An Online Application for ΔR Calculation

Reimer, R., & Reimer, P. J. (2017). An Online Application for ΔR Calculation. *Radiocarbon Journal*.
https://doi.org/10.1017/RDC.2016.117

Published in:
Radiocarbon Journal

Document Version:
Peer reviewed version

An on-line application for ΔR calculation

R. W. Reimer and P. J. Reimer

14CHRONO Centre for Climate, the Environment and Chronology, Queen's University Belfast, Belfast BT7 1NN, UK
* corresponding authors emails: r.reimer@qub.ac.uk and p.j.reimer@qub.ac.uk

Abstract

A regional offset (ΔR) from the marine radiocarbon calibration curve is widely used in calibration software (e.g. CALIB, OxCal) but often is not calculated correctly. While relatively straightforward for known age samples, such as mollusks from museum collections or annually-banded corals, it is more difficult to calculate ΔR and the uncertainty in ΔR for 14C dates on paired marine and terrestrial samples. Previous researchers have often utilized classical intercept methods that do not account for the full calibrated probability distribution function (pdf). Recently Soulet (2015) provided 'R' code for calculating reservoir ages using the pdfs but did not address ΔR and the uncertainty in ΔR. We have developed an on-line application for performing these calculations for known age, paired marine and terrestrial 14C dates and U-Th dated corals. In this paper we briefly discuss methods that have been used for calculating ΔR and the uncertainty and describe the on-line program deltar which is available free of charge at http://calib.org/deltar.

Introduction

The marine reservoir age, R(t), is the difference between a marine 14C age of a sample that derived its carbon from the marine reservoir in question and the atmospheric 14C age at the same time (t). A global marine surface mixed layer calibration curve, Marine13 (Reimer et al. 2013), has been calculated for the Holocene using an ocean-atmospheric box model (Stuiver & Braziunas 1993) and the Northern Hemisphere tree-ring based portion of the calibration curve (currently IntCal13). From 10.5–13.9 cal kBP the curve is composed of foraminifera and corals data and from 13.9 to 50 cal kBP the IntCal13 curve offset by 405 years was used. Regional differences from the global curve are handled in calibration by including an offset ΔR(t) although in practice this value is often assumed to be constant. Although ΔR(t), the time-dependent regional offset from the global marine curve, was clearly defined in Stuiver et al. (1986), there have been recent publications where calculations for samples with precisely known calendar age were made overly complicated and the results less precise (Alves et al. 2015; Faivre et al. 2015) by inappropriately using phase models in OxCal (Bronk Ramsey 2009). ΔR values calculated from independently dated samples, such as U-Th dated corals, have not always included the calendar age uncertainty (e.g. Toth et al. 2015). In addition, in more complex cases such as contemporaneous marine and terrestrial radiocarbon samples, classical intercept methods have usually been used (c.f. Southon et al. 1995; Reimer et al. 2002; Russell et al. 2011) which, because of 'wiggles' in the calibration curve, provide poor estimates of the mean (e.g. Telford et al. 2004) and can either overestimate or, more often, underestimate the uncertainty. .

We have developed an on-line application for calculating ΔR for surface mixed layer marine samples with a) known calendar age, b) independently-derived (normally distributed) calendar ages such as U-Th dated corals, and c) contemporaneous marine and terrestrial radiocarbon ages. The method uses the full calibrated probability distributions to calculate the confidence ranges of the offset between the unknown sample and the marine calibration curve, currently Marine13 (Reimer et al. 2013). The mean and standard deviation of the 68% and 95% confidence ranges is given for practical purposes for use in calibration software.

Methods

For calibration purposes, the uncertainty of ΔR does not include the marine calibration curve uncertainty since this is included in the calculation of the calibrated probability distribution (Stuiver and Reimer 1989). While this is not critical for recent ΔR values where the marine curve uncertainty is small, using the uncertainty twice for calibration of samples from further back in time where the curve uncertainty is larger would inflate the calibrated age ranges significantly.

Except for the simple case of known age samples, the calculations in deltar make use of a convolution integral. This is an integral of the pointwise product of two probability density functions (pdfs), as a function of the amount of overlap between the two as one is shifted relative to the other and is itself a probability density function. We calculate ranges of 68 and 95% probability from it in the same way that ranges are calculated from calibration probability density functions.

