Supplementary Information

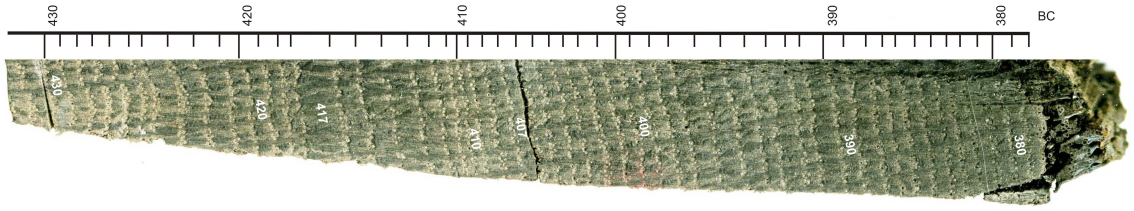

Fig. S1. Wood Specimen. Subfossil oak (*Quercus* sp.) Sample 2, radius 2 from which our data series was derived. From the Elbe River, between river km 470 and 520, Germany. Dendro archive of Curt-Engelhorn-Zentrum Archäometrie (CEZA) Mannheim, Germany.

Table S1: New ^{14}C Data

^{14}C results on α-cellulose extracted from individual oak (*Quercus sp.*) tree rings.

Year (BCE)	Year (cal BP)	Lab Ref. (GrM-)	^{14}C Age		$\Delta^{14}C$		$\delta^{13}C$ (‰, VPDB)
			^{14}C yr BP	±	‰	±	
426	2375	19961	2437	21	-16.0	2.6	-23.79
422	2371	19963	2419	21	-14.2	2.6	-23.33
418	2367	19966	2448	20	-18.3	2.5	-24.76
414	2363	20099	2453	21	-19.3	2.6	-24.78
413	2362	19968	2428	20	-16.4	2.5	-26.33
413	2362	19967	2448	20	-18.8	2.5	-26.36
412	2361	19969	2414	20	-14.8	2.5	-25.95
411	2360	19970	2425	21	-16.3	2.6	-25.45
410	2359	19971	2414	20	-15.0	2.5	-25.37
409	2358	19972	2413	20	-15.0	2.5	-25.40
408	2357	19974	2392	20	-12.6	2.5	-
408	2357	19973	2385	20	-11.7	2.5	-24.74
407	2356	19975	2436	23	-18.1	2.8	-24.62
406	2355	20100	2386	21	-12.1	2.6	-24.27
405	2354	20101	2385	20	-12.1	2.5	-24.57
404	2353	20102	2365	20	-9.7	2.5	-24.43
403	2352	20104	2393	20	-13.3	2.5	-24.27
402	2351	20106	2381	20	-11.9	2.5	-24.57
402	2351	20105	2368	21	-10.3	2.6	-24.47
401	2350	20107	2378	21	-11.7	2.6	-24.26
400	2349	20109	2390	20	-13.3	2.5	-24.46
399	2348	20112	2361	21	-9.8	2.6	-24.51
398	2347	20113	2404	20	-15.2	2.5	-23.54
397	2346	20115	2352	21	-9.0	2.6	-23.38
397	2346	20114	2374	21	-11.7	2.6	-25.10
396	2345	20116	2345	21	-8.2	2.6	-24.36
395	2344	20117	2368	21	-11.2	2.6	-25.44
394	2343	20118	2356	21	-9.8	2.6	-24.71
390	2339	20119	2316	20	-5.4	2.5	-24.78
386	2335	20120	2327	22	-7.2	2.7	-24.95
382	2331	20121	2314	21	-6.1	2.6	-25.27
375	2324	25524	2316	20	-7.2	2.4	-24.36
373	2322	25525	2294	20	-4.7	2.4	-24.24
371	2320	25526	2280	20	-3.2	2.4	-24.33
367	2316	25527	2250	20	0.1	2.5	-24.17
365	2314	25698	2268	20	-2.4	2.4	-24.25
363	2312	25699	2246	19	0.1	2.4	-24.25

