CORRESPONDENCE:

Extraterrestrial confirmation of tree-ring dating

To the Editor — Tree-ring-based temperature reconstructions represent the backbone of high-resolution palaeoclimatology by providing useful long-term perspectives on global climate. A recent dispute regarding the potential misdating of ring-width chronologies due to 'missing rings'[1–6], for trees growing near their thermal distribution limit, has raised questions about the reliability of tree-ring chronologies as annually resolved and absolutely dated climate proxy archives. Consequently, the debate introduces doubt about the validity of tree-ring-based temperature reconstructions. The claim of missing tree rings, caused by exceptional summer cooling following large volcanic eruptions, is based on the experimental results of a cambial growth model, driven by simulated climate variations, which estimates tree growth during intervals of low temperatures[4]. Although this experiment has been substantially critiqued[1–3], there has not yet been confirmation of the dating precision in temperature-sensitive ring-width chronologies using non-dendrochronological methods.

To objectively investigate the so-called threshold-response hypothesis[4–6] in tree-ring records, which was developed from different wood sources and used for temperature reconstructions before the period of ample documentary evidence, we consider a ring-width chronology that continuously covers most of the Holocene[7]. This dataset includes dendrochronologically dated wood from living trees, historical timbers from roof and wall structures in old buildings and subfossil material preserved in peat bogs, mires, lakes and glacial moraines; all from high-elevation settings in the Austrian Alps, where low temperatures during the growing season commonly trigger narrow rings[8]. This compilation of hundreds of ring-width series has been used to develop the longest annually resolved summer temperature reconstruction for Central Europe[8], providing a good test-case to evaluate the dating precision of a tree-ring temperature proxy before the past millennium.

Ten measurements of the ^{14}C to ^{12}C isotopic ratio were made on the dendrochronologically dated rings of a subfossil pine (*Pinus cembra*) excavated *in situ* from a peat bog at approximately 2,100 metres above sea level (Fig. 1a). These inter- and intra-ring-specific measurements reveal a rapid 1.2% increase in ^{14}C concentration from the year 774 to the year 775, as well as a greater than 1.5% rise between 773 and 776 (Fig. 1b). The observed peak coincides with high-resolution ^{14}C data (that is, within the 95% confidence interval) from Japan and Germany[9–11]. All other dating positions tested against high-resolution ^{14}C data[9–11] between the year 600 and the year 1000 exceeded the 99.7% confidence interval. This shows that the peak is the only possible match in the 400-year period. Thus, the radiocarbon pulse occurring at the year 775, assumed to correspond to an extraterrestrial event[9,10], is now documented in three different tree species on two continents. Moreover, it has been used to confirm the chronological integrity of a high-resolution palaeoclimatic benchmark for the Common Era and portions of the North Atlantic/European sector[8].

As none of the material in the aforementioned experiment comes from sites or trees used to produce the IntCal09 calibration curve, the radiometric time marker at the year 775 offers an independent, geochemical age determination for dendrochronologically dated tree-ring chronologies. Our

a

b

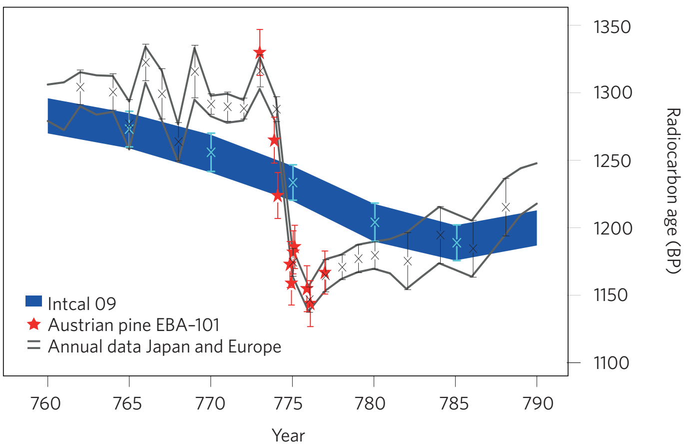

Figure 1 | Subfossil wood, radiometric dating and reconstructed temperature. **a**, A subfossil pine from the Austrian Alps. **b**, High-resolution radiocarbon ages (this study; red stars), superimposed on annually resolved radiocarbon measurements from Japan[9] and Europe[10] (grey lines and crosses) as well as the IntCal09 calibration curve based on decadal samples (blue shading), re-sampled at 5 year intervals (light blue crosses). Radiocarbon ages (that is, using ^{14}C, ^{13}C and ^{12}C isotopes) were determined at ETHZ with the MICADAS system.

