Two in one:
Climate and Solar Activity proxies from tree rings

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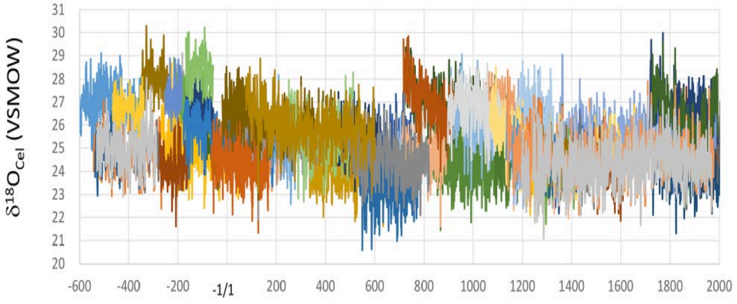
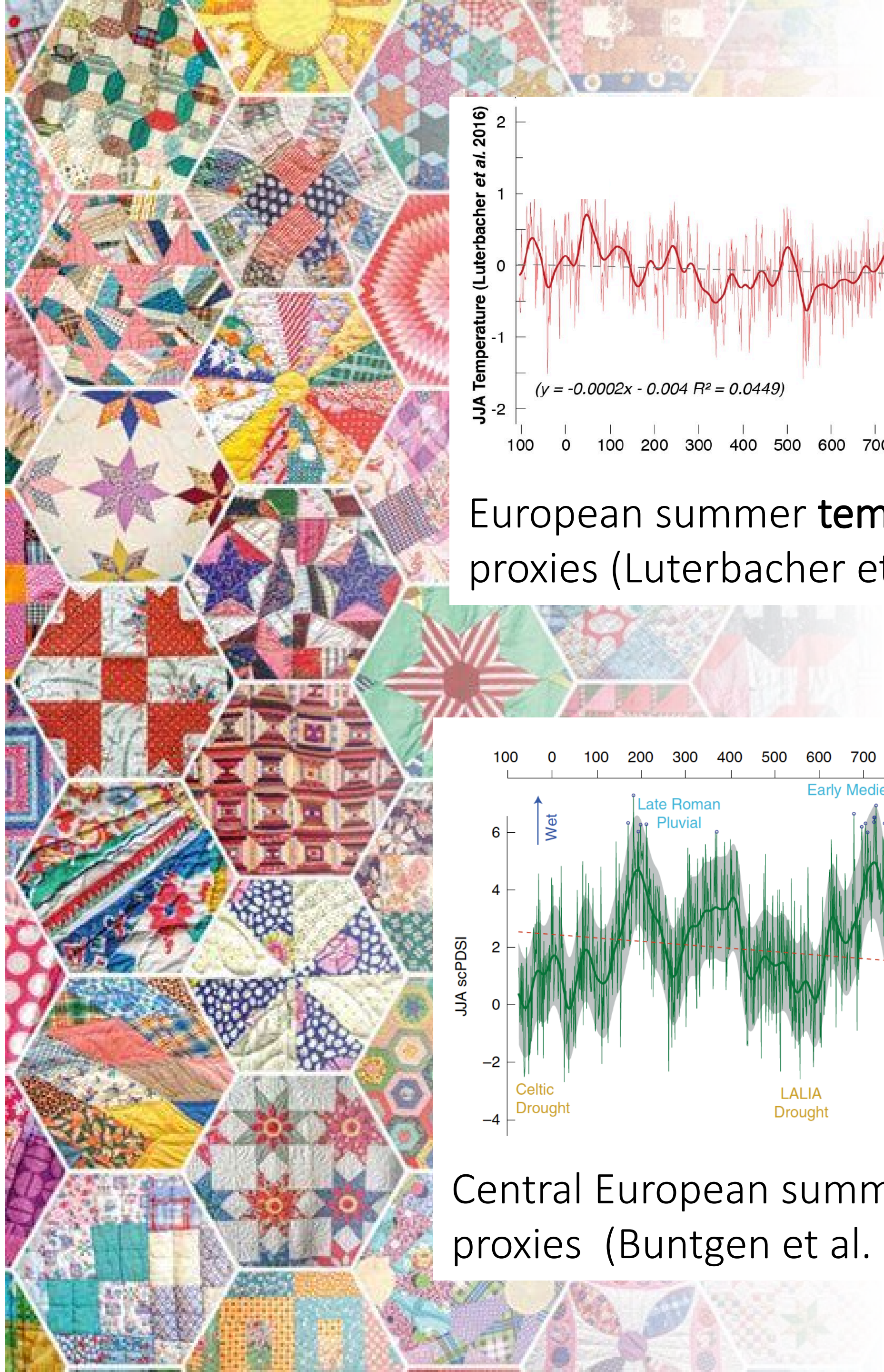
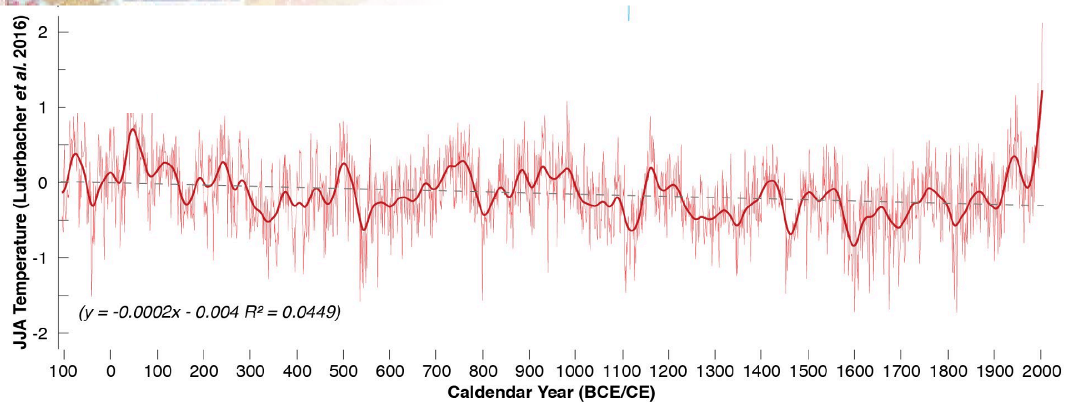
Tree-ring multiproxy for reconstruction of the past climate

- Tree-ring width
- Wood density
- $\delta^{18}O$ and $\delta^{13}C$
- Cell dimensions

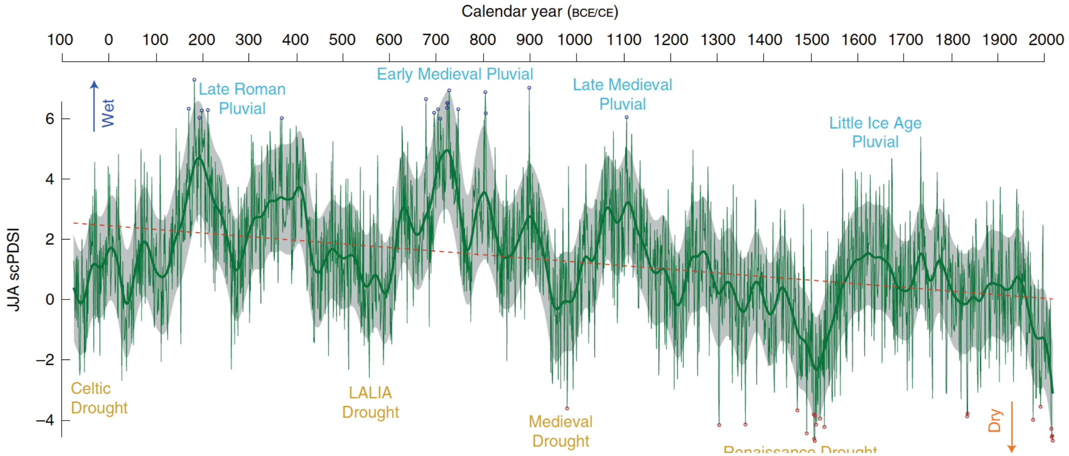


Nakatsuka et al. 2020





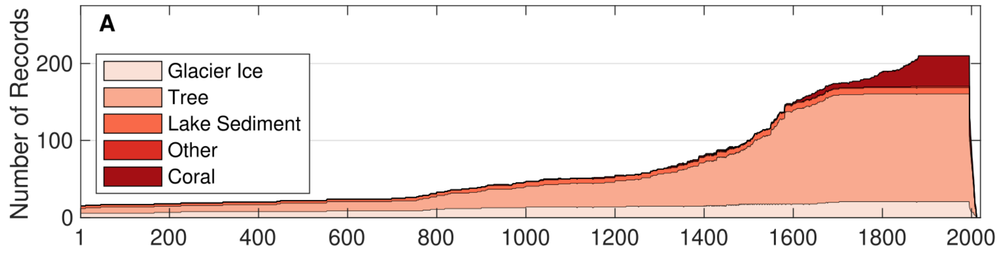
European summer **temperature** from <u>TRW</u> and <u>MWD</u> proxies (Luterbacher et al. 2010).



