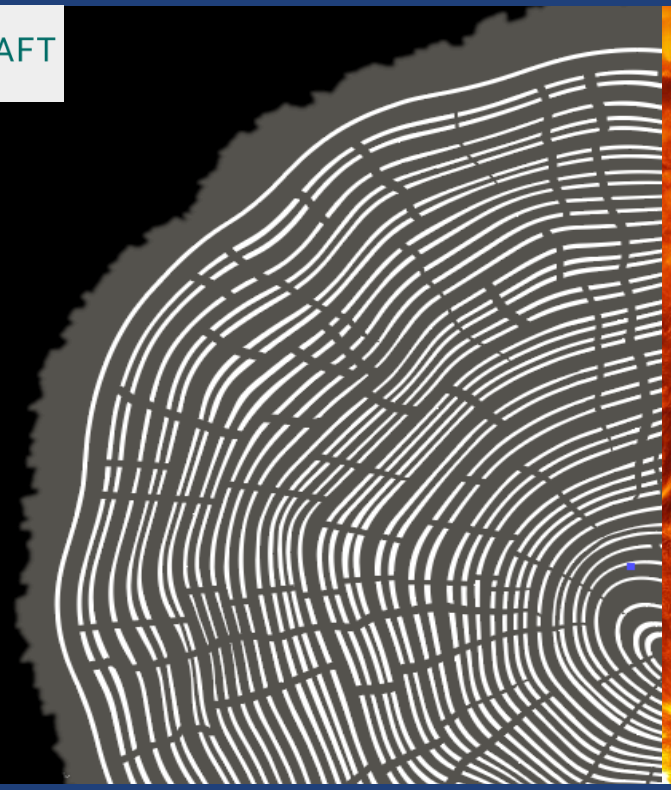
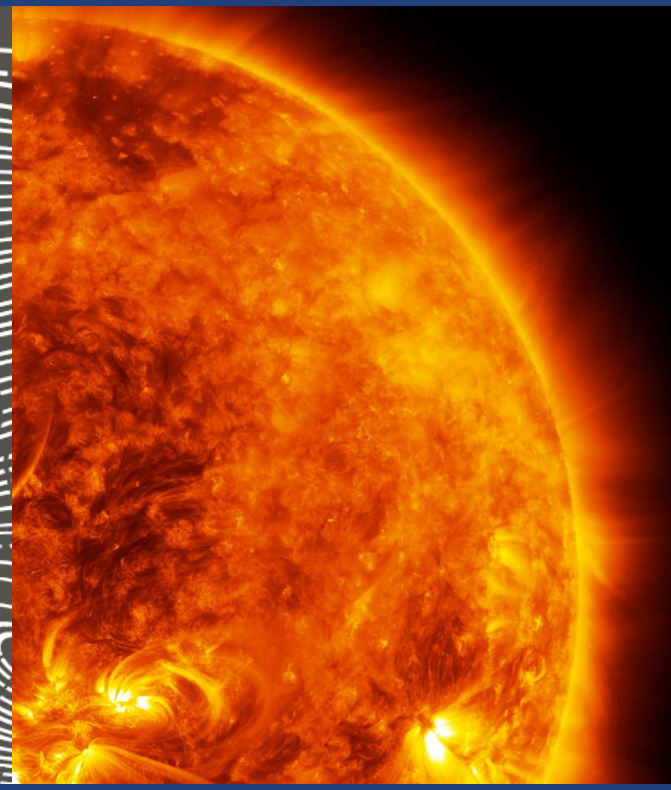
Detection of solar events by using radiocarbon in tree-rings





Nicolas Brehm[1], Marcus Christl[1], Hans-Arno Synal[1], Raimund Muscheler[2], Florian Mekhaldi[2], Chiara Paleari[2] Alex Bayliss[3], Emmanuelle Casanova[4], Timothy Knowles[4], Richard P. Evershed[4], Kurt Nicolussi[5], Thomas Pichler[5], Christian Schlüchter[5] Hanns-Hubert Leuschner[6] Charlotte Pearson[7], Matthew W. Salzer[7], Patrick Fonti[8], Daniel Nievergelt[8], Rashit Hantemirov[9], David M. Brown, Ilya Usoskin[10], Florian Adolphi[11] and Lukas Wacker[1]

[1] Laboratory of Ion Beam Physics ETH
[2] Lund University
[3] Historic England
[4] Bristol Radiocarbon Accelerator Mass Spectrometry Facility
[5] Insbruck Univerity Institut für Geographie
[6]Albrecht von Haller Institute for Plant Sciences
[7]University of Arizona, Bryant Bannister Tree-Ring Building
[8]Swiss Federal Research Institute WSL
[9] Ural Branch of Russian Academy of Sciences
[10]University of Oulu
[11]Alfred Wegener Institute, Helmholtz Center for Polar and Marine Research

The sun as it appeared in October 2017, imaged by NASA's Solar Dynamics Observatory

Radiocarbon

^{14}C

Cosmogenic radionuclide

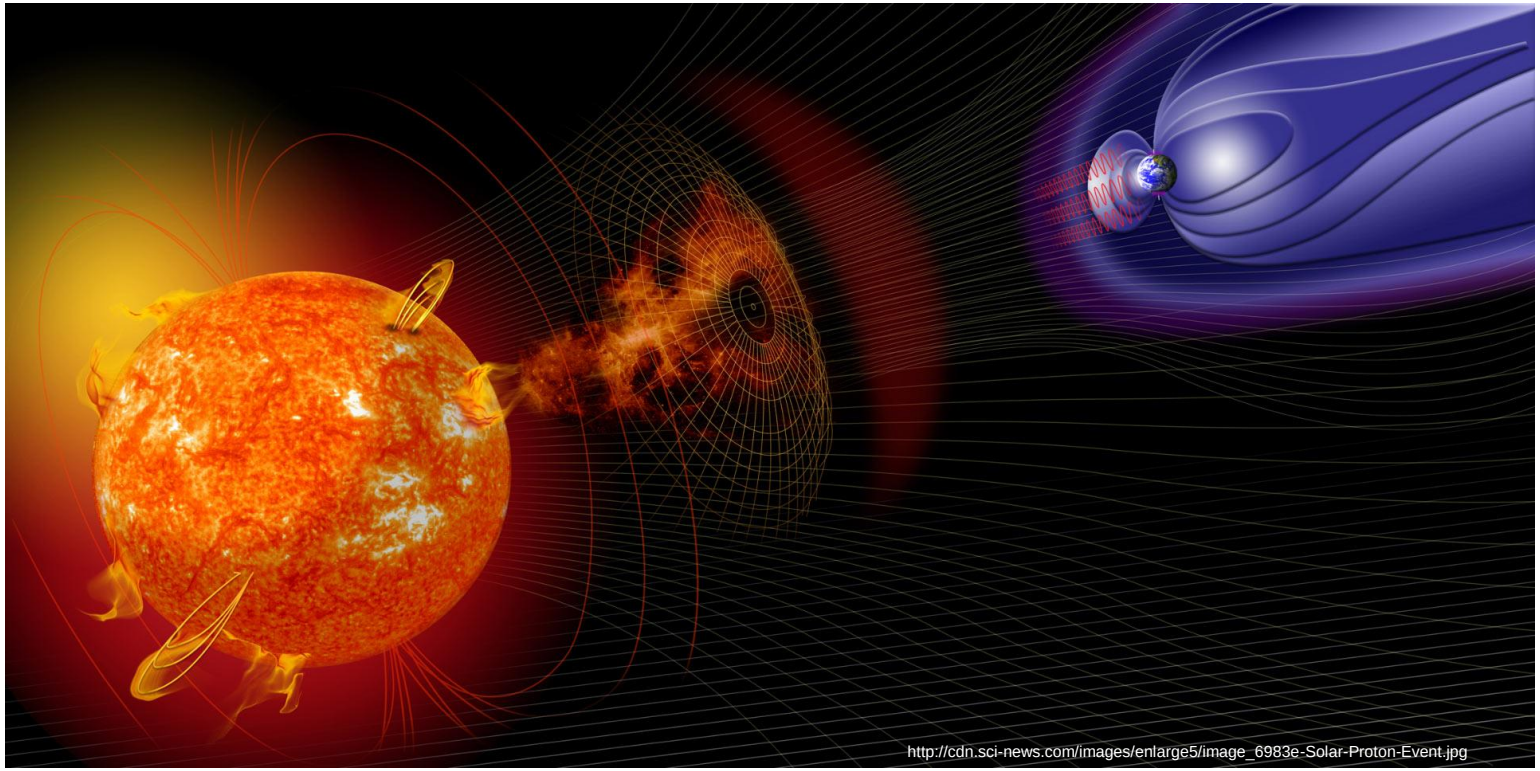
Halflife: 5700 yrs

http://www2.yukawa.kyoto-u.ac.jp/~crphys2020/

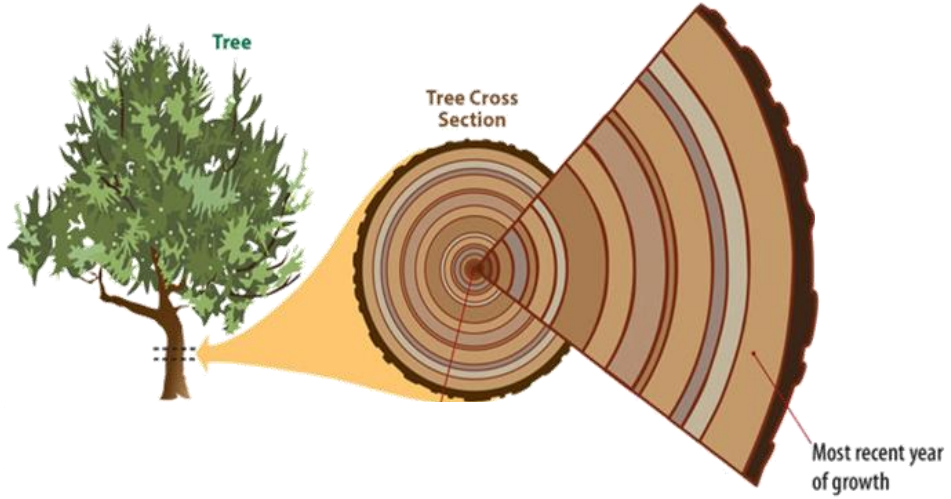
Solar energetic particle (SEP) events

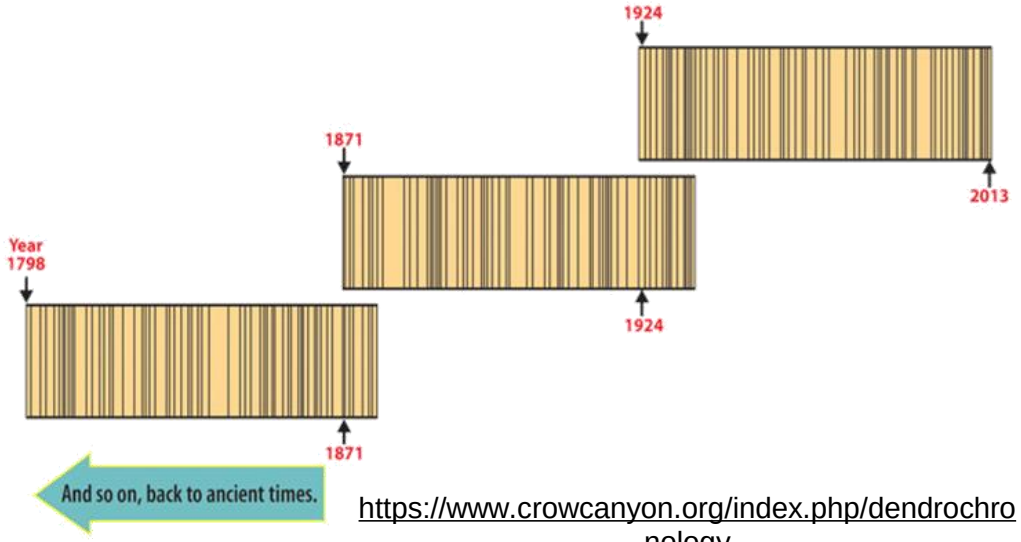
Sun irregularly expels large amounts of particles (solar flares)

Solar energetic protons (SEP) induce global radionuclide production spike



Dendrochronology





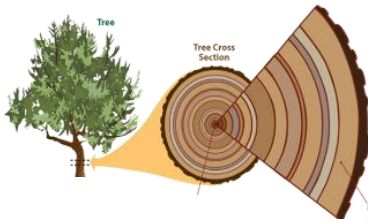
https://www.crowcanyon.org/index.php/dendrochronology

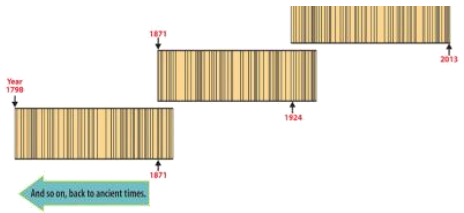
- Tree-rings grow annually
- Trees can be matched based on common tree-ring growth signal (n≥ 50)
- Overlapping trees of different ages can securely build up a chronology (n≥ 20)

Measurement of Radiocarbon in tree rings

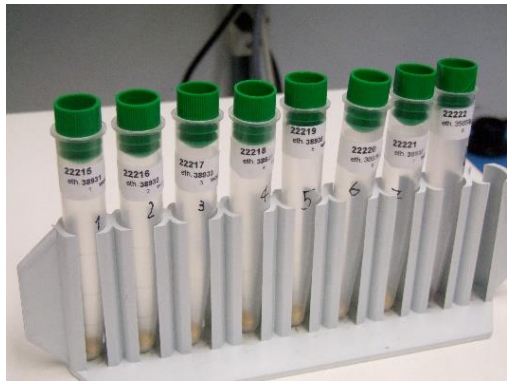
Sampling and Dendrochronology

https://www.tagesanzeiger.ch/zuerich/stadt/der-aelteste-wald-der-welt-/story/10797271

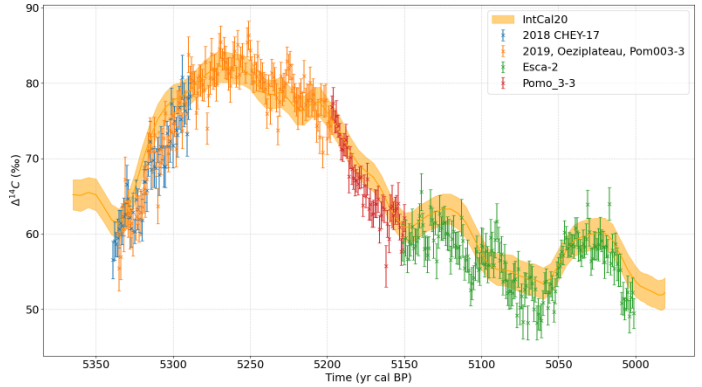


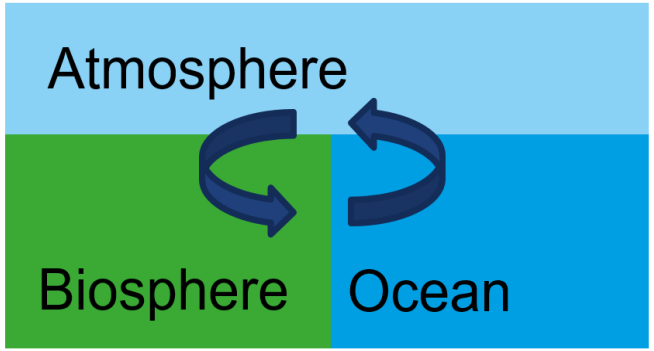


Sample preparation and Measurement



Modelling and Results

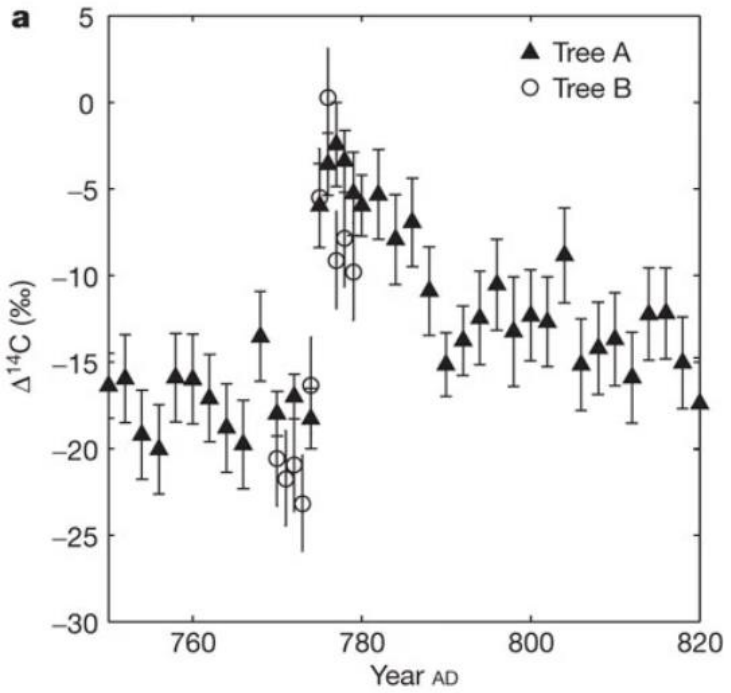




Solar energetic particle (SEP) events

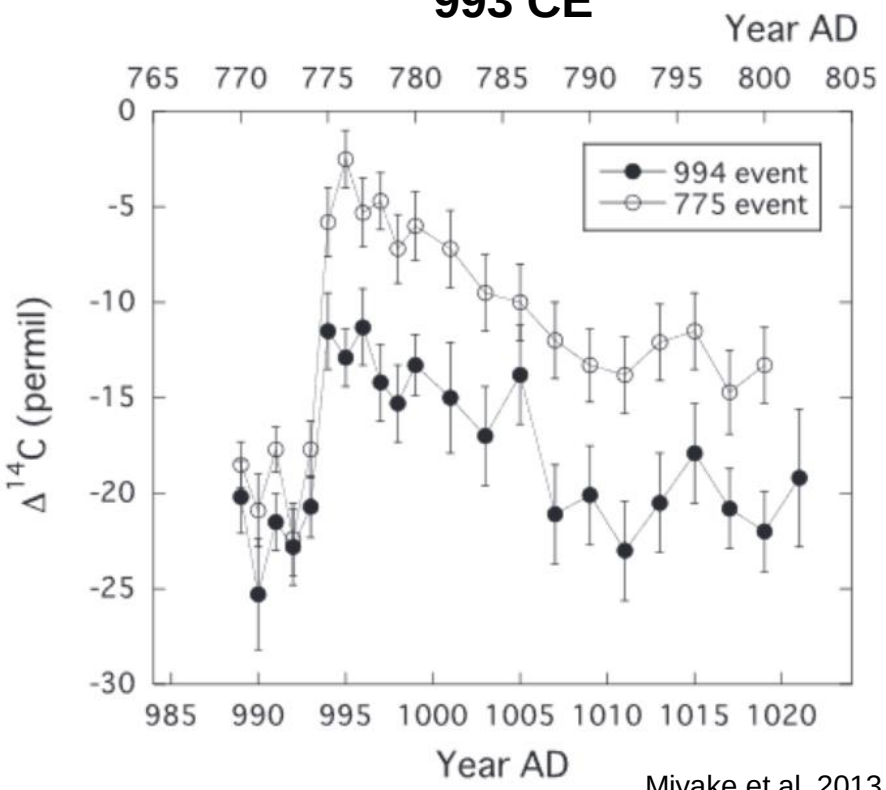
3 events were so far detected by using radionuclides (775 AD, 993 AD and 664 BC)

