



The ^{14}C and tree-ring view into solar cycles, solar flares and climate

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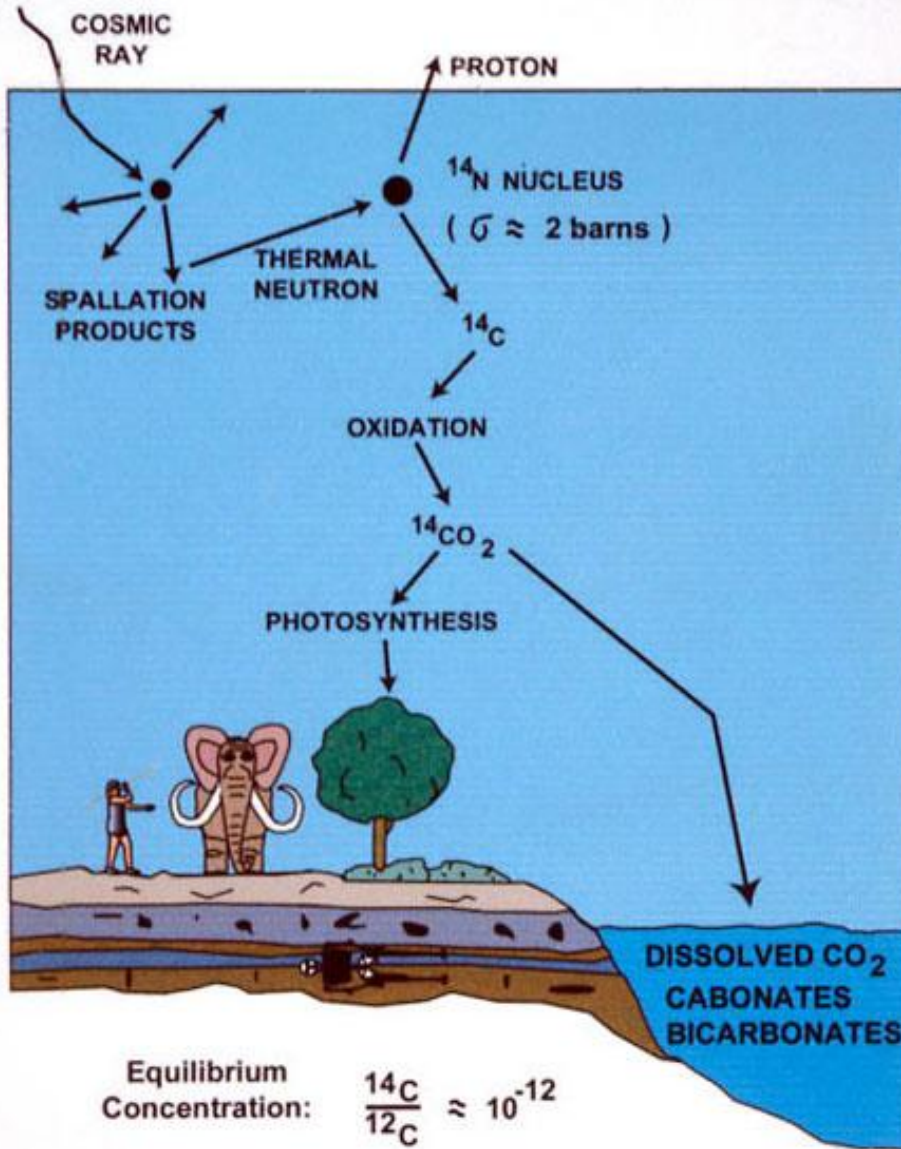
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“Sun and Climate” Symposium, Madison, WI. May 18 2022
Image: Laboratory of Tree-Ring Research, Broken Flute Cave (C-103).

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Equilibrium Concentration: $\frac{^{14}\text{C}}{^{12}\text{C}} \approx 10^{-12}$

Then: $^{14}\text{C} \rightarrow ^{14}\text{N} + e^- + \bar{\nu}$

$\tau_{1/2} = 5700 \text{ years}$

One Gram $\rightarrow \sim 10 \text{ counts/minute}$

Radiocarbon basics

Basic assumption: Radiocarbon is produced in the upper atmosphere through the action of secondary cosmic-ray neutrons on Nitrogen.

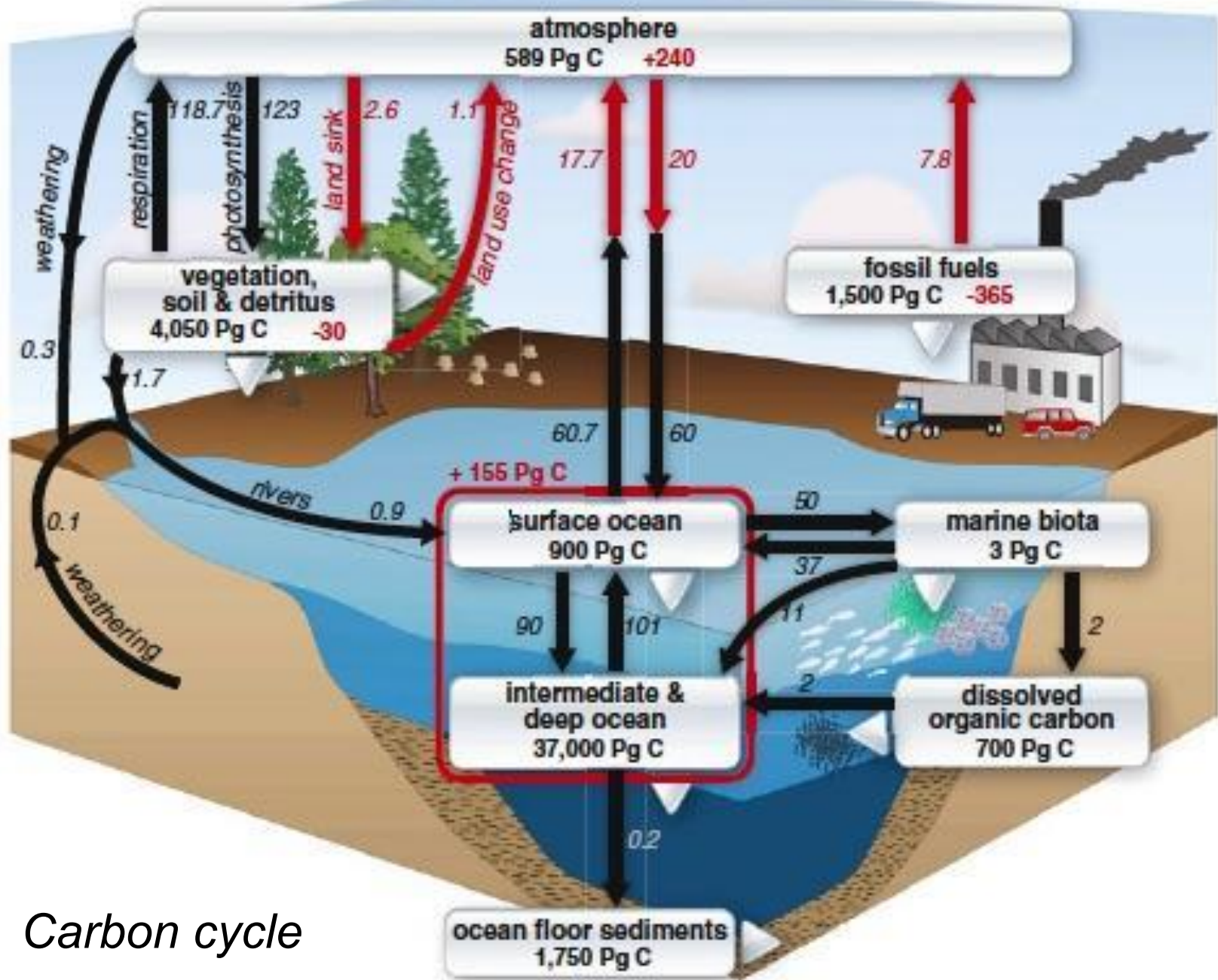
1. What we are dating was once in Equilibrium with the atmosphere, or,
2. If not, it was earlier in equilibrium with another reservoir that we understand

3. Important equations:

$$dN/dt = -\lambda N$$

$$\lambda = 0.693/t_{1/2}$$

$$N = N_0 \exp(-\lambda t)$$



Carbon cycle

J. Turnbull et al. (2015) in *Radiocarbon and Climate Change*. Springer.

Since 1950AD, an additional source of ^{14}C is from atmospheric nuclear testing.

This “spike” gives us information how Rapid changes are reflected in the Atmosphere.

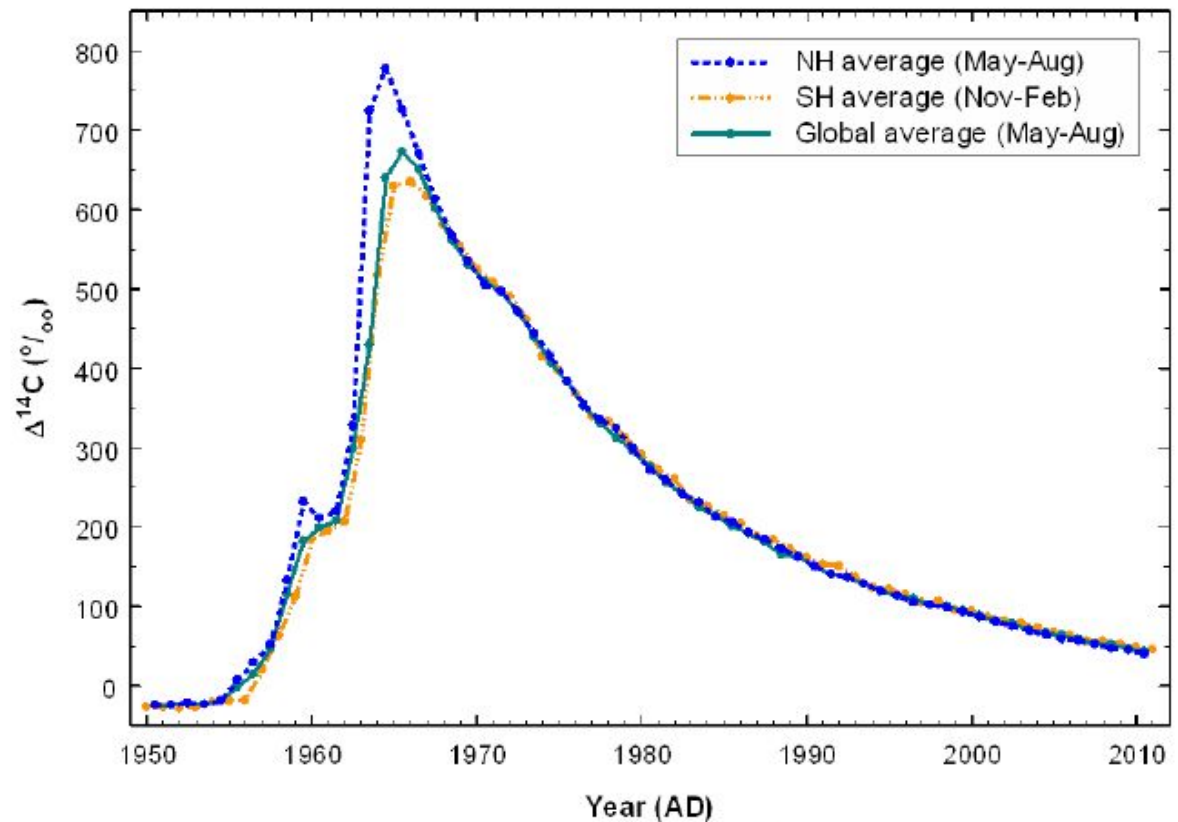


Figure 4 Compiled summer hemispheric and global ^{14}C curves. The compiled data sets are presented in Tables S2a–c.