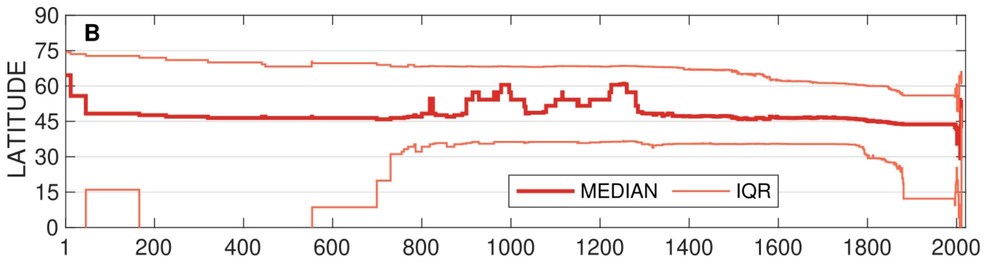
Central European summer **droughts** from *^{13}C and ^{18}O* oak proxies (Buntgen et al. 2021).

Regional to global

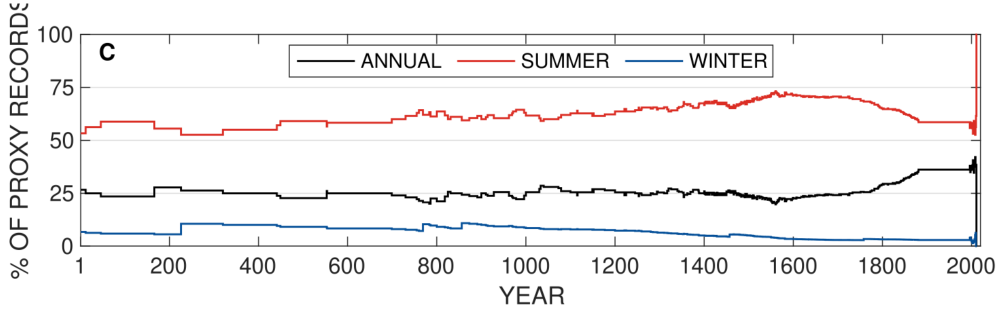
Sample depth



Latitude

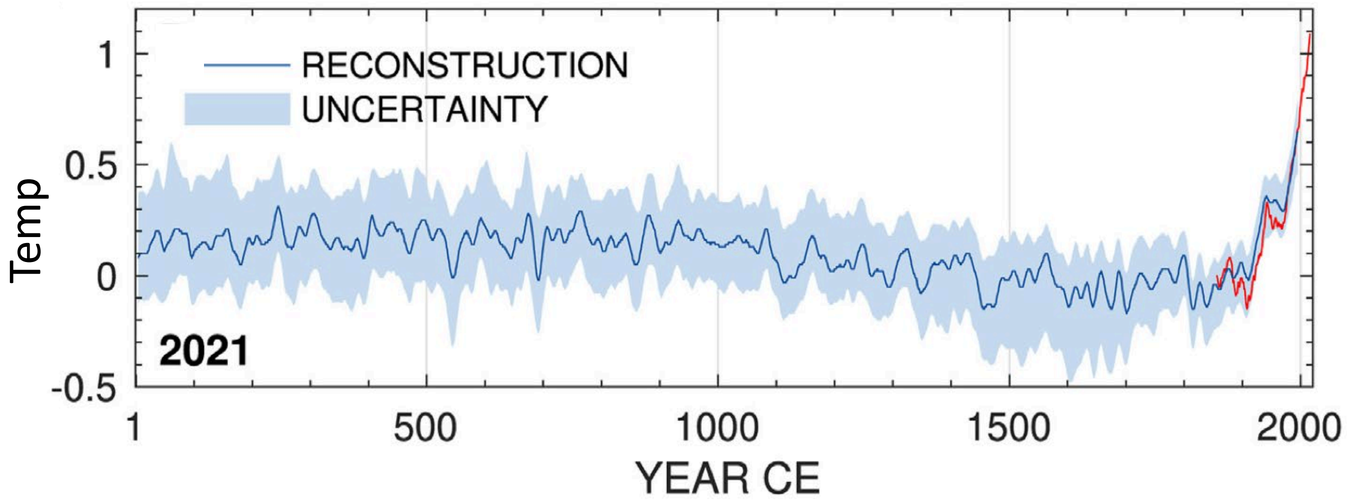


Time resolution



- Uncertainties in global temperature reconstruction

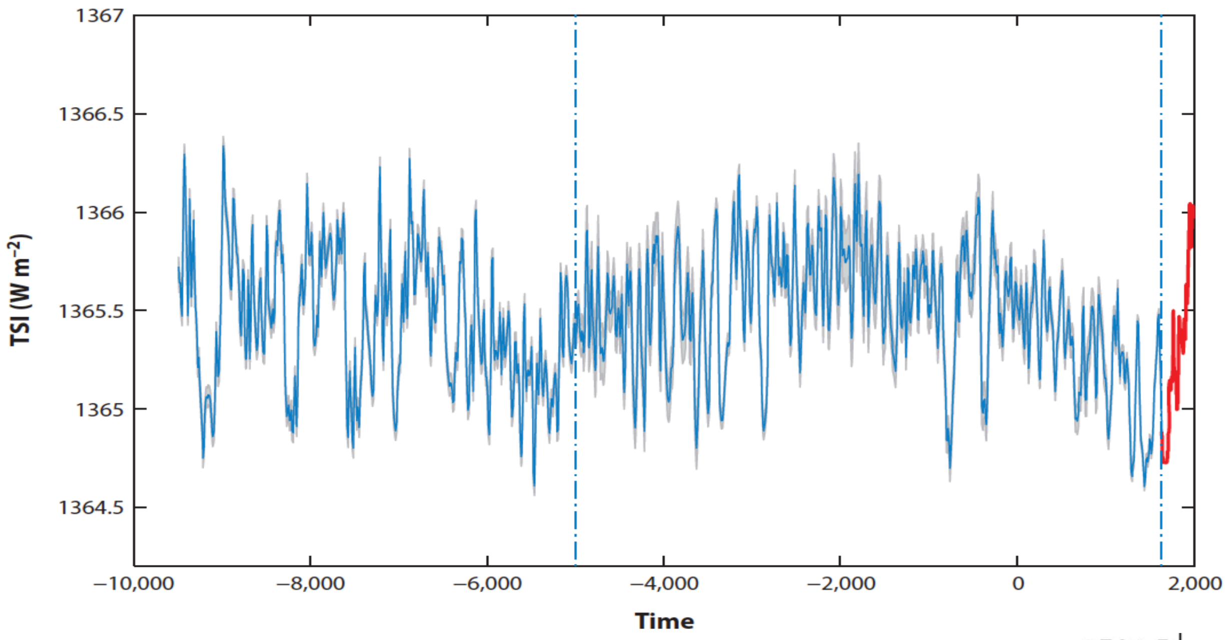
Global mean annual temperature reconstruction (PAGES 2k Consortium 2019; AR6 IPCC, 2021).



Properties of 210 proxies used in the global temperature reconstruction (from Anchukaitis & Smerdon, 2022).