Known calendar age, pre-bomb surface mixed layer samples

Known age, pre-bomb marine surface samples such as mollusk shells or coral can be used to calculate ΔR(t) relatively simply using Equation 1.

1) ΔR(t) = 14Cm - Marine13C(t)

where 14Cm is the measured radiocarbon age of the known age sample and Marine13C(t) is the radiocarbon age of Marine13 at time t.

The deltar application intersects the known calendar year of collection/growth with the marine calibration curve and determines the corresponding 14C age (reverse-calibrate). It then subtracts the reverse-calibrated age from the mean of the 14C age of the marine sample as illustrated in Figure 1. The uncertainty of ΔR is the uncertainty of the marine sample 14C measurement since the marine calibration curve uncertainty is included in the calibration process.

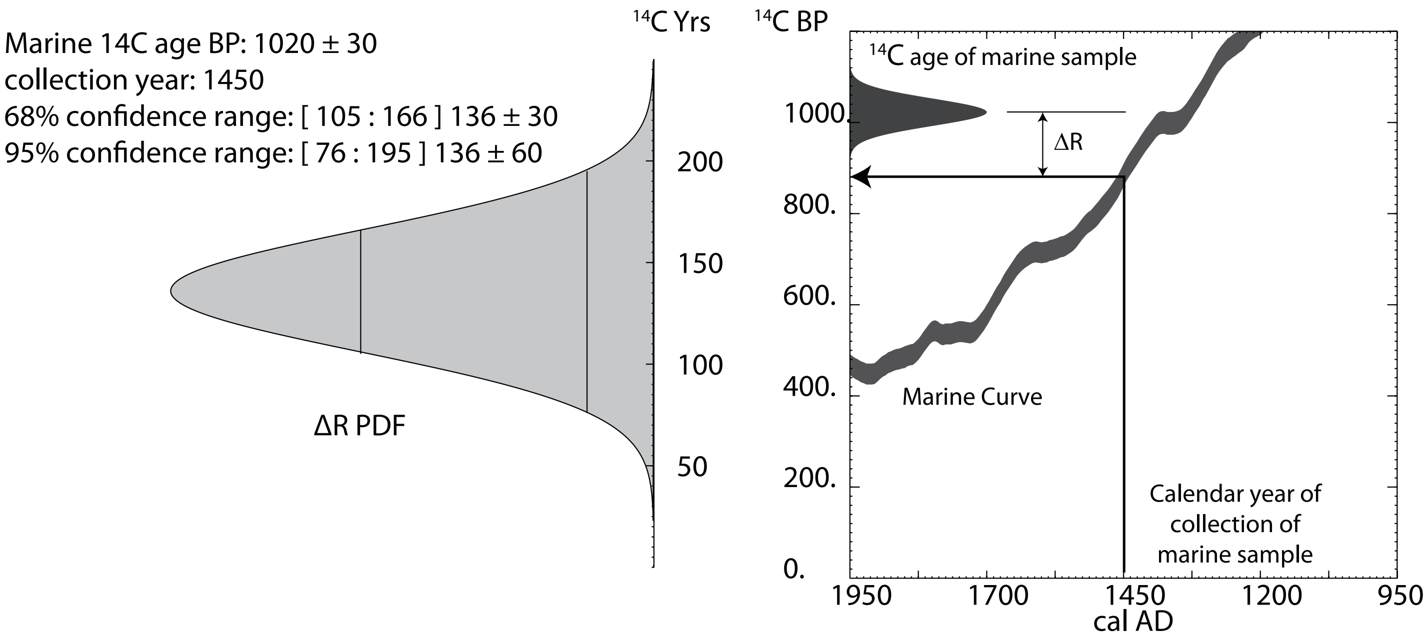

Figure 1. Illustration of ΔR and uncertainty calculation for samples with known age of collection or growth year (right) with resulting ΔR pdf and ranges on the left.

Independently measured calendar ages

For marine samples such as corals that have a calendar age derived from radiometric measurements such as U-Th the deltar application creates a normal distribution with the mean and standard deviation of the U-Th calendar age BP (Figure 2). It then reverse-calibrates discrete points on that distribution using the marine calibration curve. A convolution integral is used to determine a confidence interval for the offset between the radiocarbon dated marine sample and the uncalibrated probability density function of the U-Th age. Note that it is assumed that the U-Th calendar BP is corrected to 0 BP = 1950 AD rather than the year of measurement. Other type of measurements such as optically stimulated luminescence or varve counts could also be used as independent calendar ages if they can be approximated as normally distributed.