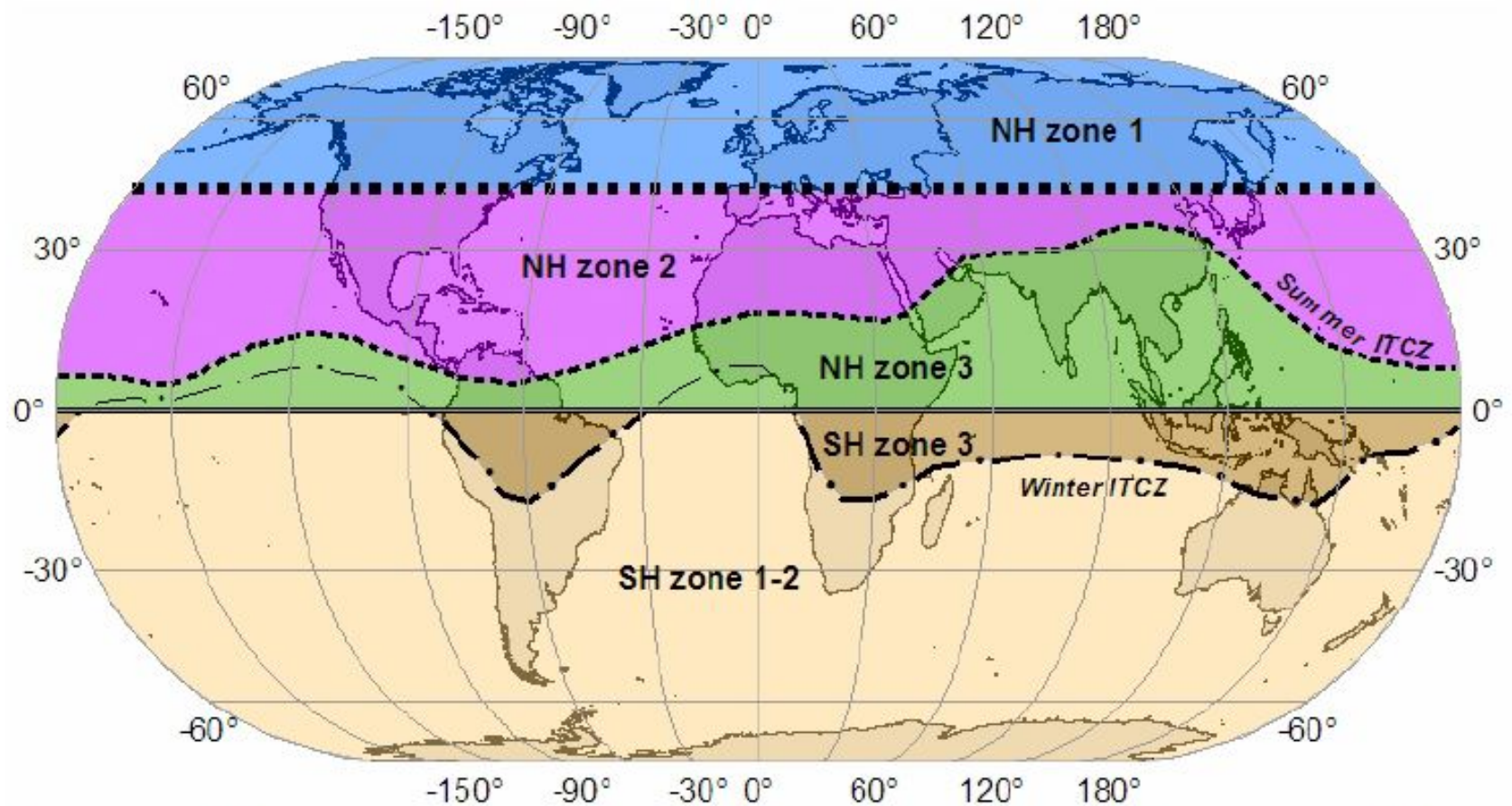
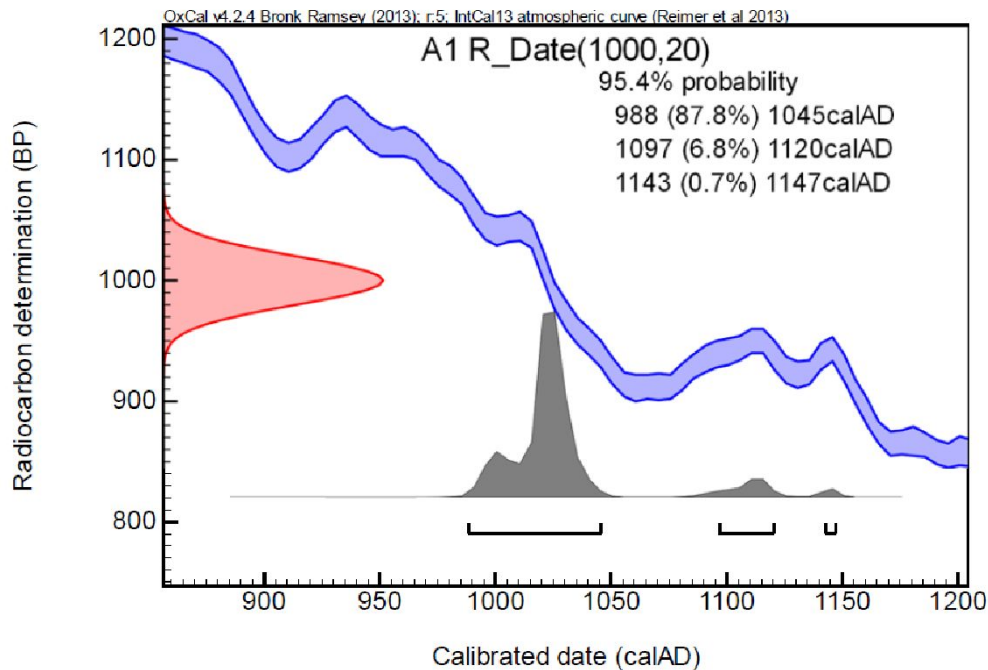


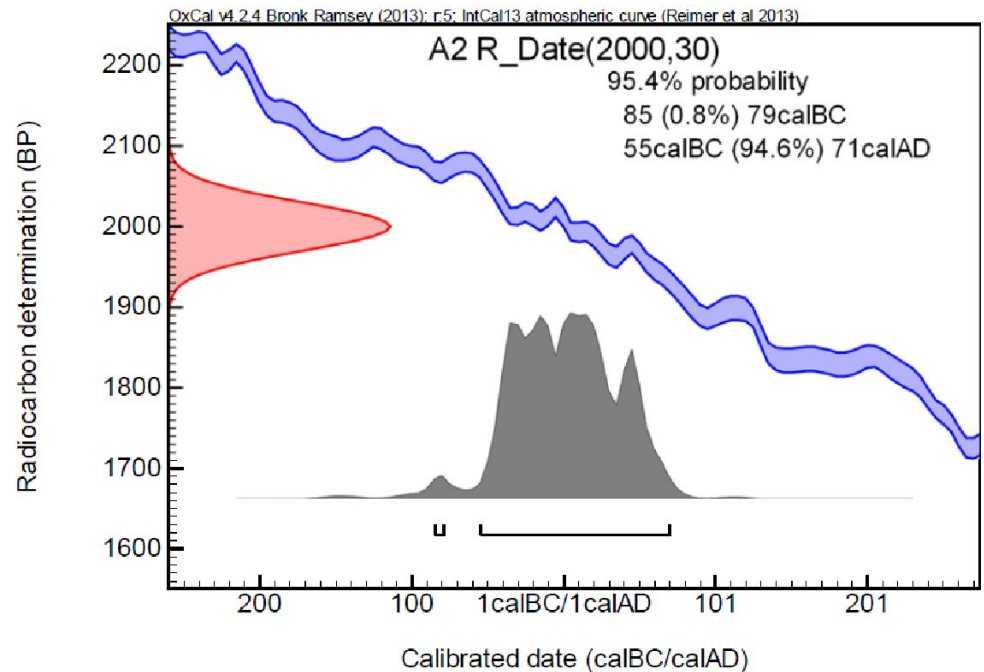
Figure 2 World map showing zonal atmospheric bomb ^{14}C . The mean positions of the summer and winter ITCZ are adapted from Linacre and Geerts (1997).

The spike of bomb ^{14}C tells us a lot about the atmosphere and its distribution (Hua et al. 2013)



What is meant by “calibration”

Because of the fluctuations in ^{14}C production, “radiocarbon ages” are calibrated against a known Chronology, either tree rings to about 13,900 yr or other proxies.



Definitions

It is useful to define $\Delta^{14}\text{C}$, which tells us the value of ^{14}C at the time of formation of the material –

Positive $\Delta^{14}\text{C}$ = increase in production or 14/12 ratio.

Negative $\Delta^{14}\text{C}$ – decrease in production or 14/12 ratio.

$$\Delta^{14}\text{C} = 1000 (F e^{\lambda(t)} - 1)$$

The value of F is the “fraction of modern carbon”, i.e.

$F = N/N_0$, where N_0 is the value at 1950AD*, and
t = true age of the sample.

If t is given in AD/BC, then $t = (1950\text{AD} - t)$, whether before or after 1950AD

λ = true decay constant of ^{14}C , 1.21×10^{-4}



Rapid events: Solar and other forcing?

- There are periods where there are rapid changes in the ^{14}C signal
- Solar-flare related events: 774-775CE, 993-994CE, 660BCE, 5410BCE, 5259BCE and 7176BCE
- Other solar phenomena: 810BCE, 5480BCE
- More events are likely.

Miyake et al. (2012) were the first to recognize a very large event at 774CE from ^{14}C in Japanese tree rings was likely due to solar-flare effects.

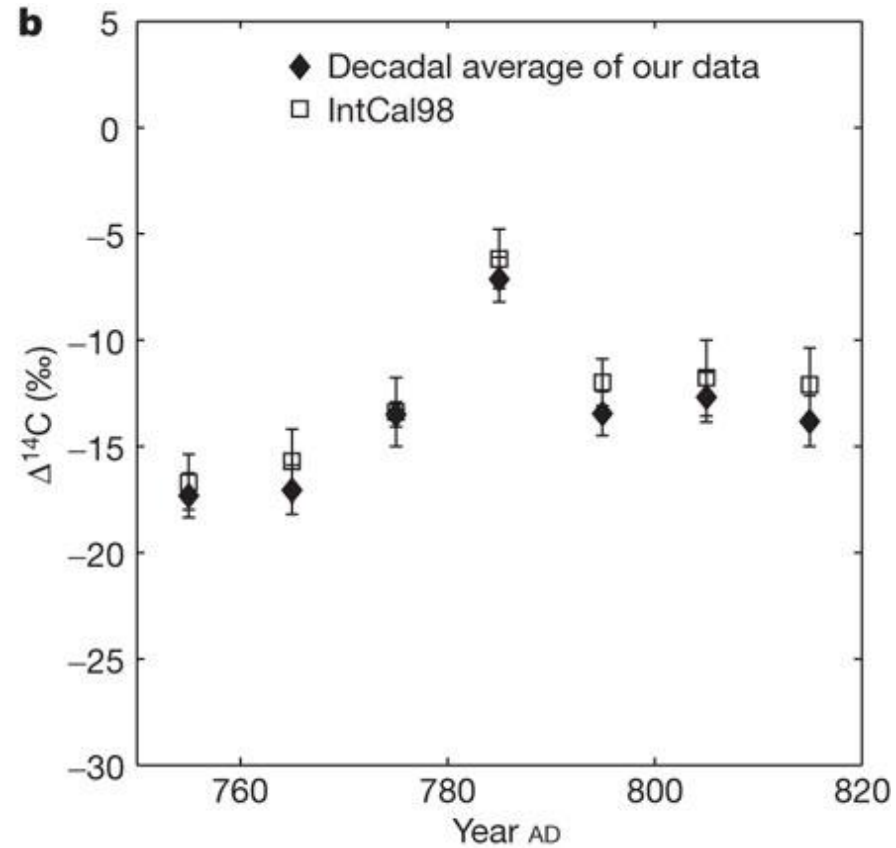
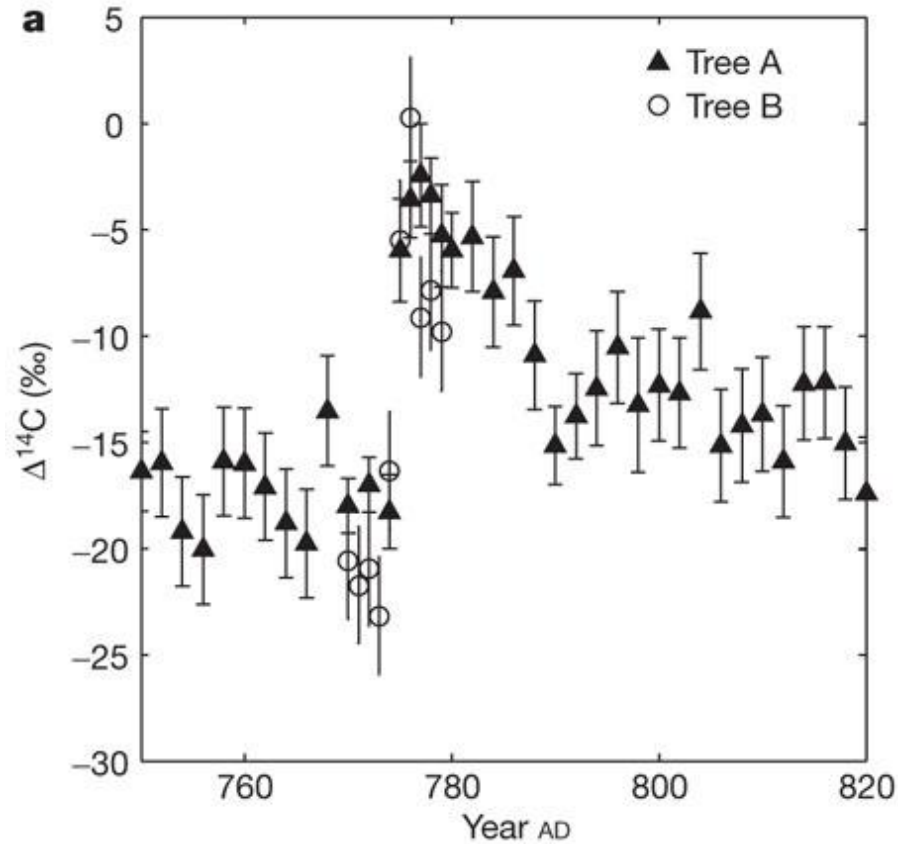
Other possible effects:
Supernovae?
 γ -ray bursts?
Carbon-cycle changes?



