rings in the early part and longer spans as we go further back in time. The calibration curve is pieced together from many separate trees and logs, using both the ^{14}C dates and characteristics of the rings (width and wood density) to ensure accurate matching.

Excellent summaries of the calibration data and methodology are given in:

Reimer P.J., et al. (2013) IntCal13 and Marine13 radiocarbon age calibration curves 0–50,000 years cal BP. *Radiocarbon* 55, 1869–1887.

Stuiver M., Long A. and Kra R. eds. (1993) Calibration 1993. *Radiocarbon* 35(1), 1-244.
and:

Reimer P. *et al.* (2004) IntCal04 Terrestrial radiocarbon age calibration, 0–26 cal kyr BP. *Radiocarbon* 46(3) 1029-1058.

The data underlying the calibration curve are available on the Web (see the link above) and are incorporated into various online and stand-alone programs (e.g. "CALIB") for calibrating ^{14}C dates. Today's lab is based on the ^{14}C calibration data set for the last 1000 years, much of which was measured by Minze Stuiver at the UW Quaternary Isotope Lab.

Use a Web browser to import the dendrochronological and C-14 age data from the class website: http://faculty.washington.edu/stn/ess_461/labs.shtml. Download both the question sheet (MS Word or pdf) and the Excel spreadsheet which contains the calibration data.

(1) To start with, notice the difference between the ^{14}C ages and the known tree-ring ages throughout the last 1000 years!

What does this tell you about the initial ^{14}C ratio (or, equivalently the ^{14}C activity) of the atmosphere over the last millenium, compared to the standard value assumed for R_0 (the hypothetical reference value for 1950) ?

(NB!! Note that the C-14 age of 1950 wood (calendar age = zero) is decidedly non-zero, because the standard value R_0 is defined to simulate the 1950 atmosphere without the addition of fossil fuel-derived carbon).

(2) **In a new column, calculate the ratio of the initial ^{14}C activity A_{init} to the 1950 reference value for each calibration point.** This ratio is referred to as $\Delta^{14}C$ when expressed as a percent deviation from the 1950 reference value ($\Delta^{14}C = 100 ((R_{init}/R_0) - 1)$). $\Delta^{14}C$ is a measure of the deviation of atmospheric ^{14}C activity from the pre-industrial baseline.

Think carefully about how to derive the expression for $\Delta^{14}C$ from the ^{14}C age and the dendrochronological age. You will need to use both the "Libby" value of the decay constant λ_{Libby} (1.2449×10^{-4} yr^{-1}) and the "correct" value λ_{true} (1.2097×10^{-4} yr^{-1}).

(3) **Plot $\Delta^{14}C$ vs calendar age. Look at the $\Delta^{14}C$ curve over the period 1900 AD - 1950 AD. What is the trend in $\Delta^{14}C$ over this time? Suggest two possible causes for the trend.** The intensification of human industrial activity since the late 1800s has resulted in significant growth of the atmospheric CO_2 concentration, from ~275 ppm in 1850 to ~315 ppm in 1950 (it has since increased to ~ 400 ppm). The added CO_2 comes from several sources, of which fossil fuel burning and clearing of forest vegetation are the two most important. **What is the likely difference in ^{14}C activity between the CO_2 that is added in each of these processes? Which source dominated the CO_2 added to the atmosphere between 1900 and 1950 ?**

The decrease in ^{14}C activity of atmospheric CO_2 over the period 1900 - 1950 (causing ^{14}C ages for this period to appear anomalously "old") is referred to as the "Suess effect", named after Hans Suess, who first documented and explained it.

low solar activity , as measured by the number of sunspots (dark areas on the Sun's surface representing regions of intense magnetic magnetic flux). The sunspot number varies through 11 year cycle of solar activity, but dropped to zero for significant periods during the Maunder Minimum, indicating a comparatively weak solar magnetic field. This allows lower energy cosmic ray particles to enter the solar system, increasing the flux received by the Earth.

(5) **Plot the Calendar Age data (x-axis) against their respective ^{14}C ages.** This is the radiocarbon calibration curve for the last 1000 years (950 AD - 1950 AD). **Set up your spreadsheet to plot a horizontal line on the same graph at the ^{14}C age of an "unknown" sample.**

Using either the graph, or the table of calibration data, calculate the calendar ages corresponding to ^{14}C ages of

(i) 740 yrs

(ii) 540 yrs

(iii) 640 yrs

Are calibrated ages always unique values ?

(6) **Enhance your spreadsheet by adding horizontal lines corresponding to the error bounds on a ^{14}C age** (i.e. for a ^{14}C age of 740 ± 80 yrs, plot the error limits as horizontal lines at 660 yrs and 820 yrs).

Using your graph, calculate the calendar age limits on samples with ^{14}C ages of:

(i) 390 ± 80 yrs

(ii) 860 ± 80 yrs

(iii) 860 ± 40 yrs

Are the error limits generally symmetrical around the calibrated age ?

Can increasing the precision of the ^{14}C age measurement decrease the ambiguity of a calendar age assignment?

(7) **Suppose you want to determine the precise time of death of a large, well-preserved log, that contains rings from 100 years of growth. The ^{14}C age of the outer few rings is 640 ± 40 yrs. How could you resolve the ambiguous calendar age of this sample ?**

A sample of the output display from the calibration program "CALamity" produced and refined by students in the 1999 & 2001 classes. The program converts conventional radiocarbon ages to calibrated (i.e. "calendrical") ages based on the INTCAL 98 C-14 data set.

CALamity

	Age	Error (1σ)	Bounds (1σ)
Your C-14 age:	2360	100	2260
			2460

Calibration results

Number of curve intersections

Your lower error bound cuts the calibration curve in	Your C-14 age cuts the calibration curve in	Your upper error bound cuts the calibration curve in
1	1	3
place	place	places

Age intercepts

Minimum age intercepts (Cal. yr BP)	C-14 age intercepts (Cal. yr BP)	Maximum age intercepts (Cal. yr BP)
		2705
		2701
		2481

	2354	

2323