Calibration of the Radiocarbon-Age based on Oaks plus Sequoias

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Abstract:

Metrological analysis of Sequoia Radiocarbon allows to interpolate missing growth rings and to identify 1886 CE[1] ±5 as base year for $\Delta^{14}C = 0$. Referring to this date, down-bends of IntCal[2] match closely with sulphate signatures of GISP2[3]. Over more than three millennia volcanic eruptions and organic relics will be dated accurately.

The carbon isotope ^{14}C has a average life-span of 8267 years. One half of the atoms within a sample will be decayed after 5730 years ('Cambridge half-life'). If, within a sample containing N_p of these atoms at the time T_p of it's creation, N remaining atoms can be found, $T = 8267 * \ln(N_p / N)$ years will have passed in the meantime.

In practice, due to various effects, the concentration of the ^{14}C in the atmosphere fluctuates slightly around a mean value. This deviation $\Delta^{14}C$ must be known for the time of the samples' formation as well as for the reference date T_{1950} at present days in order to find it's accurate radiocarbon age.

However, by the middle of the 20th century, human activities had significantly influenced the deviation $\Delta^{14}C$. In order to find the reference value of $\Delta^{14}C$ for the year 1950, V. Stuiver[4] has used an indirect approach, referring to the average of four age-documented samples from the 18th and 19th century. In view of missing alternatives, the year 130 BP (before present) <> 1820 CE up to now represents $\Delta^{14}C = 0$, as the best possible reference for the begin of the radiocarbon age scale.

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[1] C E = Common Era (The current year is 2014 C E)

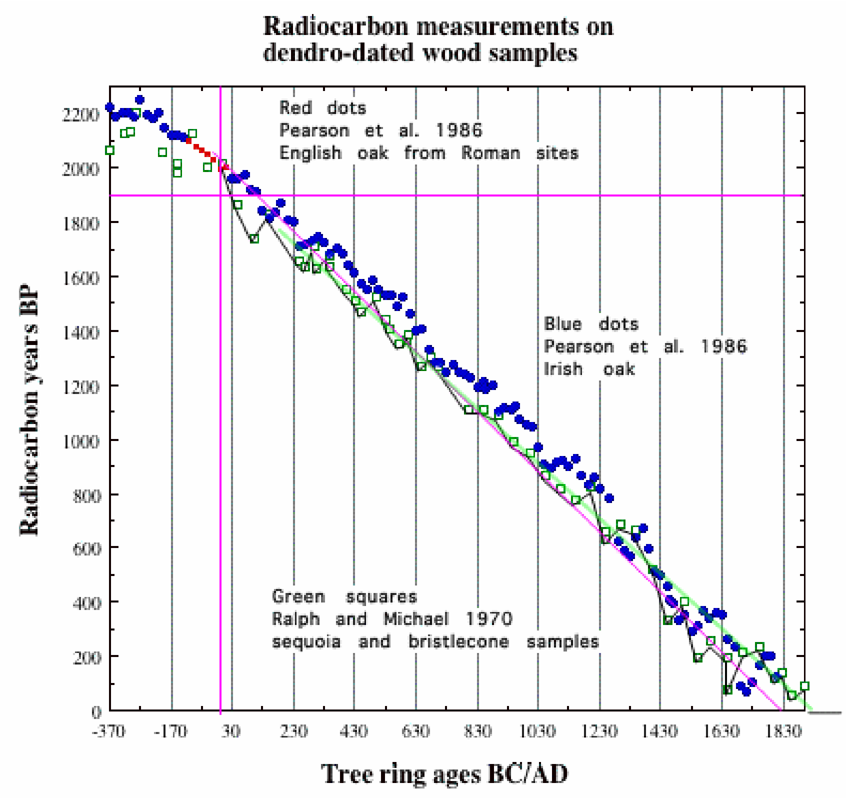
[2] IntCal09 and Marine09 Radiocarbon Age Calibration Curves, 0-50,000 Years cal BP, Reimer et al. 2009

[3] 'Greenland Ice Sheet Project', Mayewski et al, 1997

[4] Stuiver 1982

But is this really the case? The non-linear progression of the radiocarbon age based on the Irish Oak Chronology may rise some doubts. Due to W. Libby[5], a more or less constant level of ^{14}C in the atmosphere should be assumed. But now, these measurements seemed to indicate a higher level of ^{14}C for antiquity than at present, and for the middle-ages a lower value.