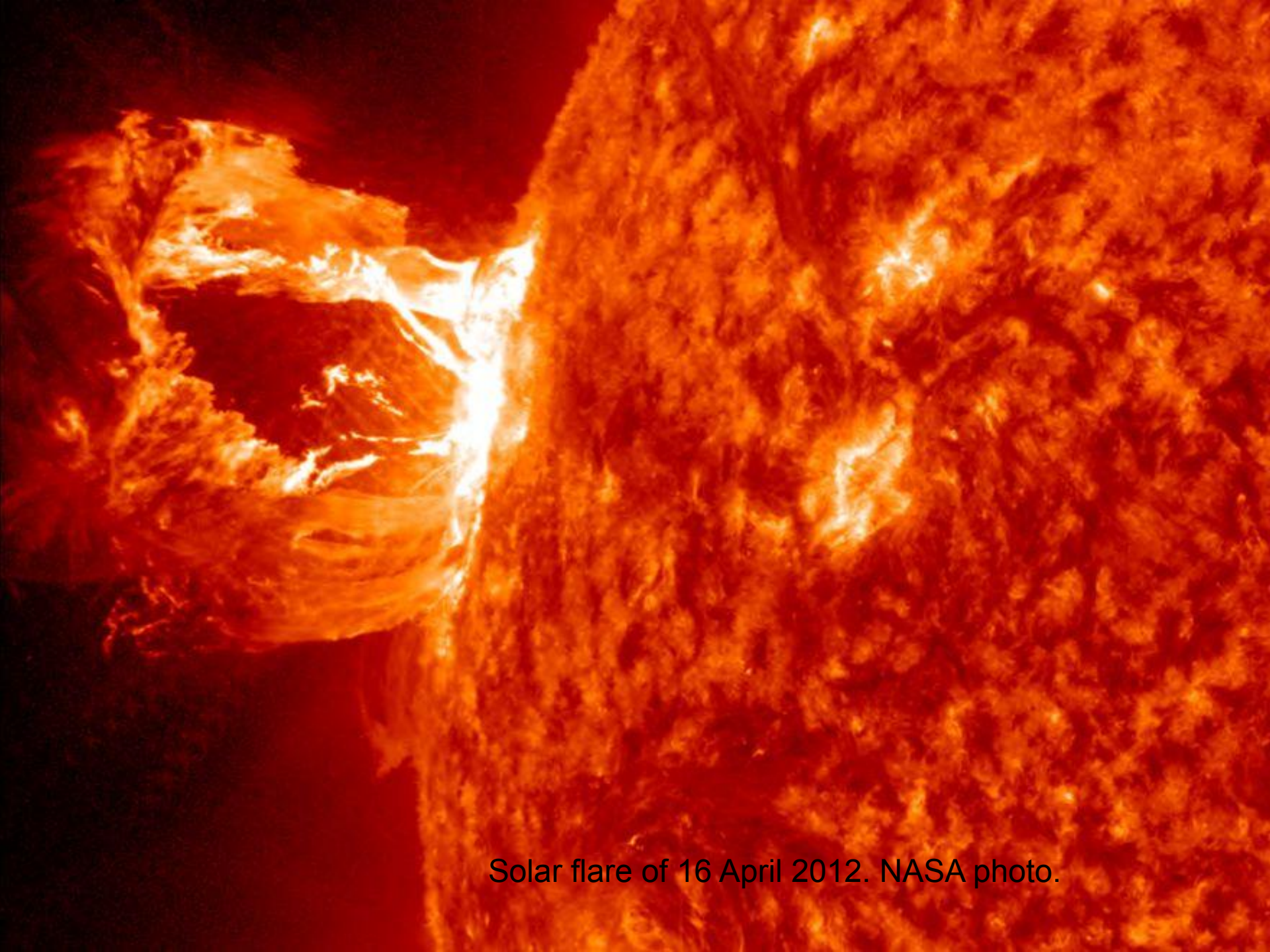
Fusa Miyake at Biosphere 2, Oracle, Arizona in 2015.

First results published in 2012.

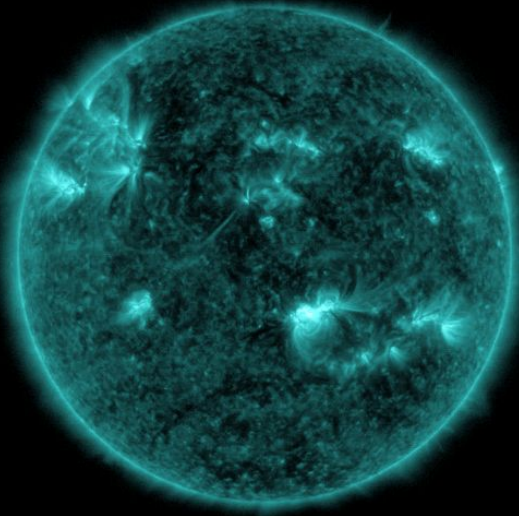
Cedar tree, Yaku Island, Japan



Miyake et al. 2012. Nature 486: 240-242. Over 211 citations.



Solar flare of 16 April 2012. NASA photo.

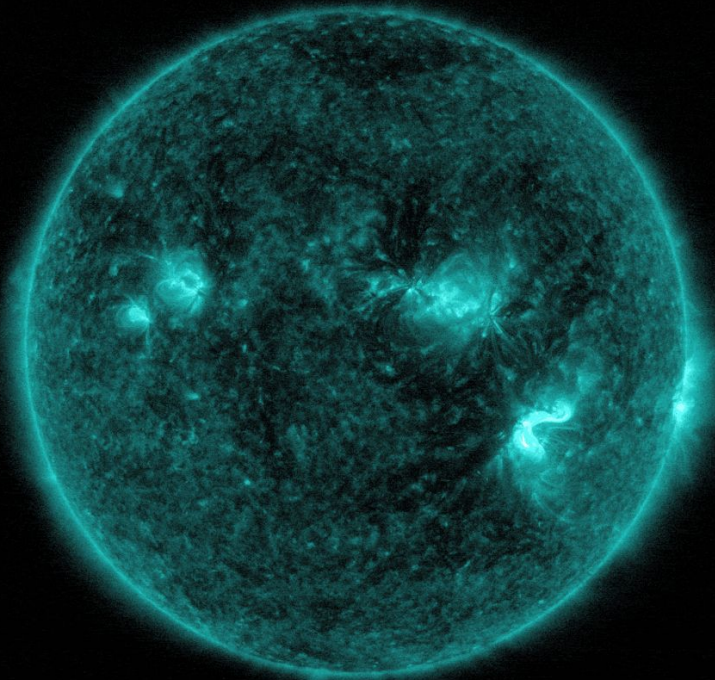


SDO/AIA 131 2011-02-15 01:20:59 UT

Giant X-class flare of 15 Feb 2011

Double X-class flare of 06 Sept 2017

from:
NASA Solar Dynamics Observatory
[www.nasa.gov/mission_pages/
sdo/videos/index.html](http://www.nasa.gov/mission_pages/sdo/videos/index.html)



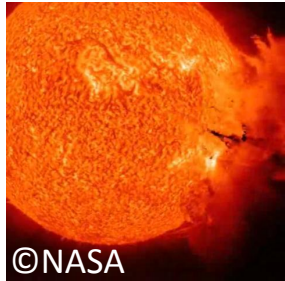
SDO/AIA 131 2017-09-06 07:12:44 UT



Solar storms generate magnetic fields on the earth and solar energetic particles Impact the Earth, creating effects like the aurora borealis. (photo: [bbc.com](https://www.bbc.com))

Possible causes of cosmic-ray variations

~ Emit a lot of CRs: Cosmic high energy phenomena ~

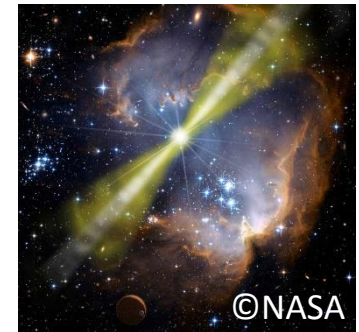


Solar Energetic Particle Event (SEP)

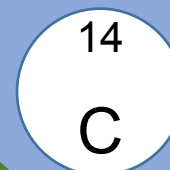
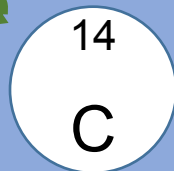
Supernova



Gamma-ray burst



- These events can make annual ^{14}C increase
- We are searching for such cosmic ray event over the tree-ring record.



Earth

Note: During periods of solar minima, the solar magnetic field is less, and $\Delta^{14}\text{C}$ will increase slowly (over decades).

