Quaternary Science Reviews 170 (2017) 98–108

Contents lists available at ScienceDirect

Quaternary Science Reviews

journal homepage: www.elsevier.com/locate/quascirev

Radiocarbon calibration uncertainties during the last deglaciation: Insights from new floating tree-ring chronologies

Florian Adolphi [a], [b], [*], Raimund Muscheler [a], Michael Friedrich [c], [d], Dominik Güttler [e], Lukas Wacker [e], Sahra Talamo [f], Bernd Kromer [c]

[a] Department of Geology, Quaternary Sciences, Lund University, Sölvegatan 12, 22362 Lund, Sweden
[b] Climate and Environmental Physics, Physics Institute, University of Bern, Sidlerstrasse 5, 3012 Bern, Switzerland
[c] Institute of Environmental Physics, University of Heidelberg, INF 229, 69120 Heidelberg, Germany
[d] Department of Botany, Hohenheim University, Garbenstr. 30, 70599 Stuttgart, Germany
[e] Ion Beam Physics, ETH Zurich, Otto-Stern-Weg 5, 8093 Zürich, Switzerland
[f] Department of Human Evolution, Max Planck Institute for Evolutionary Anthropology, Deutscher Platz 6, 04103 Leipzig, Germany

ARTICLE INFO

Article history:
Received 20 January 2017
Received in revised form
26 June 2017
Accepted 26 June 2017

Keywords:
Radiocarbon dating
IntCal
Cosmogenic isotopes
Ice cores
Tree-rings
Deglaciation

ABSTRACT

Radiocarbon dating is the most commonly used chronological tool in archaeological and environmental sciences dealing with the past 50,000 years, making the radiocarbon calibration curve one of the most important records in paleosciences. For the past 12,560 years, the radiocarbon calibration curve is constrained by high quality tree-ring data. Prior to this, however, its uncertainties increase rapidly due to the absence of suitable tree-ring ^{14}C data. Here, we present new high-resolution ^{14}C measurements from 3 floating tree-ring chronologies from the last deglaciation. By using combined information from the current radiocarbon calibration curve and ice core ^{10}Be records, we are able to absolutely date these chronologies at high confidence. We show that our data imply large ^{14}C-age variations during the Bølling chronozone (Greenland Interstadial 1e) – a period that is currently characterized by a long ^{14}C-age plateau in the most recent IntCal13 calibration record. We demonstrate that this lack of structure in IntCal13 may currently lead to erroneous calibrated ages by up to 500 years.

1. Introduction

Radiocarbon (^{14}C) dating is the backbone of late quaternary geochronology covering the last 50,000 years. It provides the most frequently used chronological framework for a variety of disciplines such as archaeology, geology, and paleoclimatology. To infer absolute ages, so-called "^{14}C-ages" (an expression derived from the ^{14}C activity of a sample, Stuiver and Polach, 1977) have to be calibrated using a calibration curve (IntCal13, Fig. 1, Reimer et al., 2013). This necessity arises from the fact that atmospheric Δ^{14}C (^{14}C/^{12}C corrected for fractionation and decay, relative to a standard, Hammer et al., 2016) has varied in the past due to changes in the ^{14}C production rate and the carbon cycle which leads to a variable relationship between ^{14}C-ages and true calendar ages. The calibration record provides an estimate of past Δ^{14}C which is inferred by combining records that, ideally, provide i) measurements of atmospheric Δ^{14}C and, ii) a fully independent and accurate timescale (Reimer et al., 2013).