Fig. 1



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[5] Libby, 1955

Sequoia-Calibration

Analysis of the year-ring pattern of Sequoias, has led to the insight, that, within many years, these mighty trees did not produce visible rings. Therefore, these trees appeared useless as a reference for the Radiocarbon-age...[6]

Obviously, due to the missing rings, an unambiguous assignment of the year of growth becomes impossible. However, the large number of measurements over two millennia allows a quite accurate extrapolation for the reference year ($\Delta^{14}C=0$) of the radiocarbon-age. Fig. 1 shows the age values measured at a sequoia together with the values from the Irish Oak Chronology.[7] The consistent gradient of the 47 Sequoia measurements should be noticed. These define the a regression line RC(t) = -1.075 t + 2022. Reference 0 BP for the radiocarbon age will be here the year 1881. The variance of the 25 measurements within the 1st AD millennium will be 43 years. The statistical error of the mean value will therefore be about 8 years. Moreover, the youngest rings can be dated quite accurately (not necessarily exact). The uncertainty with respect to the mean value, therefore, will be just some 5 years.

With their *coefficient of determination*, $R^2 = 0.98$ the relation between radiocarbon age and the growth cycles of Sequoias shows a significantly higher linearity than the data measured on the Irish Oaks, referring to the year 1820.

In addition, Sequoia measurements allow an alternative, considerably more accurate determination of the radiocarbon reference year. By definition, radiocarbon-years and growth-years last equally

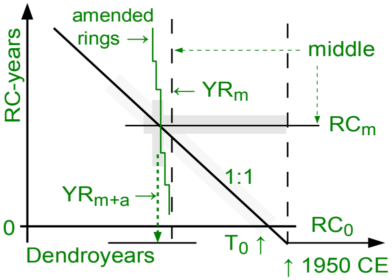

Fig. 2. Extrapolating the reference year T_0 from the mean of RC ages and the mean age of growth rings

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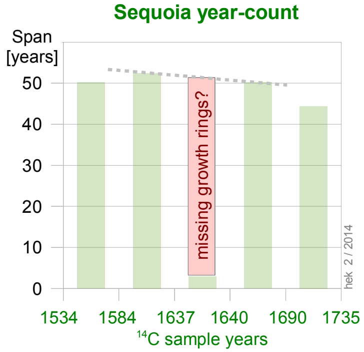
[6] Biondi, 2001

[7] Baillie, 2012 – colored lines added by the autor

long. Therefore, the average of the radiocarbon ages should be equal to the mean age of the tree rings associated. When the missing rings can be reconstructed, the mean of ring ages may be calculated (Fig. 2).

But how may missing rings be reconstructed? In fact, an analysis of the measured Sequoia data provides further information (green squares in Fig. 1): While the average distance between the measured samples amounts to 44 year rings, it is much lower for the Dendro-years '1640', '1240', '600', '360' and '330' where only between 3 and 8 rings can be counted. The quite obvious assumption: The number of real years at these places might be close to the average ring numbers for the respective neighbour-spans (Fig. 3). Reconstructing just these rings, should come close to the actual situation. If, before the years denoted, 47, 43, 31, 44 and 30 missing year-rings are inserted, the gradient of the series of measurements will change accordingly (Fig. 4, blue curve).