Tree-ring proxy of solar activity

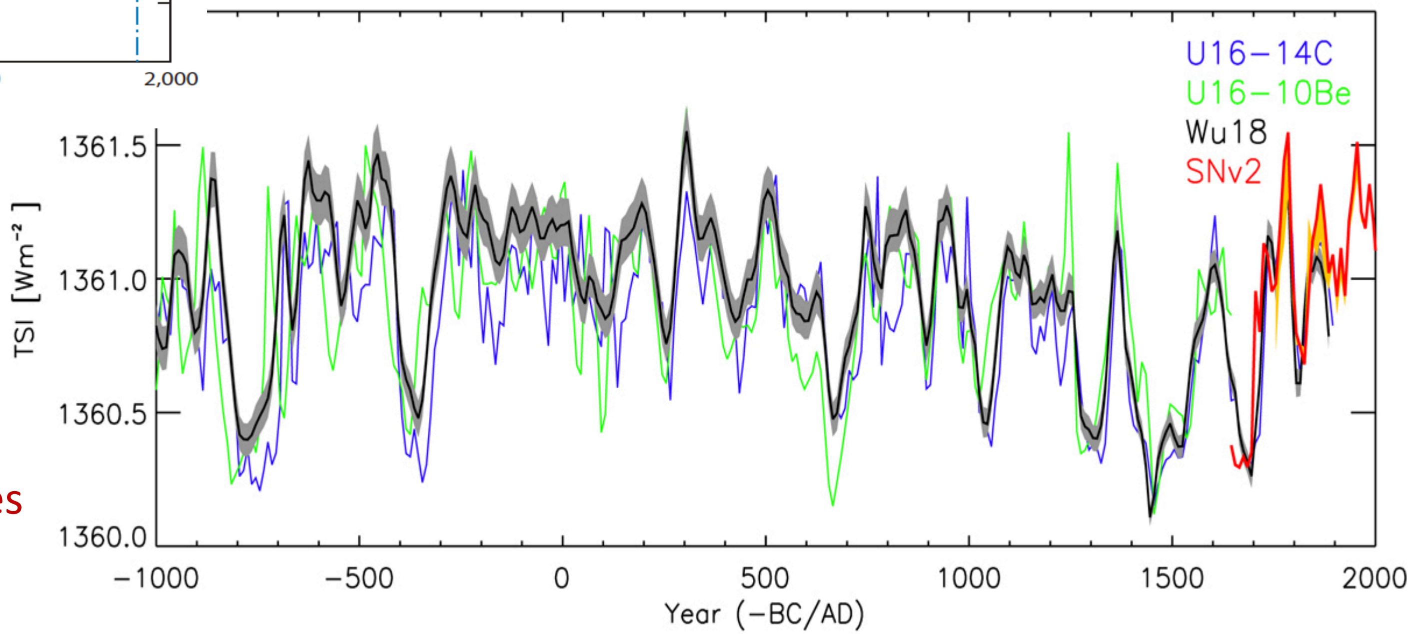
Reconstruction of solar irradiance



- Tree-ring ^{14}C

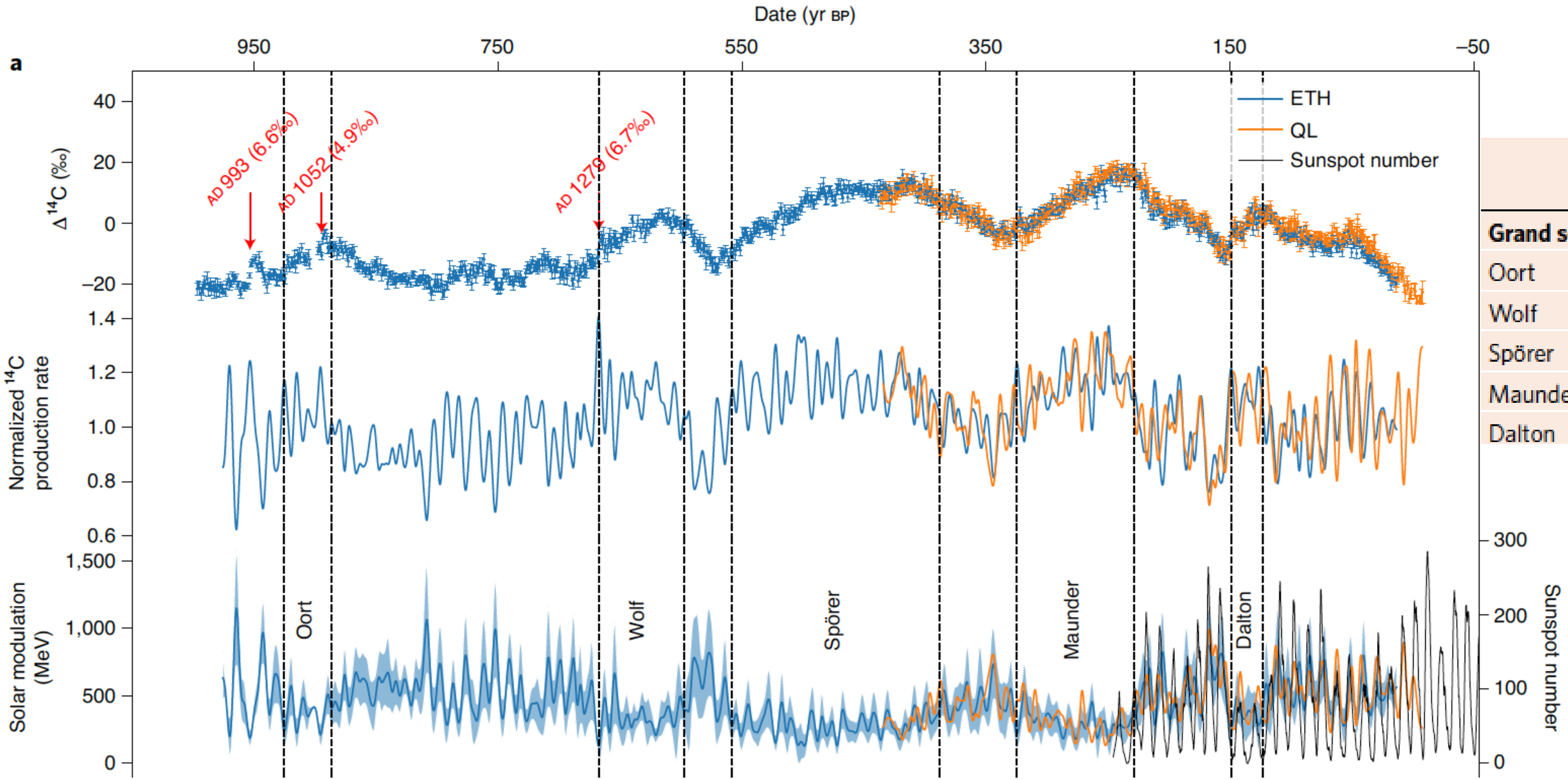
3000-year reconstruction of total solar irradiance from ^{16}U-^{14}C (blue), ^{16}U-^{10}Be (green) and their composite (black). Wu et al. 2013.

Near 10,000-year reconstruction of total solar irradiance (blue) from ^{14}C tree rings using the SATIRE-M (red). Solanki et al 2013.



