**ESS 461: Calibration of Radiocarbon Ages**

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

Calendrical ages can be recovered from radiocarbon dates by use of a "calibration curve", a plot of 14C age measured on tree rings *vs* calendar age. The presently accepted calibration curve has been painstakingly produced by 14C 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 238U-234U-230Th 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 14C age plotted in the calibration curve is the formally defined value:

**t = - ln(R/R0) / Libby = - ln(pmC) / Libby**

where: R is the measured 14C/C ratio of the sample.

R0 is the 14C/C ratio of a standard intended to represent the hypothetical 14C/C ratio of the 1950 atmosphere without industrial CO2 additions.

Libby = ln 2 / 5568 yr = 1.2449 x 10-4 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 14C. 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 14C 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:

Stuiver M.  *et al.* (1998) INTCAL98 radiocarbon age calibration 24,000 - 0 cal BP. *Radiocarbon* 40(3).

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 14C dates. Today's lab is based on the 14C 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 14C ages and the known tree-ring ages throughout the last 1000 years!

**What does this tell you about the initial 14C ratio (or, equivalently the 14C activity) of the atmosphere over the last millenium, compared to the standard value assumed for R0 (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 R0 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 14C activity Ainit to the 1950 reference value for each calibration point.**  This ratio is referred to as 14C when expressed as a percent deviation from the 1950 reference value (14C = 100 ((Rinit/R0 ) - 1) ). 14C is a measure of the deviation of atmospheric 14C activity from the pre-industrial baseline.

Think carefully about how to derive the expression for 14C from the 14C age and the dendrochronological age. You will need to use both the "Libby" value of the decay constant Libby (1.2449 x 10-4 yr-1) and the "correct" value true (1.2097 x 10-4 yr-1).

(3) **Plot 14C vs calendar age. Look at the 14C curve over the period 1900 AD - 1950 AD. What is the trend in 14C 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 CO2 concentration, from ~275 ppm in 1850 to ~315 ppm in 1950 (it has since increased to ~ 400 ppm). The added CO2 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 14C activity between the CO2 that is added in each of these processes? Which source dominated the CO2 added to the atmosphere between 1900 and 1950 ?**

The decrease in 14C activity of atmospheric CO2 over the period 1900 - 1950 (causing 14C 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.

(4) **What was the trend in 14C values over the period from ~ 1600 AD to the mid 19th century ? Was the cosmic ray flux generally higher or lower during this period than in 1950?** This period of time corresponds quite closely with the "Maunder Minimum", a time of 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 14C 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 14C age of an "unknown" sample.**

**Using either the graph, or the table of calibration data, calculate the calendar ages corresponding to 14C 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 14C age** (i.e. for a 14C 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 14C 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 14C 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 14C 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.