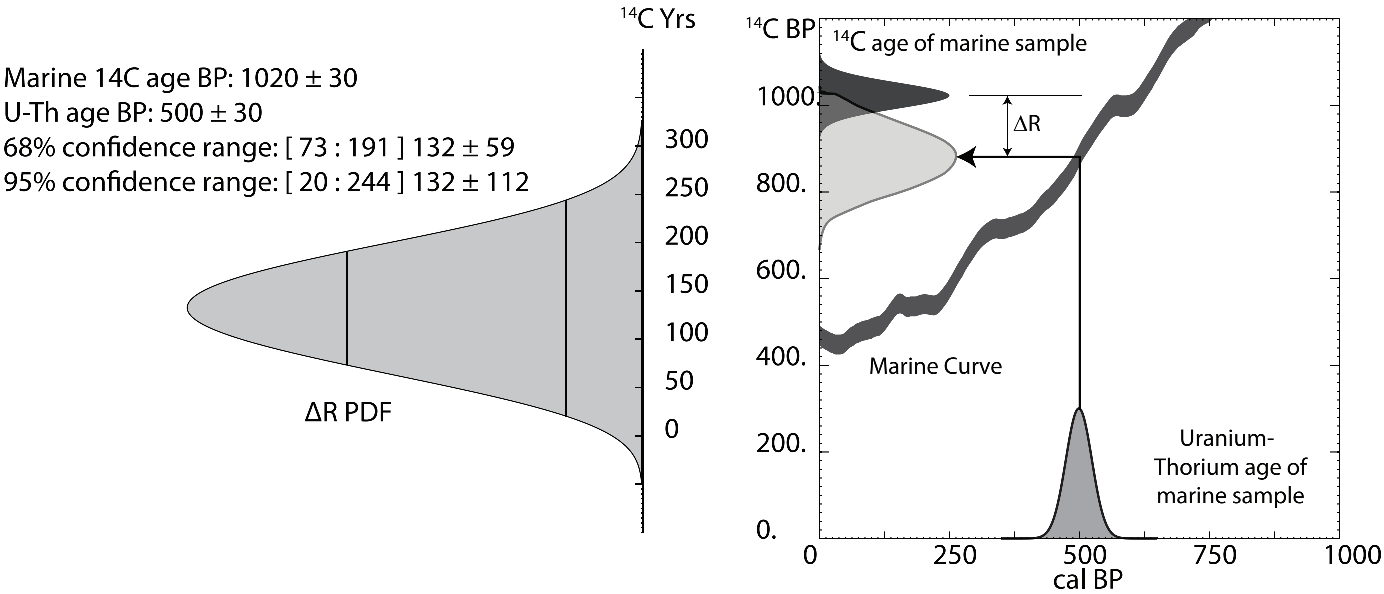

Figure 2. Illustration of ΔR and uncertainty calculation for samples with independently measured calendar age (e.g. U-Th) with resulting ΔR pdf and ranges on the left.

Contemporaneous marine and terrestrial samples

Stuiver & Braziunas (1993) suggested calculating ΔR for contemporaneous (paired) marine and terrestrial material by intersecting with a combined marine and atmospheric calibration curve (i.e. marine vs. atmospheric radiocarbon age). This method was further developed to include the uncertainty in ΔR (Reimer et al. 2002) and has been used in a number of studies (Russell et al. 2011, Dewar et al. 2012). An alternative method calibrated the terrestrial radiocarbon age, then took the mean and standard deviation of the marine calibration curve radiocarbon ages for the calibrated age ranges and subtracted this from the marine sample radiocarbon age (Southon et al. 1995). Neither of these classical methods included the probability density function and therefore should be considered as approximations.

The deltar application does this as illustrated in Figure 3 by first calibrating the terrestrial radiocarbon age with the appropriate northern or southern hemisphere calibration curve, currently IntCal13 and SHCal13 (Hogg et al. 2013), respectively. It then reverse calibrates discrete points of the resulting probability density function (pdf) with the marine calibration curve. As for the case of U-Th ages, a convolution integral is used to determine a confidence interval for the offset between the radiocarbon dated marine sample and the reverse-calibrated pdf of the atmospheric sample.