Data Source: International ^{14}C calibration curves

1,000-year annual record of atmospheric ^{14}C concentration

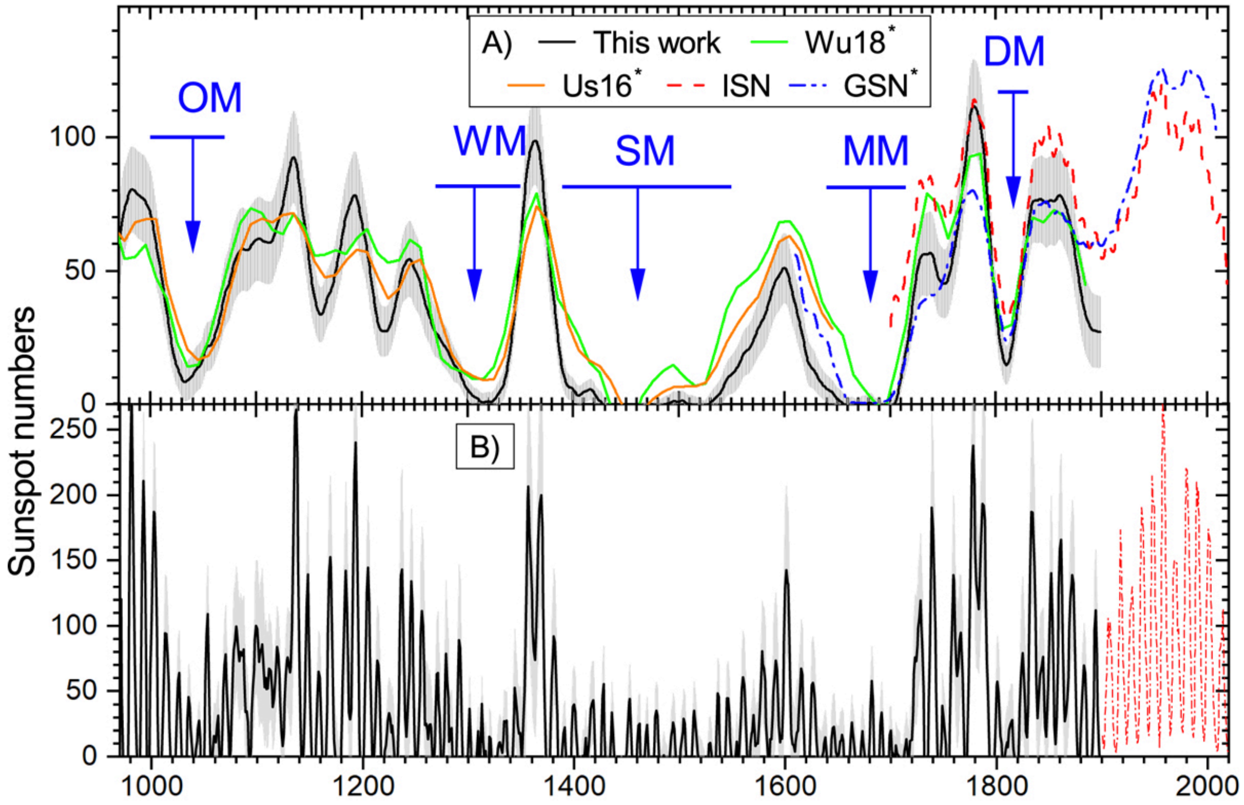


	Time period	*Φ* (MeV)
Grand solar minima		
Oort	AD 1021–1060	390 ± 25
Wolf	AD 1279–1349	350 ± 45
Spörer	AD 1388–1558	290 ± 45
Maunder	AD 1621–1718	300 ± 50
Dalton	AD 1797–1823	370 ± 10

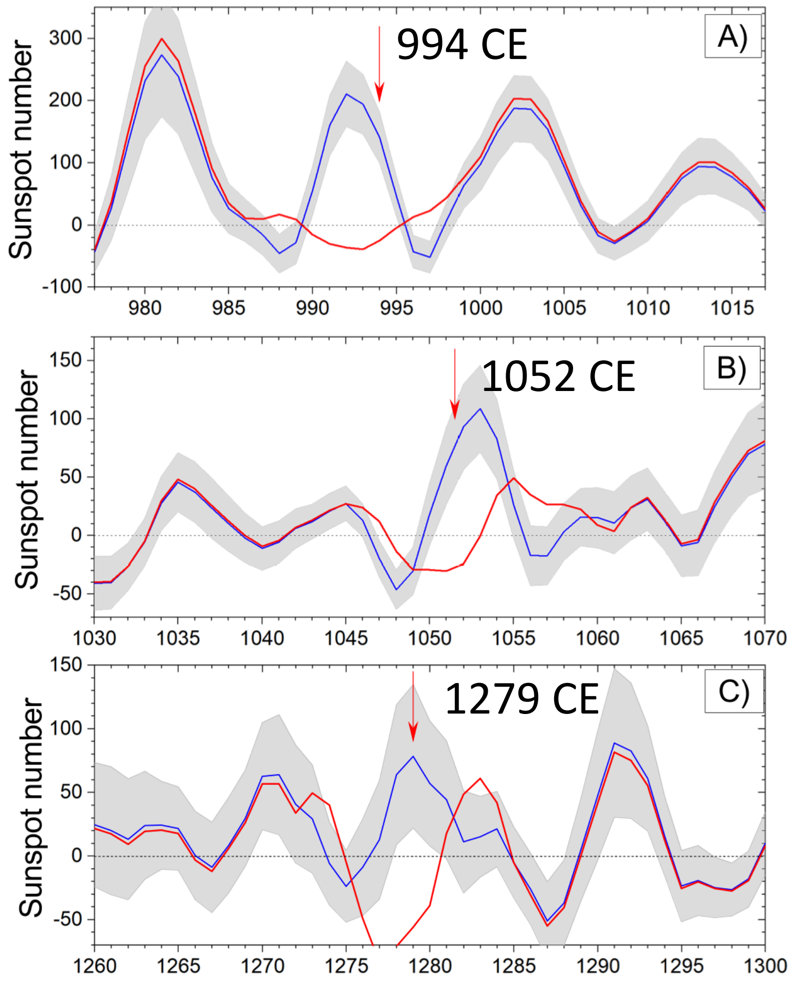
From annual $\Delta^{14}C$ records to reconstruction of solar magnetic field
(Brehm et al. 2021).

Reconstruction of sunspot numbers

- Tree-ring ^{14}C



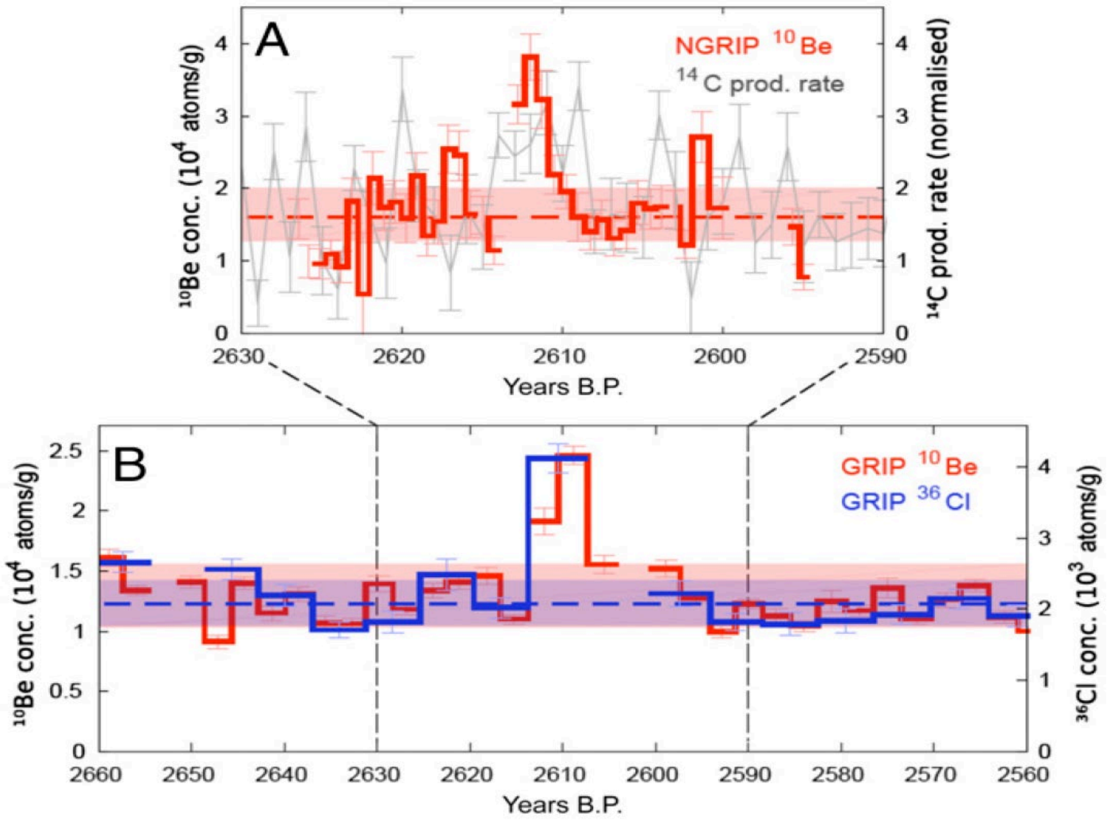
New 1000-year solar activity reconstruction from __annually__ resolved ^{14}C tree-ring record. Usoskin et al 2021.