361	2310	25528	2232	20	1.6	2.4	-24.72
359	2308	25529	2226	20	2.1	2.4	-24.83
357	2306	25700	2242	20	-0.2	2.4	-24.41
355	2304	25530	2248	20	-1.1	2.4	-24.58
353	2302	25531	2233	19	0.5	2.4	-24.57
351	2300	25532	2207	20	3.5	2.5	-24.56
349	2298	25533	2200	20	4.1	2.5	-24.26
347	2296	25534	2230	20	0.1	2.4	-24.05
345	2294	25944	2223	20	0.8	2.5	-24.54
343	2292	25945	2223	19	0.5	2.4	-25.77
341	2290	25946	2202	20	2.9	2.4	-25.25
339	2288	25947	2201	20	2.8	2.4	-25.74
337	2286	25951	2214	20	0.9	2.4	-25.07
335	2284	25952	2208	20	1.4	2.5	-24.88
333	2282	25960	2215	20	0.3	2.4	-25.49
333	2282	25953	2202	20	1.9	2.4	-25.35
331	2280	25954	2189	20	3.3	2.5	-25.92
329	2278	25957	2212	19	0.2	2.4	-25.24
327	2276	25958	2221	20	-1.2	2.4	-24.93
325	2274	25959	2211	19	-0.2	2.4	-25.31

Table S2: Weighted Averages of the Duplicates

^{14}C results on α-cellulose extracted from exactly the same tree-ring samples and taken through as full pretreatment duplicates. Shown also are the χ^2-test residuals, as defined by Ward & Wilson (1978), for which the threshold for consistency (95% probability, *df*=1) is 3.84.

Year (BCE)	Year (cal BP)	Lab Ref. (GrM-)	^{14}C Age		$\Delta^{14}C$		*t*-statistic#
			^{14}C yr BP	±	‰	±	
413	2362	19968	2428	20	-16.4	2.5	
		19967	2448	20	-18.8	2.5	
Weighted Average			**2438**	**14**	**-17.6**	**1.8**	**0.46**
408	2357	19974	2392	20	-12.6	2.5	
		19973	2385	20	-11.7	2.5	
Weighted Average			**2389**	**14.1**	**-12.2**	**1.8**	**0.06**
402	2351	20106	2381	20	-11.9	2.5	
		20105	2368	21	-10.3	2.6	
Weighted Average			2375	14.5	**-11.2**	**1.8**	**0.20**
397	2346	20115	2352	21	-9.0	2.6	
		20114	2374	21	-11.7	2.6	
Weighted Average			**2363**	**14.8**	**-10.3**	**1.8**	**0.55**
333	2282	25960	2215	20	0.3	2.4	
		25953	2202	20	1.9	2.4	
Weighted Average			**2209**	**14.1**	**1.1**	**1.7**	**0.21**

Table S3: $\Delta^{14}C$ Data for Main Figures 2 and 3

The new data for 400 BCE and existing IntCal20 data (Reimer *et al*. 2020) over the five recent GSM. The years in which the GSM were defined to start and end (bold horizontal lines below) are specified in Table 1 and Table 2 of the main text.