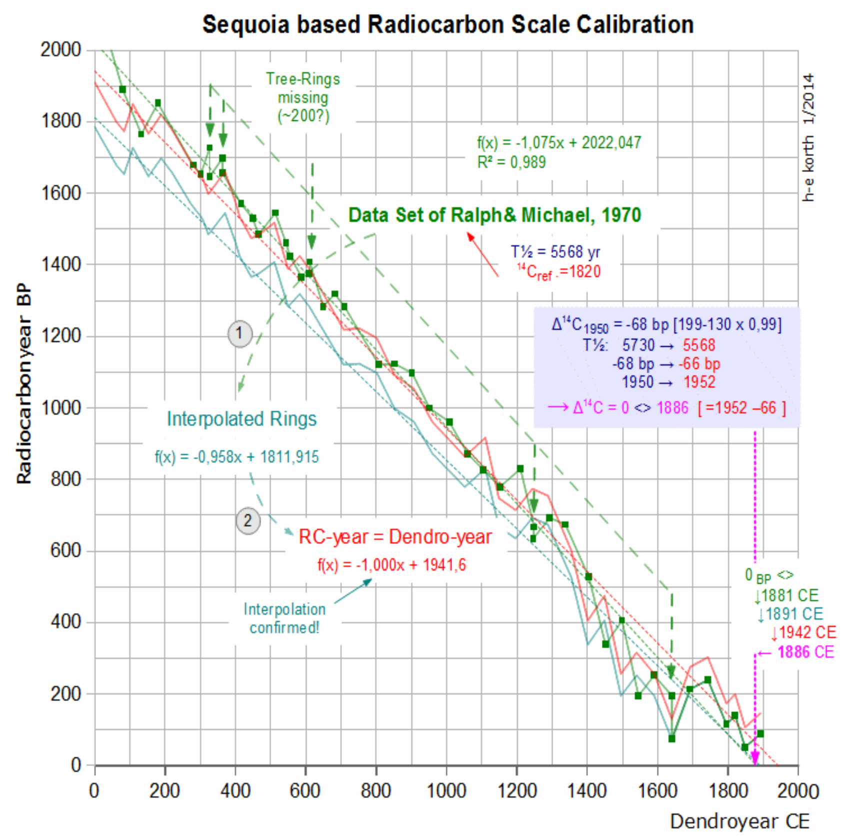
Fig. 3



This procedure will move the reference year for $\Delta^{14}C = 0$ up to 1891. A small error with respect to the number and placement of the reconstructed rings will be of minor impact: The variance of the averaged radiocarbon age for the 5 interpolated groups amounts to 4,37 years.

Radiocarbon samples measured between incorrectly inserted rings will have some effect on the average. The middled age of all rings still will have a variance of some five years. However, as compared to the metrological uncertainty of about 20 years for the radiocarbon age, this makes no big difference for the outcome.

Fig. 4



Obviously, the $^{14}C/^{12}C$-ratio within the atmosphere has been constant for many centuries – as confirmed by the highly linear gradient of the Sequoia. Therefore, when the missing rings will be reconstructed as described above, the age span of Sequoia-rings should be equal to the span of radiocarbon ages.

De facto, the two middled age values will differ by 4.1%. But the Sequoia measurements were taken as early as 1970, based on the reference year 1950 and a ^{14}C half-life of 5568 years was assumed. And, of course, the identical length of radiocarbon year and growth year was taken for granted. Therefore, with the radiocarbon scale based on the half-life of 5730 years, the measured age will decrease by 2,9%.

In 1982, the reference year was newly defined as 130 BP <> 1820. For the year 1950, now a deviation of 199 years against 1820 was measured. Due to the distortions within the 20th century, the radiocarbon age for 1950 will, therefore, appear 199-130 years too old. This corresponds to a further 1,2% (=69/8267).

Thus, the necessary corrections have a total of 4.1%. This may be a good argument for the rightness of our considerations. Otherwise, if the presumed distribution of the interpolated growth rings should not come close to reality, there would be no match between measured and calculated ratio of Radiocarbon years and Sequoia rings.

Due to the change of the assumed ^{14}C half-life, the radiocarbon-age '0' of Sequoias must be placed 69 x 5730/5568 years before '1950' (= '1820' + '130'). As a consequence, the count of 'Dendroyears' will be shifted likewise by two years against the year-count. With this final correction, the Sequoia data eventually identify the reference year for $\Delta^{14}C = 0$ as
64 BP <> 1886 CE ± 5.