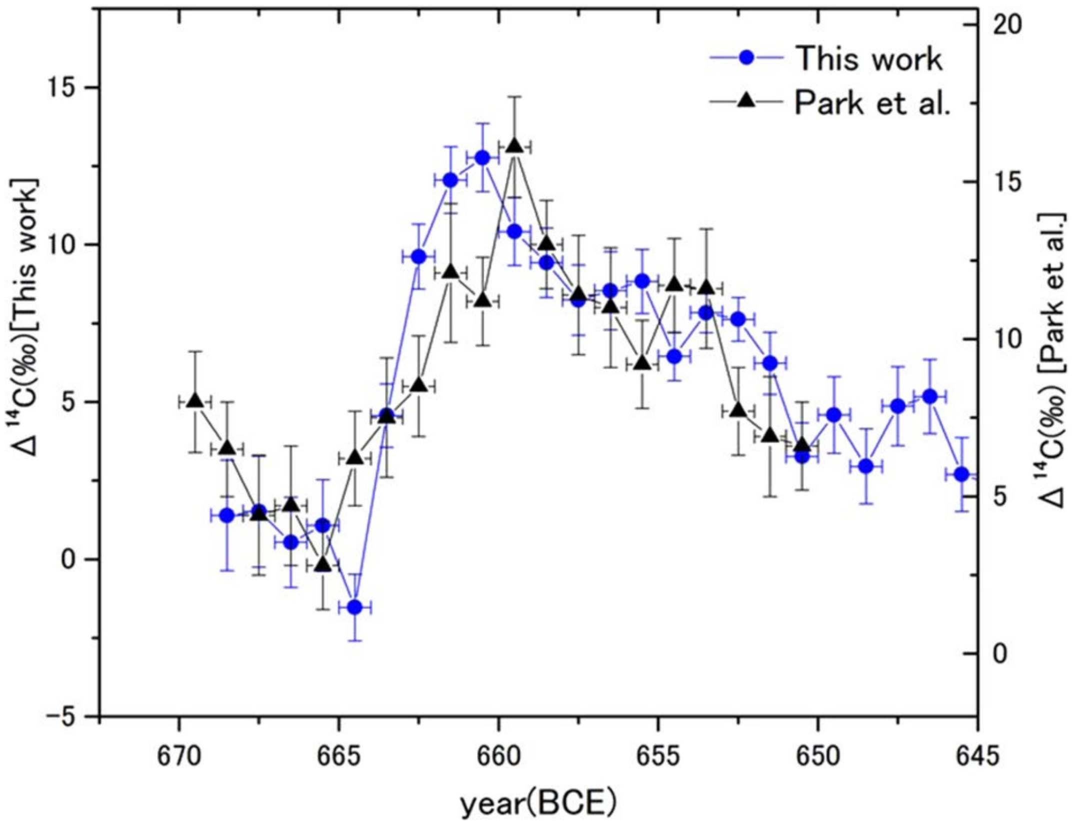
Corrected (Blue) reconstruction of sunspot numbers. Red- before the correction. Usoskin et al. 2021.

Near 660 BCE ^{14}C spike

*Park et al. 2017 reports a rapid Δ ^{14}C increase ~13‰ over six years **near** 660 BCE measured on annual time series of ^{14}C from German oak.*

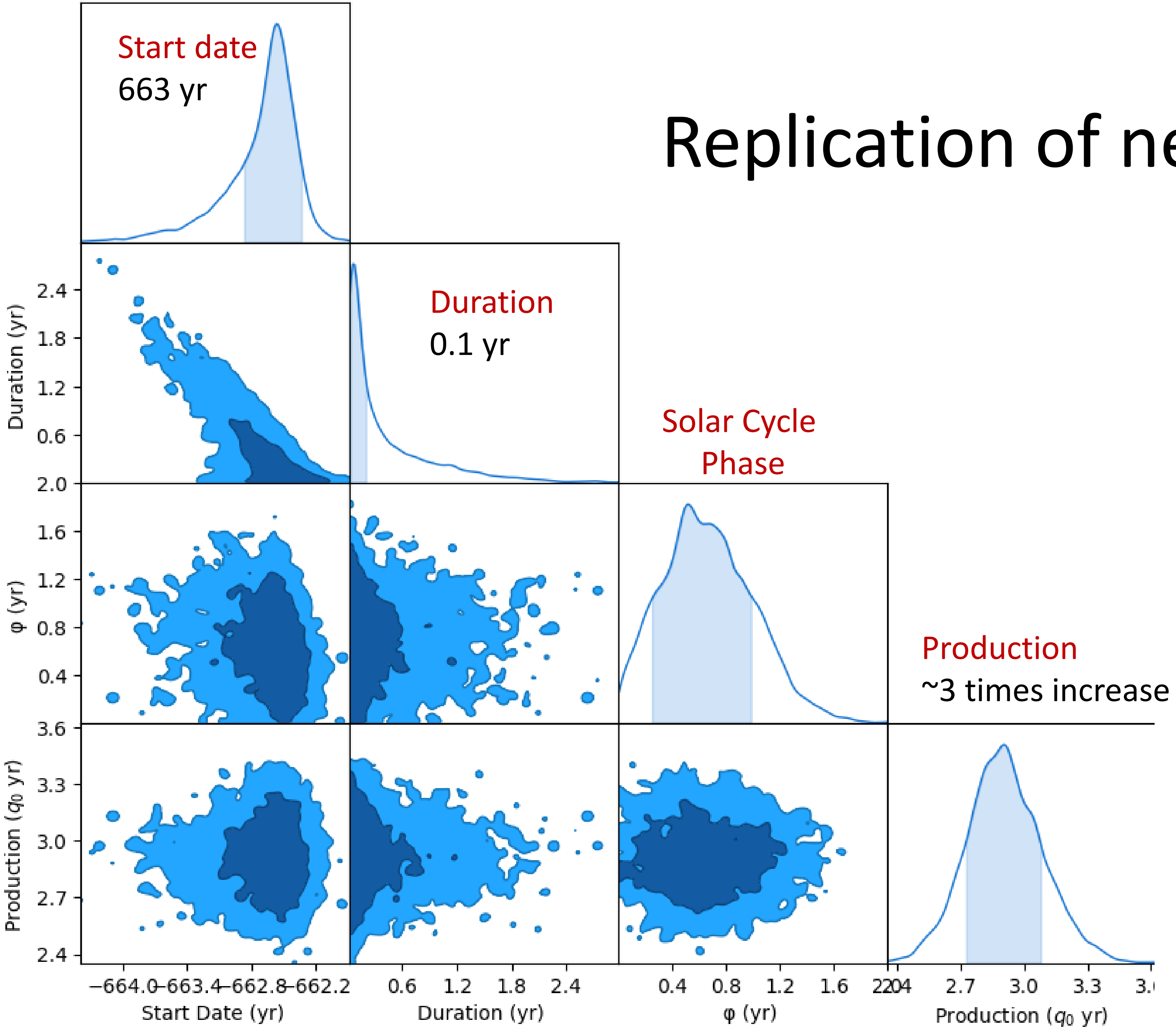


^{10}Be (red) and ^{36}Cl (blue) series from two Greenland ice cores ~660 BCE (O'Hare et al. 2019). 3-4 factor concentration peaks.



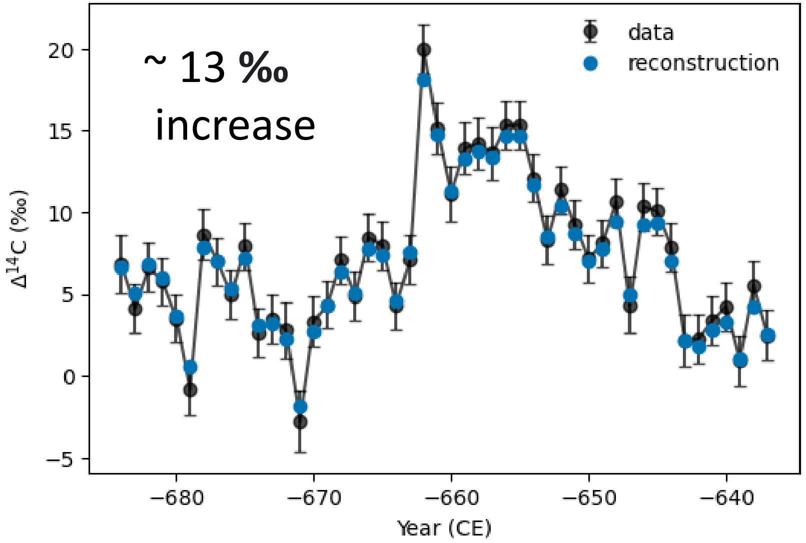
Signature of ***Δ*** ^{14}C **~**660 BCE, Sakurai et al. 2020. Replication of the spike in Japanese cedar.