measurements of ^{14}C from high-elevation trees in the Austrian Alps are consistent with corresponding values from temperate sites in Japan[9], Germany[10] and more thermally constrained forests in the Swiss Alps[12]. All studies demonstrate the precision of tree-ring dating back to the year 775. No single volcanic eruption was strong enough to trigger summer cooling sufficient to cause trees to remain dormant throughout the growing season, thus forcing a dating error due to missing rings. This behaviour has now been observed for records from different tree species growing at temperate low-elevations[9,10] and near the upper treeline[12], which is evidence that the records are correctly dated. The finding is striking because there have been at least 14 eruptions that exceeded a Volcanic Explosivity Index (VEI) of five over the past 1,200 years.

Given our motivation for testing the so-called temperature threshold-response hypothesis[4], it should be noted that state-of-the-art palaeoclimatic models use volcanic-induced forcings derived from sulfate loadings in polar ice cores[13] to define the timing and duration of atmospheric cooling after eruptions. Our study subscribes to the mounting evidence for the precise dating of tree rings. Accepting this as fact, we are left with four plausible explanations to account for the reported discrepancy between simulated and reconstructed post-eruption temperatures[4,6]: (1) the use of ring width instead of maximum latewood density[14]; (2) estimates of volcanic forcing are too strong for some events[15,16]; (3) models are too sensitive to volcanic forcing[17,18]; (4) incorrectly dated ice cores[3,19].

High-resolution ^{10}Be measurements from ice cores are, however, expected to improve ice-core dating, as well as the detection and attribution of climate forcing signals among different palaeoclimatic archives[19]. Furthermore, it is indisputable that a more systematic dendrochronological assessment of ^{14}C measurements around the year 775, including various species from a wider range of ecological settings around the globe, would offer additional independent evidence for our argument. ❐

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Author contributions
U.B. designed the study with input from J.E., L.W., M.S. and W.T. D.G. and L.W. (K.N.) performed Isotopic (dendro) measurements. All authors contributed to discussion and writing.

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CORRESPONDENCE:

Priorities for conservation corridors

To the Editor — Jantz *et al.*[1] take advantage of new, high-resolution estimates of biomass and vegetation carbon storage (VCS) to map areas throughout the tropics that, if protected, could simultaneously connect existing protected areas while also retaining large carbon stores. This study highlights how the growing wealth of remotely-sensed data can be used to intelligently and purposely design protected areas. Given the recent emphasis on carbon sequestration in establishing and funding protected areas[2], it is understandable that the authors took a largely carbon-centric approach when identifying their proposed conservation corridors. We argue, however, that there are more important factors that should be considered when evaluating and prioritizing potential corridors.

The principle motivation for establishing corridors is not to protect VCS but to allow individuals and even entire species to move between otherwise disconnected habitats[3]. Corridors should ideally be set up to connect similar habitats and cross through habitats similar to those being connected. Jantz *et al.* did not consider the habitat type or the species composition of the areas that they were connecting. Likewise, they did not consider the type of habitats contained within the proposed corridors in relation to the connected protected areas. Instead, the authors proposed corridors that would contain the greatest possible density of carbon and the greatest possible diversity of mammal species. Following these guidelines, high-priority corridors could theoretically be placed through high-biomass, high-diversity areas to connect different low-biomass habitats with distinct species compositions (for example, a corridor of rainforest connecting a savannah park to a dry forest park). In several places, such as in the southeastern Amazon, Jantz *et al.* suggest corridors through areas that are already heavily-modified and under intense human cultivation.