IntCal – Calibration

But how can these deviations be explained against the currently used calibration with the help of the Irish Oak Chronologies? In order to find a plausible reference year for $\Delta^{14}C = 0$, V. Stuiver relied to the arithmetic mean of just 4 samples of known age:

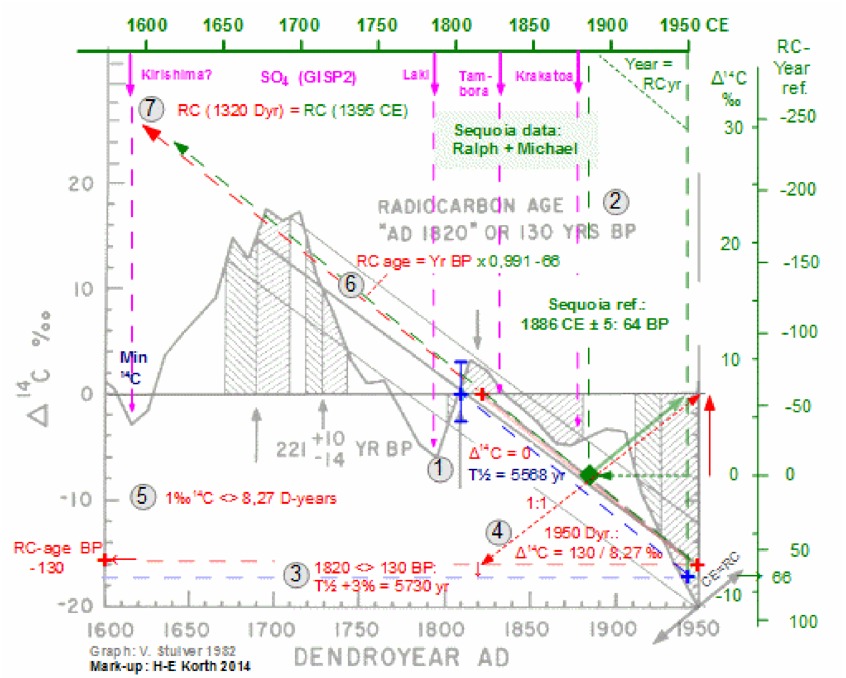
> This delta^{14}C level (measured in later years but age-corrected back to the year 1950) is **the only available information** we have from the ^{14}C counts, and results in a radiocarbon age of 130 years ("AD 1820") for all four samples. The calculation of a conventional radiocarbon age is based on the **5568**-year half-life, which is different from the **5730**-year half-life used for the actual decay; (Stuiver, 1982, p.11)

Without other data for a comparison, the remaining deviations were attributed to a different half-life of ^{14}C. The possibility of a $\Delta^{14}C$ not equal '0' at the time when the samples formed, could not be investigated then. Apparently, this may have led to several post-hoc fallacies (Fig. 5):

1. The 'best possible' mean value from four samples was now presupposed as 'correct' (in contradiction to the Sequoia data measured).

2. Therefore, the presumption 1820 CE <> $\Delta^{14}C = 0$ cannot be correct.

3. Because the mean of the samples came close to the Dendroyear '1810', while Radiocarbon-year and growth-year



Graph: V. Stuiver 1982
Mark-up: H-E Korth 2014

Fig. 5

by definition will be equally long, a deviating half-life had to be postulated.

4. This, however, led to a slightly different reference year '1820' and implied a shift of the 'Dendro-years' against the C.E. time-line (abscissa).