Dendrochronologically dated tree-rings are the gold standard for the construction of a ^{14}C-calibration. Each ring directly reflects the atmospheric Δ^{14}C at its time of growth and can be absolutely and accurately dated via dendrochronology. The current framework of absolutely dated tree-ring extends back to 12,560 cal BP (calibrated before present, 1950 CE, Friedrich et al., 2004; Hua et al., 2009) albeit the oldest approximately 700 years may contain chronological errors (Hogg et al., 2016a, 2013, 2016b). These data form the basis of the most recent calibration curve, IntCal13, back to 12,560 cal BP (Fig. 1). Between 12,560 and 13,900 cal BP IntCal13 is based on the previously floating Late Glacial Pine chronology (Kromer et al., 2004) which has been anchored in time by radiocarbon wiggle-matching (Hua et al., 2009). Hence, this dataset satisfies criterion i) above, but compromises on point ii) since it is radiocarbon dated itself. However, the associated timescale uncertainties are probably in the order of only a few decades (Hogg et al., 2016a; Hua et al., 2009; Bronk Ramsey et al., 2012;

---

[*] Corresponding author. Department of Geology, Quaternary Sciences, Lund University, Sölvegatan 12, 22362 Lund, Sweden.
E-mail address: Florian.Adolphi@geol.lu.se (F. Adolphi).

http://dx.doi.org/10.1016/j.quascirev.2017.06.026
0277-3791/

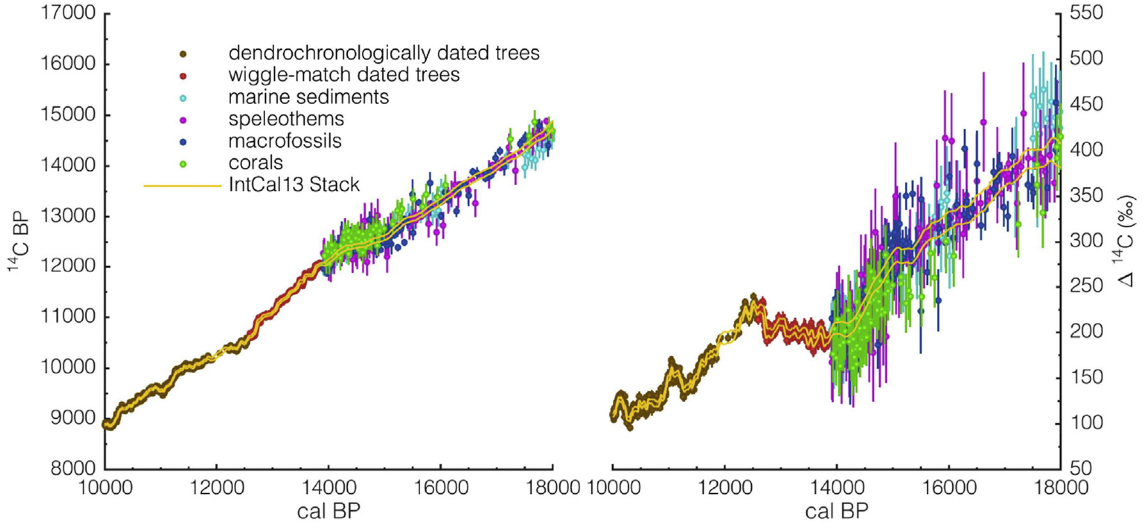

Fig. 1. The current radiocarbon dating calibration record, IntCal13 (yellow, Reimer et al., 2013 and references therein), and its underlying raw datasets grouped by archive type (symbols) between 10,000 and 18,000 calibrated years before present (cal BP; present is CE, 1950). The data are displayed as ^{14}C ages (left) and Δ^{14}C (right). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Muscheler et al., 2008; Hogg et al., 2016b). Thus, back to 13,900 cal BP IntCal13 captures atmospheric Δ^{14}C changes at approximately decadal resolution with uncertainties of typically less than 5‰.