775 CE



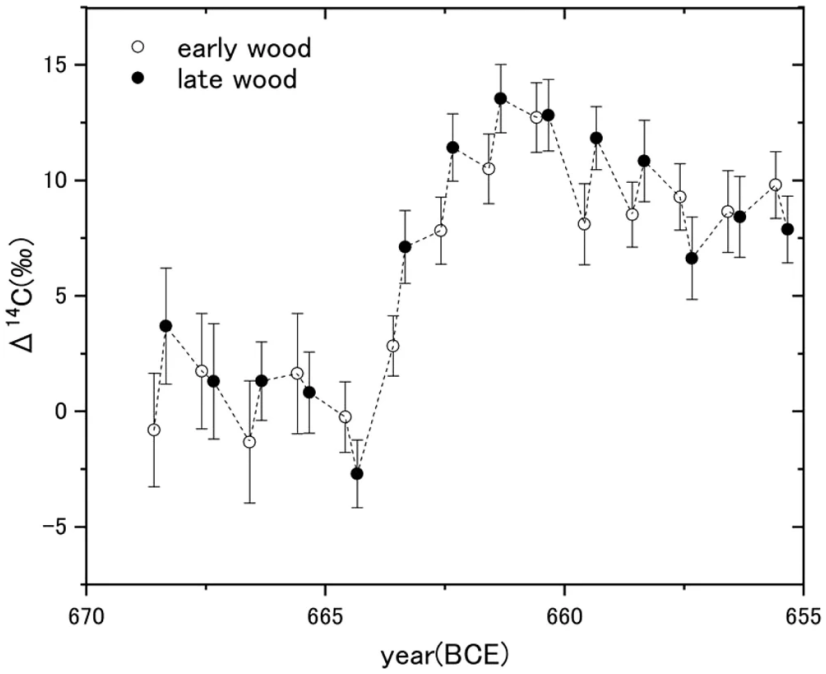
Miyake et al. 2012

993 CE



Miyake et al. 2013

664 BC



Sakurai et al. 2020

Solar energetic particle (SEP) events

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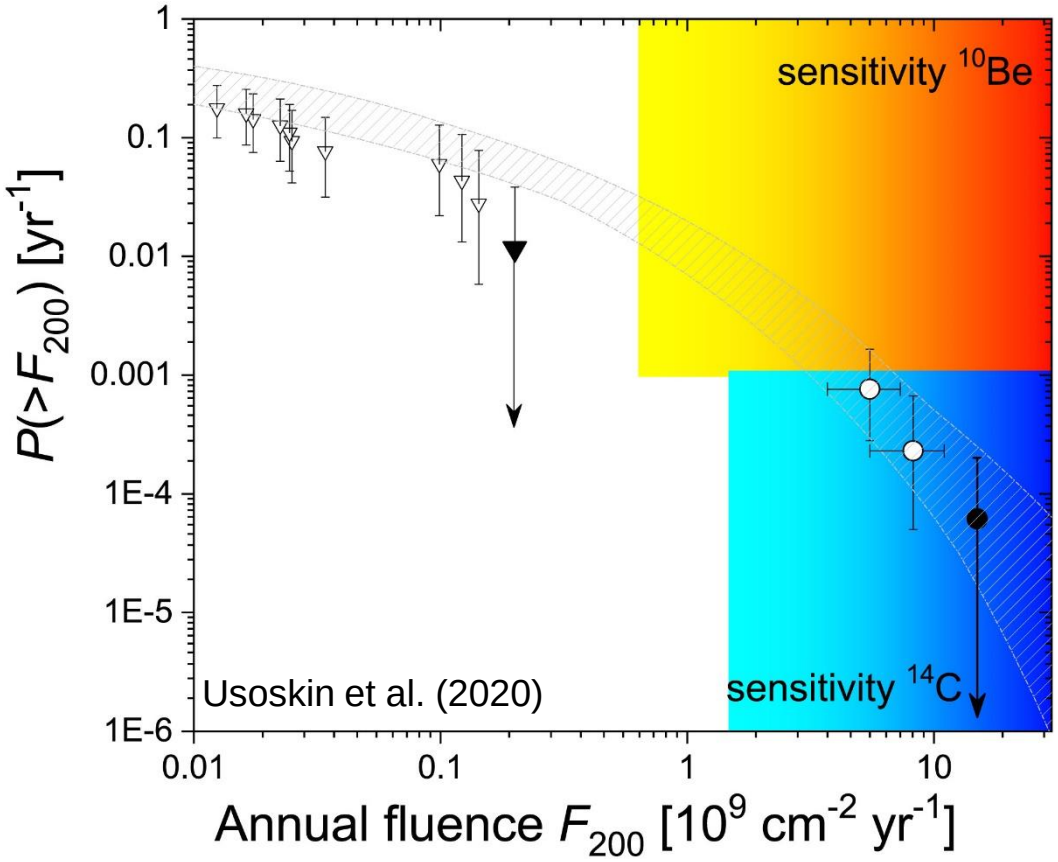
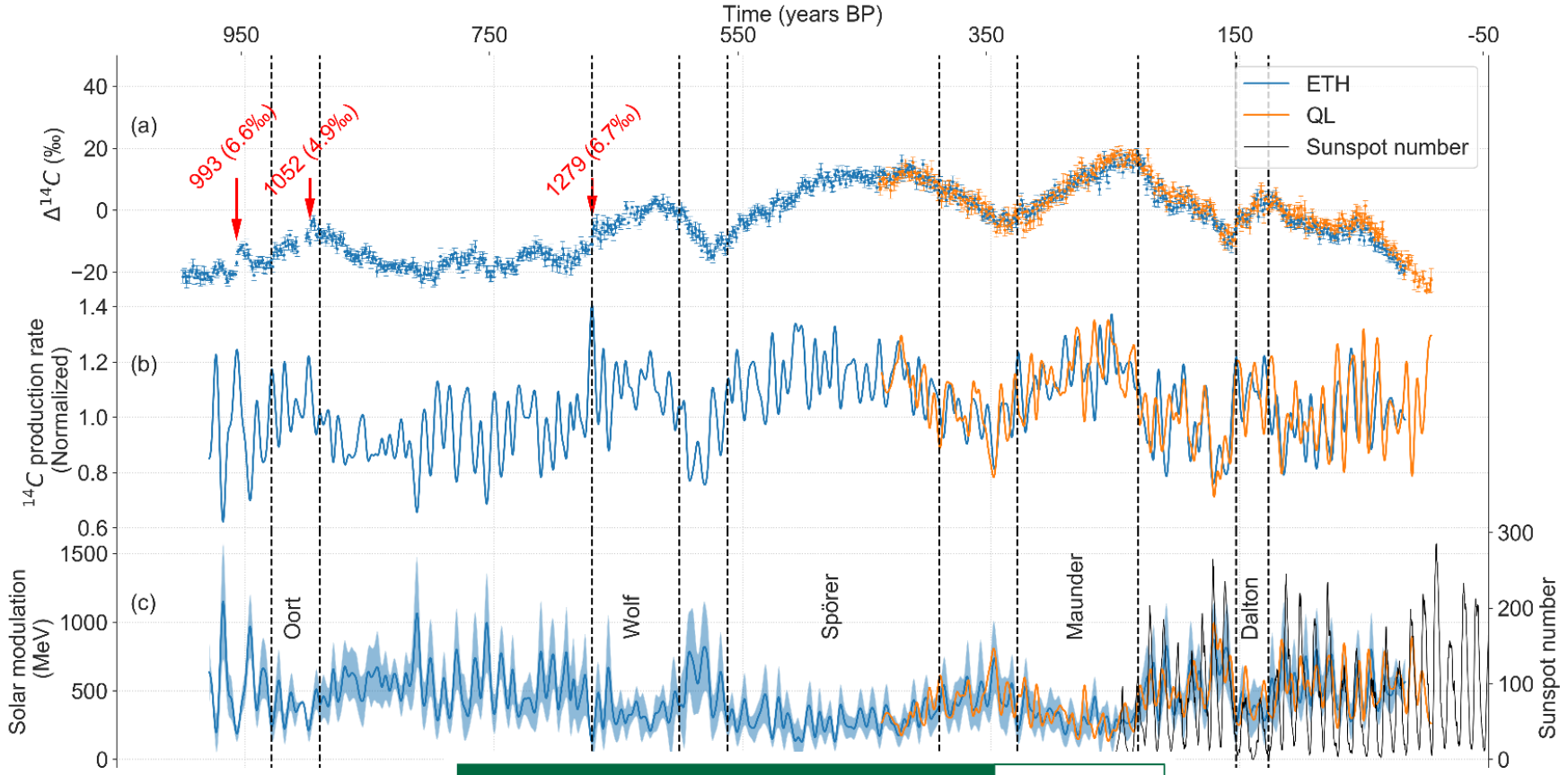


Reconstruction of solar activity



ARTICLES
https://doi.org/10.1038/s41561-020-00674-0
nature geoscience
Check for updates

Eleven-year solar cycles over the last millennium revealed by radiocarbon in tree rings

Nicolas Brehm[1], Alex Bayliss[2], Marcus Christl[1], Hans-Arno Synal[1], Florian Adolphi[3,4,5,13], Jürg Beer[6], Bernd Kromer[7], Raimund Muscheler[3], Sami K. Solanki[8,9], Ilya Usoskin[10,11], Niels Bleicher[12], Silvia Bollhalder[1], Cathy Tyers[2] and Lukas Wacker[1]

2021

Reconstruction of solar activity

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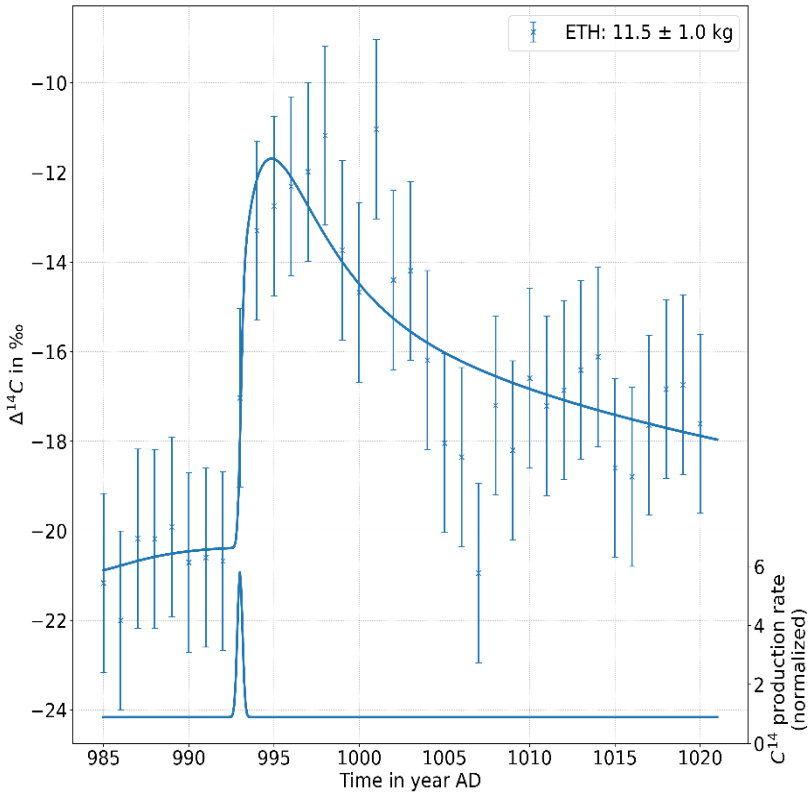
2021

Solar energetic particle (SEP) events during the last 1000 years

993



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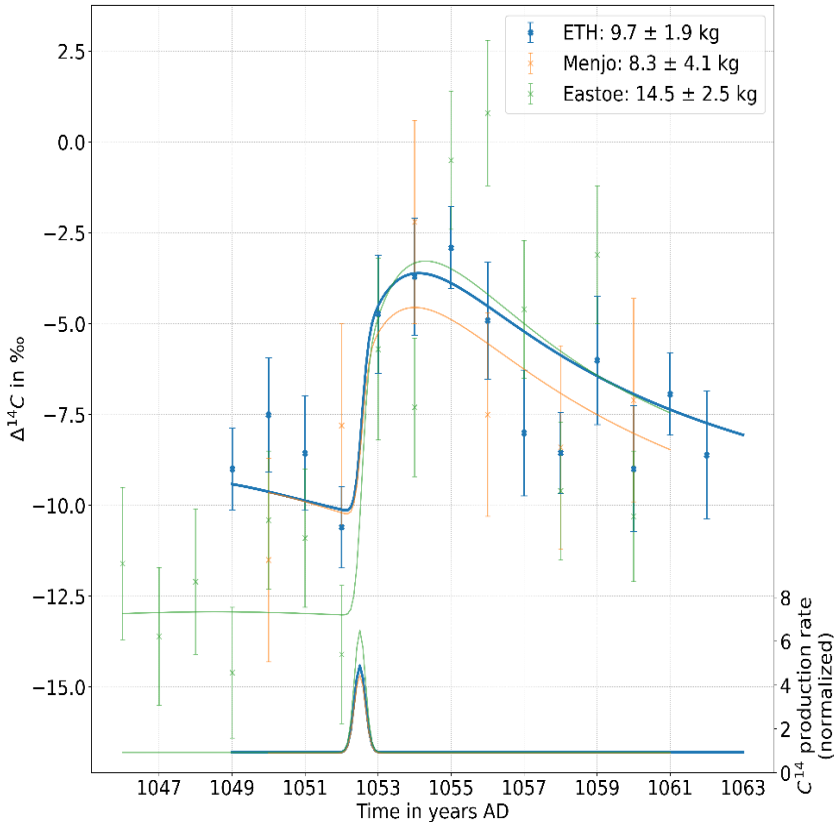

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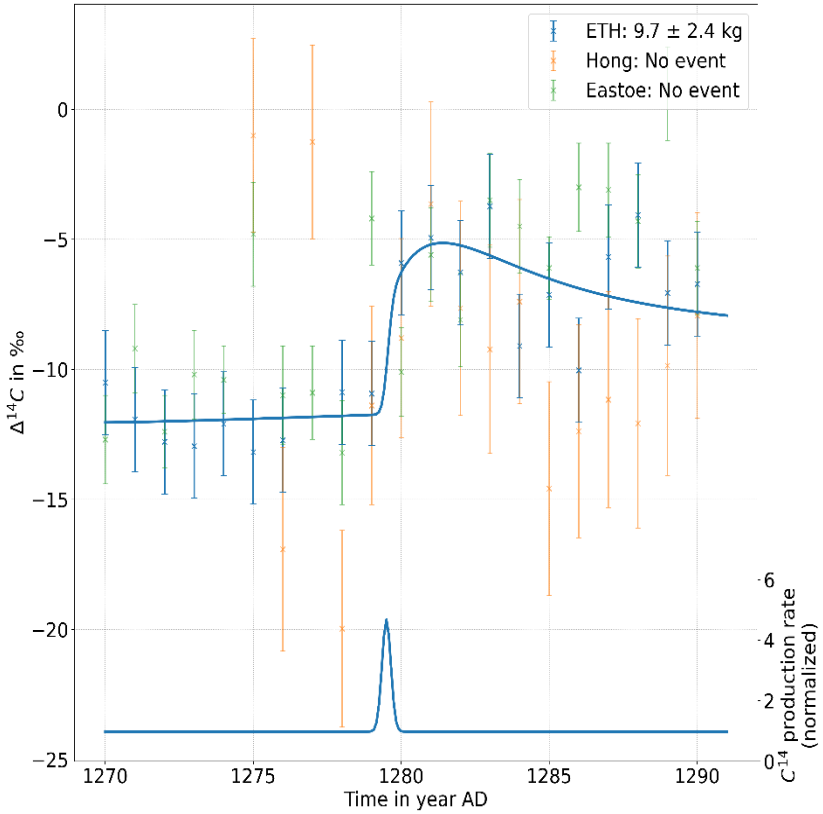

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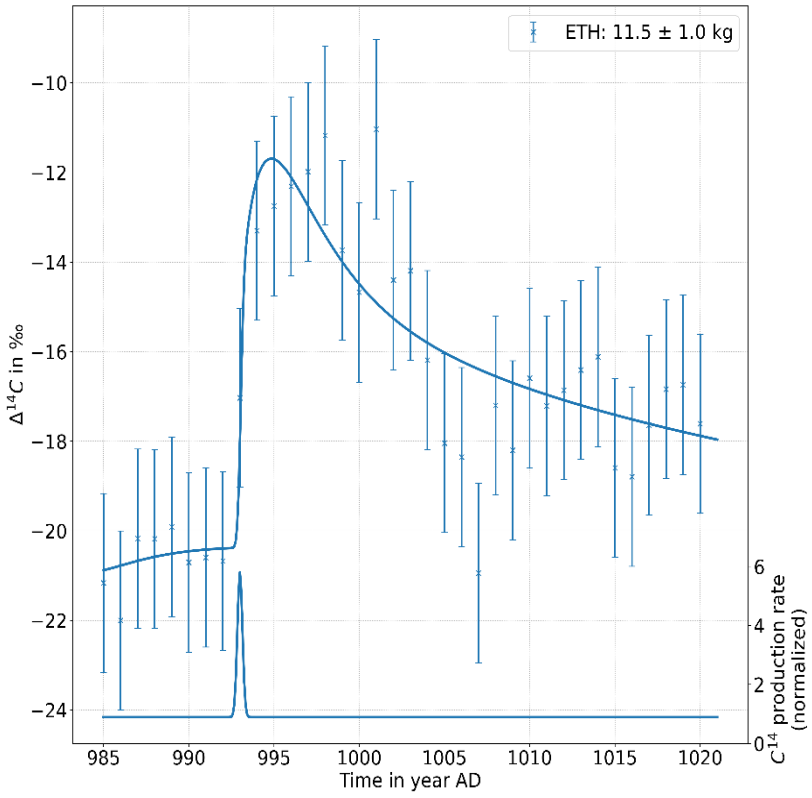
993



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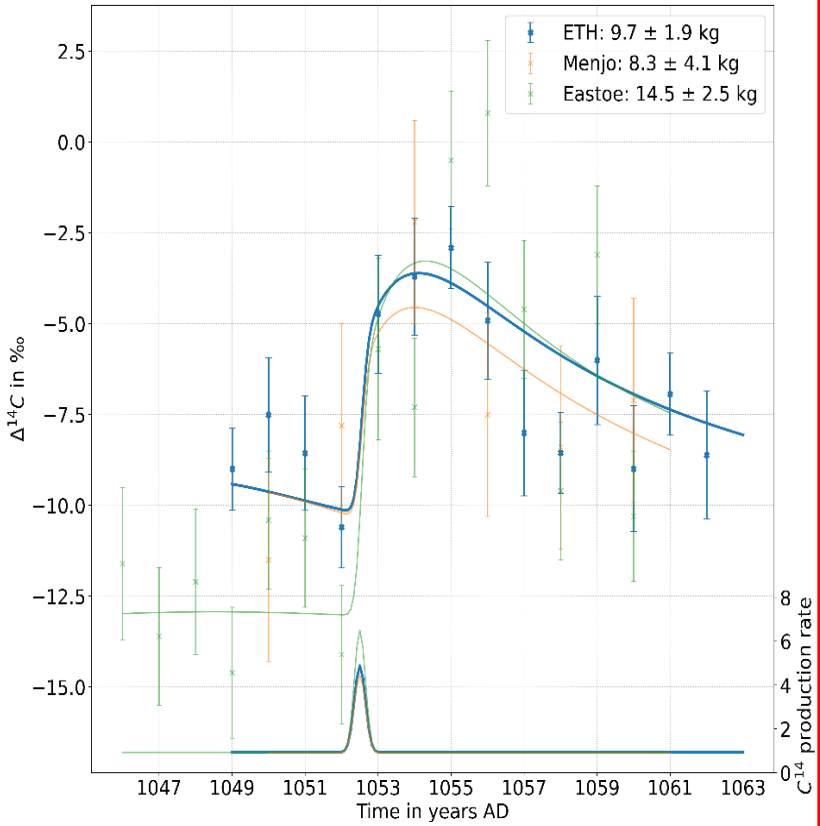

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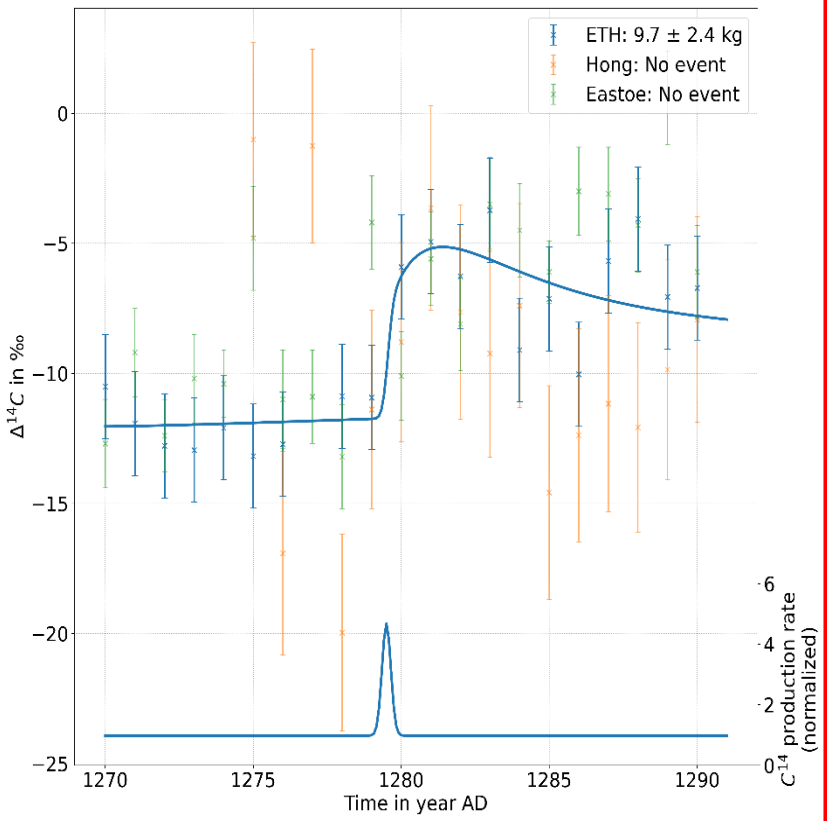

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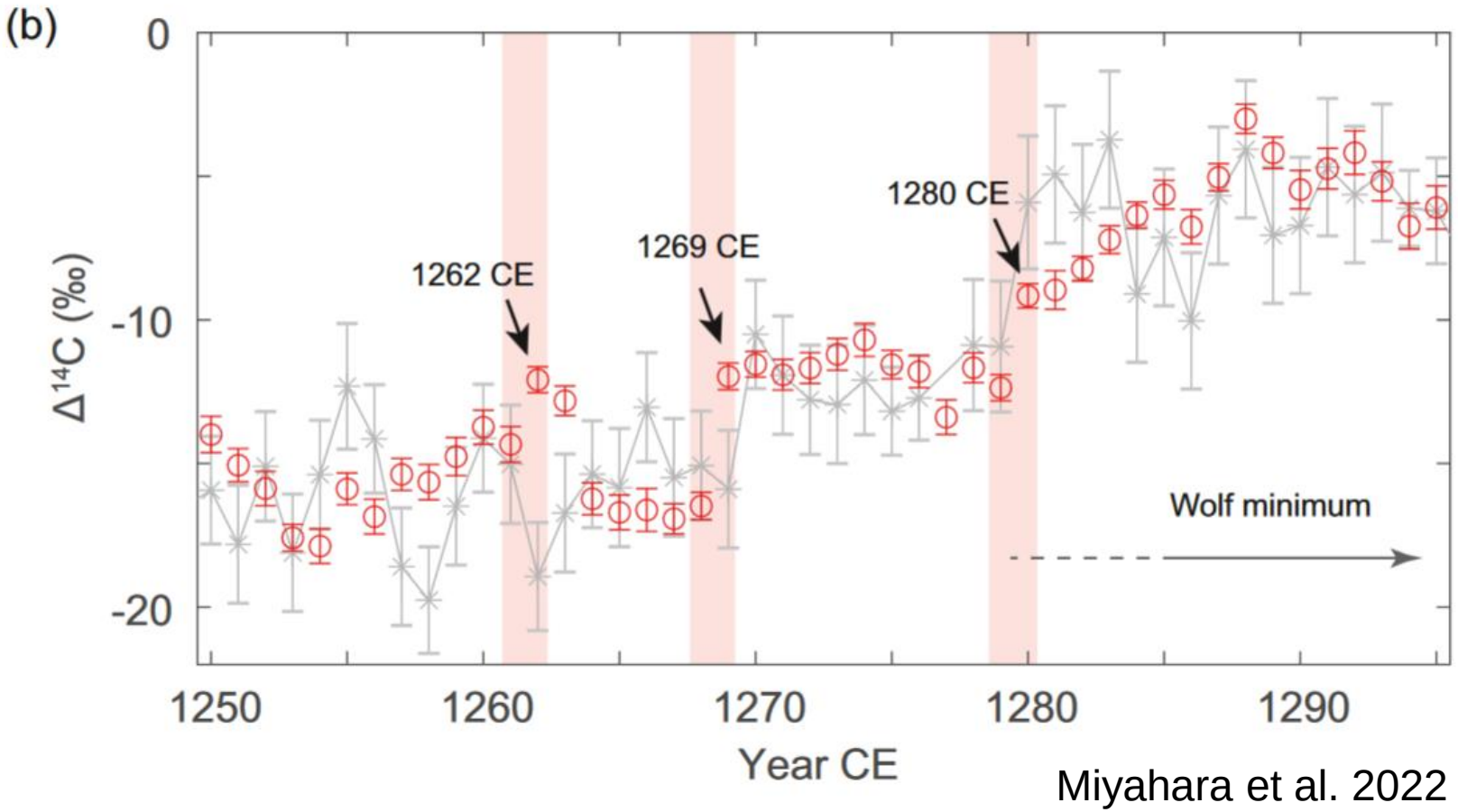
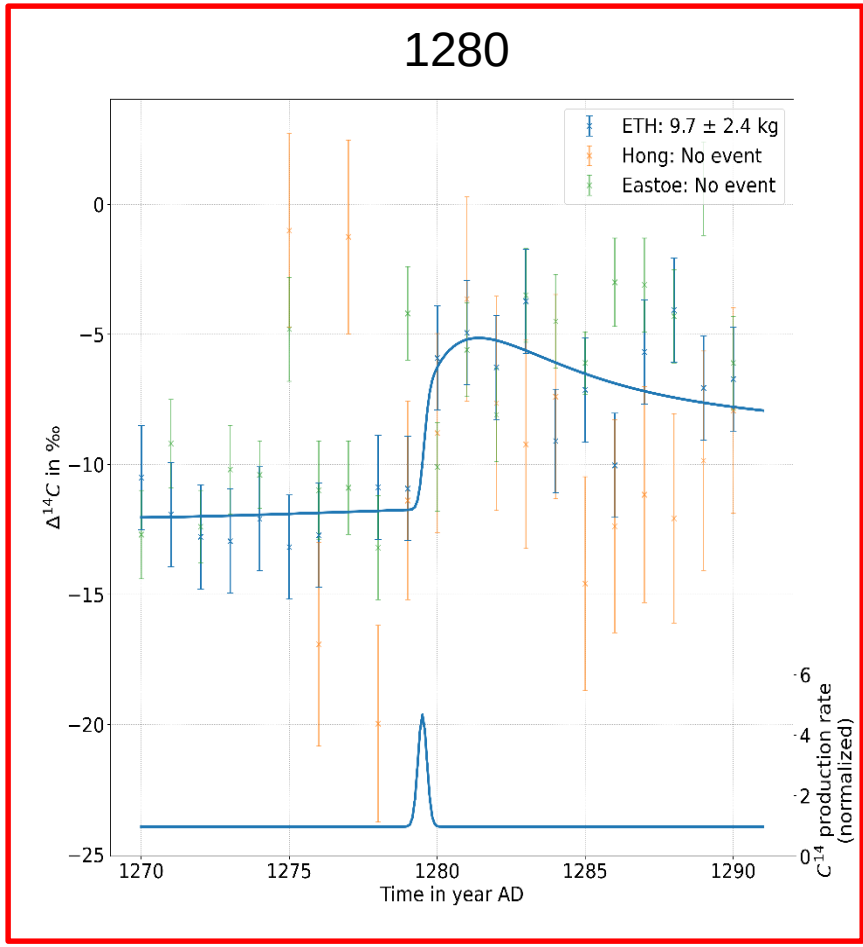