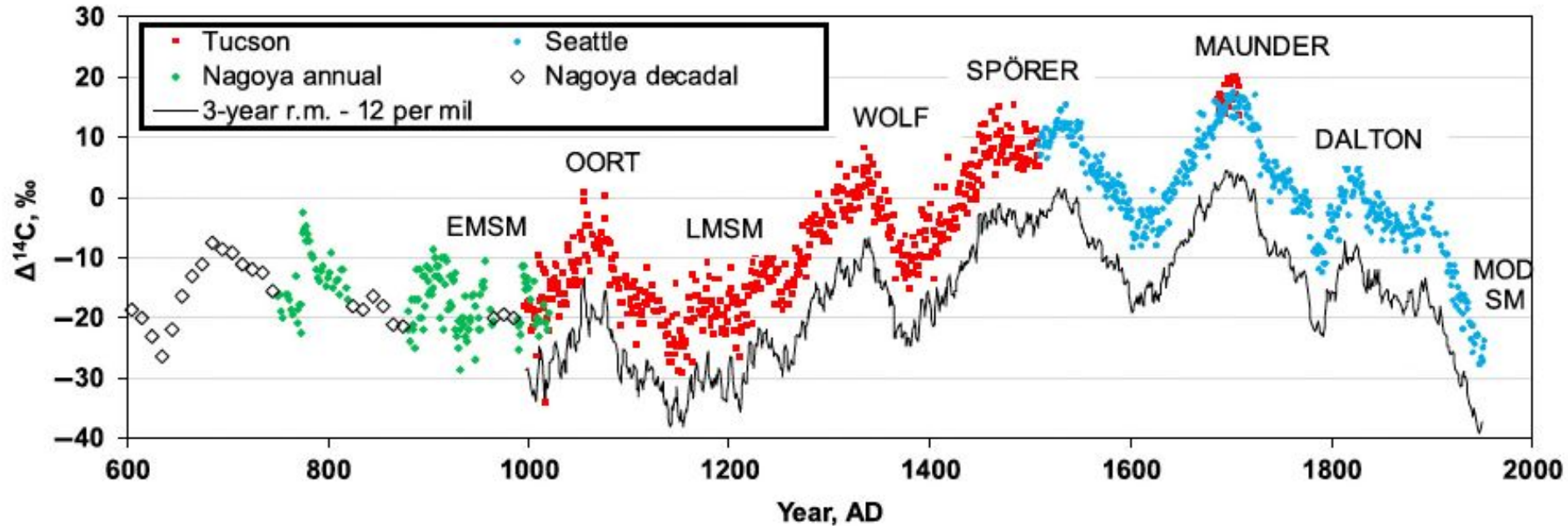
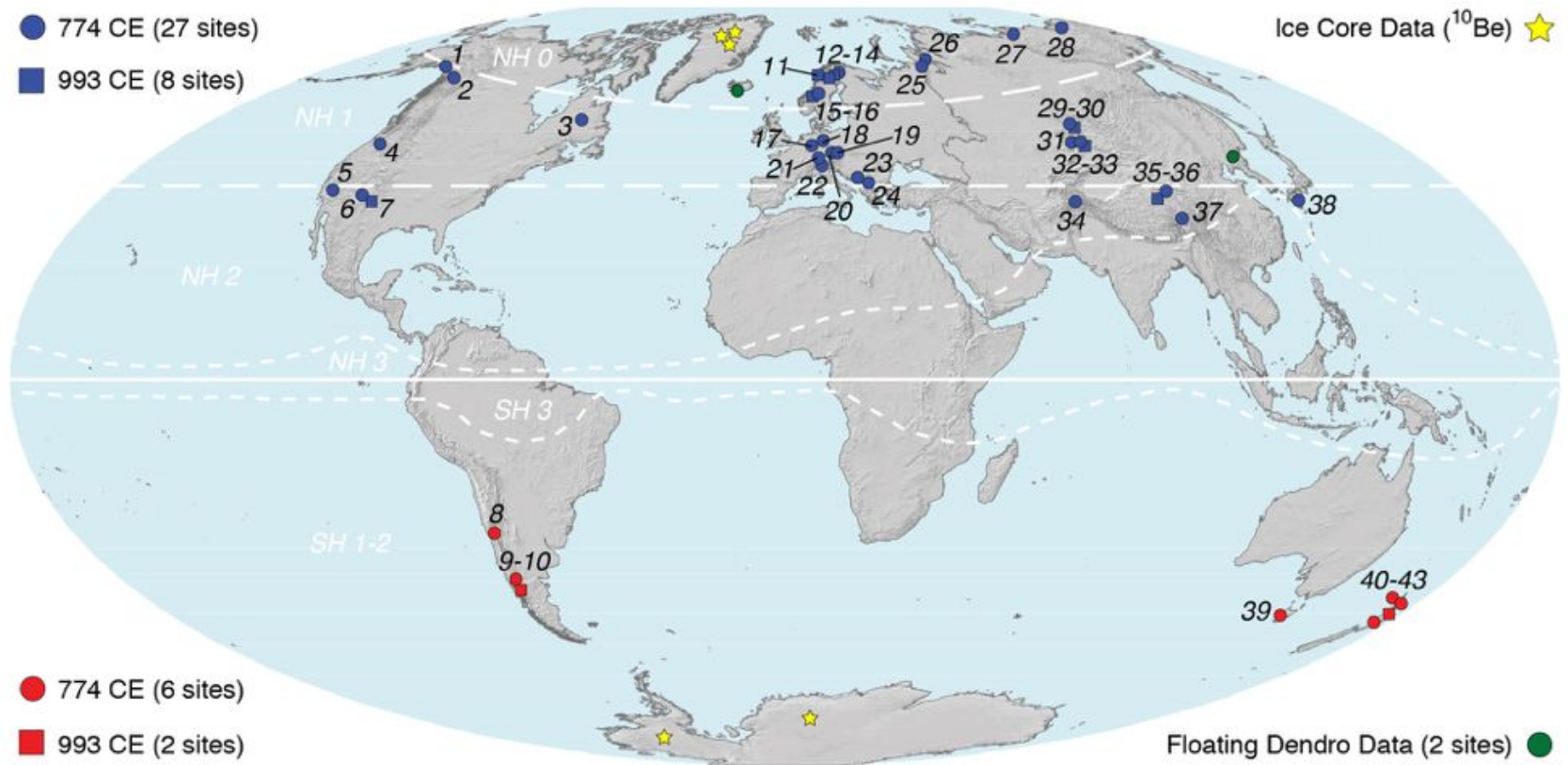


Figure 2 Annual and decadal $\Delta^{14}\text{C}$ time series for tree rings since AD 600 (Tucson laboratory: this study; Seattle laboratory: Stuiver et al. 1998; Nagoya laboratory; some data expressed as decadal means: Miyahara et al. 2004; Miyake et al. 2012, 2013a, 2013b), with a 3-yr running mean (displaced downwards by 12‰) for AD 998–1954. Named Grand Solar Minima and Maxima are shown. E(L)MSM = Early (Late) Medieval Solar Maximum, MOD SM = Modern Solar Maximum.

774-775 and 993-994AD: Geographic distribution.



(from Büntgen et al. 2018)

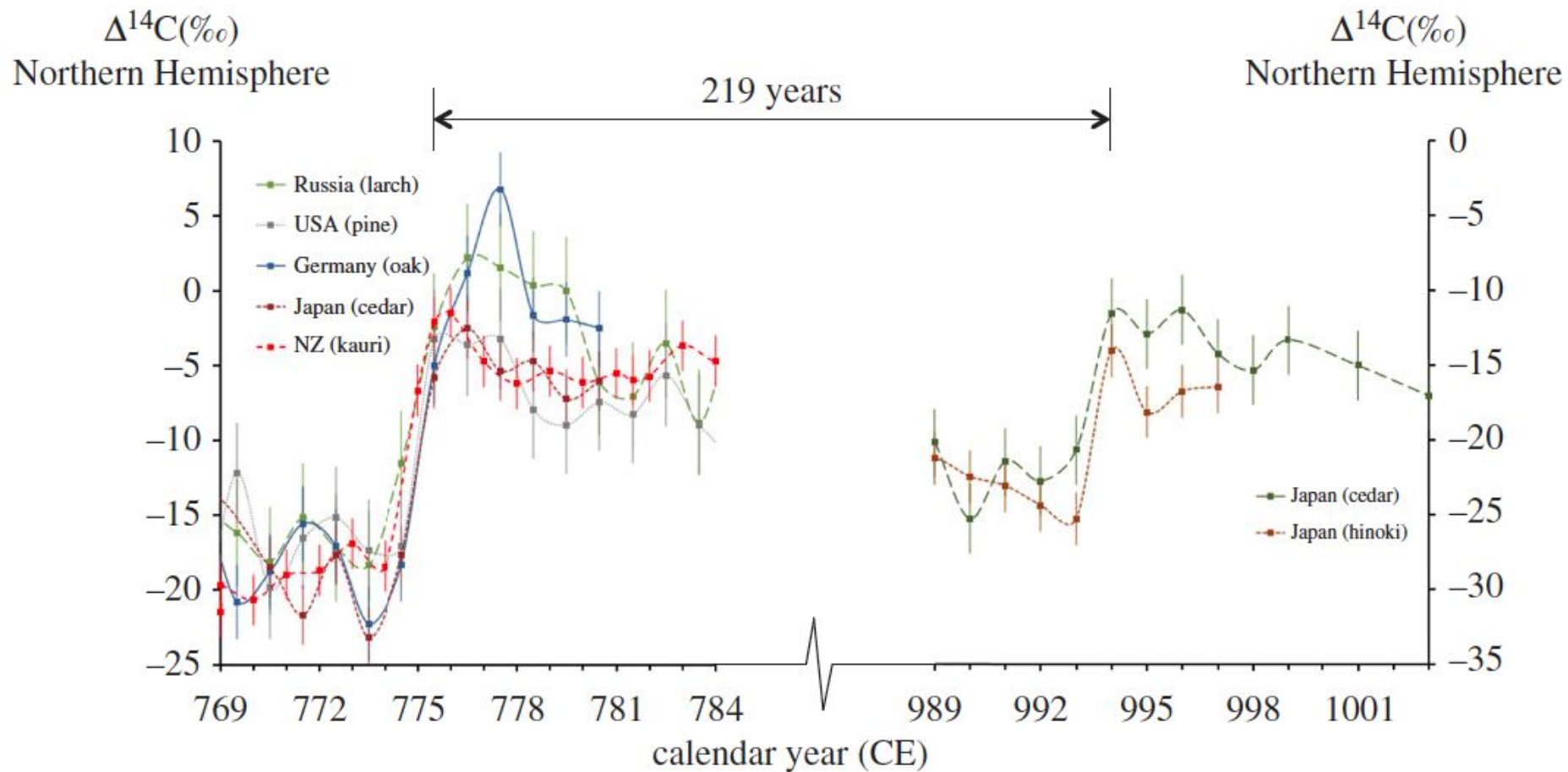
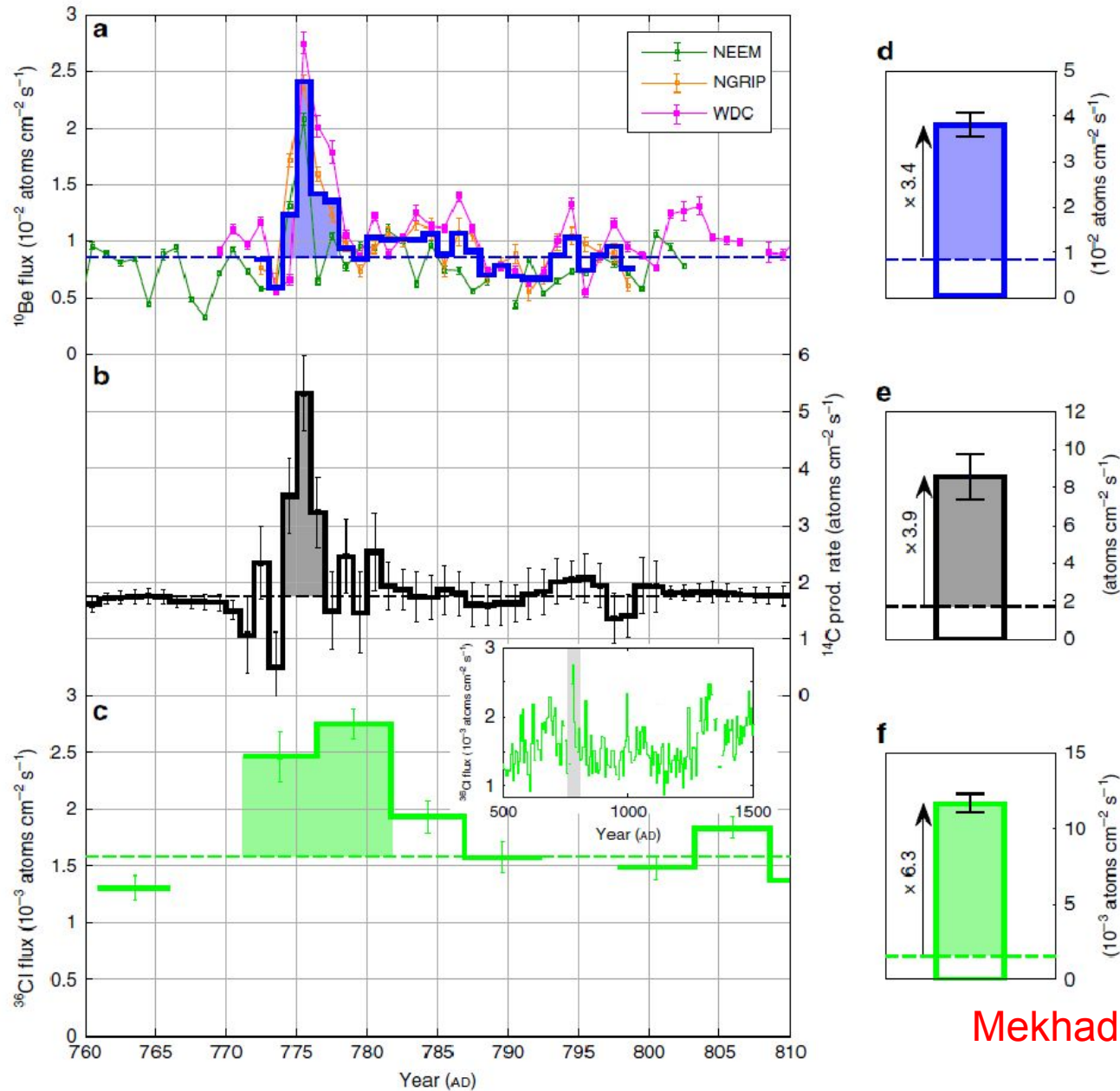


Figure 1. Time profiles of the measured $\Delta^{14}\text{C}$ content in tree-rings from different species and different locations around the world. The two spikes are obvious, and separated by exactly 219 calendar years. For ease of display, the data obtained on the kauri samples from New Zealand have all been elevated by 5‰, an amount which approximately corresponds to the offset between Northern and Southern Hemisphere $\Delta^{14}\text{C}$ values. (Online version in colour.)