Prior to 13,900 cal BP the uncertainties of IntCal13 increase rapidly, while its spectral resolution decreases so that Δ^{14}C variations faster than about 500 years are not captured anymore (Fig. 2). This is a direct consequence of the underlying data and their combination (Niu et al., 2013). Except for the macrofossil record of Lake Suigetsu (Bronk Ramsey et al., 2012), all ^{14}C-data going into the construction of the calibration curve have to be corrected for system specific reservoir effects (see Reimer et al., 2013, and references therein). Their recorded atmospheric Δ^{14}C variations are offset, attenuated, and delayed compared to the atmosphere since they do not sample the atmosphere directly but an upper mixed ocean (marine corals and foraminifera) or soil water (speleothems) reservoir (Siegenthaler et al., 1980). In IntCal13, only the offset is accounted for using an archive specific correction constant including an uncertainty estimate. However, the assumption of a constant correction may be erroneous and is difficult to assess through time (Singarayer et al., 2008; Muscheler et al., 2008; Noronha et al., 2014). In addition to the reservoir corrections, only the U/Th dated corals and speleothems have truly independent absolute timescales. The marine foraminifera records, with the exception of the varved section of Cariaco basin between 10,503 and 14,673 calBP, are indirectly tied to the Hulu Cave U/Th timescale (Wang et al., 2001) via “climate wiggle-matching” and thus, rest on the assumption of a correct identification of tie-points and synchronicity of the observed features, introducing additional uncertainty (Heaton et al., 2013; Lane et al., 2013; Rohling et al., 2009). The terrestrial macrofossil record of Lake Suigetsu on the other

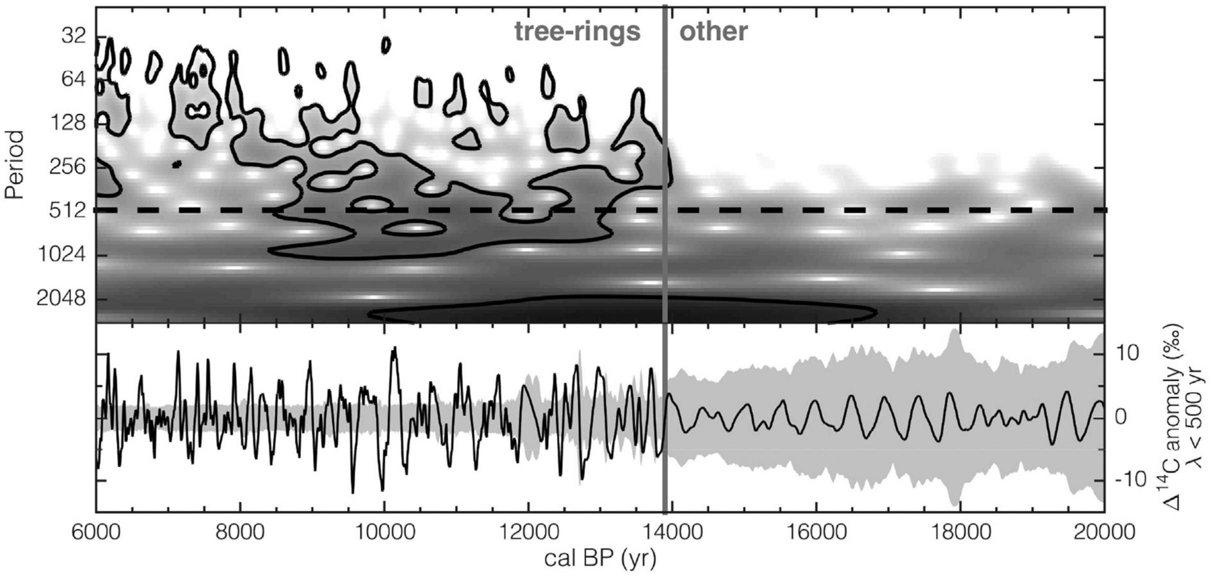

Fig. 2. Top: Continuous wavelet power spectrum of IntCal13 Δ^{14}C from 6000 to 20,000 cal BP. The data has been linearly detrended prior to analysis. The grayscale depicts the power spectrum at each point in time, darker colours corresponding to higher power. The black dashed line indicates the frequency cut-off applied to the Δ^{14}C record as shown in the lower panel. The gray vertical line highlights the transition from tree-rings to other archives underlying IntCal13. Bottom: IntCal13 high-pass filtered (cut-off 1/500 years^{-1}) Δ^{14}C variations (black line). The grey shading shows the Δ^{14}C uncertainties of IntCal13 at each point in time (±1σ) for comparison.