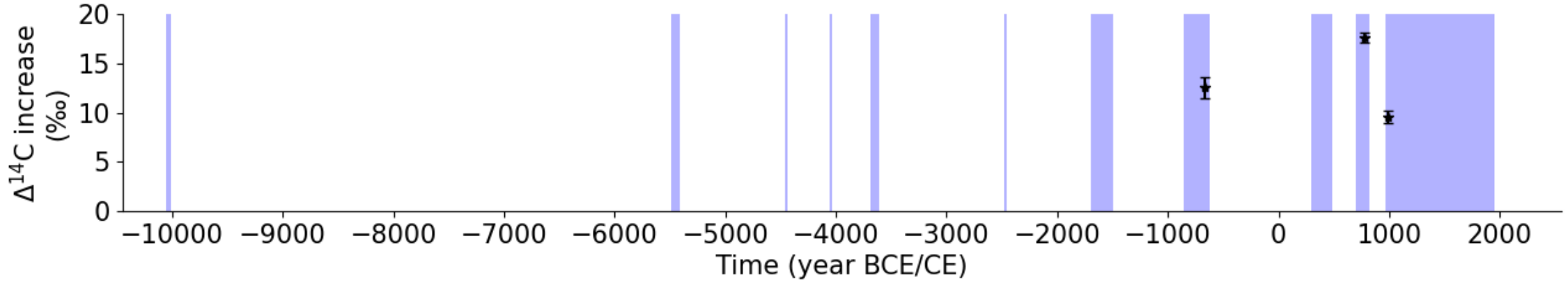
Miyahara et al. 2022



Search for new SEP events

Past ~ 12‘000 years available from tree rings

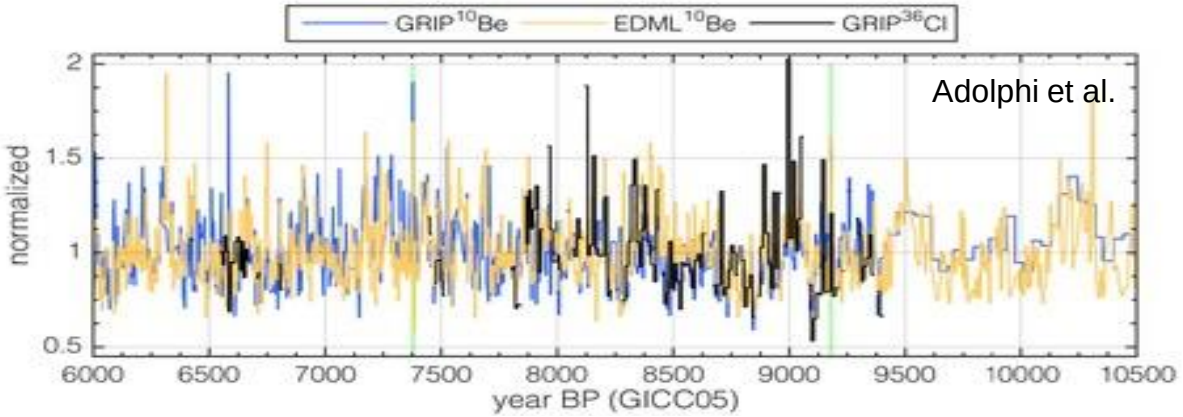
~16% Measured annually (~2000 yr)

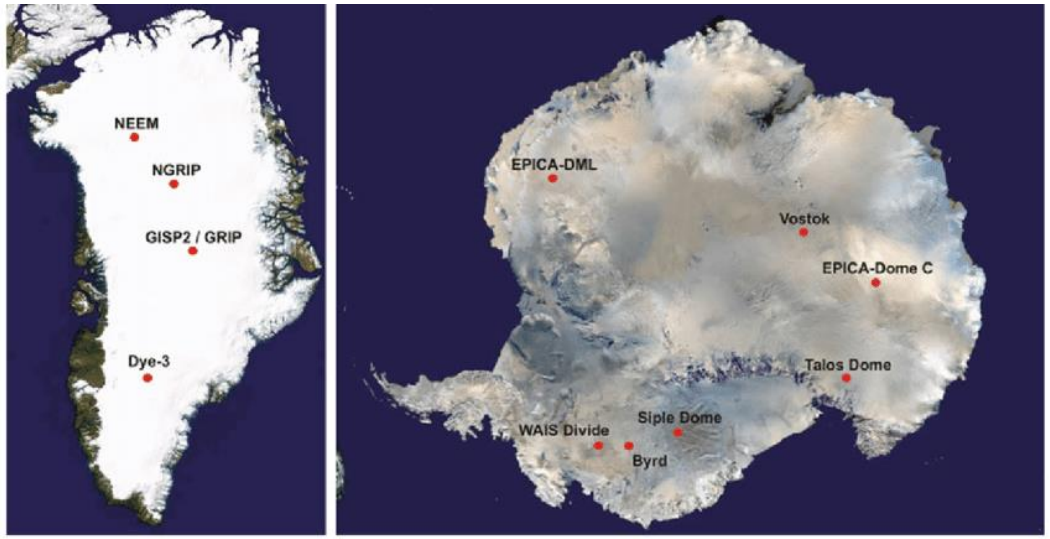


Search for new SEP events

- Looking at different low temporal resolution ^{10}Be and ^{36}Cl records from ice cores

- Finding time periods where multiple records show anomaly





https://www.researchgate.net/figure/Map-of-both-polar-regions-indicating-selected-ice-core-drilling-sites-in-Greenland-NEEM_fig6_301173005

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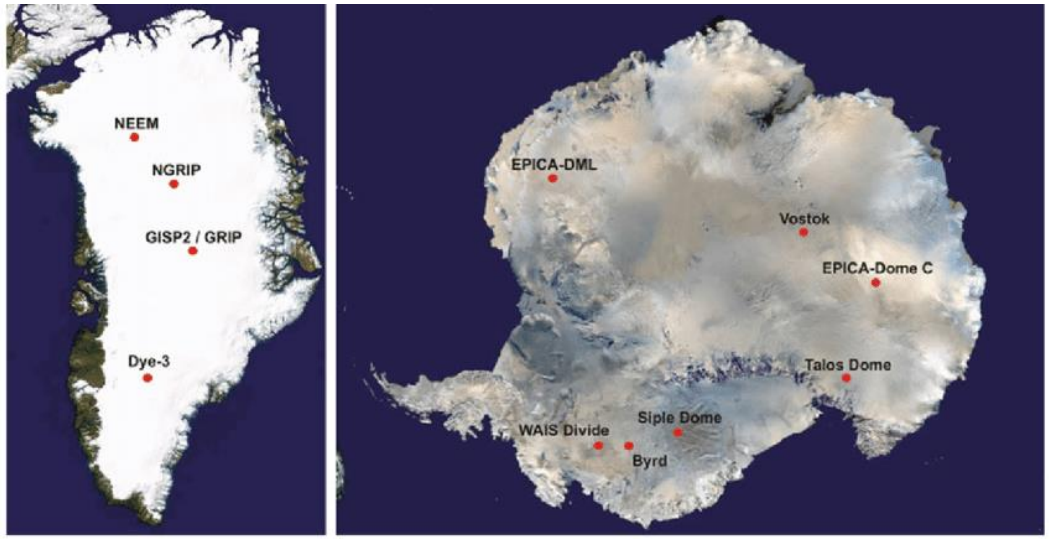

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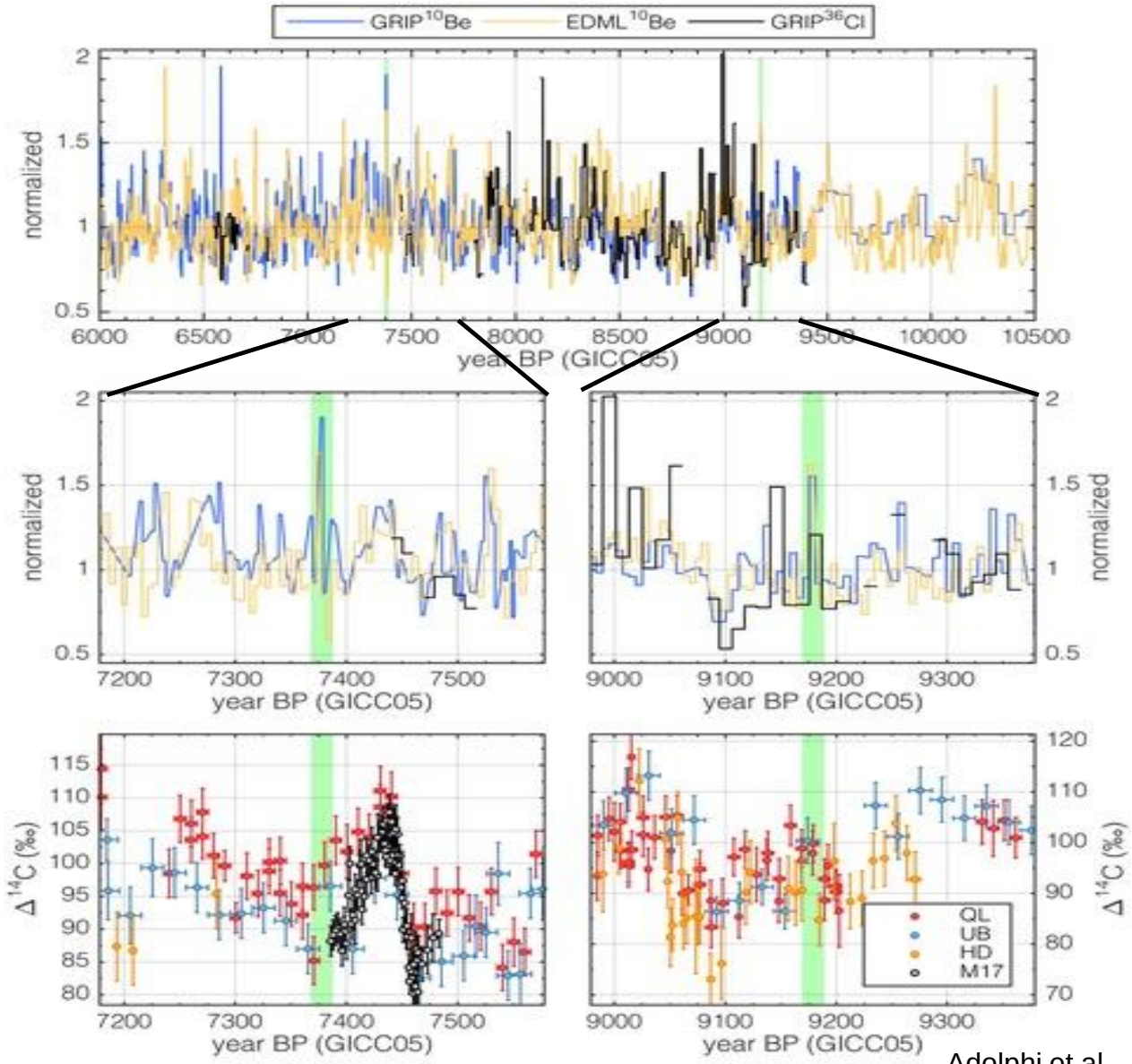

Adolphi et al.

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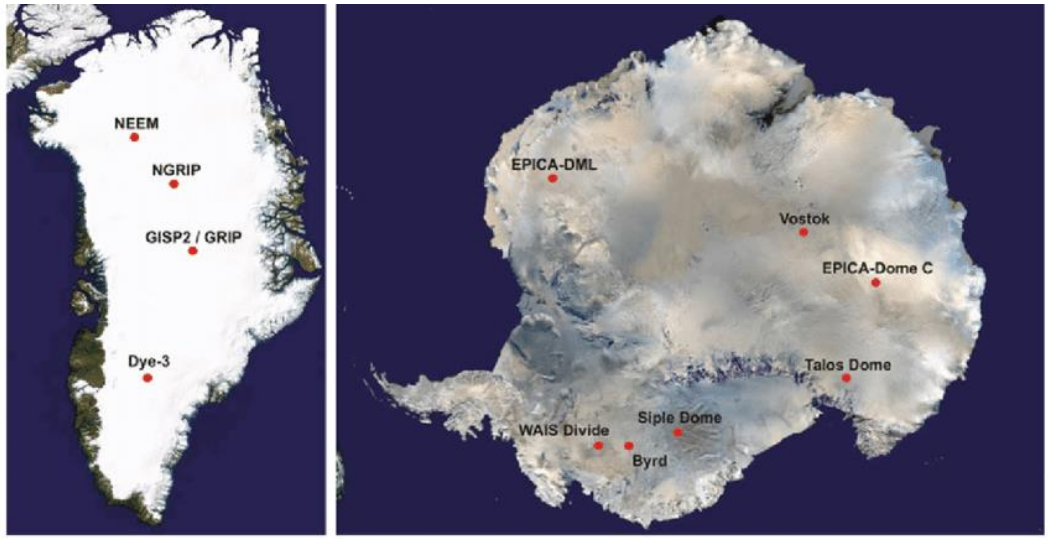

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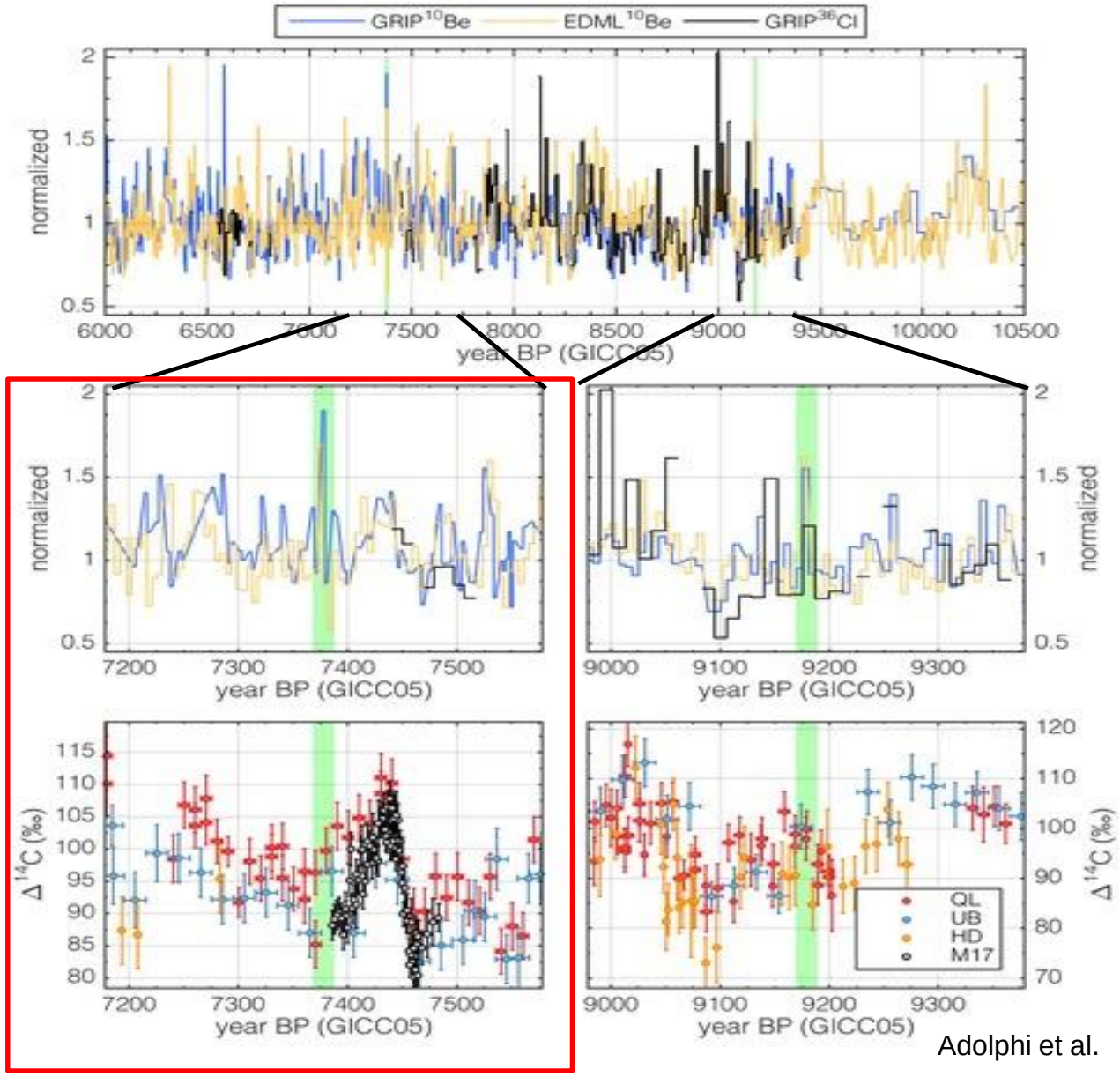

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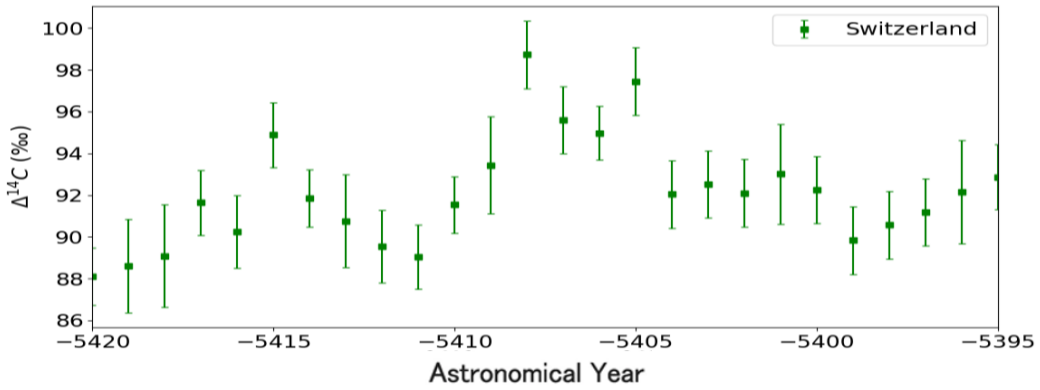

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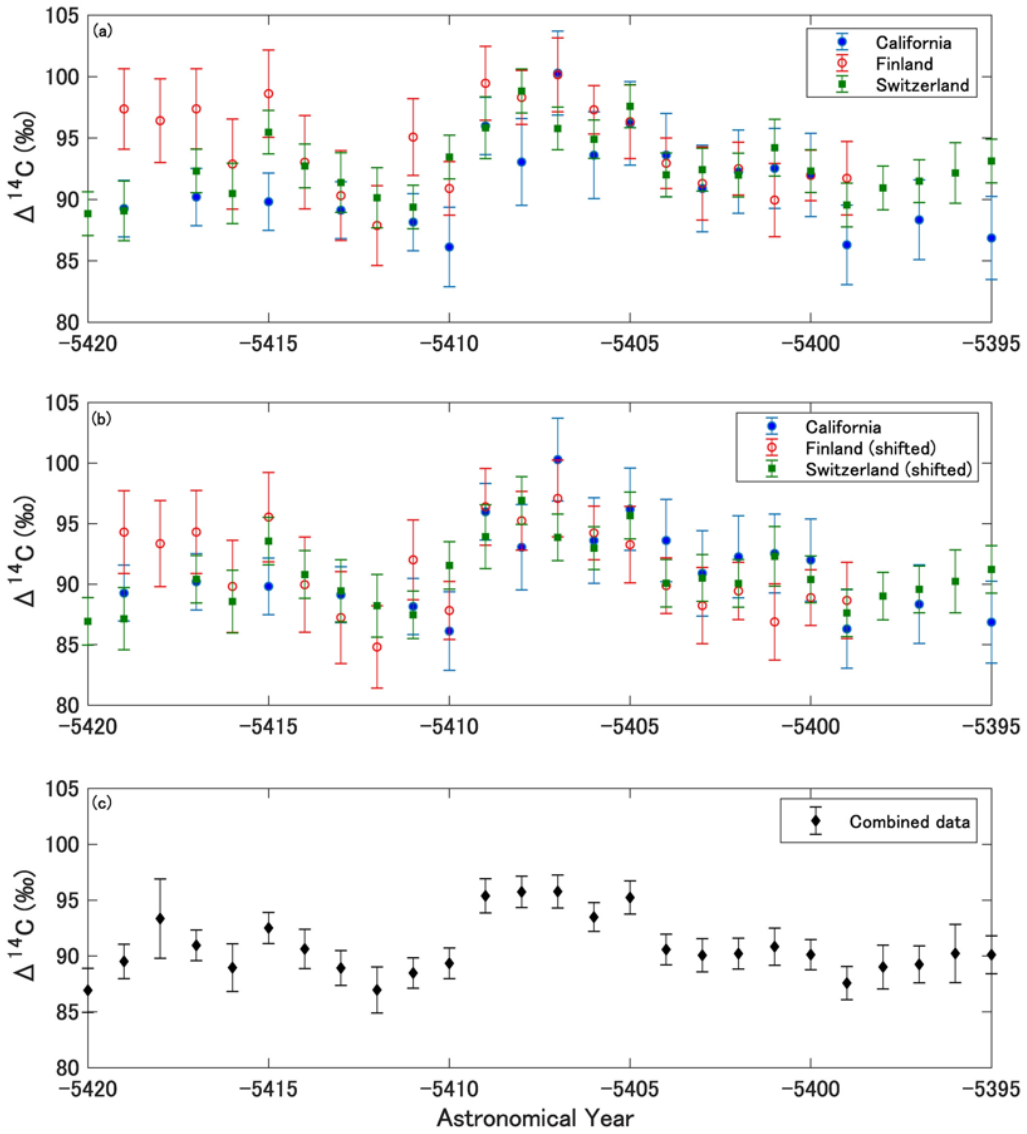