Replication of near 660 BCE spike



Surface distributions of modeled posterior probability of spike parameters calculated with Carbon Box -13 model.

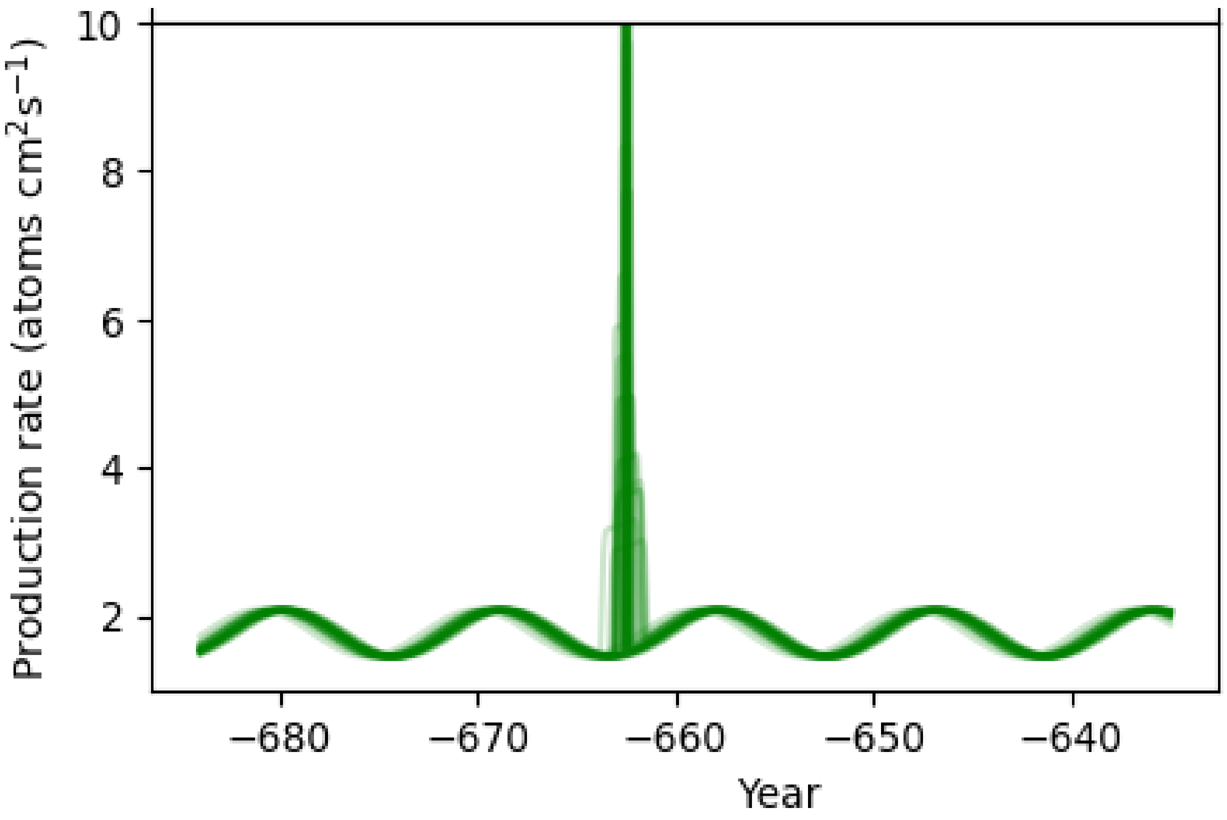
Altai larch tree rings



Measured and simulated ^{14}C delta.

Note: Astronomical year -662 is Calendar year 663 BCE.

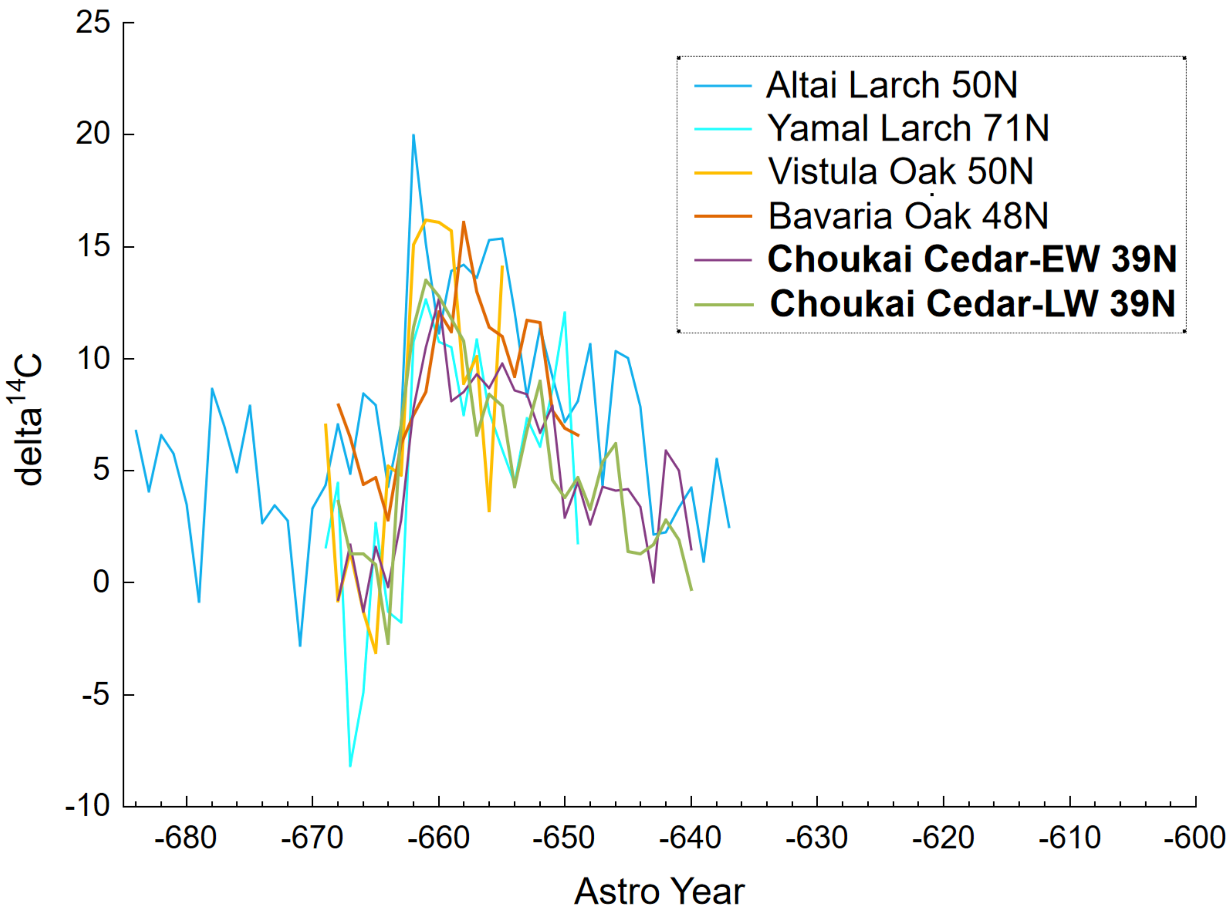
Amplitude of 663 BCE spike from Altai tree rings