New Data			Oort			Wolf			Spörer			Maunder			Dalton		
Year (BCE)	$\Delta^{14}C$ (‰)	±	Year (CE)	$\Delta^{14}C$ (‰)	±	Year (CE)	$\Delta^{14}C$ (‰)	±	Year (CE)	$\Delta^{14}C$ (‰)	±	Year (CE)	$\Delta^{14}C$ (‰)	±	Year (CE)	$\Delta^{14}C$ (‰)	±
-433	-16.2	2.4	990	-19.4	1.2	1270	-13.2	1.3	1390	-8.8	1.3	1640	1.8	1.2	1797	-5.0	1.2
426	-16.0	2.6	991	-18.9	1.2	1271	-12.9	1.3	1391	-8.3	1.3	1641	2.2	1.2	1798	-4.0	1.2
423	-14.3	1.6	992	-18.0	1.2	1272	-12.7	1.3	1392	-7.8	1.3	1642	2.6	1.2	1799	-3.3	1.2
422	-14.3	1.6	993	-16.8	1.2	1273	-12.4	1.3	1393	-7.2	1.3	1643	3.0	1.2	1800	-2.7	1.2
418	-14.1	1.6	994	-15.4	1.2	1274	-12.1	1.3	1394	-6.7	1.3	1644	3.3	1.2	1801	-2.3	1.2
414	-19.3	2.6	995	-14.2	1.2	1275	-11.7	1.3	1395	-6.1	1.3	1645	3.6	1.2	1802	-2.1	1.2
413	-17.6	1.8	996	-13.3	1.2	1276	-11.1	1.3	1396	-5.6	1.3	1646	3.9	1.2	1803	-2.0	1.2
412	-14.8	2.5	997	-12.8	1.2	1277	-10.5	1.3	1397	-5.1	1.3	1647	4.2	1.2	1804	-1.9	1.2
411	-16.3	2.6	998	-12.6	1.2	1278	-9.8	1.4	1398	-4.7	1.3	1648	4.5	1.2	1805	-1.8	1.2
410	-15.0	2.5	999	-12.7	1.2	1279	-9.0	1.4	1399	-4.4	1.3	1649	4.7	1.2	1806	-1.6	1.2
409	-15.0	2.5	1000	-13.0	1.2	1280	-8.3	1.4	1400	-4.1	1.3	1650	4.9	1.2	1807	-1.3	1.2
408	-12.2	1.8	1001	-13.4	1.2	1281	-7.7	1.4	1401	-4.0	1.3	1651	5.1	1.2	1808	-0.8	1.2
407	-18.1	2.8	1002	-13.8	1.2	1282	-7.2	1.4	1402	-3.9	1.3	1652	5.2	1.2	1809	-0.3	1.2
406	-12.1	2.6	1003	-14.3	1.2	1283	-6.8	1.4	1403	-3.7	1.3	1653	5.2	1.2	1810	0.4	1.2
405	-12.1	2.5	1004	-14.9	1.3	1284	-6.5	1.4	1404	-3.4	1.3	1654	5.3	1.2	1811	1.1	1.2
404	-9.7	2.5	1005	-15.5	1.3	1285	-6.2	1.4	1405	-3.1	1.3	1655	5.4	1.2	1812	1.6	1.2
403	-13.3	2.5	1006	-16.0	1.3	1286	-6.0	1.4	1406	-2.7	1.3	1656	5.5	1.2	1813	2.1	1.2
402	-11.2	1.8	1007	-16.5	1.3	1287	-5.9	1.4	1407	-2.3	1.3	1657	5.7	1.2	1814	2.4	1.2
401	-11.7	2.6	1008	-16.8	1.3	1288	-5.7	1.4	1408	-1.9	1.3	1658	5.9	1.2	1815	2.7	1.2
400	-13.3	2.5	1009	-17.0	1.3	1289	-5.6	1.4	1409	-1.6	1.3	1659	6.2	1.2	1816	2.8	1.2
399	-9.8	2.6	1010	-17.0	1.3	1290	-5.5	1.4	1410	-1.2	1.3	1660	6.6	1.2	1817	2.9	1.2
398	-15.2	2.5	1011	-17.0	1.2	1291	-5.5	1.4	1411	-1.0	1.3	1661	7.0	1.2	1818	2.9	1.2
397	-10.3	1.8	1012	-17.0	1.2	1292	-5.4	1.4	1412	-0.8	1.3	1662	7.3	1.2	1819	2.9	1.2
396	-8.2	2.6	1013	-16.9	1.2	1293	-5.3	1.3	1413	-0.7	1.2	1663	7.7	1.2	1820	2.7	1.2
395	-11.2	2.6	1014	-17.0	1.2	1294	-5.3	1.3	1414	-0.7	1.2	1664	8.0	1.2	1821	2.6	1.2
394	-9.8	2.6	1015	-17.0	1.2	1295	-5.1	1.3	1415	-0.8	1.2	1665	8.4	1.2	1822	2.5	1.2
390	-5.4	2.5	1016	-17.0	1.2	1296	-4.9	1.3	1416	-0.9	1.2	1666	8.8	1.2	1823	2.5	1.2
386	-7.2	2.7	1017	-17.0	1.2	1297	-4.6	1.3	1417	-1.0	1.2	1667	9.2	1.2	1824	2.5	1.2
382	-6.1	2.6	1018	-16.9	1.2	1298	-4.2	1.3	1418	-1.0	1.2	1668	9.7	1.2	1825	2.7	1.2
375	-7.2	2.4	1019	-16.6	1.2	1299	-3.8	1.3	1419	-1.0	1.2	1669	10.2	1.2	1826	2.8	1.2
373	-4.7	2.4	1020	-16.2	1.2	1300	-3.4	1.3	1420	-0.8	1.3	1670	10.7	1.2	1827	2.9	1.2
371	-3.2	2.4	1021	-15.7	1.2	1301	-2.9	1.3	1421	-0.5	1.3	1671	11.1	1.2	1828	2.9	1.2
367	0.1	2.5	1022	-15.2	1.2	1302	-2.5	1.3	1422	-0.1	1.3	1672	11.4	1.2			