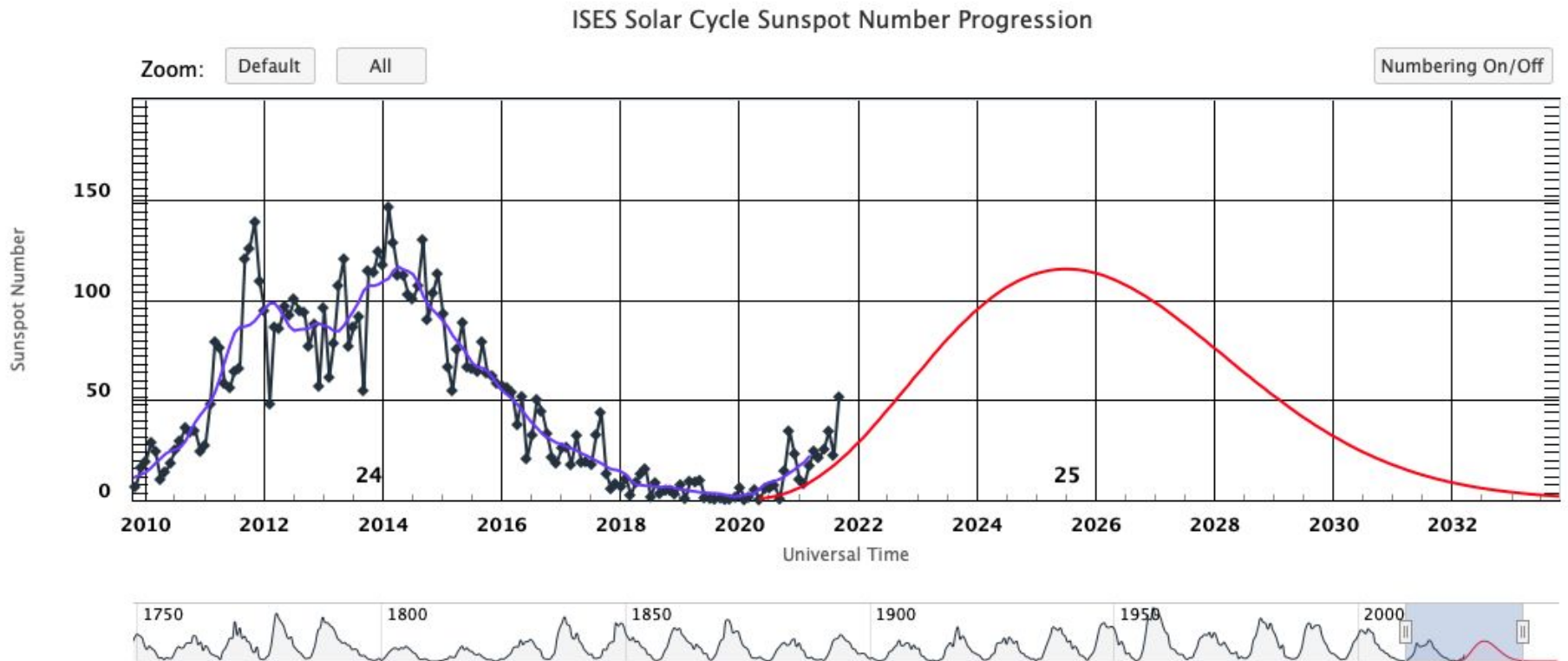
Summary from Dee and Pope (2016), Proc. Roy. Soc. Lond. A472:20160263

Miyake Event 774-775AD shown in ^{10}Be and ^{36}Cl in ice cores

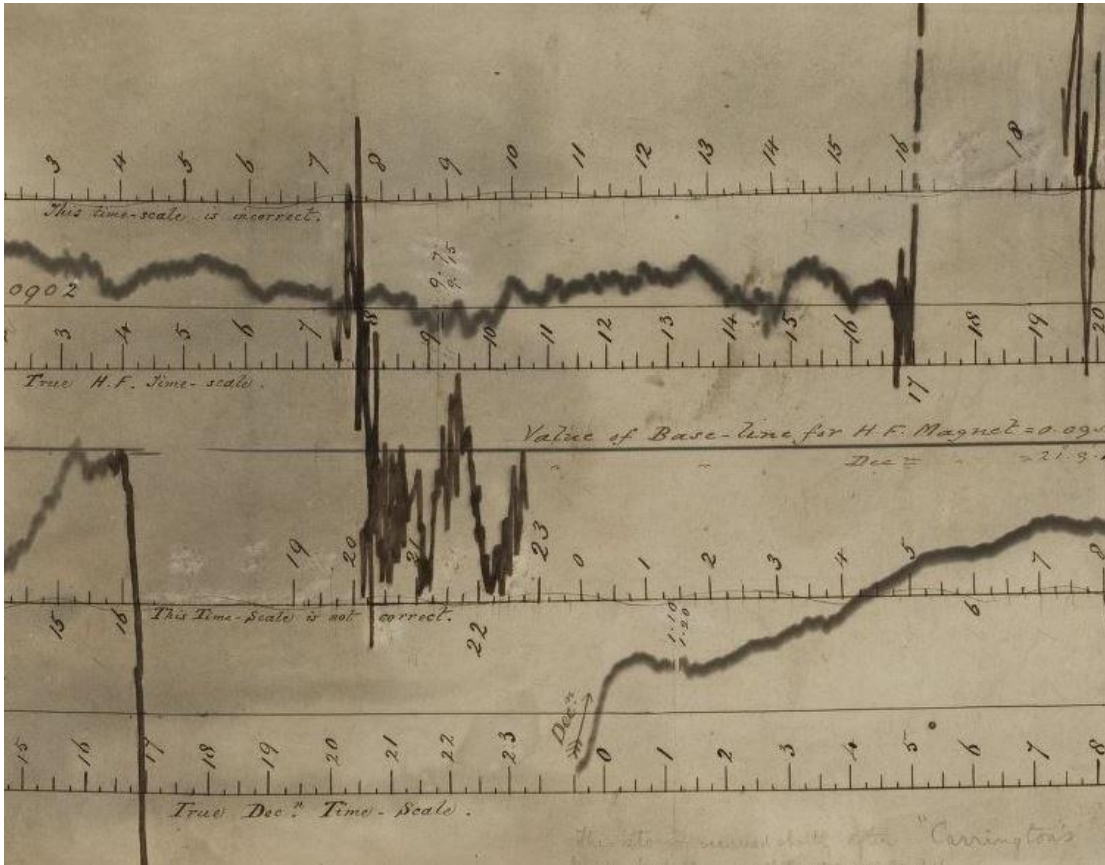


Mekhadi et al. 2015

Solar cycle and sunspots



Source: swpc.noaa.gov

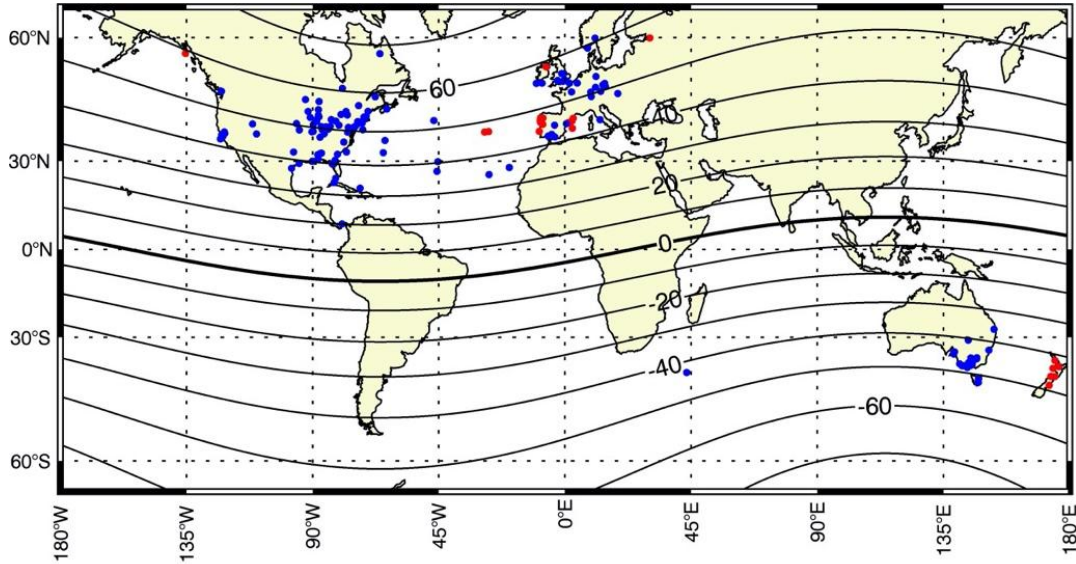


Horizontal intensity (upper) and declination (lower) observed at the Greenwich Observatory (London) on 01 Sept 1859.

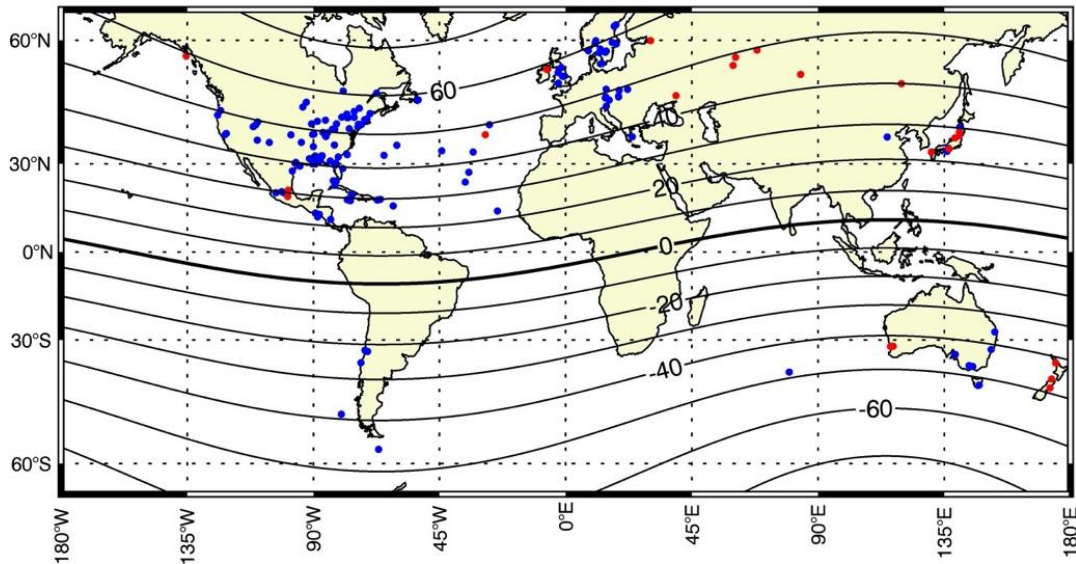
- “Modern estimates of Dst for the Carrington Event itself range from -800 nT to a staggering -1750 nT”

(science.nasa.gov)

Solar superstorm of 27 Aug to 7 Sep 1859 (Carrington Event)



Carrington Event (Sep 1859):
Aurora observed as far south
as Havana, Cuba and the Azores



Latitudinal observability of aurorae during the Carrington event (Hayakawa et al.)