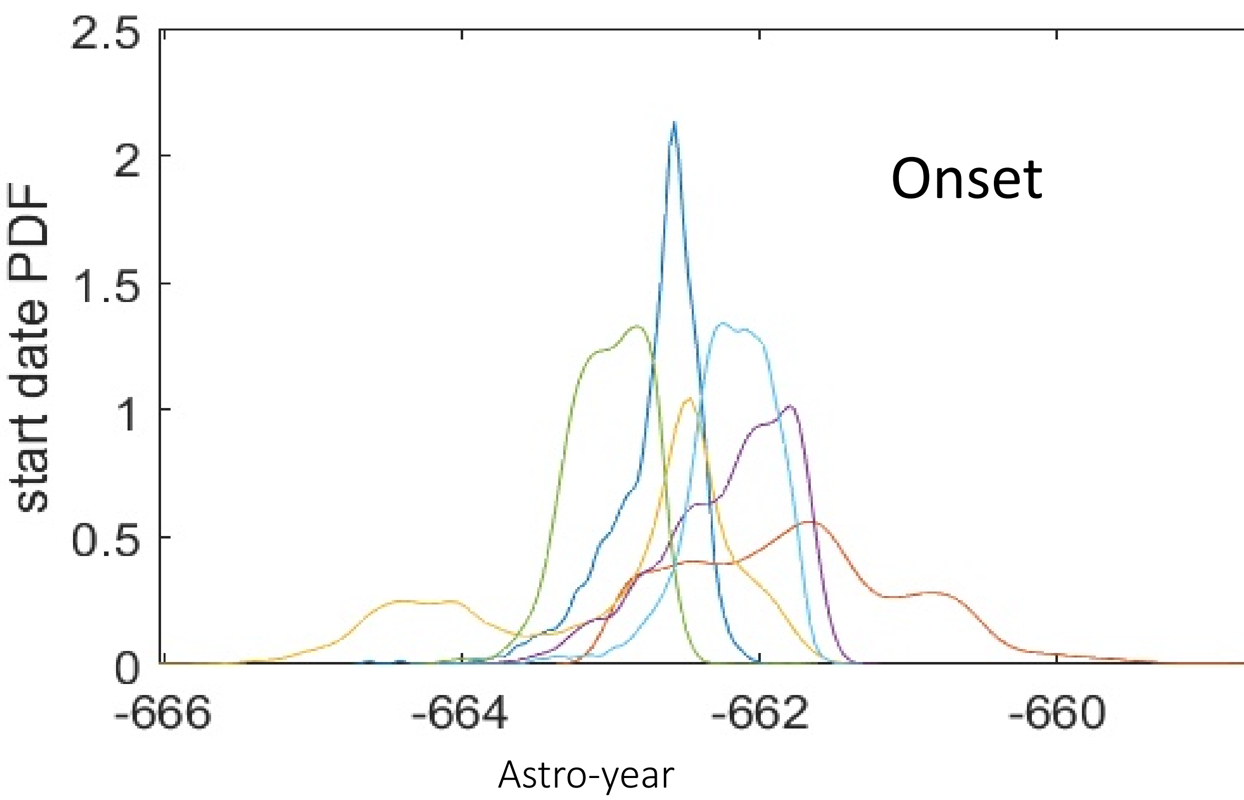
Global average
2 atoms cm^2/s

^{14}C production rate calculated with parametric fitting of 11-box carbon model.

Further replication of 663 BCE spike

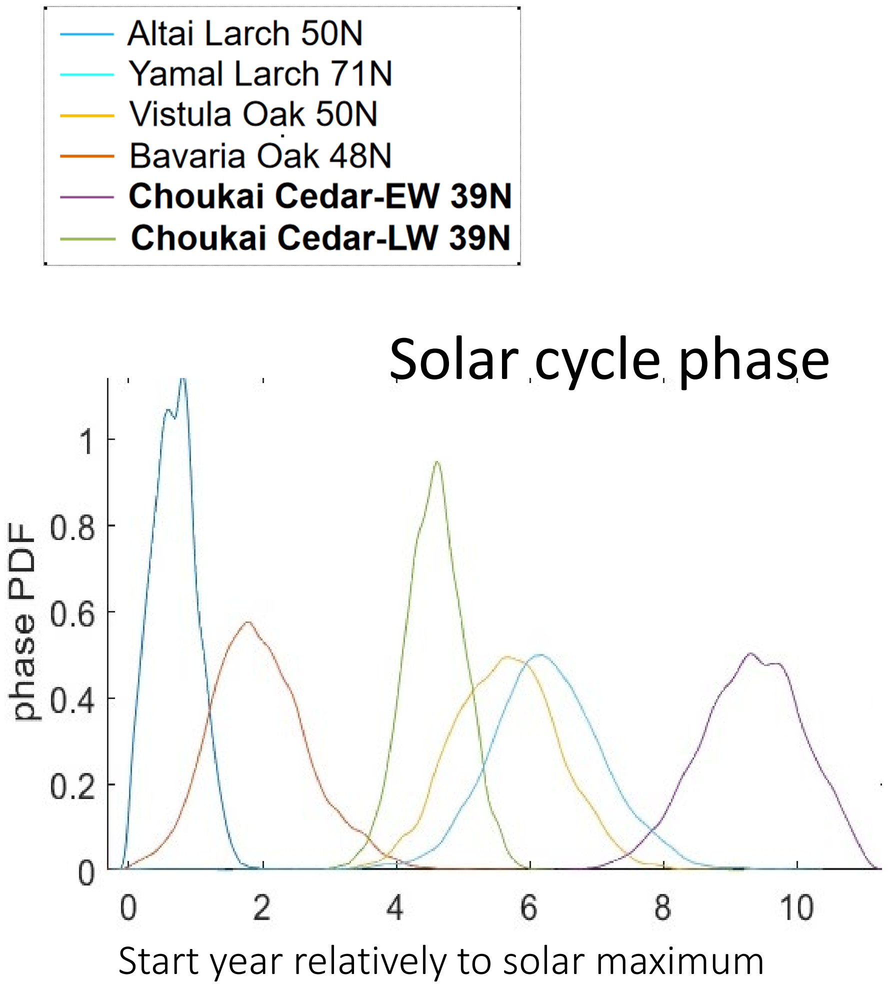


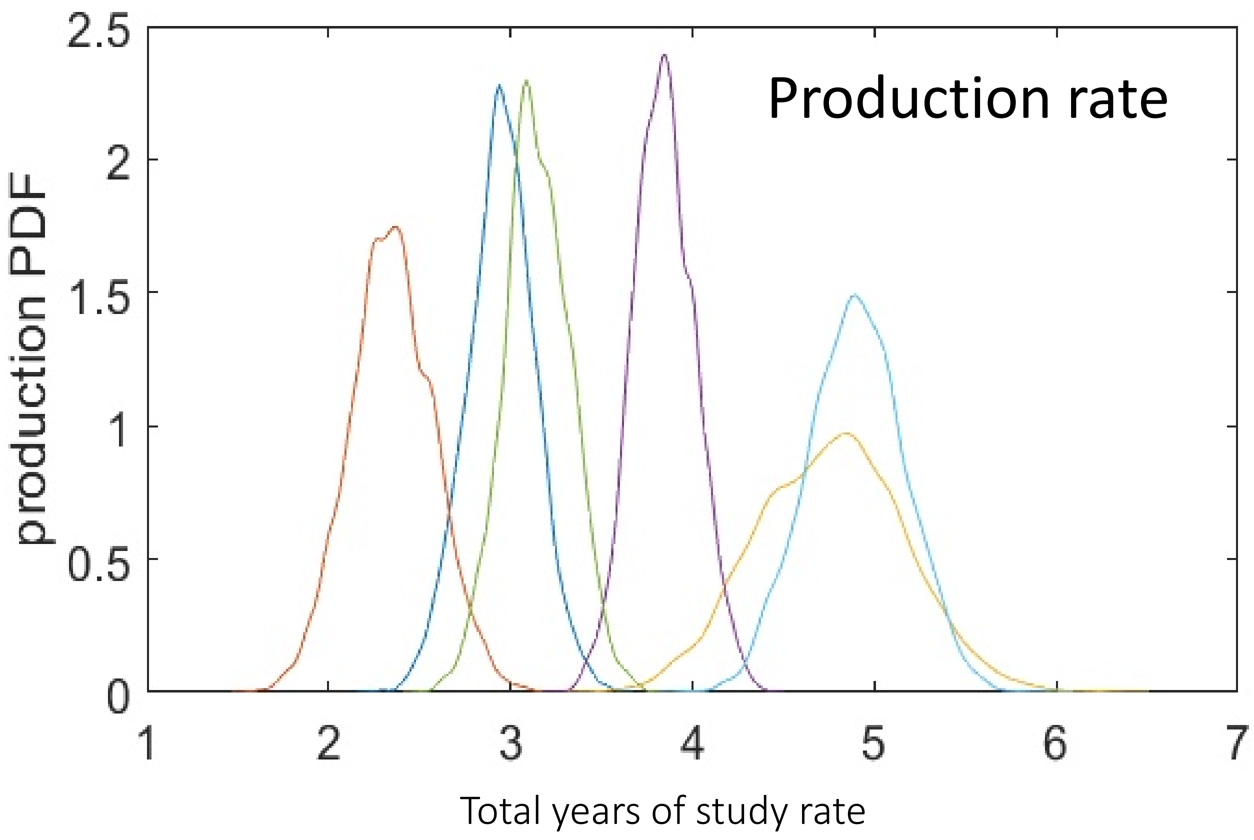
^{14}C content of tree rings from 5 locations (NHZ1 and NHZ3).