Miyake et al 2021

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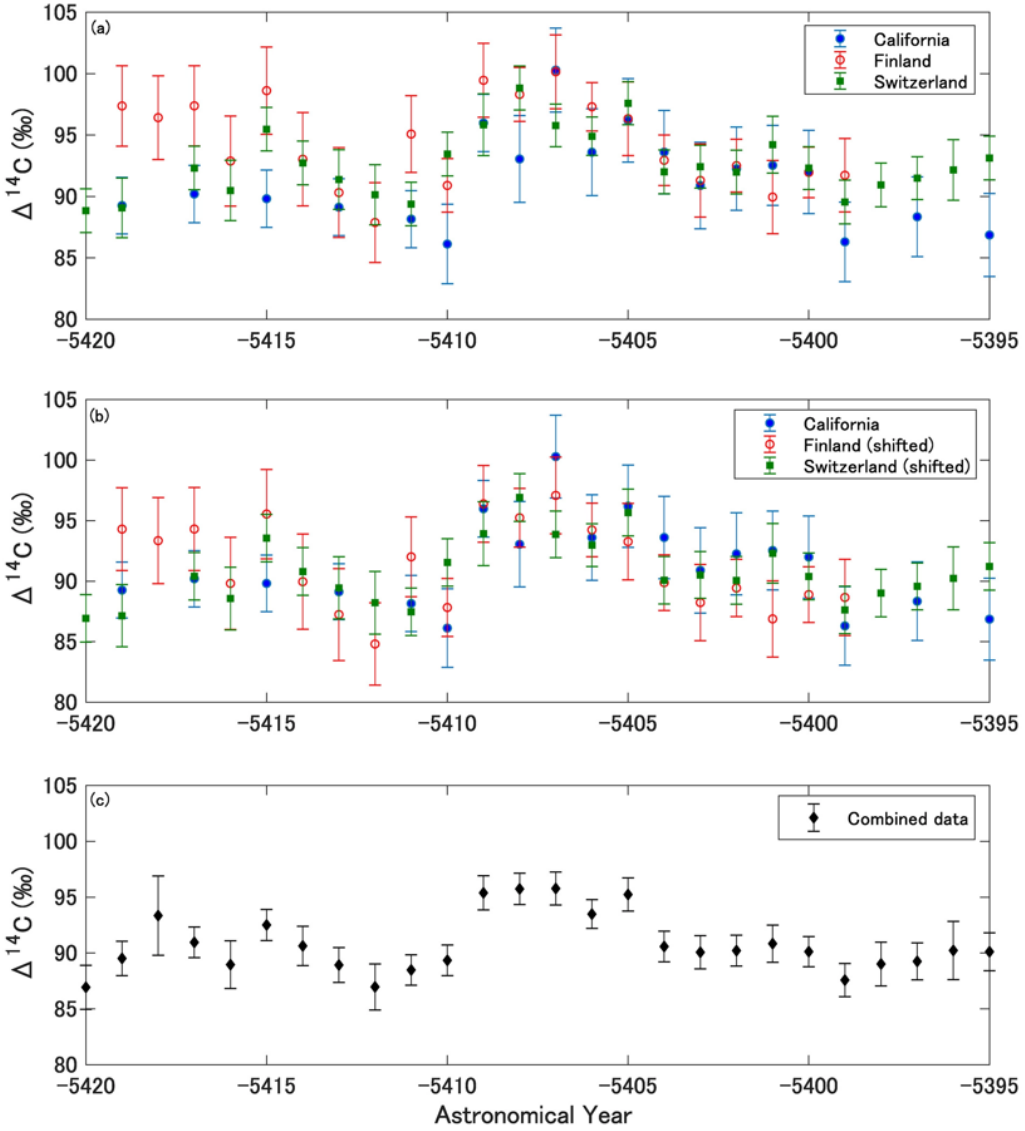

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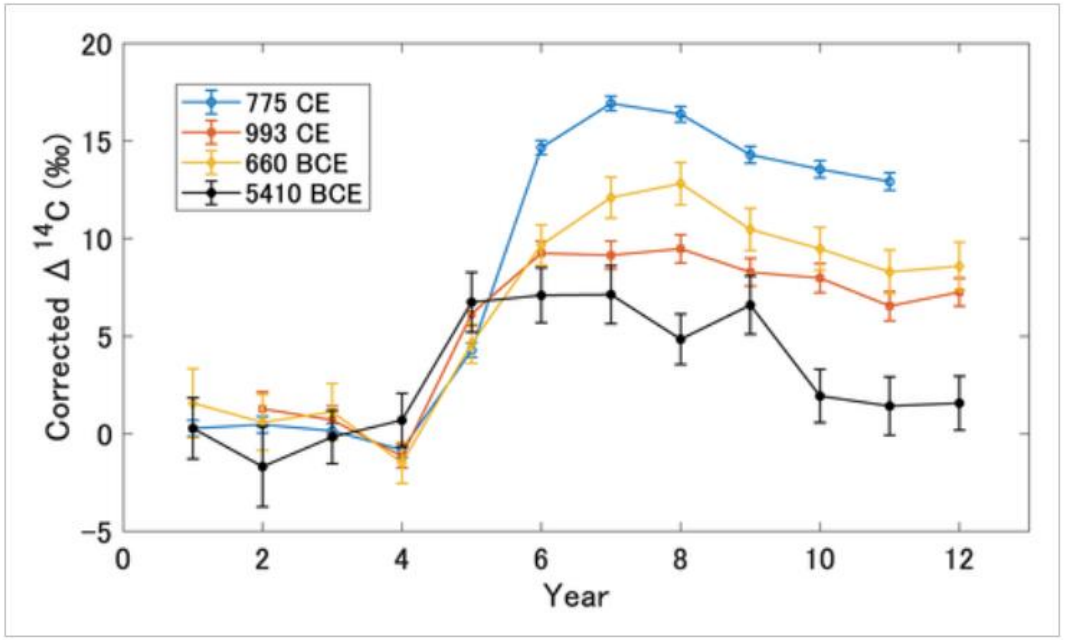

A Single-Year Cosmic Ray Event at 5410 BCE Registered in ^{14}C of Tree Rings

F. Miyake[1], I. P. Panyushkina[2], A. J. T. Jull[3,4], F. Adolphi[5], N. Brehm[6], S. Helama[7], K. Kanzawa[1], T. Moriya[8], R. Muscheler[9], K. Nicolussi[10], M. Oinonen[11], M. Salzer[2], M. Takeyama[8], F. Tokanai[8], and L. Wacker[6]

[1]Institute for Space-Earth Environmental Research, Nagoya University, Nagoya, Japan, [2]Laboratory of Tree Ring Research, University of Arizona, Tucson, AZ, USA, [3]Department of Geosciences, University of Arizona, Tucson, AZ, USA, [4]Isotope Climatology and Environmental Research Centre, Institute for Nuclear Research, Debrecen, Hungary, [5]Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research, Bremerhaven, Germany, [6]Laboratory for Ion Beam Physics, ETH Zürich, Zürich, Switzerland, [7]Natural Resources Institute Finland, Rovaniemi, Finland, [8]Faculty of Science, Yamagata University, Yamagata, Japan, [9]Department of Geology, Faculty of Science, Lund University, Lund, Sweden, [10]Department of Geography, Universität Innsbruck, Innsbruck, Austria, [11]Finnish Museum of Natural History, University of Helsinki, Helsinki, Finland

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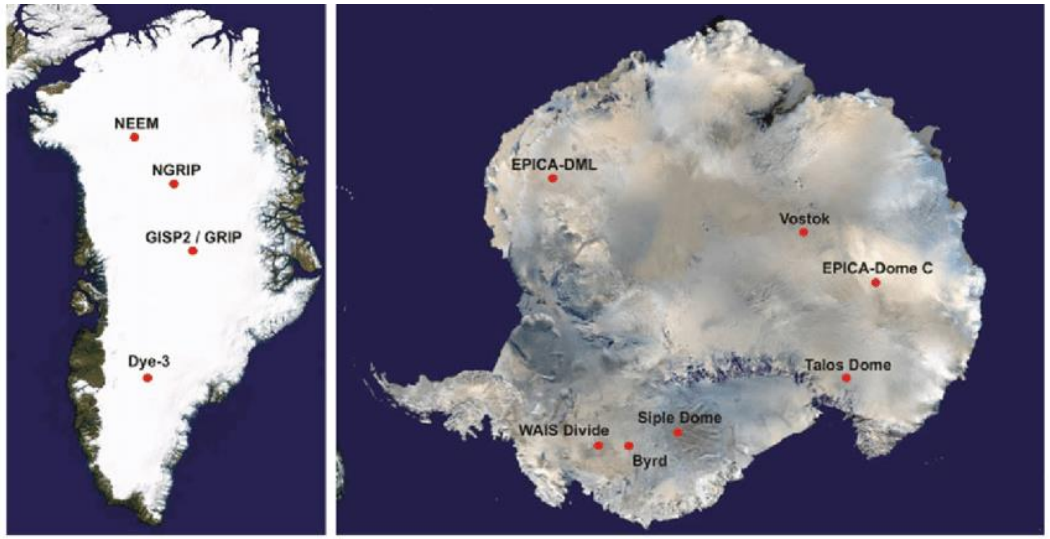

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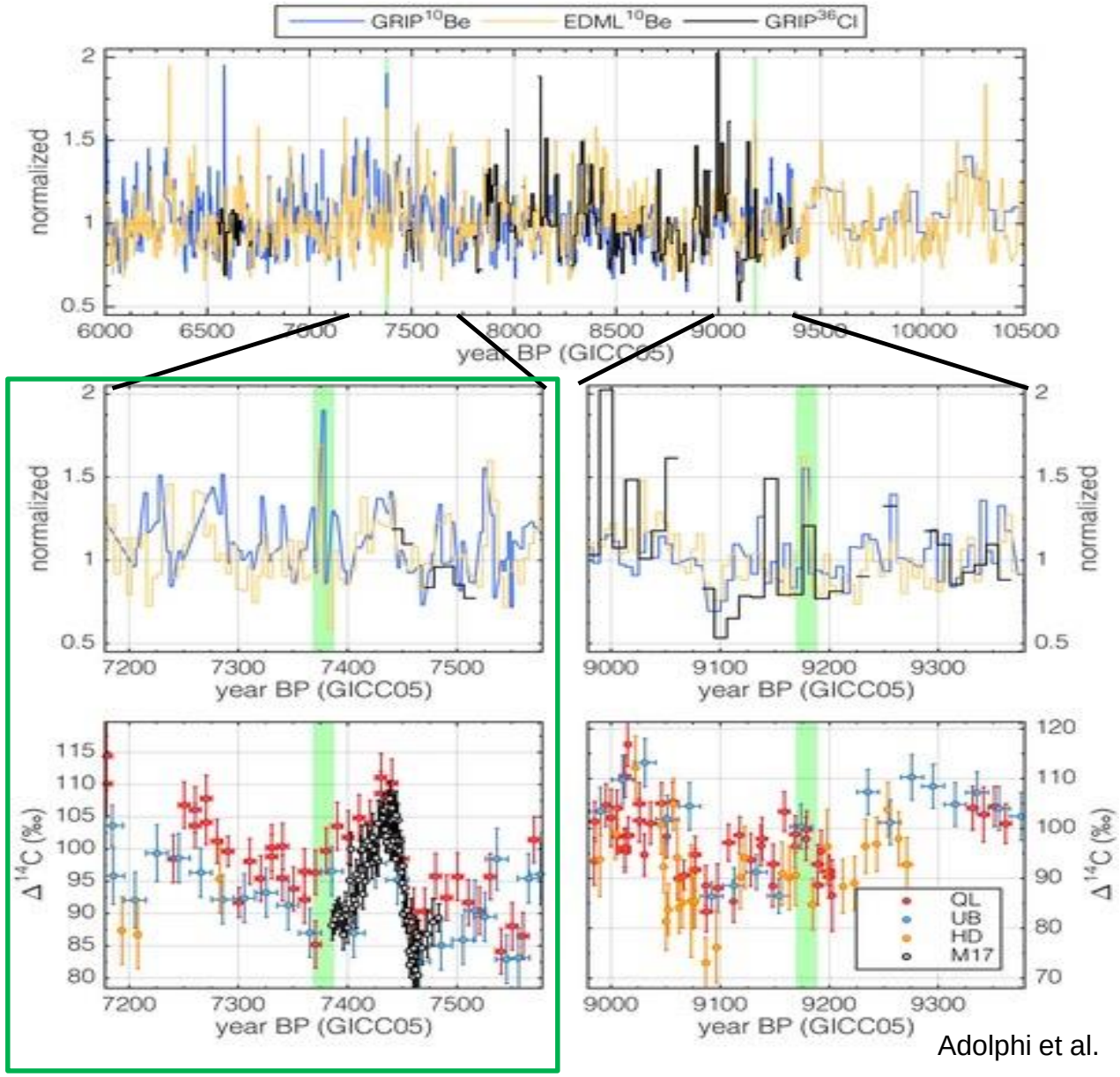

Adolphi et al.

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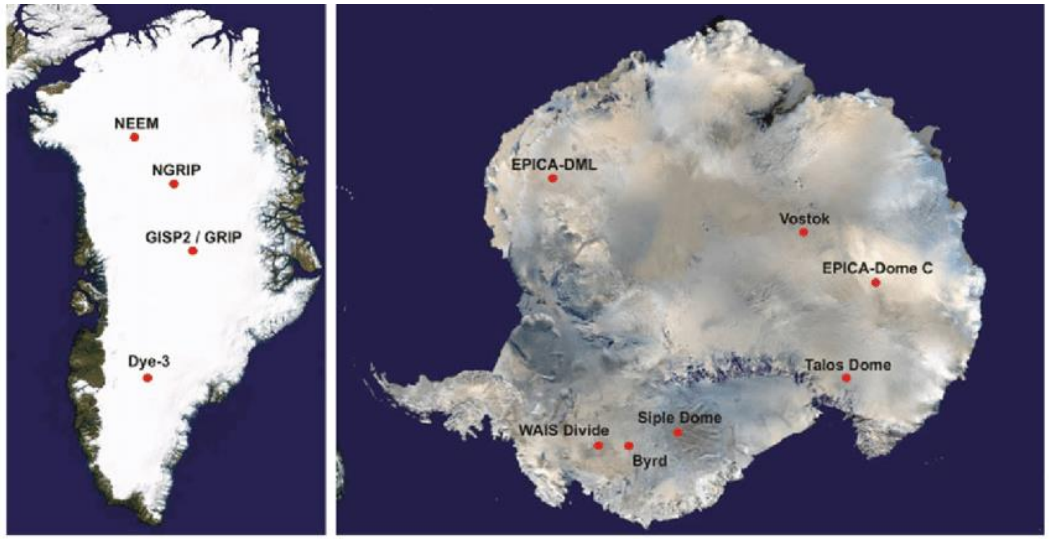

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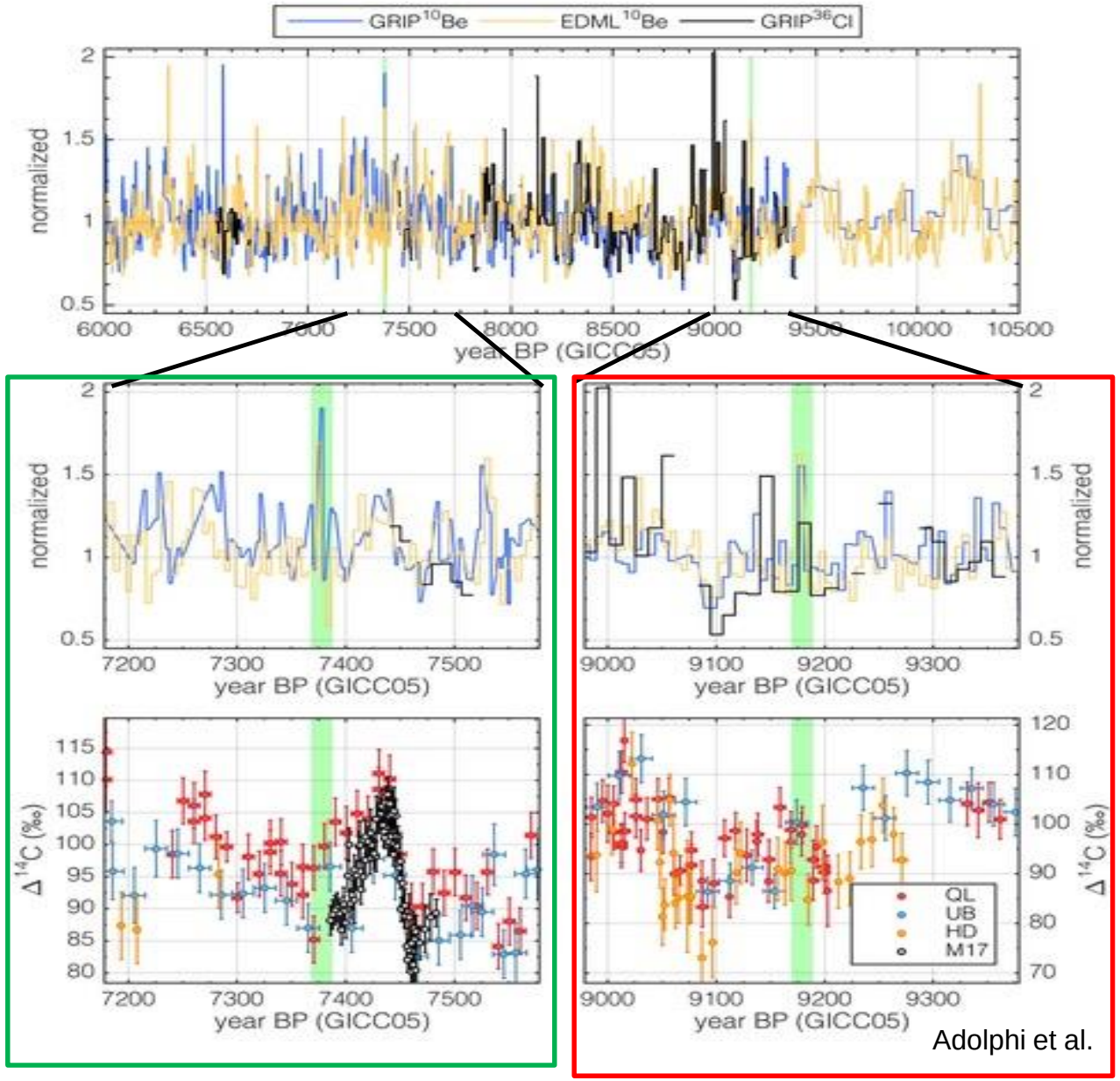
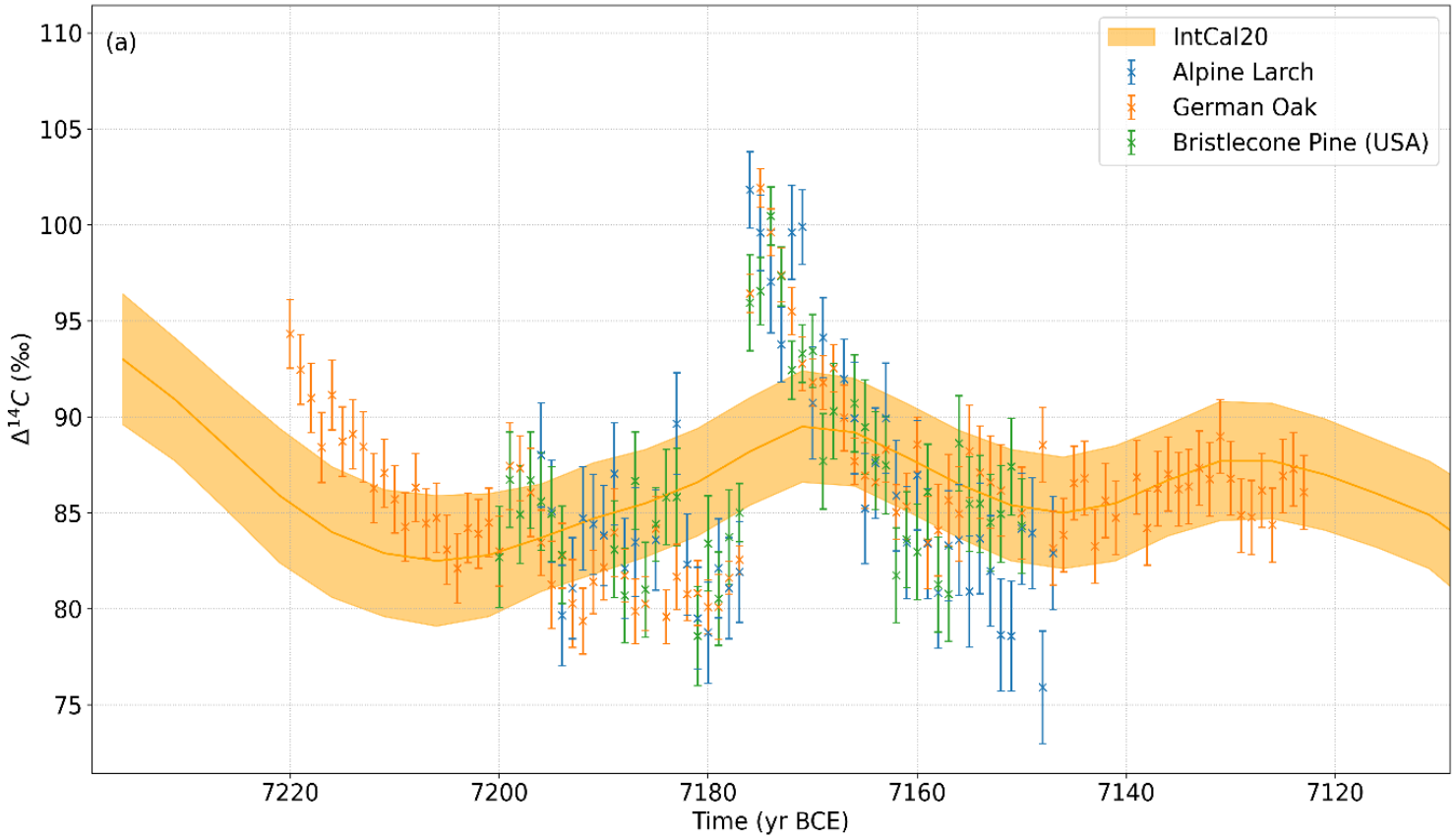


Adolphi et al.