The resulting confidence interval will generally not be normally distributed. However, existing calibration programs are unable to handle non-normal distributions of ΔR so the result will have to be approximated as a normal distribution. Note also that radiocarbon ages that impinge on the end of the calibration curves will produce spurious ΔR results.

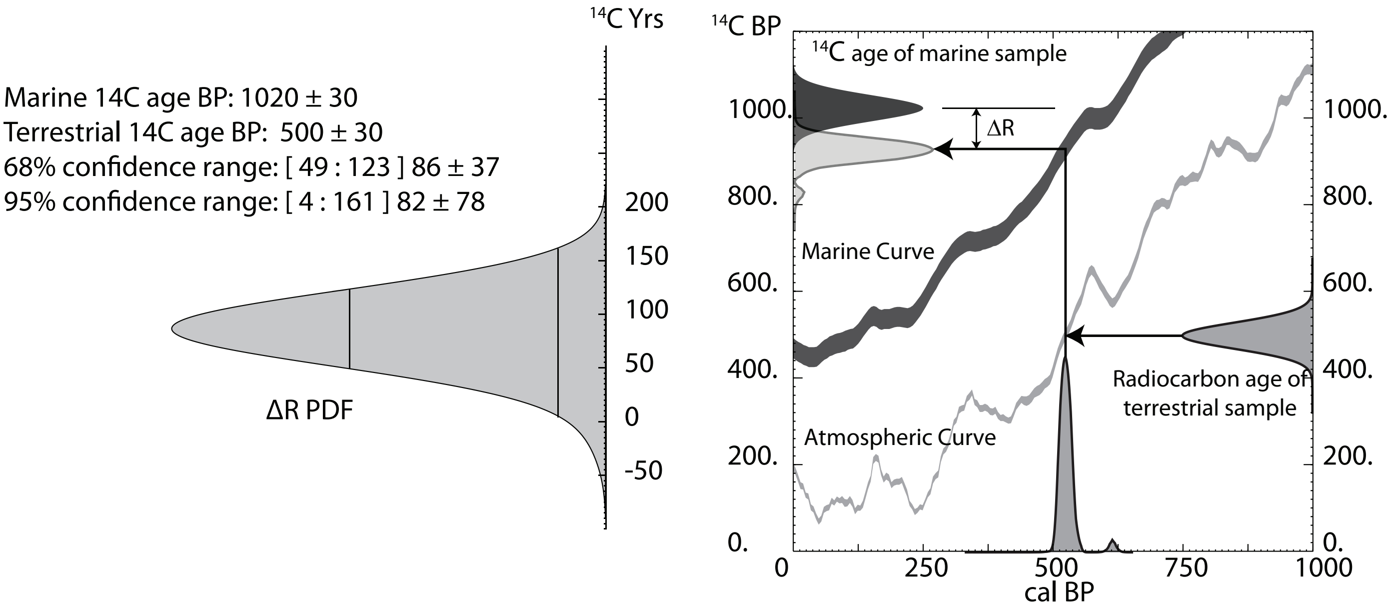

Figure 3. Illustration of ΔR and uncertainty calculation for paired (contemporaneous) radiocarbon dated samples with (right) with resulting ΔR pdf and ranges on the left.

A comparison of ΔR and uncertainties calculated using the classical intercept method and deltar for contemporaneous samples from South Africa (Dewar et al. 2012) is given in Table 1. While the differences in ΔR for these examples are not large (0-26 14C yrs), the uncertainties are probably more realistic.

Table 1. Comparison of ΔR and uncertainties recalculated using the classical intercept method as described in Dewar et al. 2012 using SHCal13 and Marine13 and calculated with deltar. The ΔR value calculated with deltar is taken as the midpoint of the 68% confidence interval.