5. Nevertheless, the original scale for the radiocarbon age has been maintained.

6. Hereby, in turn, a 1:1 slope of the radiocarbon-age before the Dendro-year '1820' has been assumed. However, from the Sequoia data follows another dependency, based on these scales: RC-age = Year BP x 0,991 - 66 years

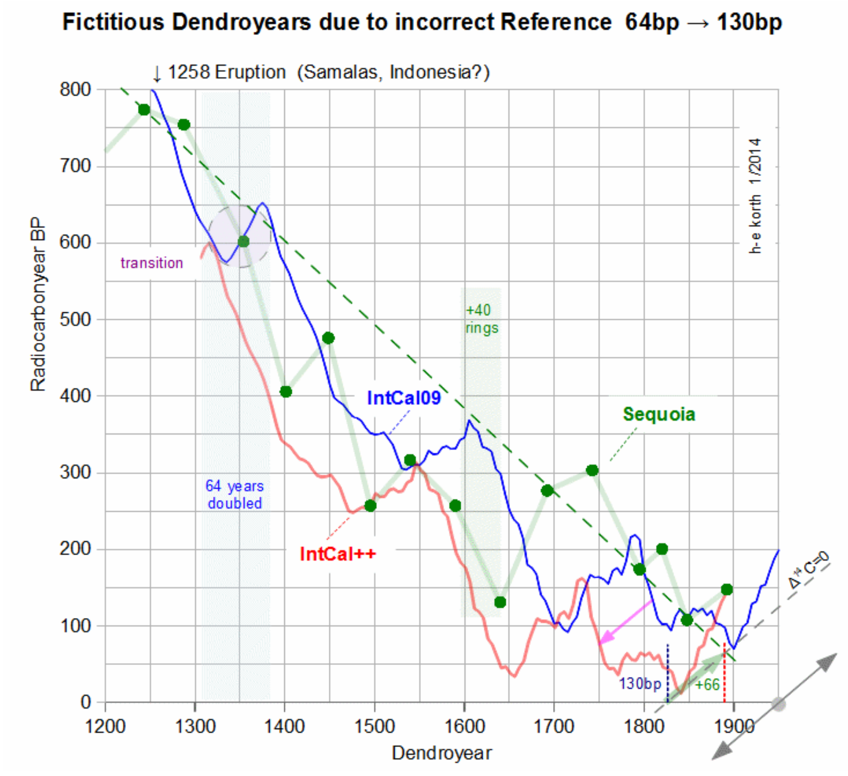


Fig. 6

7. When the IntCal-series will be traced back under the two values assumed for $\Delta^{14}C = 0$ (1820 and 1886 resp.), Radiocarbon-ages for the Dendro-years '1320' and 1396 CE will be identical. Eventually, Radiocarbon-years counted backwards from presence will find here a steady and smooth transition into the samples based on modern age dendrochronology.

Fictitious Dendro-years

Consequence of the '1820' base year was an duplication within the 'Belfast AD' Oak Chronology[8], serving as a reference. If the time-scale of IntCal did change just for the modern era, there will be now an overlap towards the middle-ages, i.e. the year-rings of several decades were inserted twice within the calibration curve! As a consequence, all the earlier ^{14}C values will appear too old.

Fig. 6 shows the progression of IntCal (blue curve) together with the identical curve, referring now to 0 BP <> 1886 and stretched by 1% (red). Near the year 1320 CE, there will be a continuous and smooth transition between the curves.

The break within the abscissa of IntCal will be confirmed by a direct comparison between the radiocarbon data of Oak and Sequoia (Fig. 7): The systematic deviation between IntCal and Sequoia become evident, in the difference between RC-age and Dendro-year. For more than a millennium the mean distance between the curves amounts to some 70 years. As both curves refer to radiocarbon-years of '1820', all difference values will appear some 6 years too high.

In 1258 CE, '*The little Ice Age*' began with the most cataclysmic volcano (Samalas, Indonesia?) eruption of the AD period. For more than 200 years, the ^{14}C level in the atmosphere in-

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[8] After three decades, these data were eventually published in April 2010. However, the 'Cadzow' (Q2825, Q2652) and the 'Shaw's bridge' (Q1987, Q2054) wood representing the 1400 to 1810 time-span were missing or not usable. Meanwhile, the Dendro data have been removed from the QUB homepage.

creased steeply. A cause for an interruption of this process within the 14th century, as suggested by the IntCal data, cannot be identified. This anomaly will be explained as an artefact due to the duplicated section of Dendro-years.