Detection of SEP events (at 7176 BCE/9125 BP)



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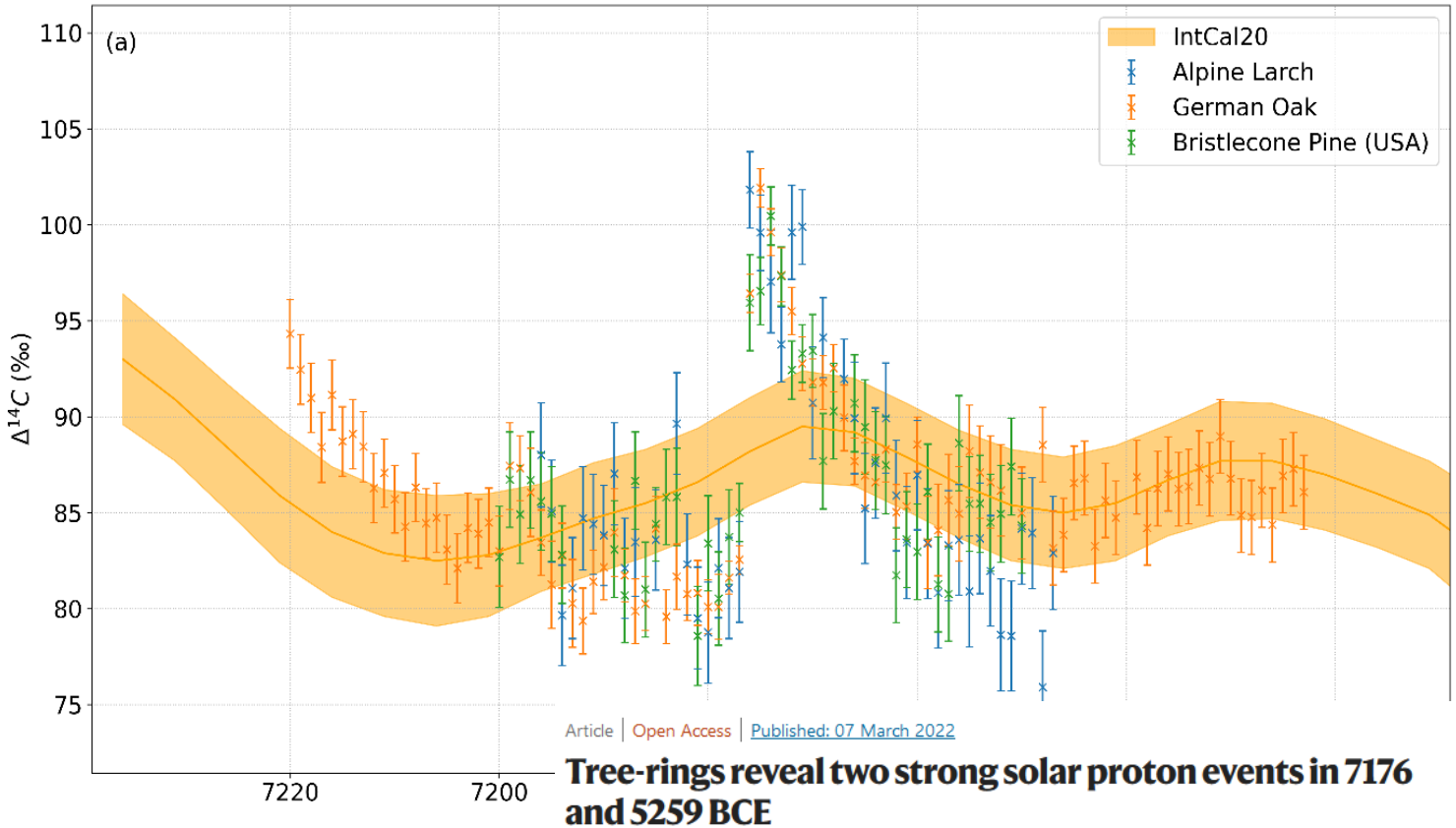
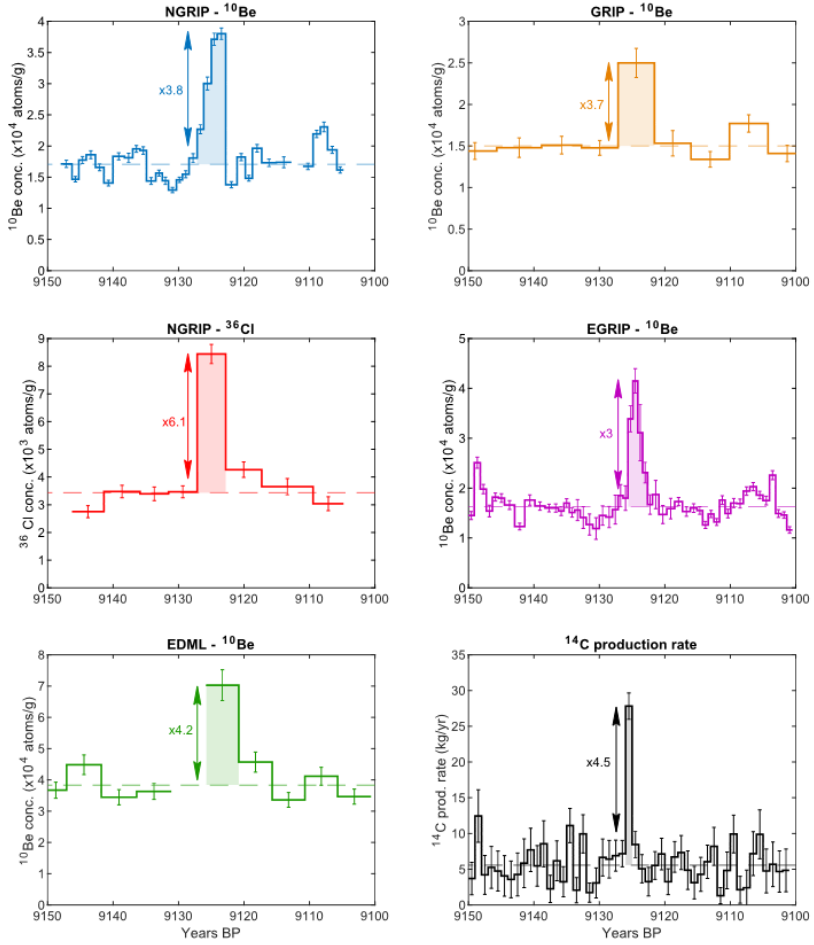


Article | Open Access | Published: 07 March 2022

Tree-rings reveal two strong solar proton events in 7176 and 5259 BCE

Nicolas Brehm, Marcus Christl, Timothy D. J. Knowles, Emmanuelle Casanova, Richard P. Evershed, Florian Adolphi, Raimund Muscheler, Hans-Arno Synal, Florian Mekhaldi, Chiara I. Paleari, Hanns-Hubert Leuschner, Alex Bayliss, Kurt Nicolussi, Thomas Pichler, Christian Schlüchter, Charlotte L. Pearson, Matthew W. Salzer, Patrick Fonti, Daniel Nievergelt, Rashit Hantemirov, David M. Brown, Ilya Usoskin & Lukas Wacker

Nature Communications **13**, Article number: 1196 (2022) | Cite this article



Article | Open Access | Published: 11 January 2022

Cosmogenic radionuclides reveal an extreme solar particle storm near a solar minimum 9125 years BP

Chiara I. Paleari, Florian Mekhaldi, Florian Adolphi, Marcus Christl, Christof Vockenhuber, Philip Gautschi, Jürg Beer, Nicolas Brehm, Tobias Erhardt, Hans-Arno Synal, Lukas Wacker, Frank Wilhelms & Raimund Muscheler

Nature Communications **13**, Article number: 214 (2022) | Cite this article

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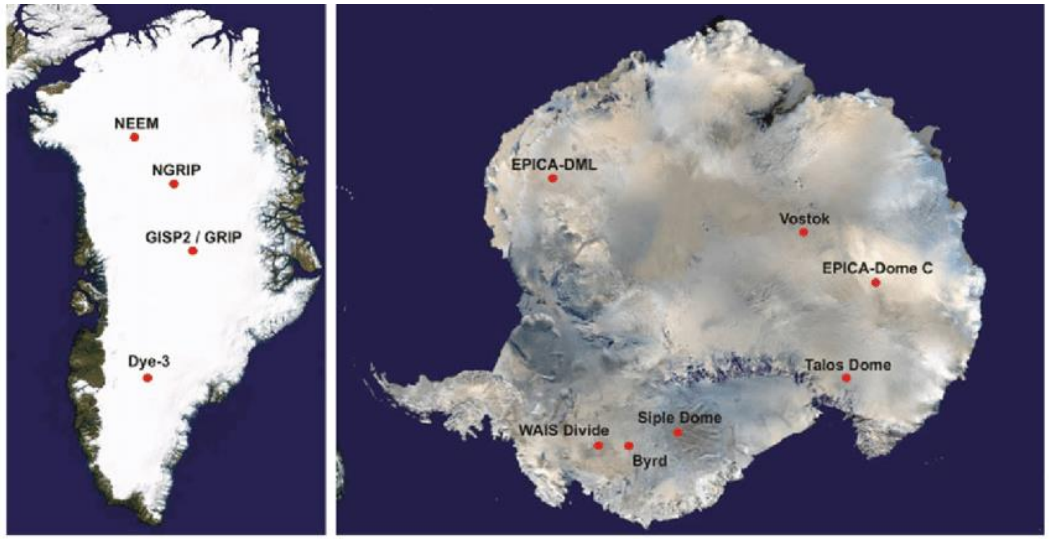

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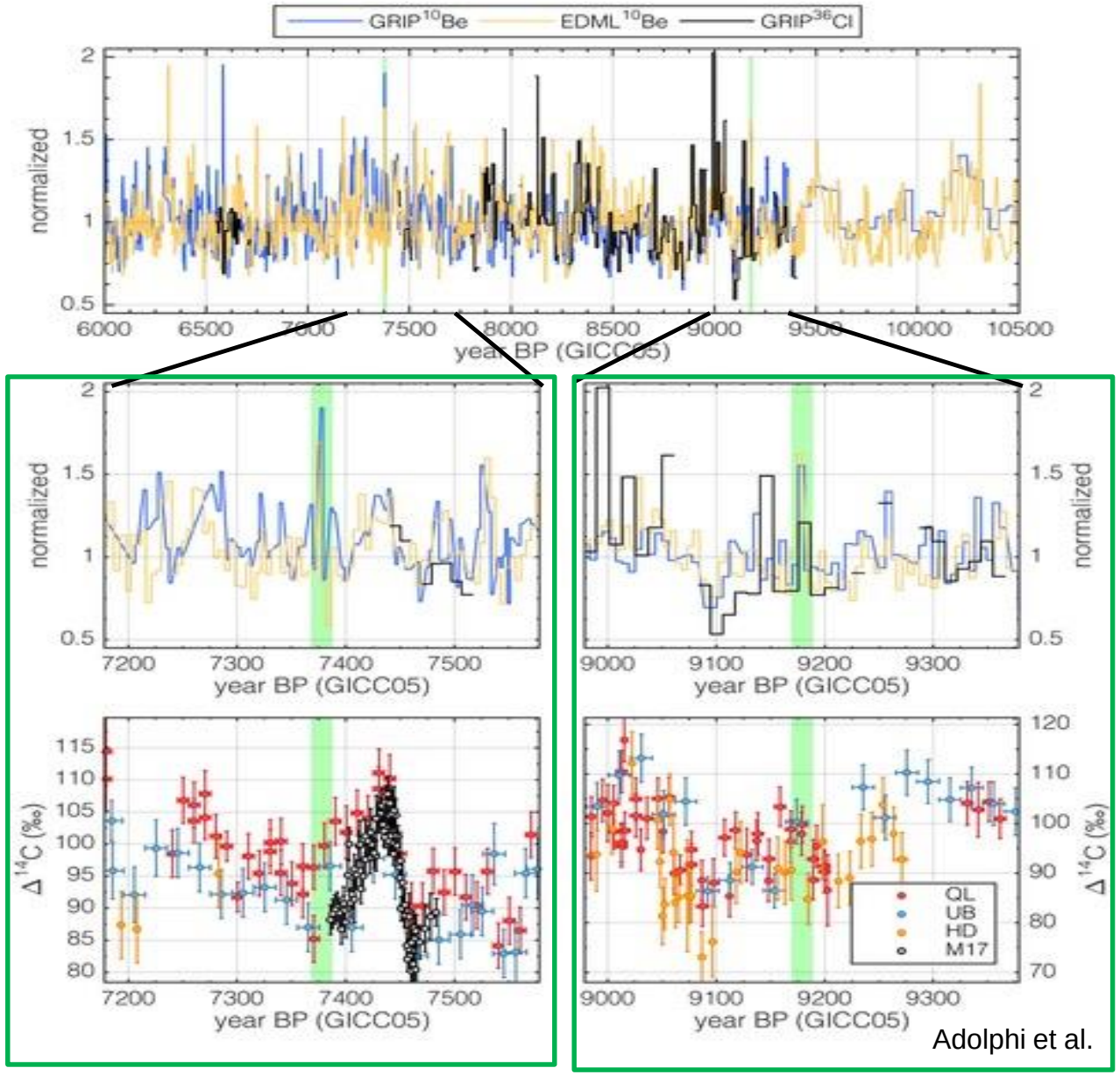

Adolphi et al.

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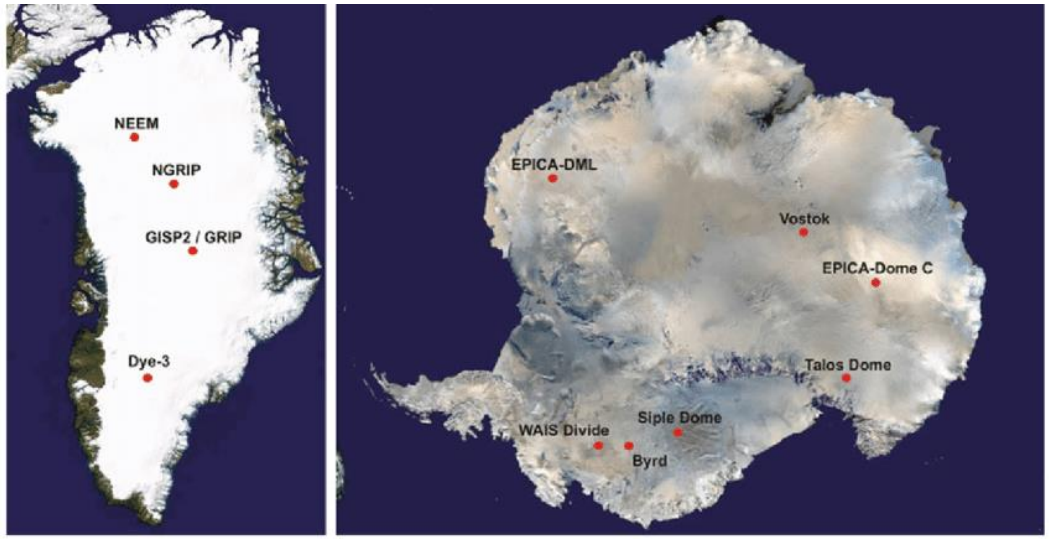
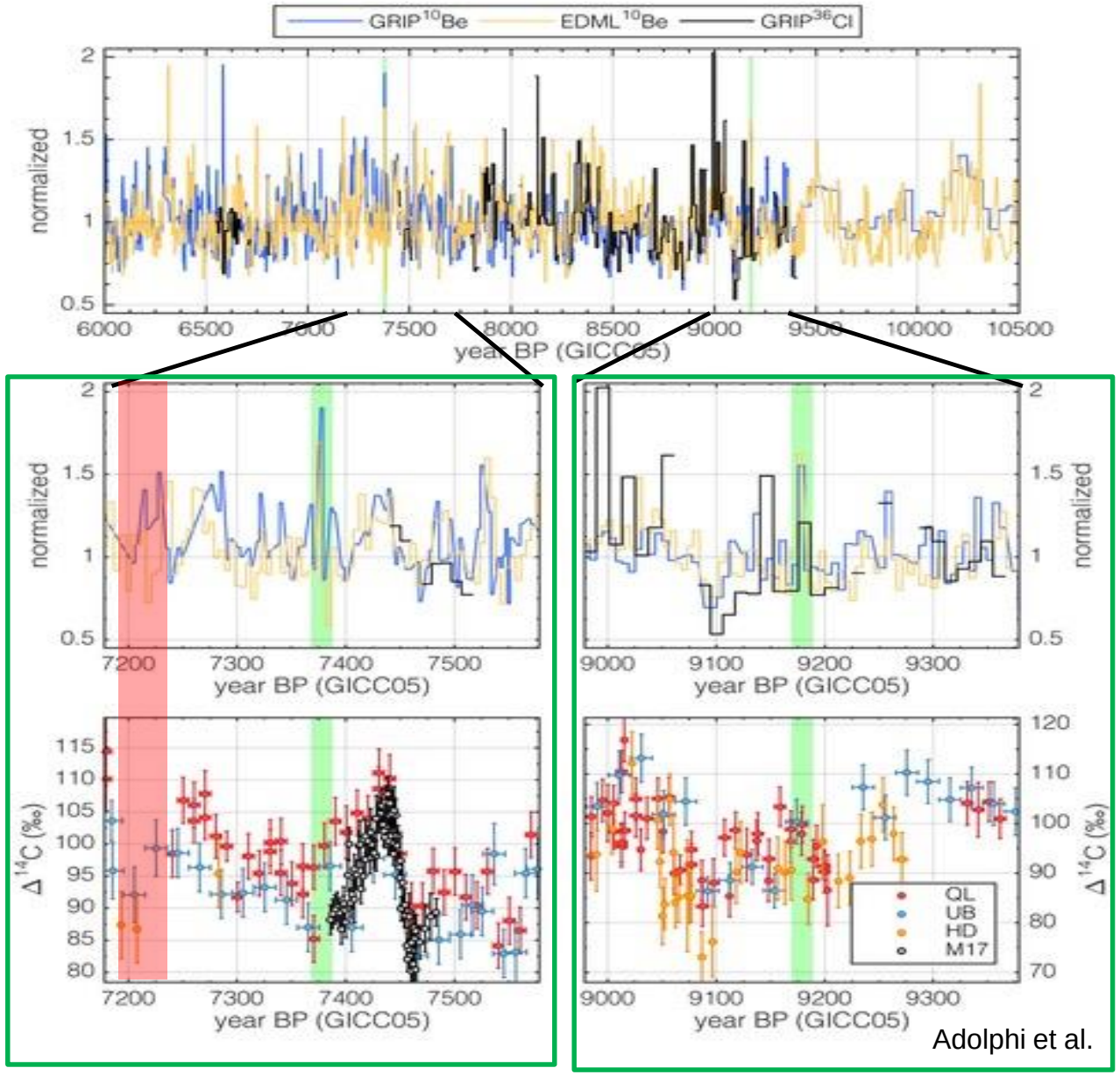
- Looking at different low temporal resolution ^{10}Be and ^{36}Cl records from ice cores

- Finding time periods where multiple records show anomaly

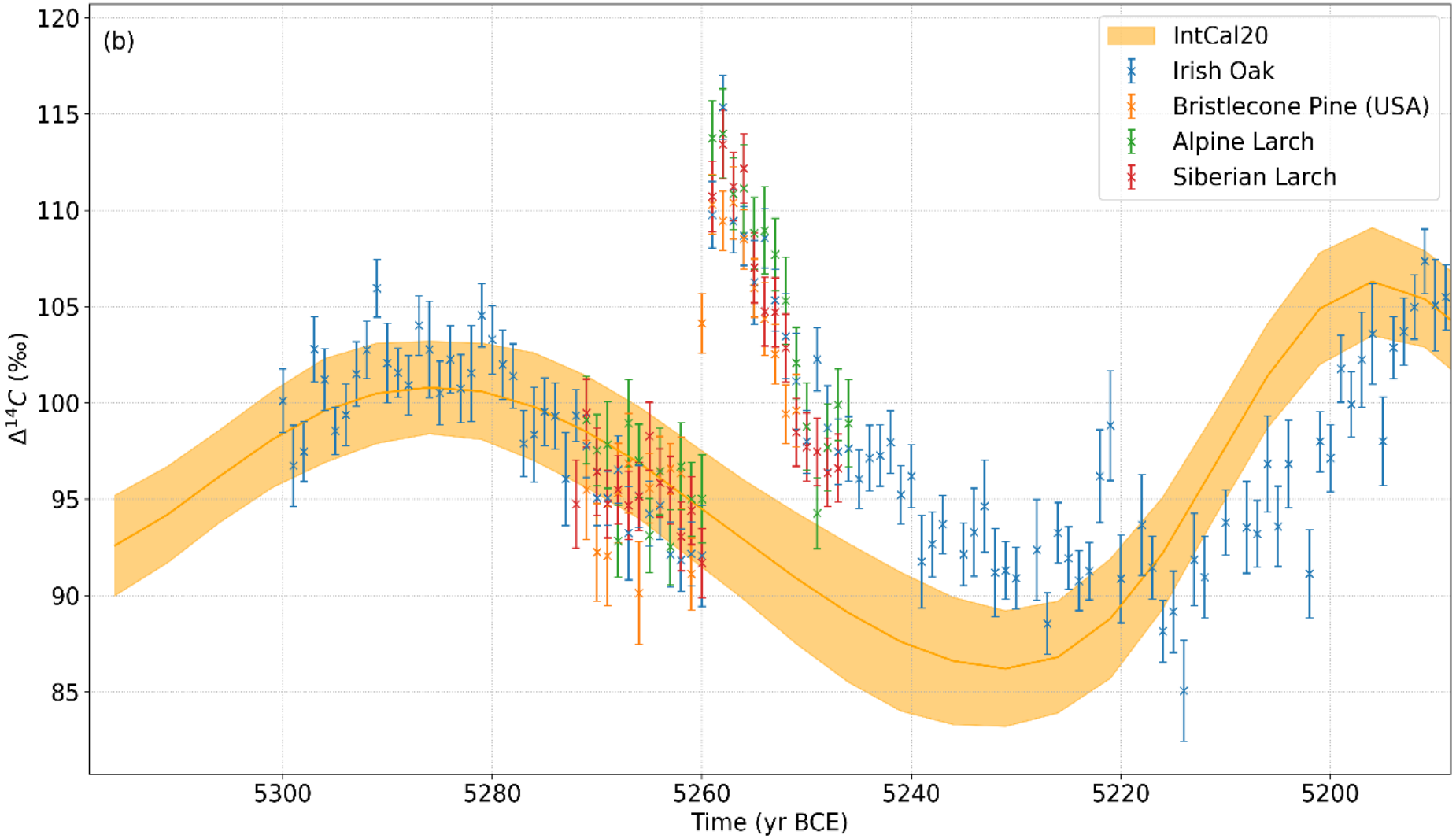


https://www.researchgate.net/figure/Map-of-both-polar-regions-indicating-selected-ice-core-drilling-sites-in-Greenland-NEEM_fig6_301173005