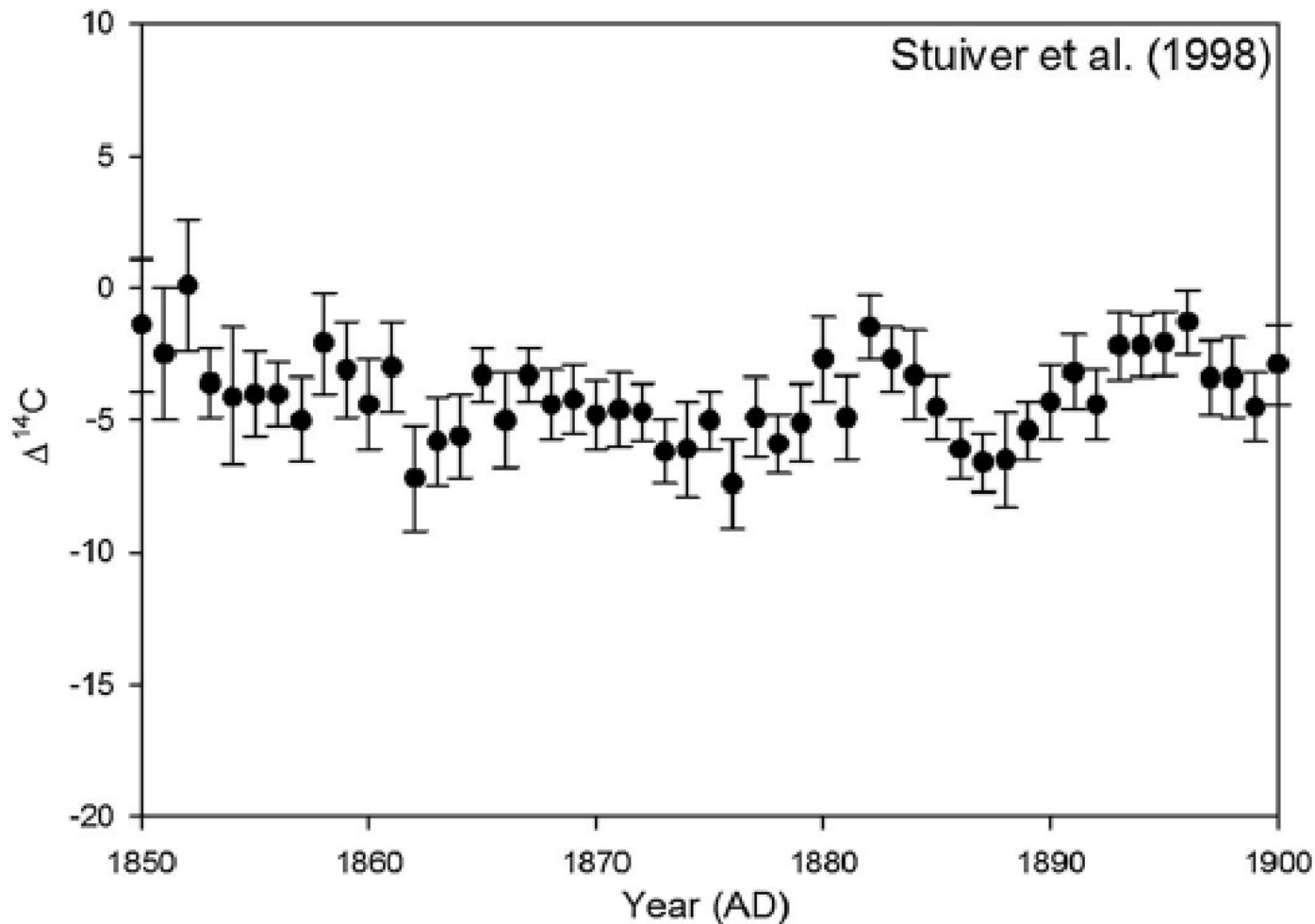
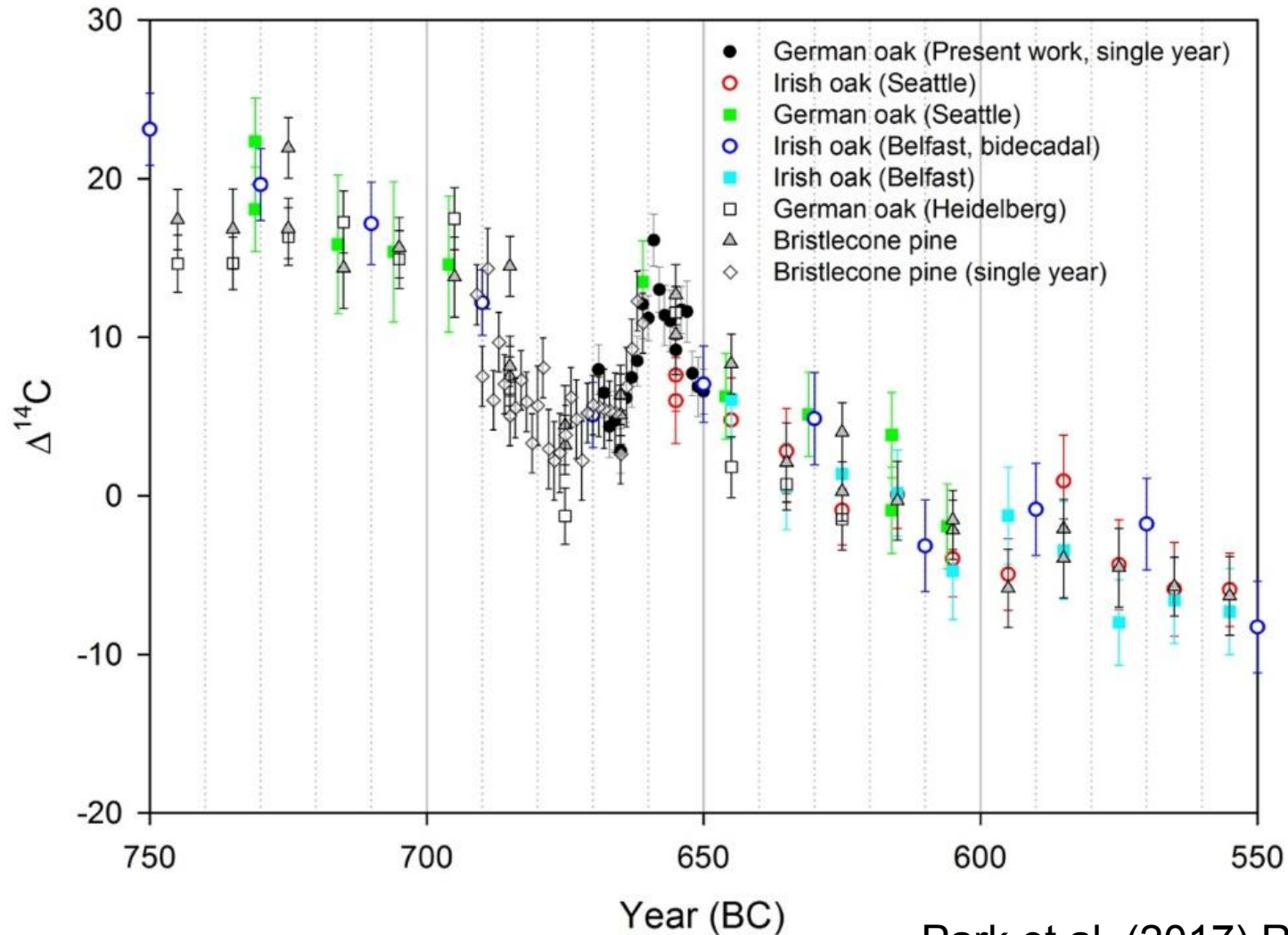


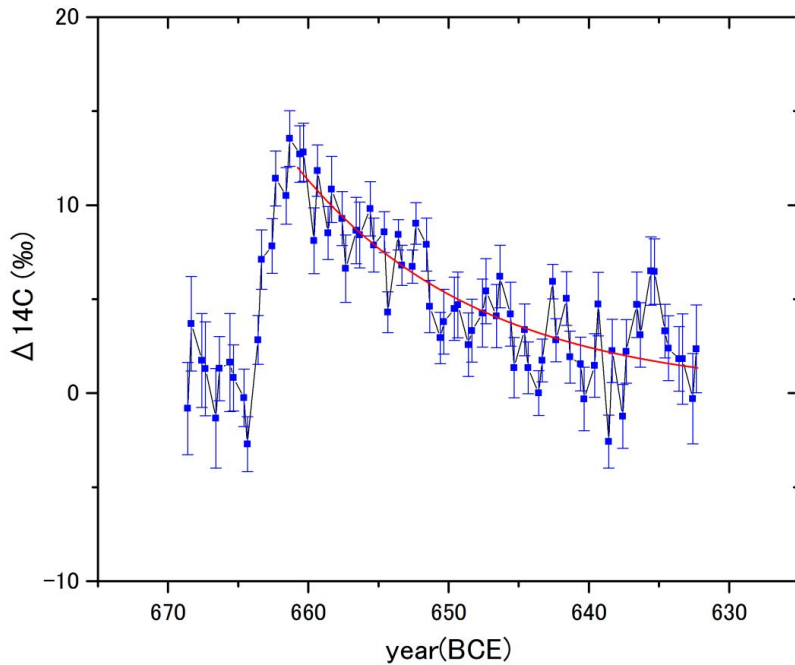
Figure 3. Record of $\Delta^{14}\text{C}$ (‰) between A.D. 1850 and A.D. 1900 from *Stuiver et al. [1998]*.

What about the Carrington event? Estimated F30 1.9×10^{10} p/cm². Apparently, not observable in the tree-ring record

Park et al. (2017) 660BC “spike”:

Note the effect of these single-year data relative to the calibration curve





Sakurai et al. (2020) measured a record
In Choukai-Jindai cedar (*Cryptomeria
japonica*) showing an excellent record.

Scientific Reports 10: 660 (2020)