Radiocarbon production rate modeled with 13-box carbon model as described in Buntgen et al 2018.

Range of 663 BCE ^{14}C-spike parameters

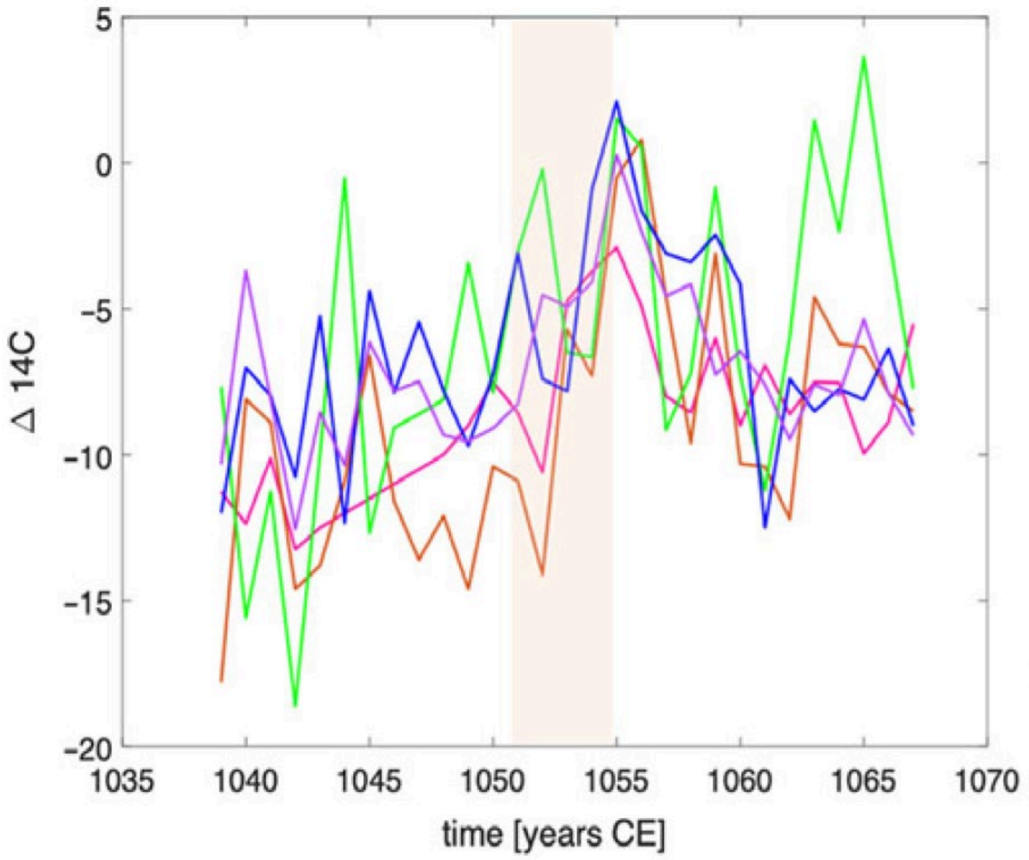




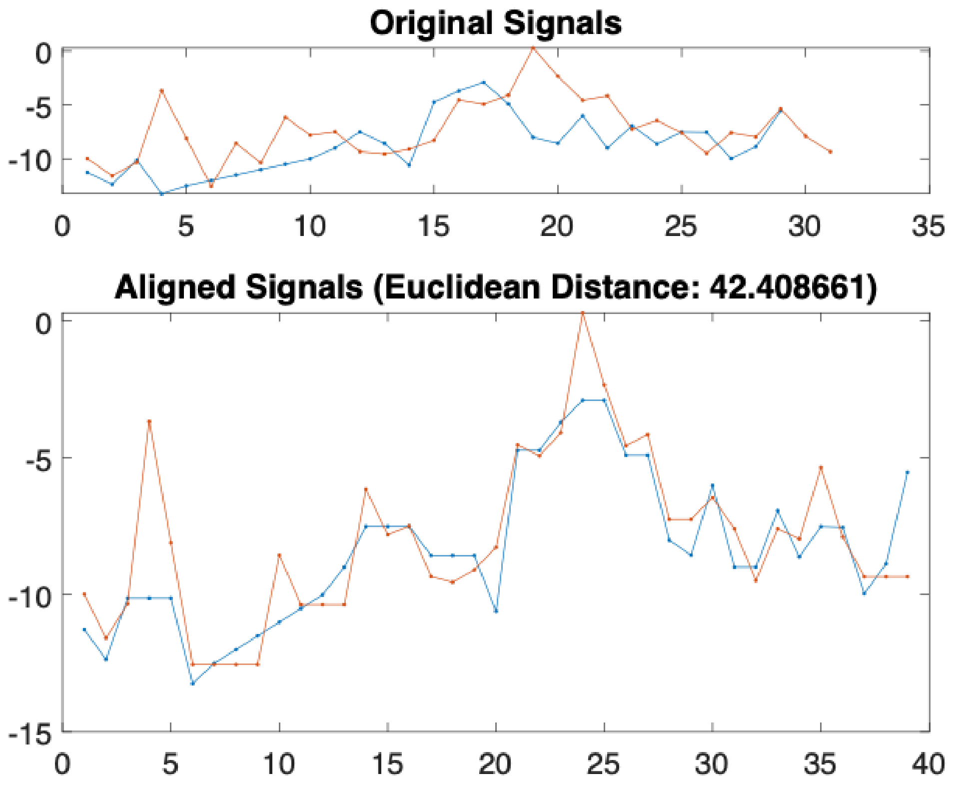
Posterior probability distribution for the ^{14}C production rate of 5 tree-ring series.

Scaling the spike signal with Dynamic Time Warping

1052 CE or 1054 CE?



1052-55 CE fingerprint of 1054CE spike in radiocarbon of tree rings from CA sequoia (blue-brown), Finnish pine (magenta), English oak (green).



Blue: English Oak (ETHZ)
Red: LW Sequoia (ICER)

Elastic matching of the signals with DTW, Panyushkina et al 2022.

Final remarks

- ^{14}C spike research has ignited the development of long annually-resolved ^{14}C measurements from tree rings.
- Common Era delta ^{14}C high- resolution datasets are already available for modeling solar activity.
- Continuous long-term/annual delta-^{14}C data is in high demand, BUT our efforts must be coordinated to address the spatial and temporal biases in tree-ring availability, seasonality.
- There is no need to wait for the next version of the IntCal radiocarbon curve to be released in 6-8 years from 2023 to experiment with high-resolution and long-term reconstructions of sunspots and total solar irradiance.

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14C variations cand changes in global carbon cycle

From 1980s: box-diffusion model for the carbon cycle is used to estimate the magnitude of 14C variations caused by changes of reservoir sizes and exchange fluxes in the
global carbon system. The influence of changes in atmospheric CO2 concentration, biomass, CO2 exchange rate between atmosphere and ocean, and ocean mixing is considered

Significant variations of reservoir parameters can be expected
during periods of major climatic change.

build-up of biosphere in Anthropocene