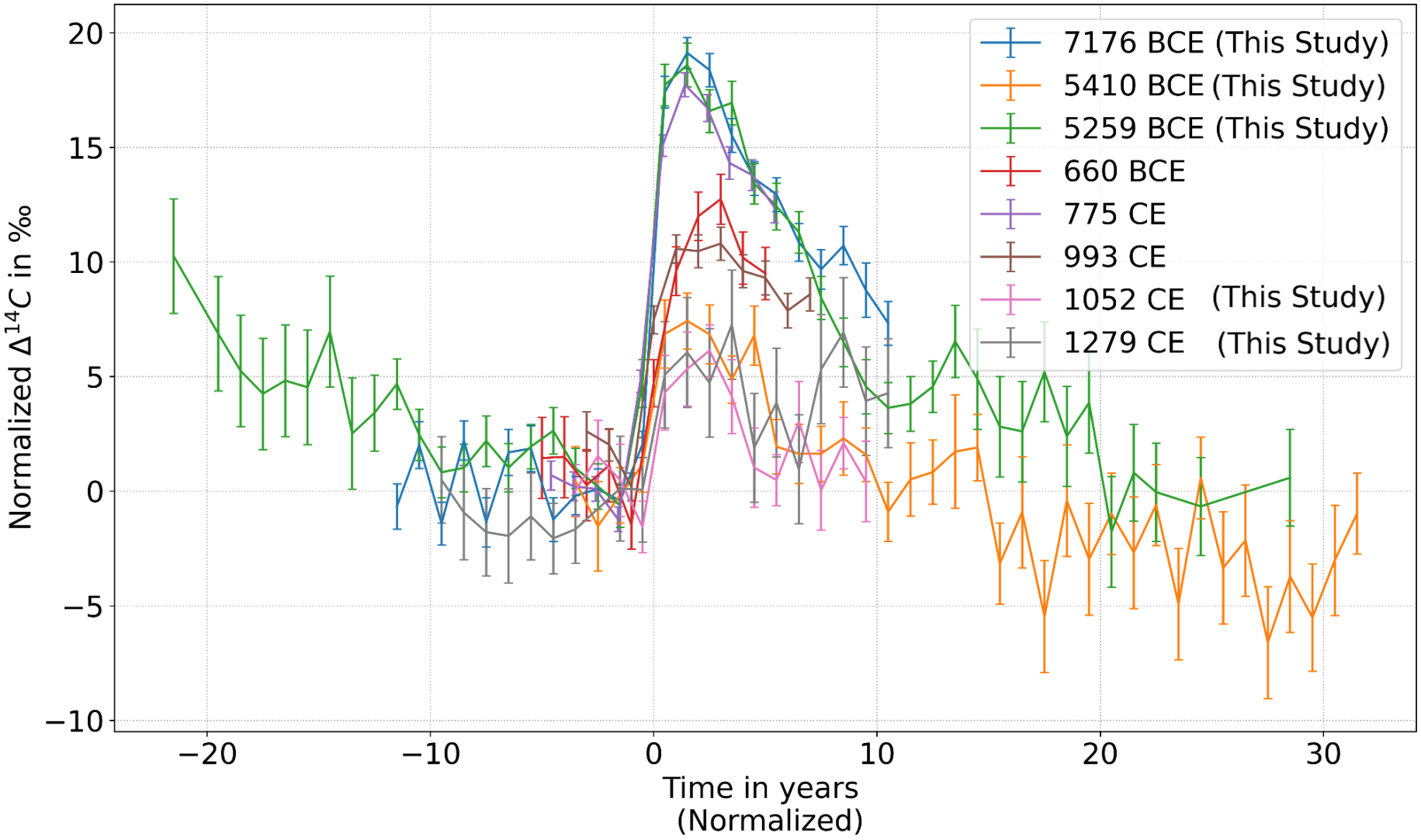


Adolphi et al.

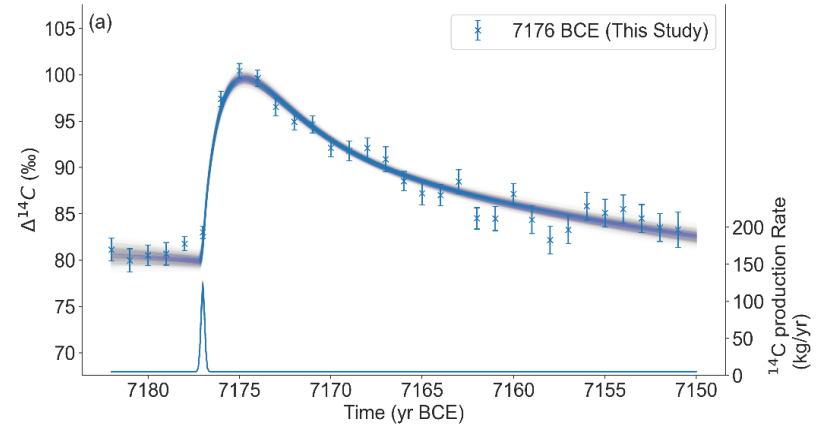
Detection of SEP events (at 7176 BCE/ 7208 BP)

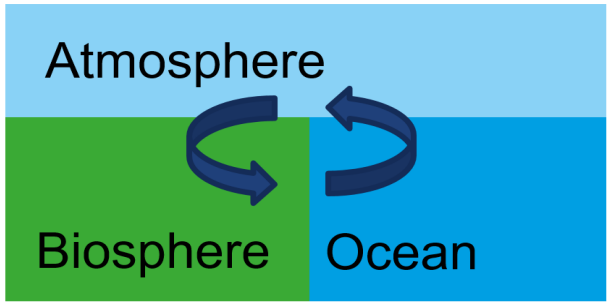


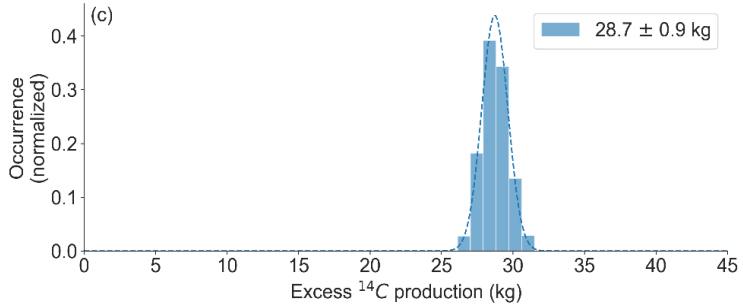
Comparison of different events



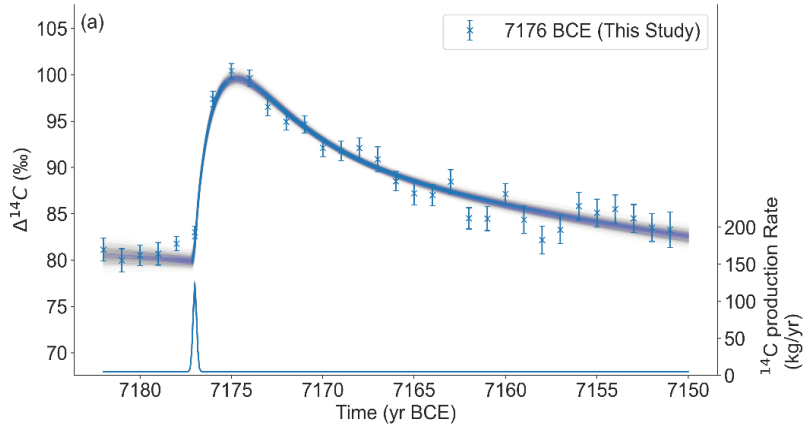
Characterization of events using a carbon cycle box model

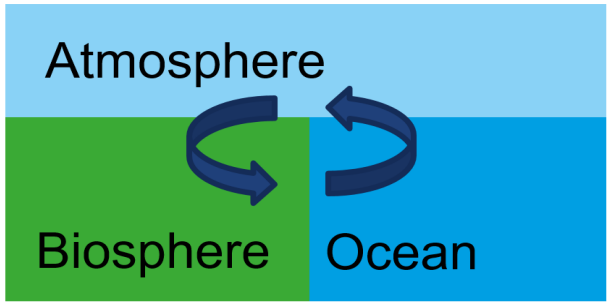


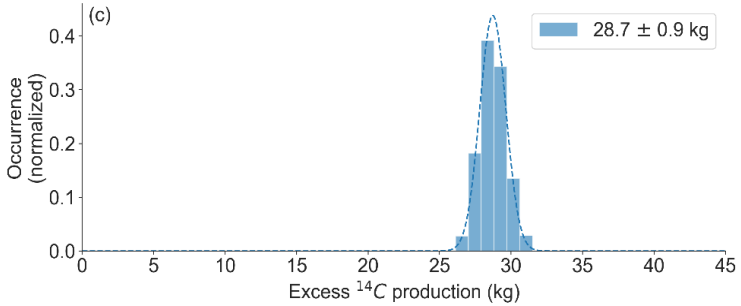


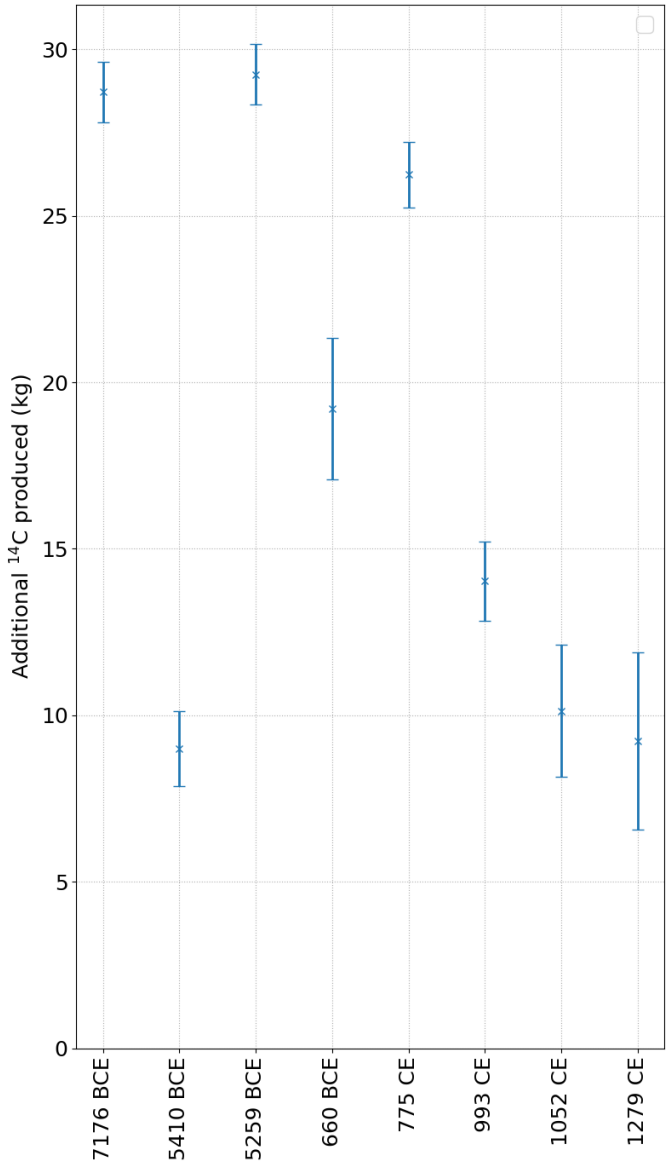


Characterization of events using a carbon cycle box model





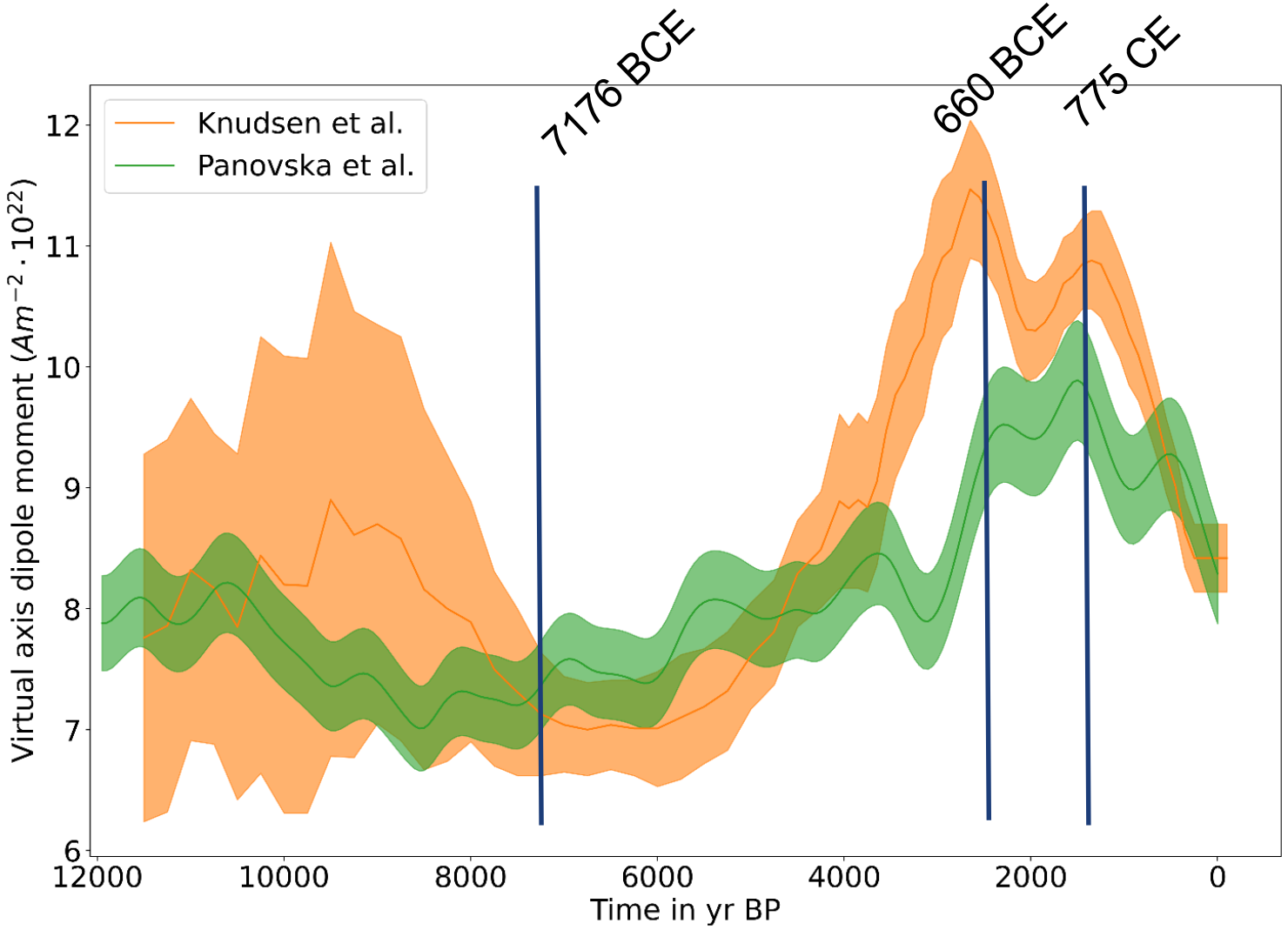




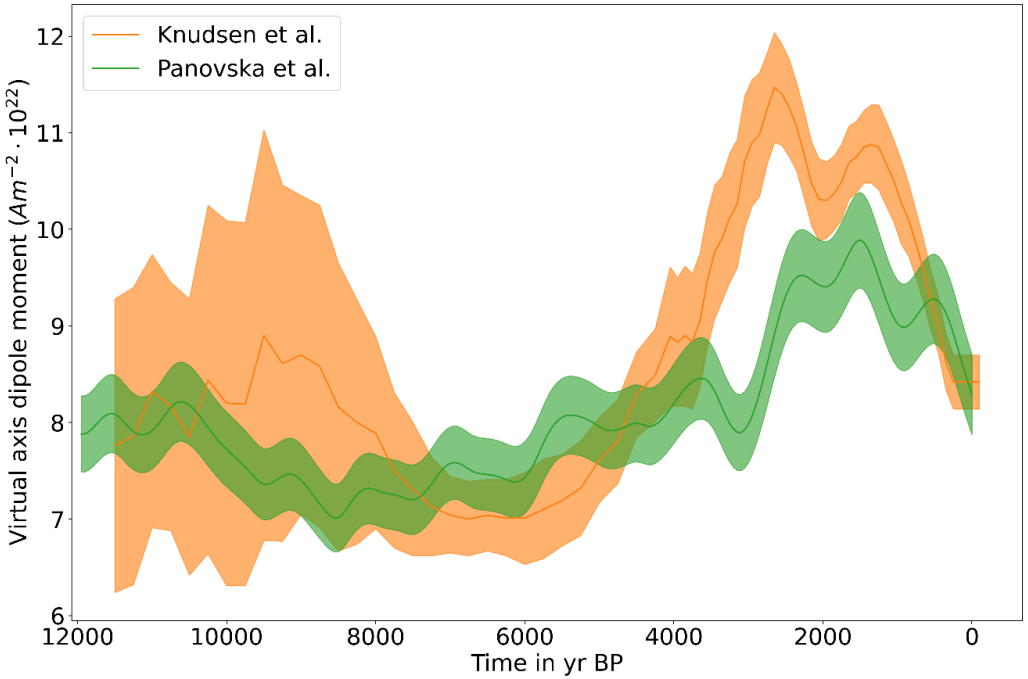
Influence of Geomagnetic shielding

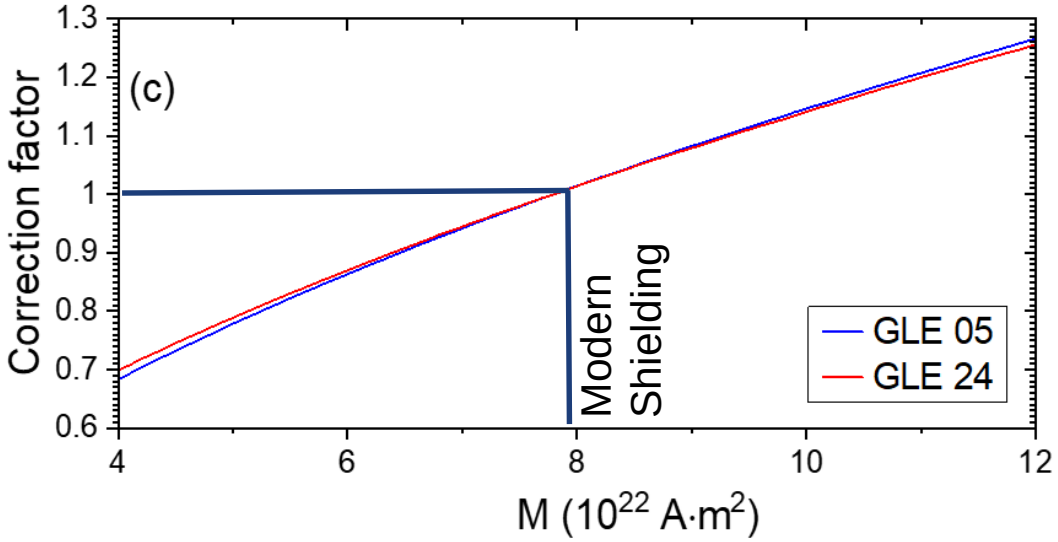
Earth magnetic field is not constant over time