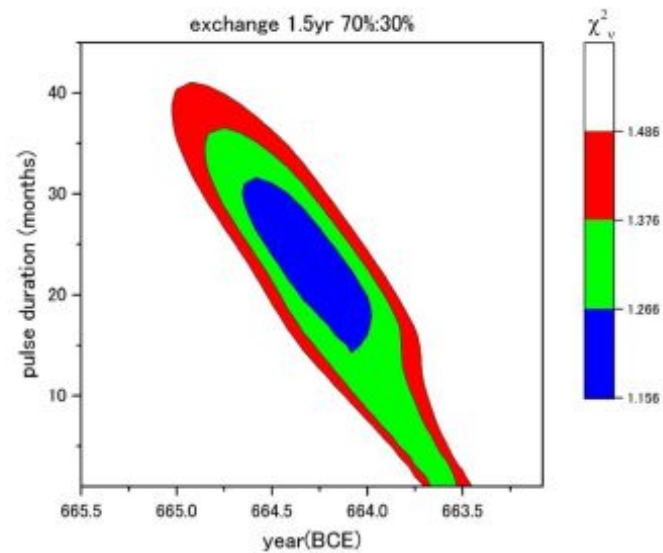
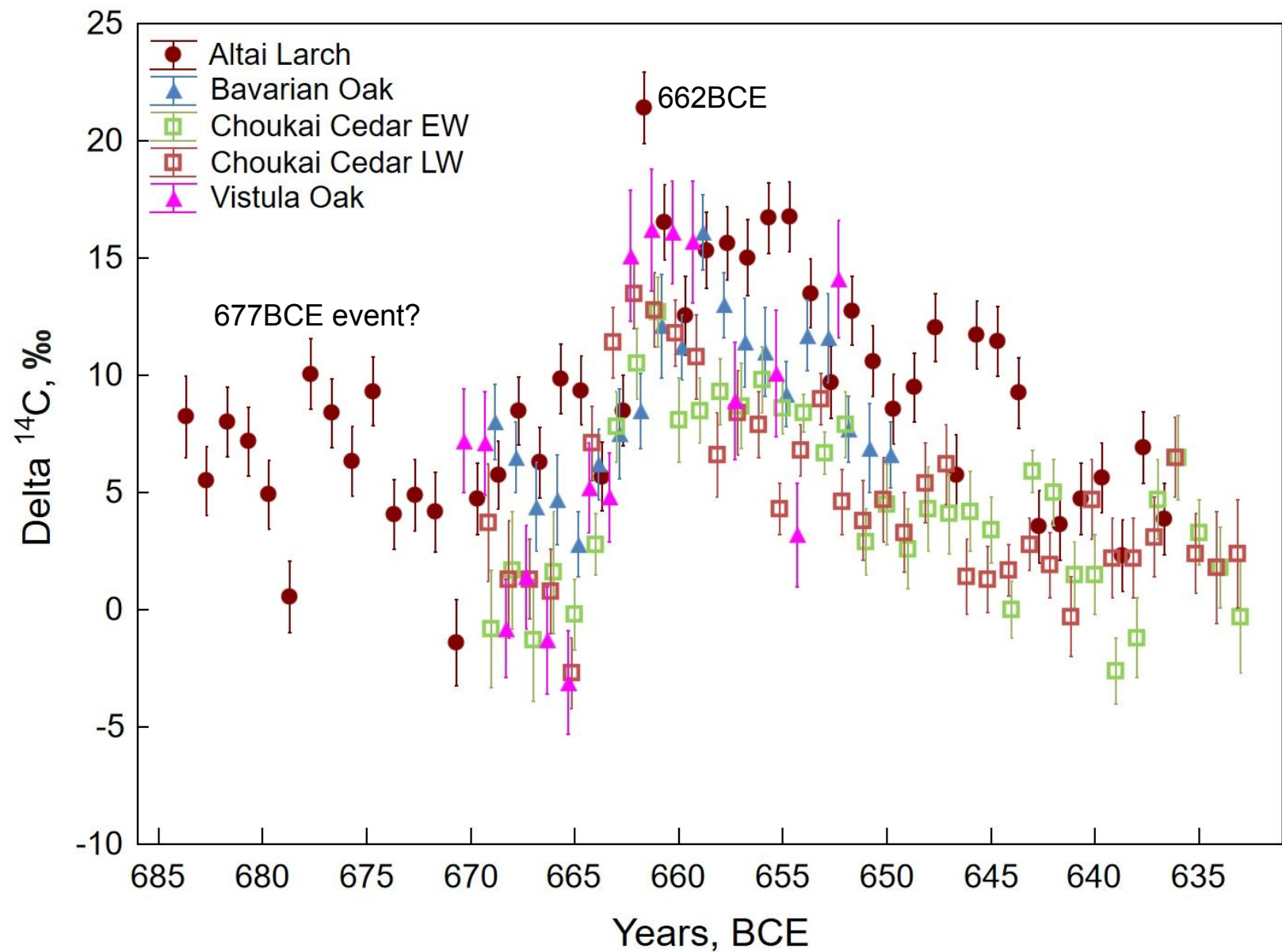


Figure 3. Contour map of reduced χ^2_v values as a function of pulse duration and pulse start date for the pulse height including the best-fitted single-pulsed event. The conditions of fitting calculation in the 11-box model are 1.5 years, and 70%: 30% for the exchange time and share rate of input ^{14}C production between the stratosphere and troposphere, respectively. Outside of the red region is rejected with 95% confidence level.



We obtained a new series for the period 684-634 BCE from wood collected from a kurgan in the Altai region (Siberia)



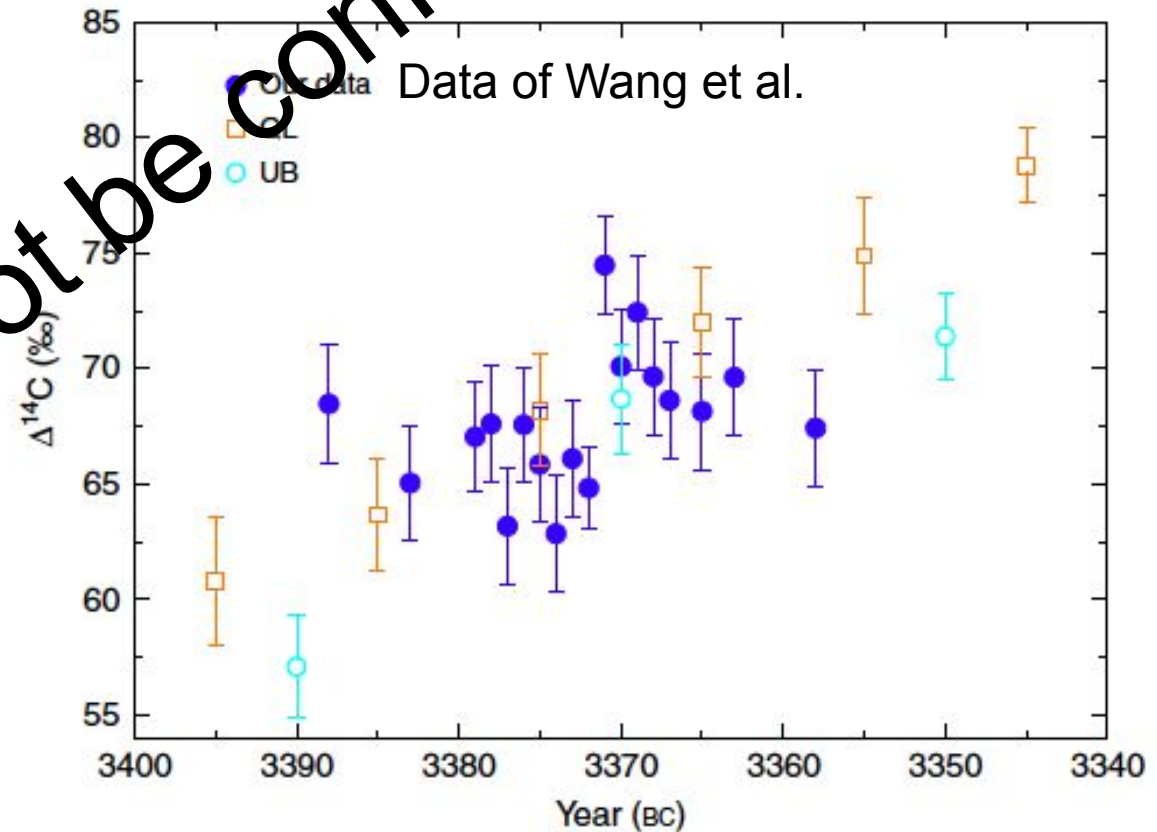
New results from Altai larch (684-634BCE) compared to other records.

Wang et al. (2017) – possible 3372-3371 BC event ?

Fossil Chinese wignut tree

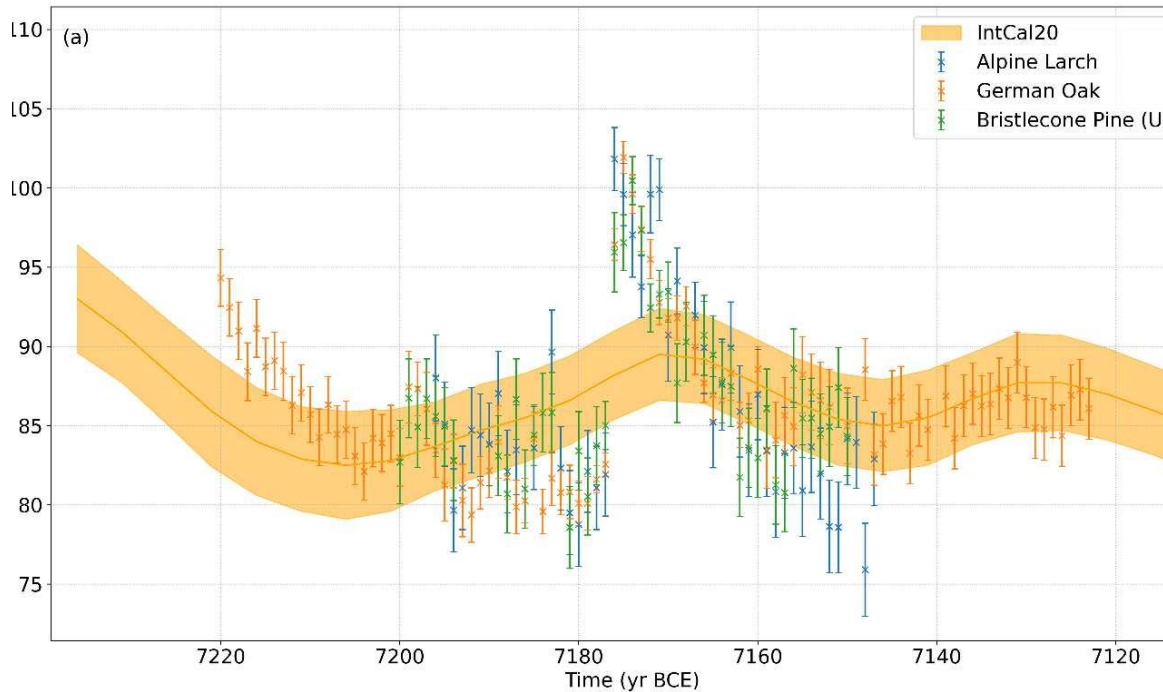
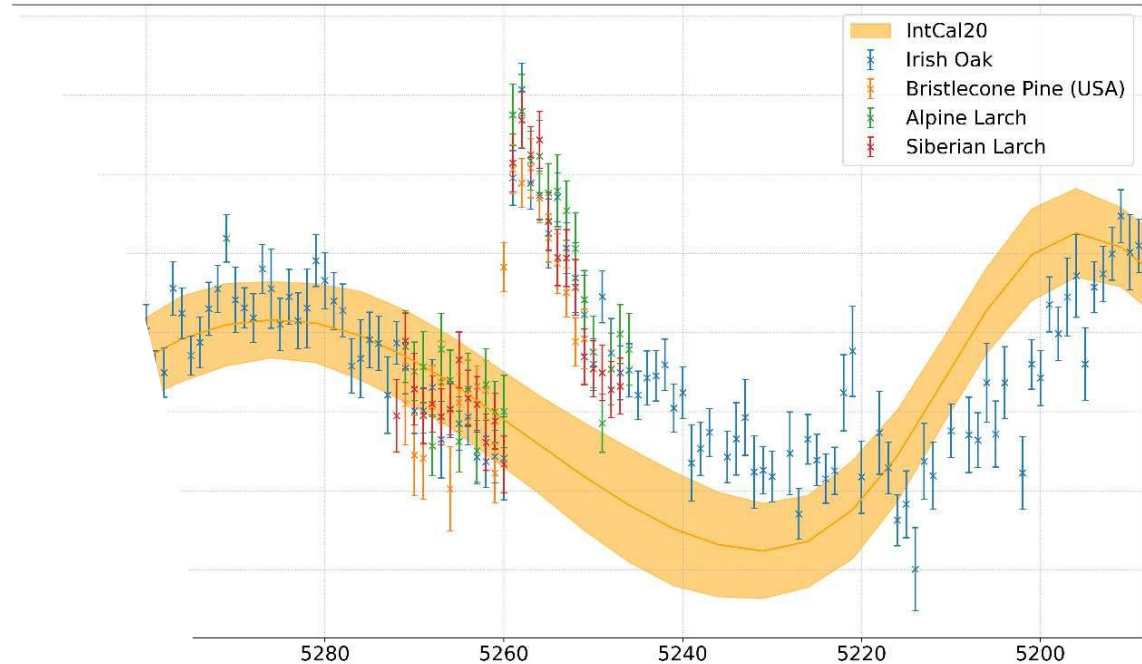