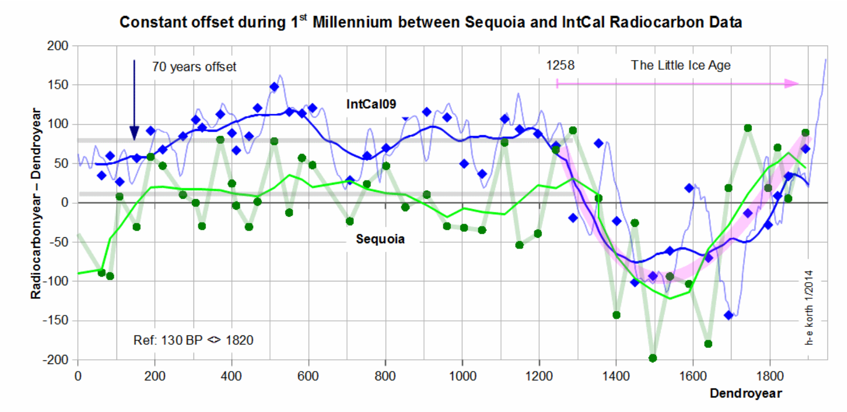

Fig. 7

Δ^{14}C and Measurement Errors

Eventually, the direct comparison between the measurements at Oaks (IntCal) and Sequoias allows to separate the variations of atmospheric ^{14}C from the measurement fault. To match the 48 Sequoia dates, the corresponding radiocarbon ages were taken from the IntCal list:

For the variance σ of Sequoia and IntCal, and for their difference, the following values will result:

$\sigma_{14C+Sequoia}$ =44 years; $\sigma_{14C+IntCal}$ =38 years; $\sigma_{IntCal-Sequoia}$ =51 years

These variances result from the natural fluctuations of ^{14}C, caused mainly by volcanism and the limited precision of ^{14}C measurement.

$$\sigma^2_{14C+Sequoia} = \sigma^2_{14C} + \sigma^2_{Error\ Sequoia}$$

$$\sigma^2_{14C+IntCal} = \sigma^2_{14C} + \sigma^2_{Error\ IntCal}$$

$\sigma^2_{\text{IntCal-Sequoia}} = \sigma^2_{\text{Error IntCal}} + \sigma^2_{\text{Error Sequoia}}$

$4x\ \sigma^2_{14C} = \sigma^2_{\text{IntCal-Sequoia}} - \sigma^2_{\text{14C Sequoia}} - \sigma^2_{\text{14C IntCal}}$

Solving of this system of equations allows to determine the three independent components:

σ_{14C} = 20 years.; $\sigma_{\text{Error Sequoia}}$ = 39 years; $\sigma_{\text{Error IntCal}}$ = 32 years

As can be seen, the measurement errors are nearly twice as big as the variance of the Radiocarbon. The elder Sequoia measurements are scattering somewhat more than those of IntCal.

The deviations of atmospheric ^{14}C follows volcanism, as can be concluded from the synchronism against the sulphate peaks within the GISP2 Ice-core. Devastating eruptions do cause a cool-down of the atmosphere, which in turn reduces evaporation of sea-water and rainfalls. As a result, ^{14}C accumulates within the atmosphere. Volcanism can be identified, therefore, as the predominant cause of the ^{14}C fluctuations. When this effect is understood, the dramatic impact of the man-made changes within the last century becomes obvious.

Amending the IntCal-Scales

For an optimal use of the IntCal calibration, it must refer to the year 64 BP <> 1886 CE ±5. This will shift the calibration curve for the modern era. In Addition, the radiocarbon year will now appear about 1 % longer (Fig. 8).

Within the 14th century, 66 duplicated growth rings must be eliminated. Both effects together make the radiocarbon age some 72 years younger. Over the middle-ages, there is a linear increase of the age - again with an additional steepness of 1%. As a consequence, the currently found cal BP dates are between 72 and 82 years too old.