For direct comparison of the event the magnetic field has to be considered

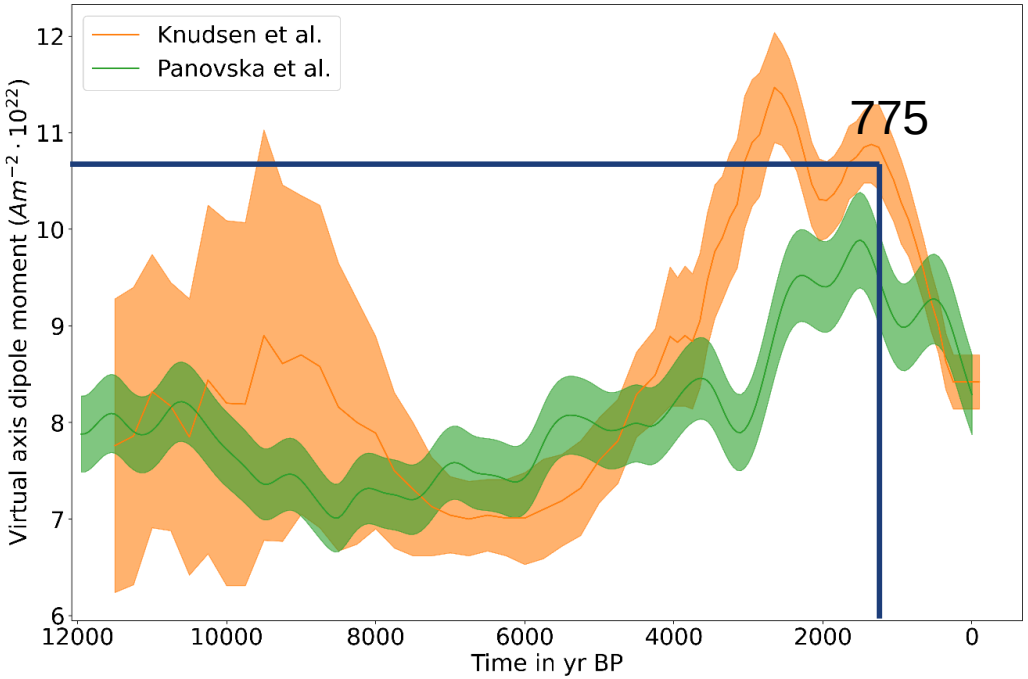


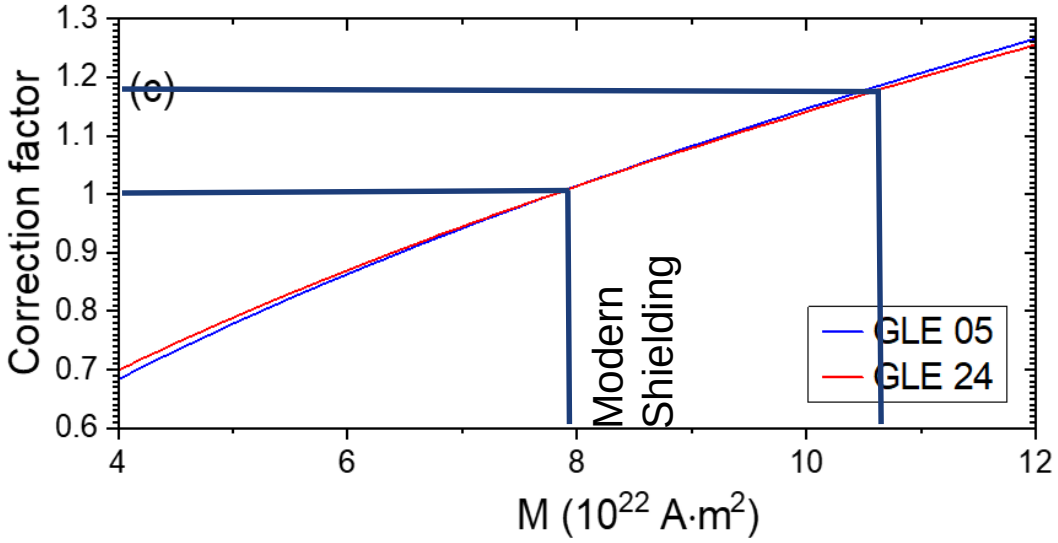
Influence of Geomagnetic shielding



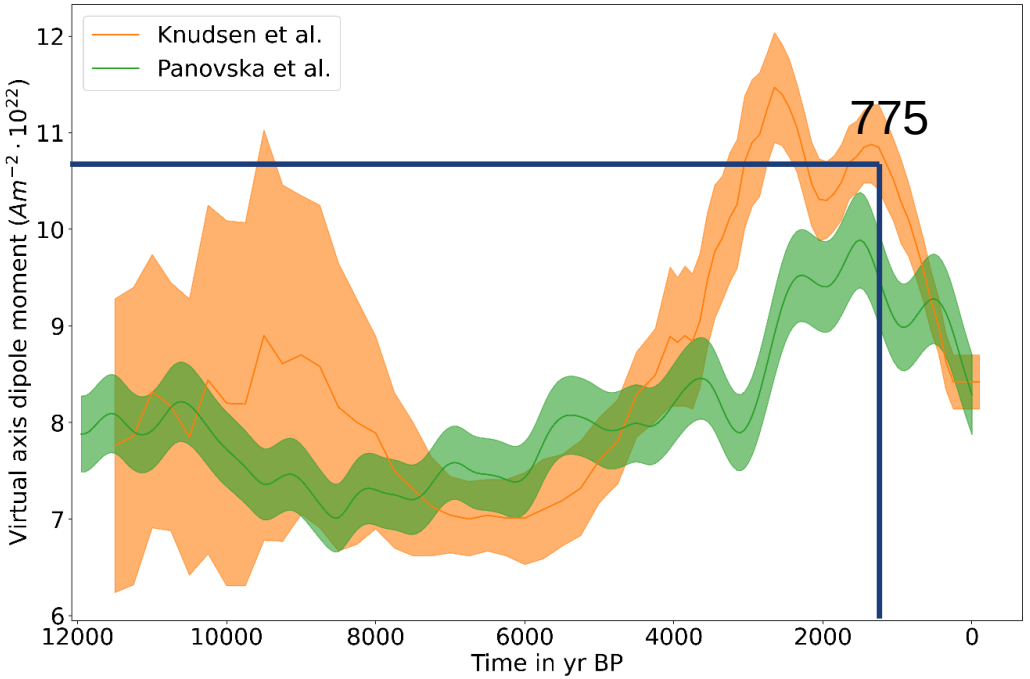


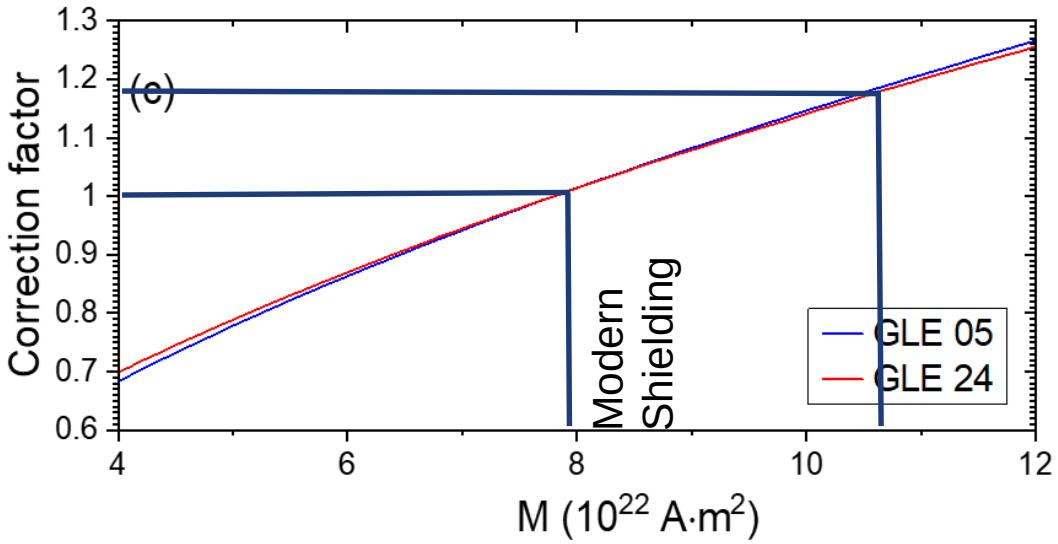
Influence of Geomagnetic shielding

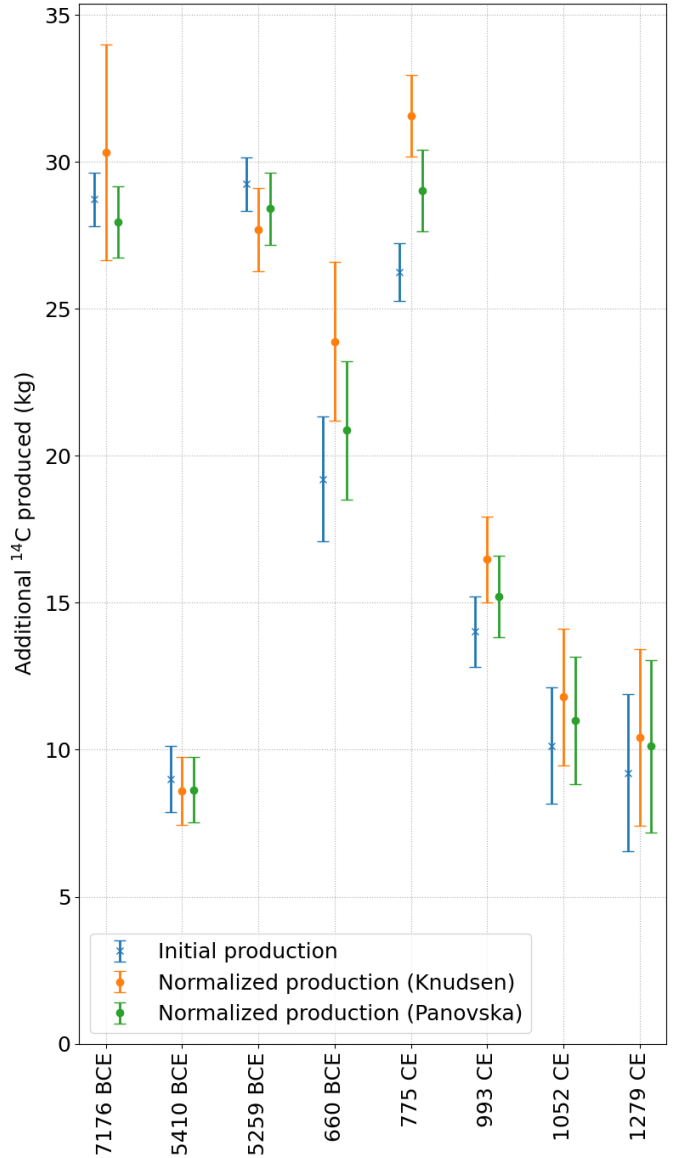




Influence of Geomagnetic shielding





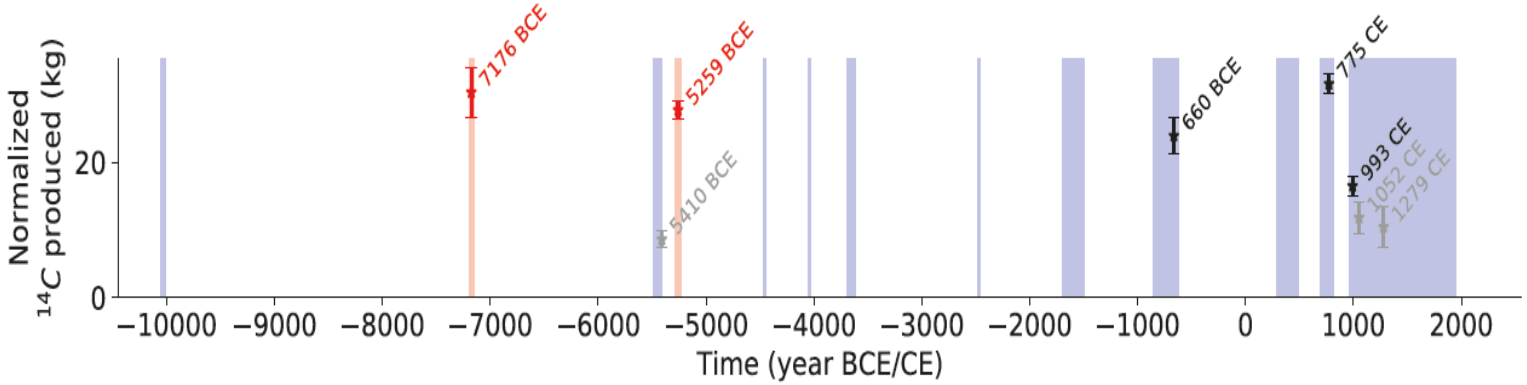


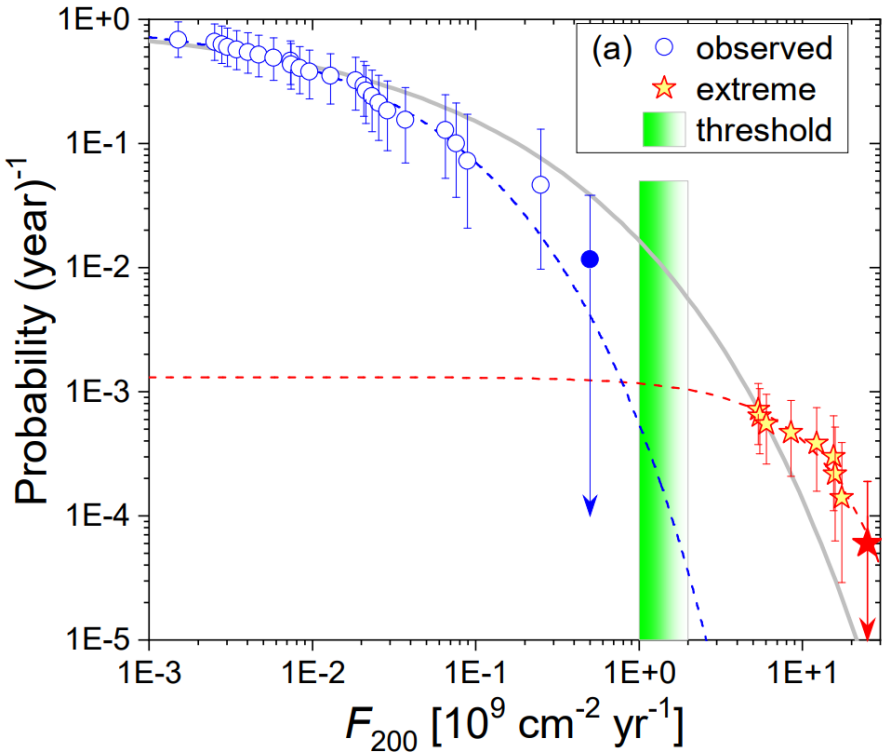
Conclusion

5 new SEP events found!

Events compared and characterized in terms of additionally produced Radiocarbon

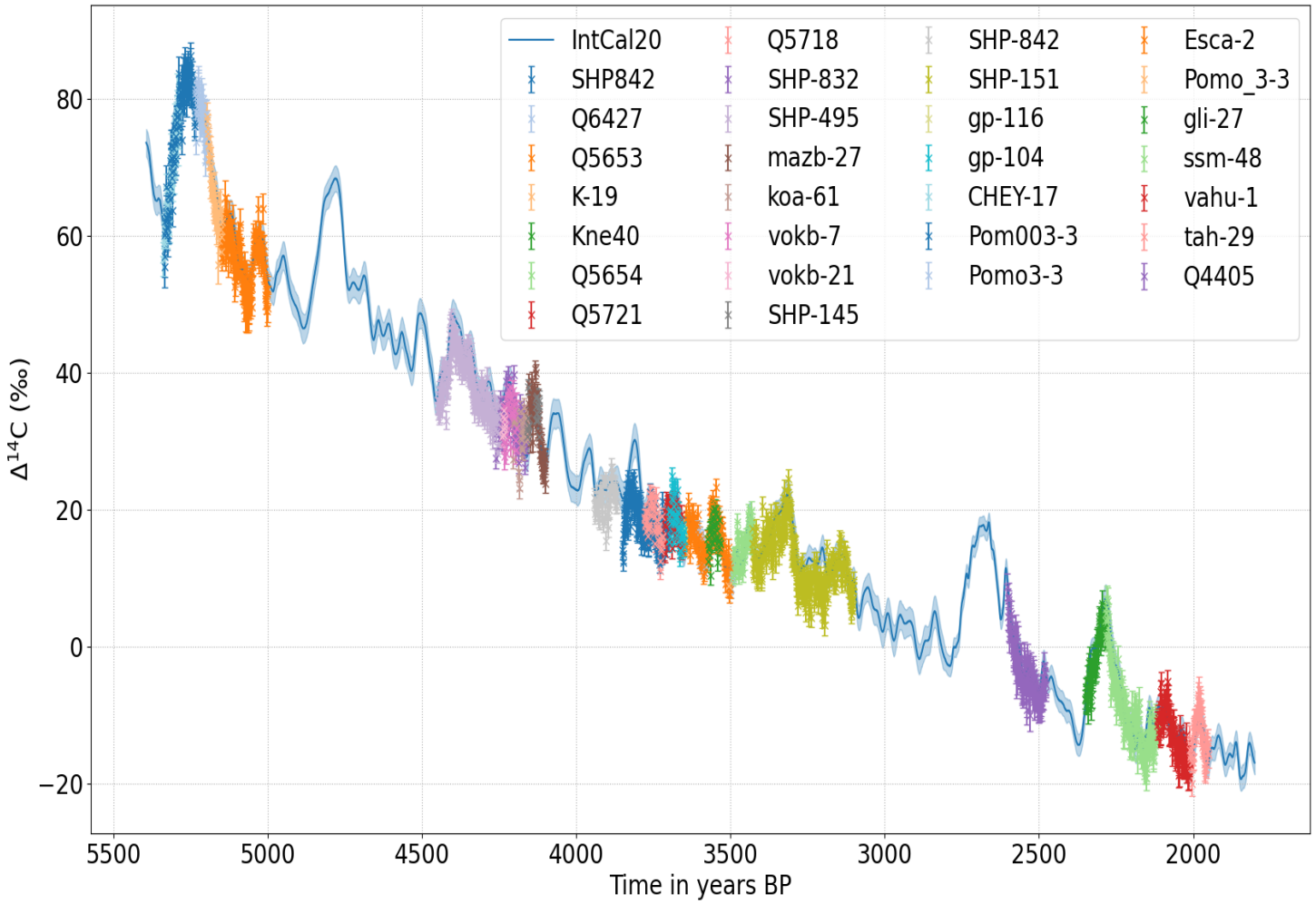
Better statistics for such extreme events can be obtained

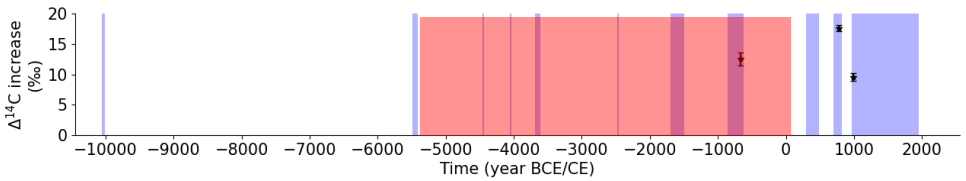




Usoskin et al.
in preparation

Outlook


IntCal20
SHP842
Q6427
Q5653
K-19
Kne40
Q5654
Q5721
Q5718
SHP-832
SHP-495
mazb-27
koa-61
vokb-7
vokb-21
SHP-145
SHP-842
SHP-151
gp-116
gp-104
CHEY-17
Pom003-3
Pomo3-3
Esca-2
Pomo_3-3
gli-27
ssm-48
vahu-1
tah-29
Q4405
Δ14C (‰)
Time in years BP


Δ14C increase (‰)
Time (year BCE/CE)

Thank you!

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Kurt Nicolussi, Timothy Knowles,
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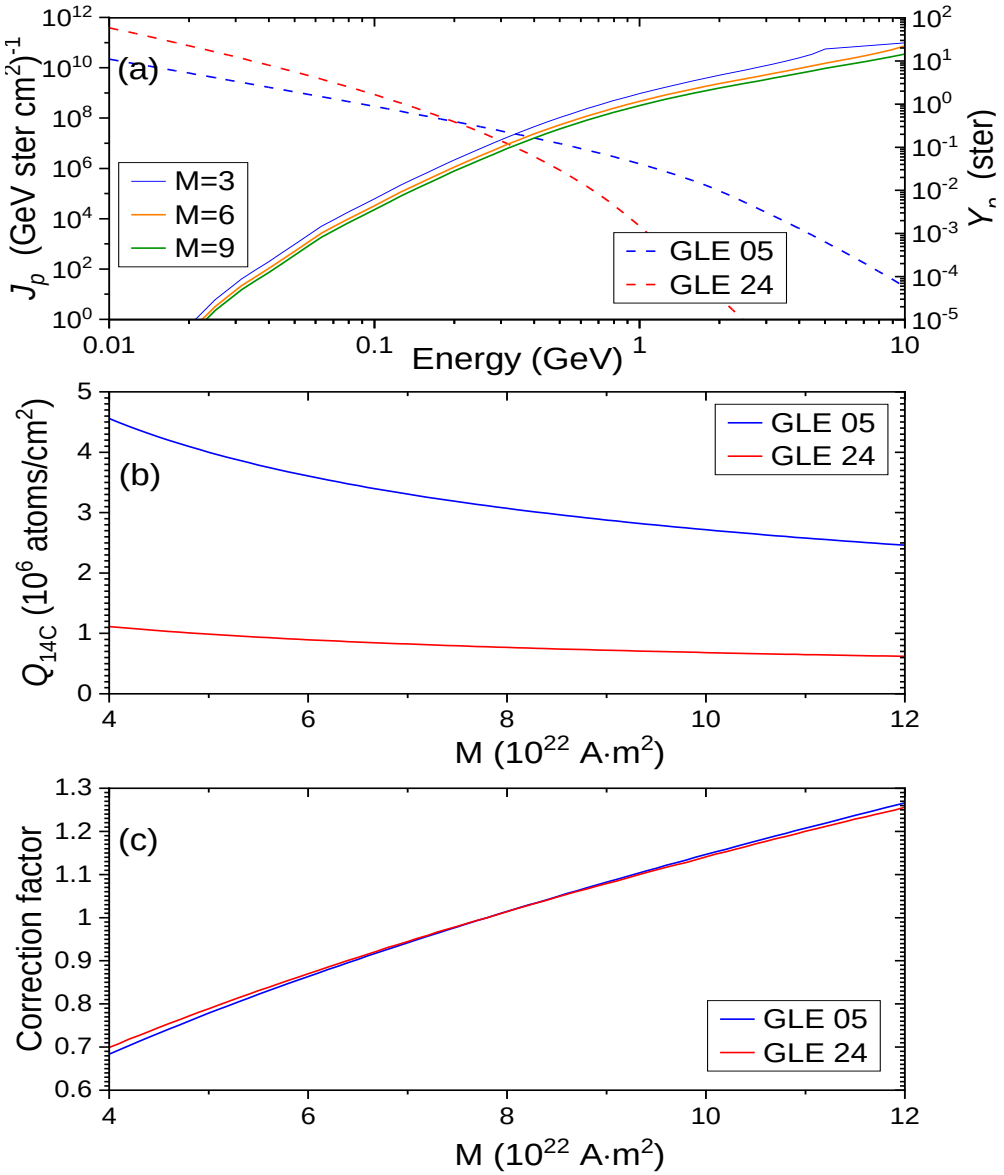
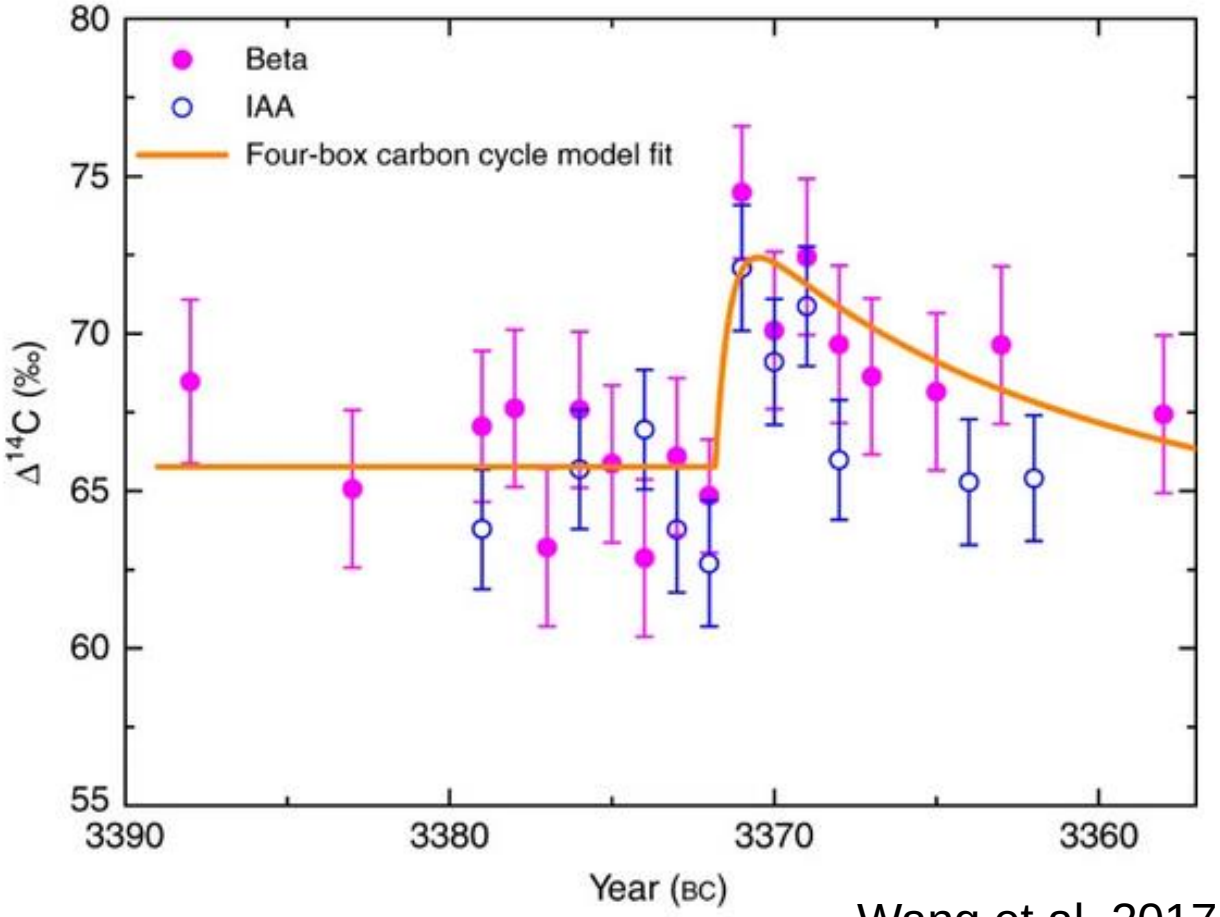
Florian Mekhaldi, Charlotte Pearson,
Rashit Hantemirov, Ilya Usoskin, Daniel
Nievergelt, Sami Solanki