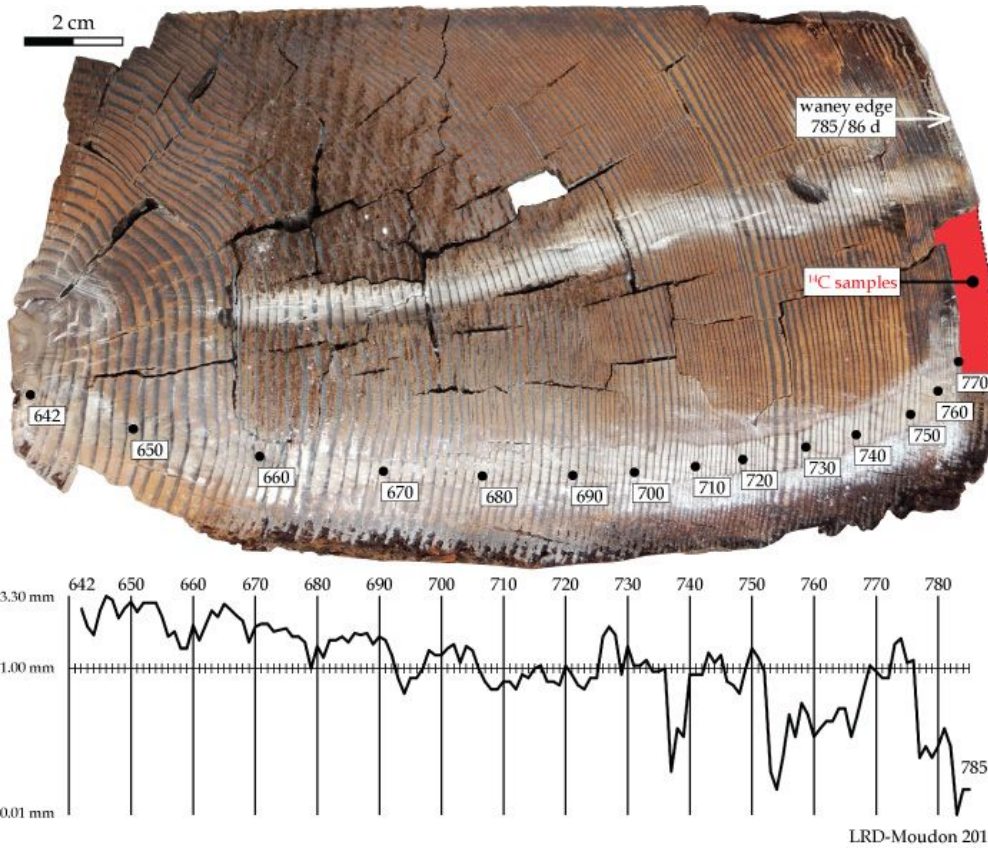
Nature Communications 8: 1487.
DOI: 10.1038/s41467-017-01698-8



2 newest events reported

Two new spikes (20 per mil)
5260 and 7176BC
(Brehm et al. 2021,
Nature Communications).





Wacker et al. (2014) used wood from the Holy Cross Chapel (St. John Abbey, Mustair, CH) to date it precisely, since it included the 774AD event.

Radiocarbon 56(2): 573-579.



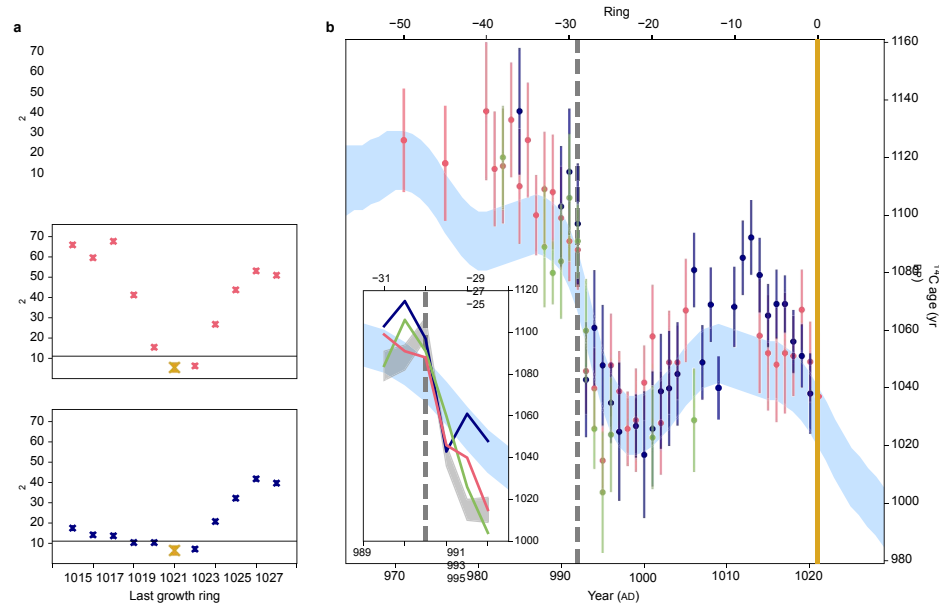
Date: 786AD. Abbey established about 780AD on the order of the Bishop of Chur.



“Leif Erikson discovers America”, National Gallery of Norway. C. Krohg 1893.

993AD event
Used for accurate
dating

Kuitems et al. 2021
Nature (today)




Article

Evidence for European presence in the Americas in AD 1021

<https://doi.org/10.1038/s41586-021-03972-8>

Received: 21 May 2021

Accepted: 31 August 2021

 Check for updates

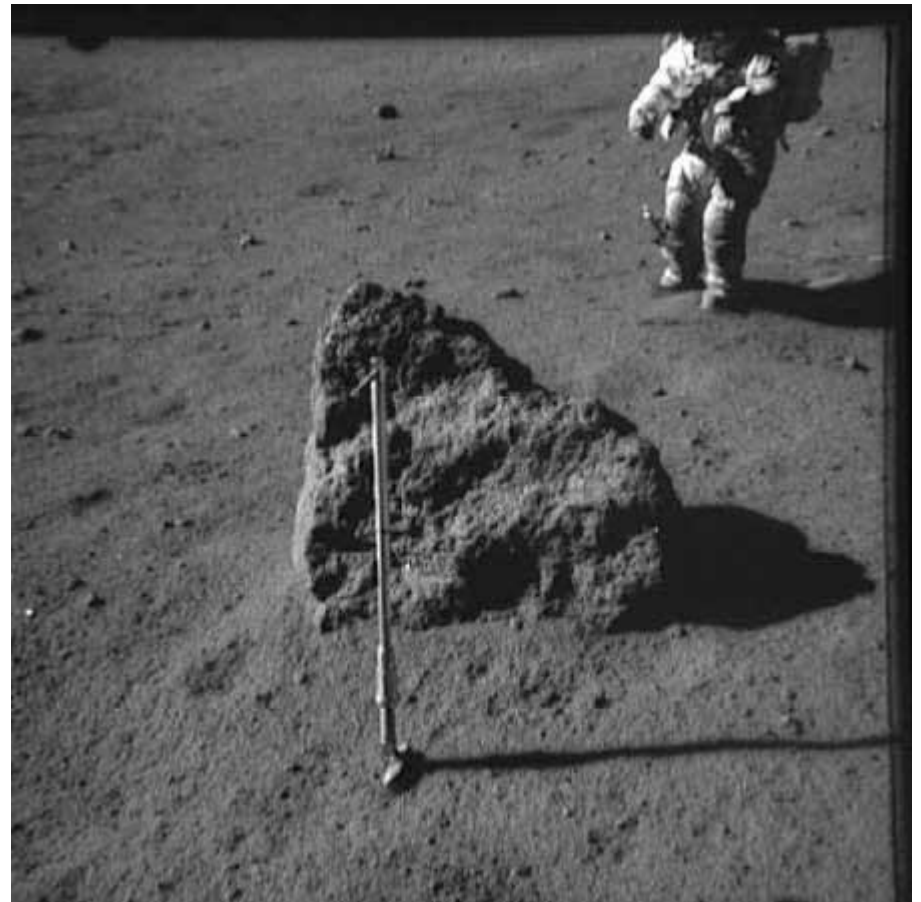
Margot Kuitems¹✉, Birgitta L. Wallace², Charles Lindsay², Andrea Scifo¹, Petra Doeve^{3,4}, Kevin Jenkins², Susanne Lindauer⁵, Pinar Erdil¹, Paul M. Ledger^{6,7}, Véronique Forbes⁶, Caroline Vermeeren⁸, Ronny Friedrich⁵ & Michael W. Dee¹✉

Transatlantic contact took place centuries before the crossing of Columbus. Physical evidence for early European presence in the Americas can be found in Newfoundland, Canada^{1,2}. However, it has thus far not been possible to determine when this activity took place^{3–5}. Here we provide evidence that the Vikings were present in Newfoundland in AD 1021. We overcome the imprecision of previous age estimates by making use of the cosmic-ray-induced upsurge in atmospheric radiocarbon concentrations in AD 993 (ref. ⁶). Our new date lays down a marker for European cognisance of the Americas, and represents the first known point at which humans

Is there other information to constrain the total fluence of solar proton events?



Lunar rock 68815. NASA photos.



Jull et al. (1998).
Rock 68815

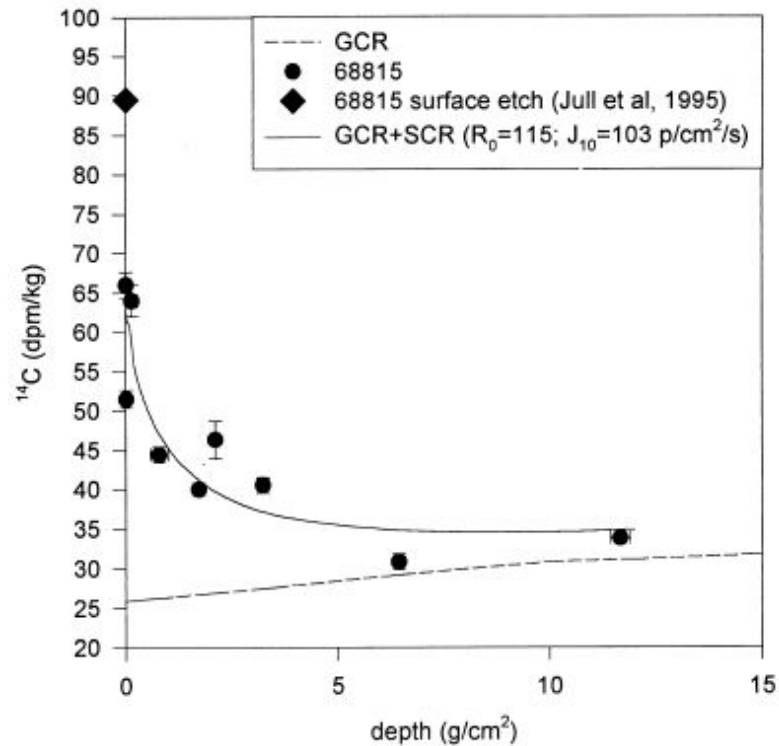
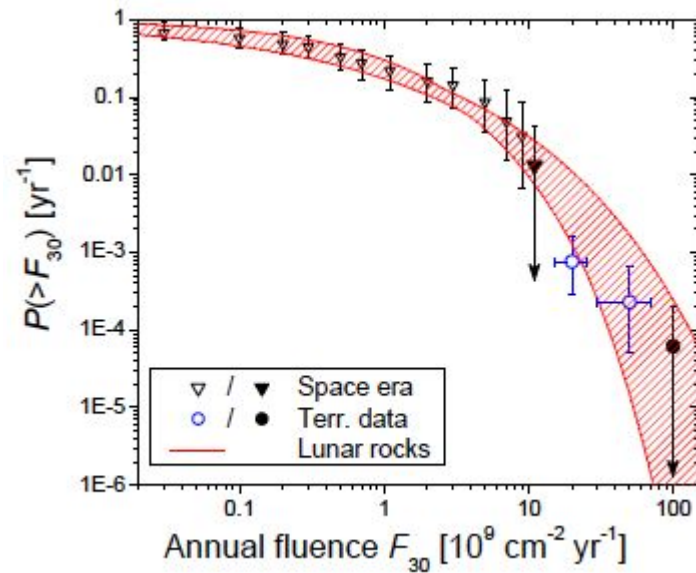


Fig. 6. ^{14}C (dpm/kg) as a function of depth in Apollo 16 rock 68815,292. The plot shows the experimental measurements (●) compared to the best fit of SCR of $R_0 = 115$ MV and $J_0 = 103$ p/cm²/s, plus GCR (solid line), as well as the calculated GCR production, plotted as the dashed line. Bulk density of the rock is 2.8g/cm³ (Kohl et al, 1978). Also shown is the higher surface value measured by Jull et al. (1995) from acid etching of the rock surface. This sample shows the effects of surface implantation by solar-wind ^{14}C in the top few nm.

Poluianov et al. 2018

Astronomy and Astrophysics.

<https://arxiv.org/pdf/1807.10153.pdf>



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- Dr. Jull has disclosed an outside interest in Hungarian and Czech Academies of Sciences to the University of Arizona. Conflicts of interest resulting from this interest are being managed by The University of Arizona in accordance with its policies.