^{14}C-Calibration within Antiquity

A further break has been discovered by P. and L.-Å. Larsson at the transition between a sequence based on Oaks from Roman sites and various modern dendrochronolgies: The cross correlation data here give proof for an age 218 years lower than presumed.[9]

But how is this possible? Over many years, it was not feasible to find a satisfactory linkage between the Roman wood and a number of independent dendrochronologies, reaching back from presence (ref. Fig. 1). ^{14}C measurements always yielded

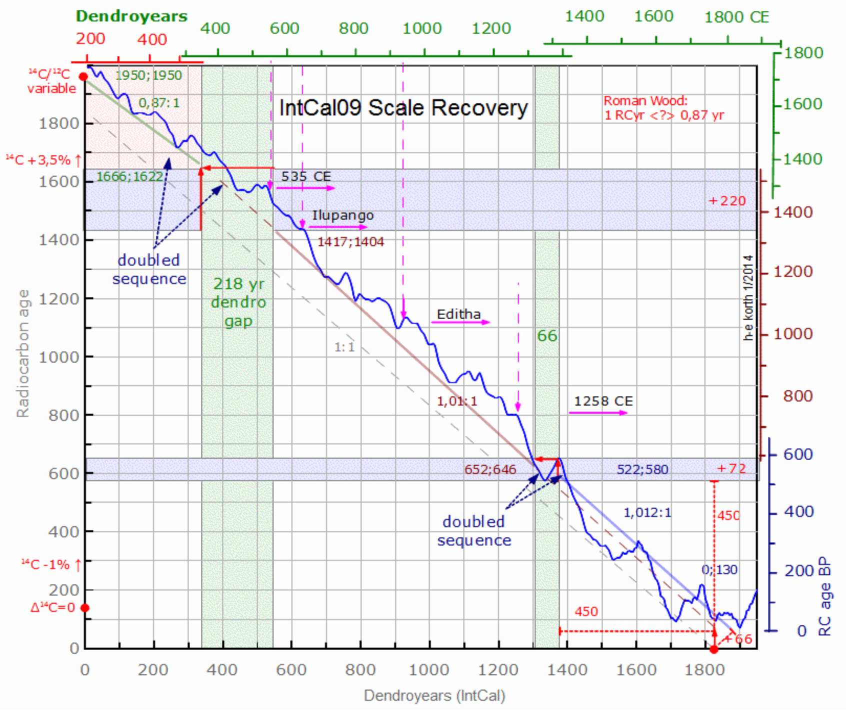

Fig. 8

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[9] Larsson, 2013
1. Matching Danish oak – absolutely dated to AD 1986
2. Matching Roman time oak of NW Europe – conventionally dated to AD 328

an age some three centuries too late. As the validity of the historical dates was beyond question, researchers had to assume for antiquity a ^{14}C level some 3% higher than today. Because a 1% deviation of ^{14}C corresponds to some 82 years, this explained the strange deviation observed.

If, however, as Larsson could show, more than two centuries within dendrochronology appear doubled, then an 1:1 relation between Radiocarbon-year and Dendroyear existed even during antiquity. The ratio between these variables must, therefore, have been different than presumed. On the basis of a practically constant atmospheric ^{14}C, the abscissa of the Int-Cal-curve does not any more refer to the same 'Dendroyear'-scale of the modern era, but to the total age presumed.

This is indeed the case: A direct comparison between IntCal and the year-count of the GISP2 ice-core[10] gives proof: Big volcanic eruptions lead to sulphate precipitations. Likewise, they caused a temporary increase of ^{14}C. The corresponding 'down-bends' can be made visible as minima by a twofold difference operation applied onto the IntCal data-set:

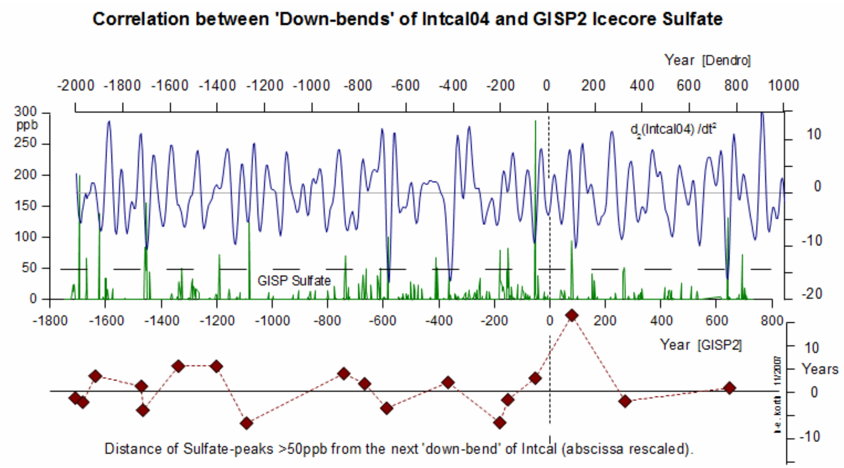

Fig. 9

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[10] Korth, 2013, S. 198ff.
– The Eruption '60' CE [GISP] is <u>not</u> the one of Mount Vesuvius in 79 AD.

$$\Delta_2 \mathrm{IntC}(n) = \{\mathrm{IntC}(n)-\mathrm{IntC}(n-1)\} - \{\mathrm{IntC}(n+1)-\mathrm{IntC}(n)\}$$

A comparison over 18 eruptions having deposited more than 50 ppb of Sulphate, shows a variance of less than five years, under the assumption of a scale for Dendro-years that had been shrunk by 15% and shifted by 290 years towards antiquity (Fig. 9). An accidental match of 18 values appears more than unlikely. Without a rescaling of the abscissa, contrariwise, no correlation can be found.

The deviating time-scale can be traced back for many millennia: The increase of the CO_2 level at the begin of the Holocene, measured in an ice-core from Antarctica had been juxtaposed to the corresponding rise of Earth's temperature, represented by 'proxies' (e.g. yearly growth layers of corals and varves). The measurements seem to indicate a delay of nearly two millennia at a time 15.000 years ago (Fig. 10). With respect to the findings presented here, the assumption will appear quite obvious that an accurate time-line dates the temperature, while the CO_2 is referring indirectly to ^{14}C and, therefore, dates by some 15% too old.

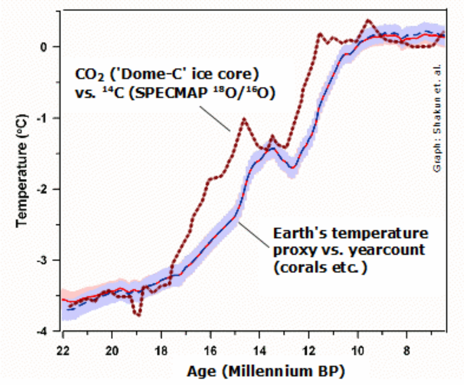

Fig. 10

Summary

Analysis of the radiocarbon-age measured at Sequoias yields the statistically confirmed reference year 1886 CE ± 5. Going backwards from here, the calibration curve joins with the regular dendrochronology near the begin of the 14th century, skipping 64 surplus 'Dendro-years'. The irregular course of $\Delta^{14}C$ at this time is due to this artefact.

Therefore, customary IntCal-ages for late Antiquity and middle-ages will be too old by some 80 years. After a correction, the years of big volcanic eruptions match with sudden increase of $\Delta^{14}C$. Unintelligible deviations of the radiocarbon-age of history-dated objects will disappear likewise.

Cross-confirmed by Larssons' proof for a 218 year break between Roman and modern dendrochronology, the duplicate spans within IntCal can now be corrected, and the 15% shortage of antique Radiocarbon-years likewise.

The overall accuracy of the radiocarbon method will now be limited by the measurement only and may be further reduced by 'wiggle matching'. [11]

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[11] vgl. Newton, 1728

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