Terrestrial (14C BP)	Marine (14C BP)	classical method ΔR (14C yrs)	deltar ΔR (14C yrs)	uncertainty
510 ± 40	820 ± 50	-118 ± 57	-92	66
685 ± 35	1291 ± 25	225 ± 71	236	46
2470 ± 60	3120 ± 60	324 ± 117	320	98
2540 ± 50	2930 ± 40	71 ± 105	71	87

Discussion and Conclusions

The deltar application calculates ΔR and the uncertainty for single samples. The uncertainty is more accurate than those provided by many other methods because it uses the full probability distribution functions rather than simple intercepts. The on-line program deltar is available free of charge at http://calib.org/deltar. For multiple contemporaneous samples, such as might occur in secure archaeological contexts, the standard error for predicted values has been proposed for determining the variability in ΔR (Russell et al. 2011) rather than using a simple standard deviation. For samples that are not strictly contemporaneous but come from within the same archaeological context, phase models in OxCal (Bronk Ramsey 2009) have been effectively used to calculate ΔR for samples from shell middens (Macario et al. 2015). In sedimentary sequences ΔR(t) can be calculated with depositional models in OxCal (Bronk Ramsey et al. 2012). For calculating the reservoir age, R, the Bayesian program ResAge (Soulet et al. 2015) can be utilized

References

Alves, E et al., 2015. Radiocarbon reservoir corrections on the Brazilian coast from pre-bomb marine shells. Quaternary Geochronology 29:30-35.

Bronk Ramsey, C. 2009. Bayesian analysis of radiocarbon dates. Radiocarbon 55(1):337-360.

Bronk Ramsey, C et al., 2012. A Complete Terrestrial Radiocarbon Record for 11.2 to 52.8 kyr BP. Science 338(6105):370-374.

Dewar G, Reimer PJ, Sealy J, Woodborne S. 2012. Late-Holocene marine radiocarbon reservoir correction (Delta R) for the west coast of South Africa. Holocene 22(12):1481-9.

Faivre, S, Bakran-Petricioli, T, Barešić, J, Horvatinčić, N. 2015. New Data on Marine Radiocarbon Reservoir Effect in the Eastern Adriatic Based on Pre-Bomb Marine Organisms from the Intertidal Zone and Shallow Sea. Radiocarbon 57:527–538.

Hogg, AG et al., 2013. SHCal13 Southern Hemisphere Calibration, 0–50,000 Years cal BP. Radiocarbon 55(2):1889 - 1903.

Macario, KD et al., 2015. Marine reservoir effect on the Southeastern coast of Brazil: results from the Tarioba shellmound paired samples. Journal of Environmental Radioactivity 143: 14-19.

Reimer PJ, McCormac FG, Moore J, McCormick F, Murray EV. 2002. Marine radiocarbon reservoir corrections for the mid- to late Holocene in the eastern subpolar North Atlantic. Holocene 12(2):129-35.

Reimer, P.J. et al., 2013. IntCal13 and Marine13 radiocarbon age calibration curves 0-50,000 years cal BP. Radiocarbon 55(4):1869–1887.

Russell N, Cook GT, Ascough PL, Scott EM, Dugmore AJ. 2011. Examining the inherent variability in Delta R: new methods of presenting Delta R values and implications for MRE studies. Radiocarbon 53(2):277-88.

Soulet G. 2015. Methods and codes for reservoir–atmosphere 14C age offset calculations. Quaternary Geochronology 29:97-103.

Southon, JR, Rodman, AO, True, D. 1995. A comparison of marine and terrestrial radiocarbon ages from northern Chile. Radiocarbon 37(2): 389-393.

Stuiver, M, Pearson, GW, and Braziunas, T. 1986. Radiocarbon Age Calibration of Marine Samples Back to 9000 Cal Yr BP. Radiocarbon 28:980-1021.

Stuiver, M, Reimer, P J. 1989. Histograms obtained from computerized radiocarbon age calibration. Radiocarbon (31):817-823.

Stuiver, M, Braziunas, TF, 1993. Modeling Atmospheric C-14 Influences and C-14 Ages of Marine Samples to 10,000 BC. Radiocarbon 35(1): 137-189.

Telford, RJ, Heegaard, E, and Birks, HJB. 2004. The intercept is a poor estimate of a calibrated radiocarbon age. The Holocene (14):296-298.

Toth, LT, Aronson, RB, Cheng, H, Edwards, R.L. 2015. Holocene variability in the intensity of wind-gap upwelling in the tropical eastern Pacific, Paleoceanography (30):1113-1131.