Ion Beam Physics Group

Influence of Geomagnetic shielding

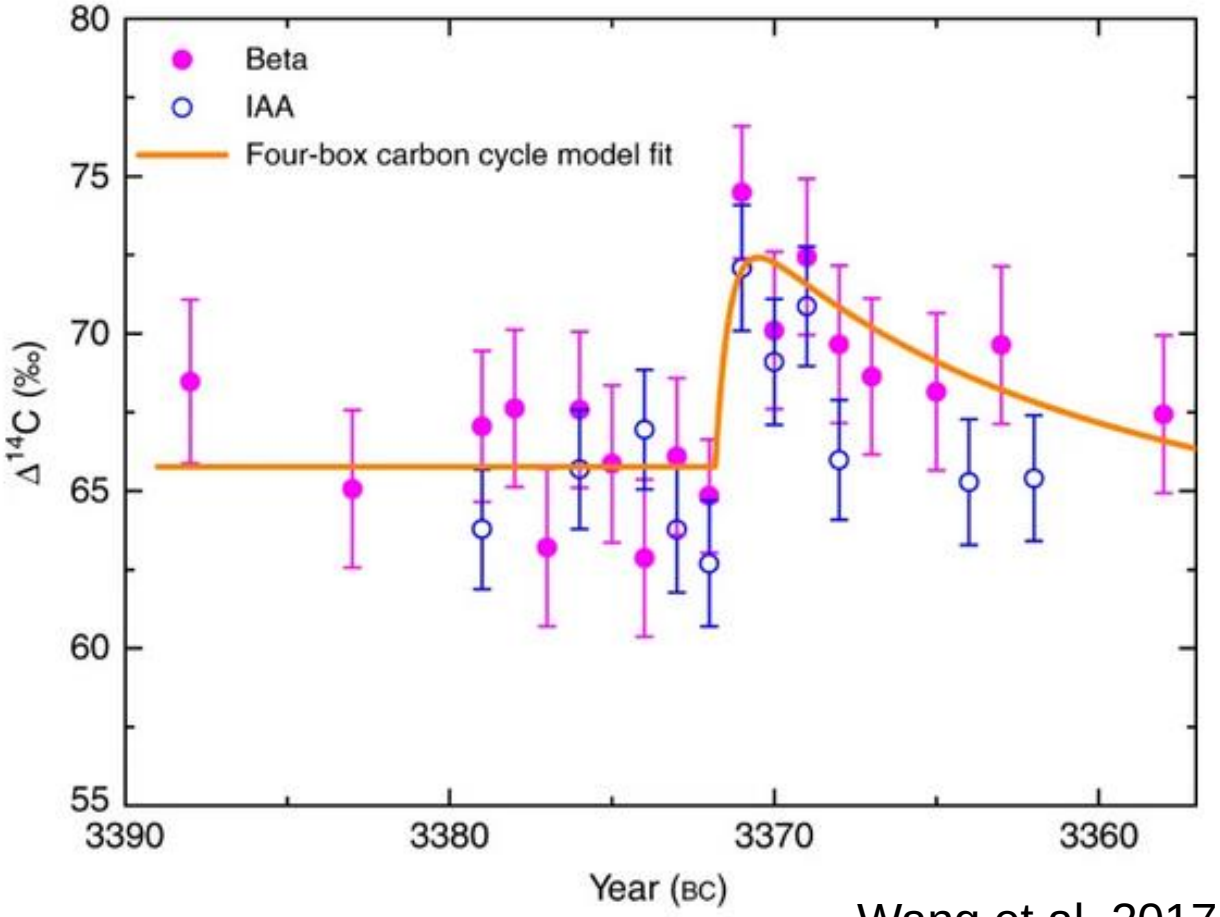


Solar energetic particle (SEP) events

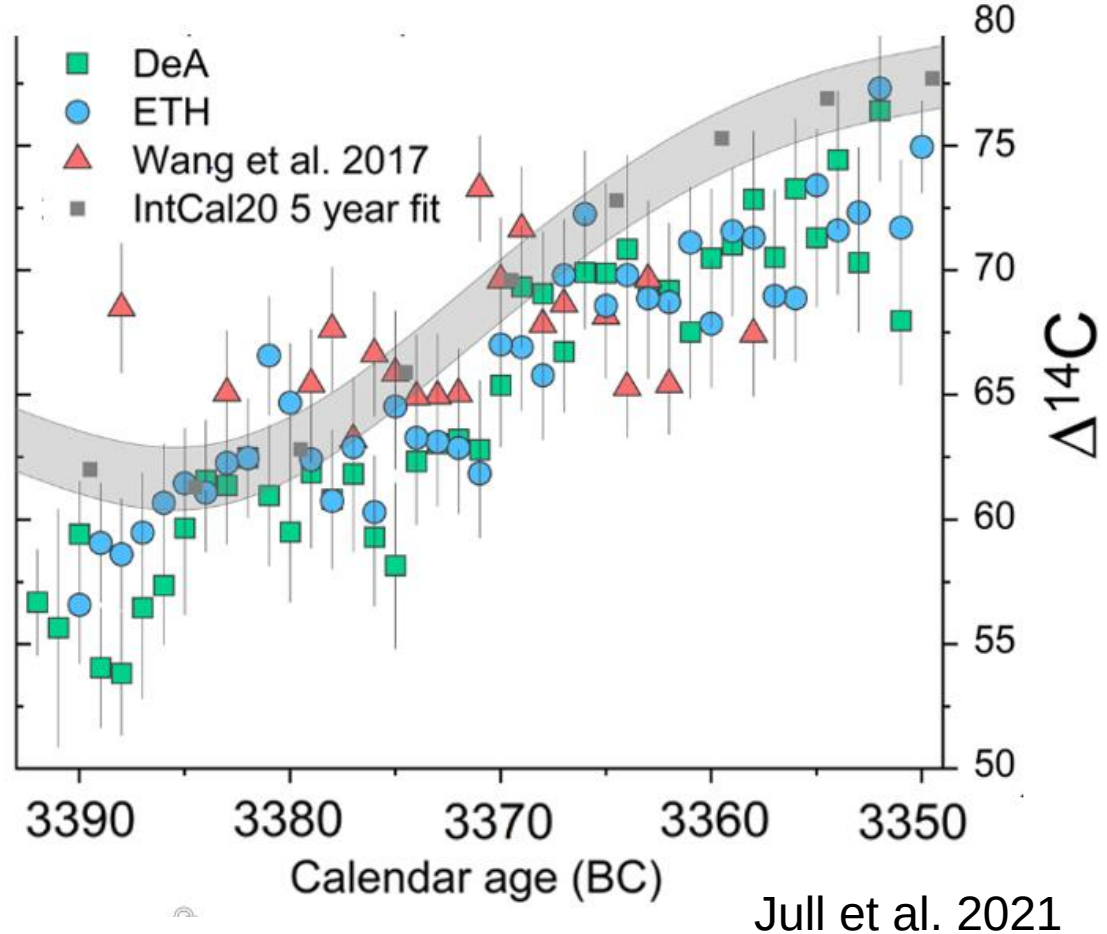


Wang et al. 2017

Solar energetic particle (SEP) events

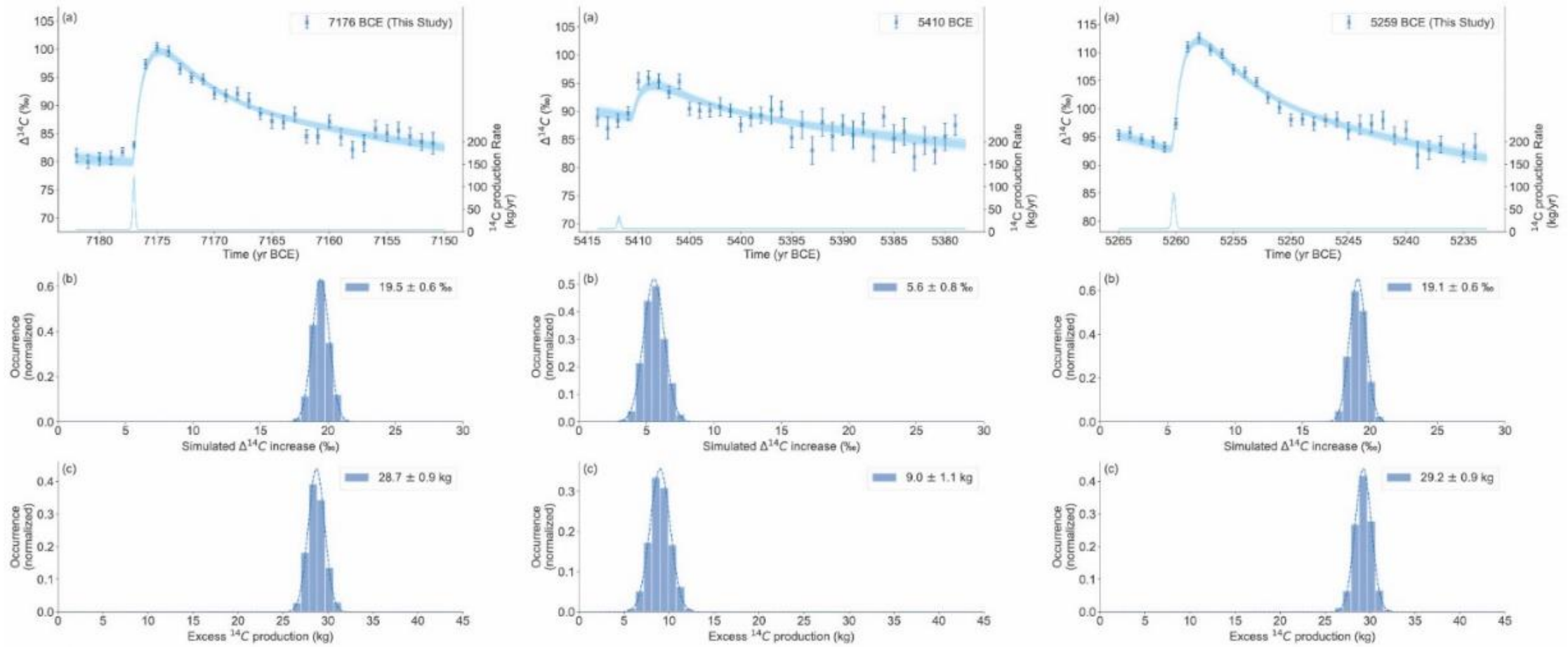


Wang et al. 2017

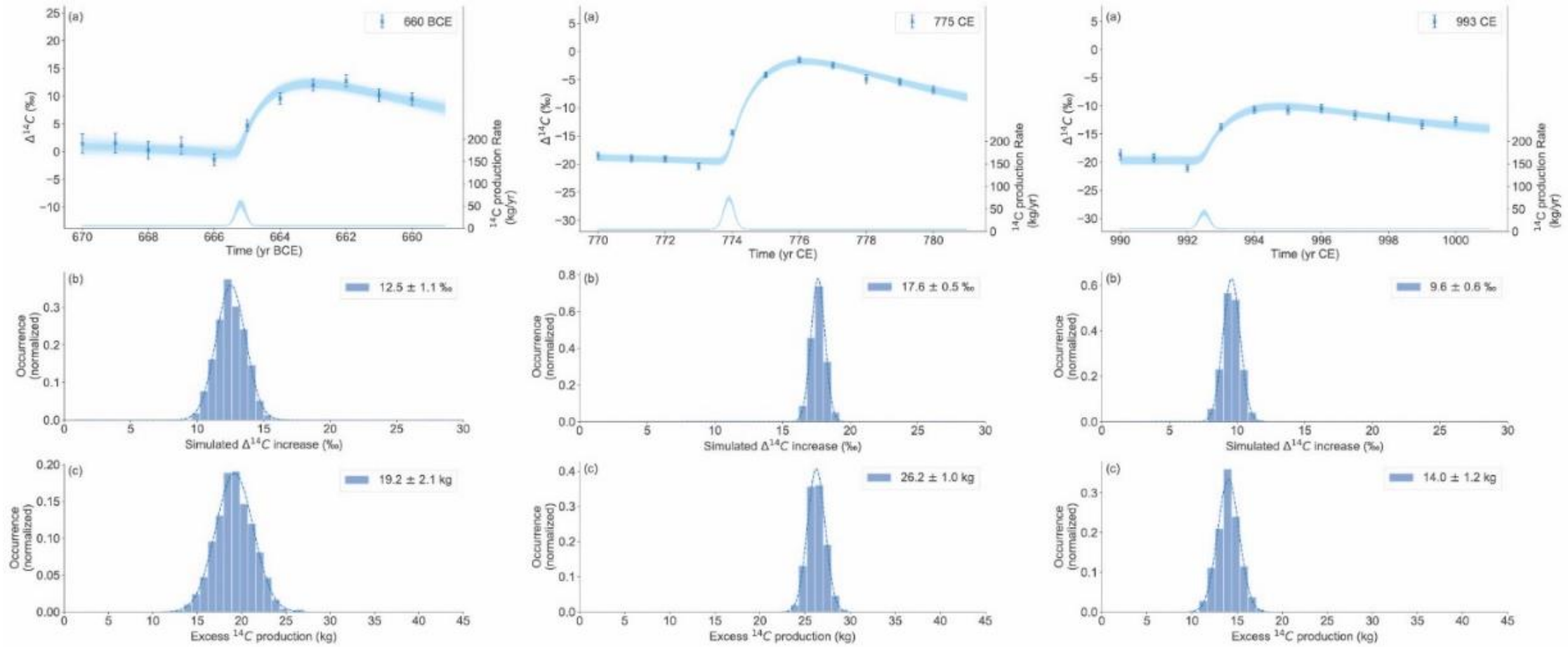


Jull et al. 2021

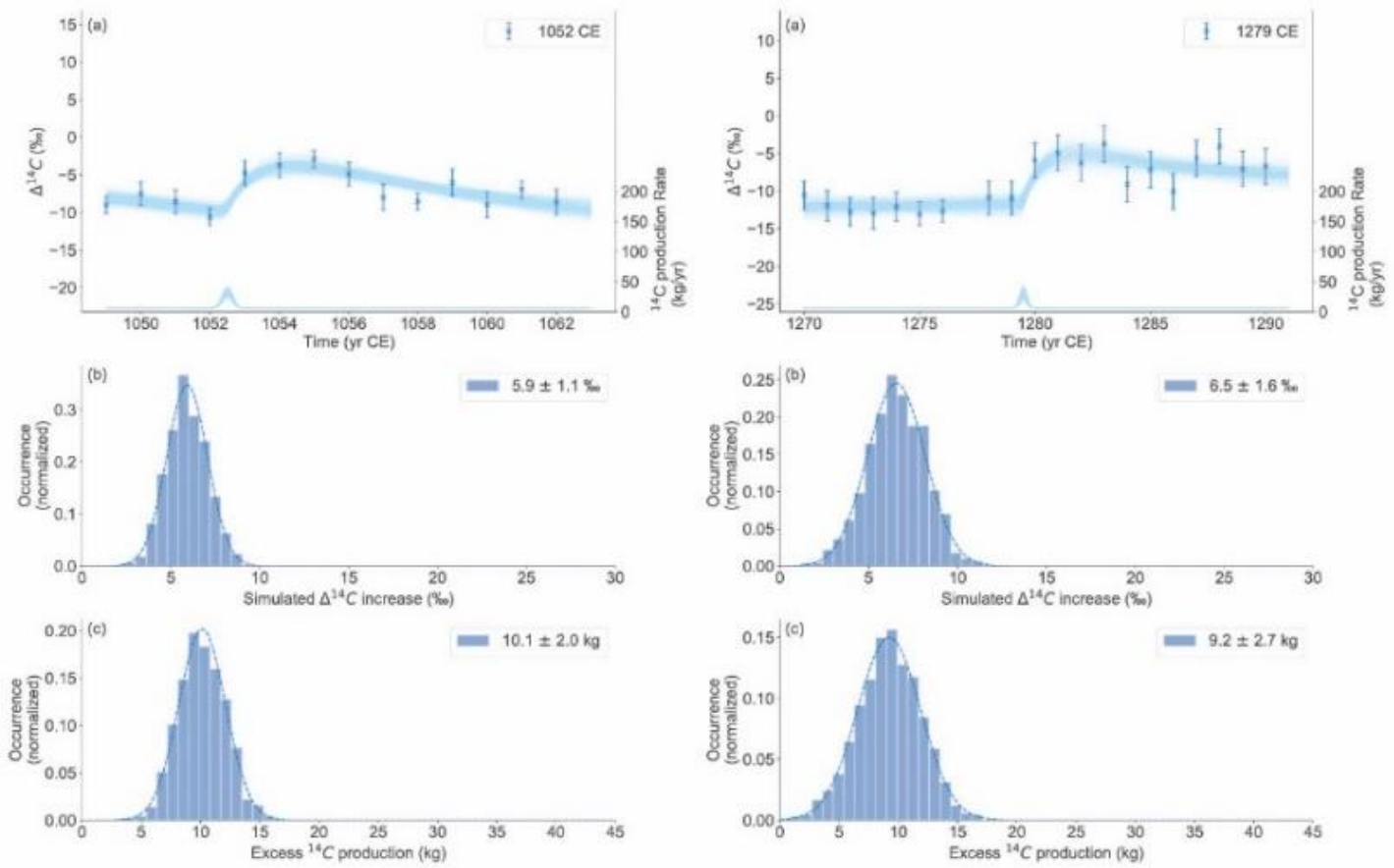
Modelling


(a)
7176 BCE (This Study)
Δ14C (‰)
14C production Rate (kg/yr)
Time (yr BCE)
(b)
19.5 ± 0.6 ‰
Occurrence (normalized)
Simulated Δ14C increase (‰)
(c)
28.7 ± 0.9 kg
Excess 14C production (kg)
(a)
5410 BCE
Δ14C (‰)
14C production Rate (kg/yr)
Time (yr BCE)
(b)
5.6 ± 0.8 ‰
Occurrence (normalized)
Simulated Δ14C increase (‰)
(c)
9.0 ± 1.1 kg
Excess 14C production (kg)
(a)
5259 BCE (This Study)
Δ14C (‰)
14C production Rate (kg/yr)
Time (yr BCE)
(b)
19.1 ± 0.6 ‰
Occurrence (normalized)
Simulated Δ14C increase (‰)
(c)
29.2 ± 0.9 kg
Excess 14C production (kg)

Modelling


(a)
660 BCE
Δ14C (‰)
14C production Rate (kg/yr)
Time (yr BCE)
(b)
12.5 ± 1.1 ‰
Occurrence (normalized)
Simulated Δ14C increase (‰)
(c)
19.2 ± 2.1 kg
Excess 14C production (kg)
(a)
775 CE
Time (yr CE)
(b)
17.6 ± 0.5 ‰
(c)
26.2 ± 1.0 kg
(a)
993 CE
(b)
9.6 ± 0.6 ‰
(c)
14.0 ± 1.2 kg

Modelling


(a)
1052 CE
Δ14C (‰)
14C production Rate (kg/yr)
Time (yr CE)
(b)
5.9 ± 1.1 ‰
Occurrence (normalized)
Simulated Δ14C increase (‰)
(c)
10.1 ± 2.0 kg
Excess 14C production (kg)
(a)
1279 CE
Δ14C (‰)
14C production Rate (kg/yr)
Time (yr CE)
(b)
6.5 ± 1.6 ‰
Occurrence (normalized)
Simulated Δ14C increase (‰)
(c)
9.2 ± 2.7 kg
Excess 14C production (kg)