365	-2.4	2.4	1023	-14.6	1.2	1303	-2.1	1.3	1423	0.3	1.3	1673	11.5	1.2
363	0.1	2.4	1024	-14.1	1.2	1304	-1.7	1.3	1424	0.8	1.3	1674	11.5	1.2
361	1.6	2.4	1025	-13.7	1.2	1305	-1.3	1.3	1425	1.3	1.3	1675	11.4	1.2
359	2.1	2.4	1026	-13.3	1.2	1306	-0.9	1.3	1426	1.6	1.3	1676	11.3	1.2
357	-0.2	2.4	1027	-13.0	1.3	1307	-0.7	1.3	1427	1.9	1.3	1677	11.2	1.2
355	-1.1	2.4	1028	-12.7	1.2	1308	-0.5	1.3	1428	2.0	1.3	1678	11.2	1.2
353	0.5	2.4	1029	-12.4	1.2	1309	-0.5	1.3	1429	2.0	1.3	1679	11.3	1.2
351	3.5	2.5	1030	-12.1	1.2	1310	-0.5	1.3	1430	2.0	1.3	1680	11.4	1.2
349	4.1	2.5	1031	-11.7	1.2	1311	-0.5	1.3	1431	2.0	1.3	1681	11.6	1.2
347	0.1	2.4	1032	-11.4	1.2	1312	-0.6	1.3	1432	2.1	1.3	1682	11.9	1.2
345	0.8	2.5	1033	-11.0	1.2	1313	-0.8	1.3	1433	2.3	1.2	1683	12.1	1.2
343	0.5	2.4	1034	-10.6	1.2	1314	-0.9	1.3	1434	2.5	1.2	1684	12.4	1.2
341	2.9	2.4	1035	-10.3	1.2	1315	-1.0	1.3	1435	2.7	1.2	1685	12.7	1.2
339	2.8	2.4	1036	-10.0	1.2	1316	-1.1	1.3	1436	3.1	1.2	1686	13.0	1.2
337	0.9	2.4	1037	-9.7	1.2	1317	-1.2	1.3	1437	3.4	1.2	1687	13.2	1.2
335	1.4	2.5	1038	-9.5	1.2	1318	-1.1	1.3	1438	3.7	1.2	1688	13.5	1.2
333	1.1	1.7	1039	-9.3	1.2	1319	-1.0	1.3	1439	3.9	1.2	1689	13.8	1.2
331	3.3	2.5	1040	-9.2	1.3	1320	-0.7	1.3	1440	4.1	1.2	1690	14.0	1.2
329	0.2	2.4	1041	-9.1	1.3	1321	-0.4	1.2	1441	4.3	1.2	1691	14.3	1.2
327	-1.2	2.4	1042	-9.1	1.3	1322	0.0	1.2	1442	4.6	1.2	1692	14.5	1.2
325	-0.2	2.4	1043	-9.1	1.3	1323	0.4	1.2	1443	4.9	1.2	1693	14.8	1.2
			1044	-9.1	1.3	1324	0.8	1.2	1444	5.2	1.2	1694	15.1	1.2
			1045	-9.0	1.3	1325	1.3	1.2	1445	5.5	1.2	1695	15.4	1.2
			1046	-8.9	1.3	1326	1.8	1.2	1446	5.8	1.2	1696	15.7	1.2
			1047	-8.7	1.3	1327	2.2	1.2	1447	6.2	1.2	1697	16.1	1.2
			1048	-8.4	1.3	1328	2.5	1.2	1448	6.6	1.2	1698	16.3	1.2
			1049	-8.1	1.3	1329	2.7	1.2	1449	6.9	1.2	1699	16.6	1.2
			1050	-7.6	1.3	1330	2.8	1.2	1450	7.0	1.2	1700	16.7	1.2
			1051	-7.1	1.2	1331	2.7	1.2	1451	7.2	1.2	1701	16.8	1.2
			1052	-6.6	1.2	1332	2.6	1.2	1452	7.3	1.2	1702	16.8	1.2
			1053	-6.1	1.2	1333	2.3	1.2	1453	7.5	1.2	1703	16.6	1.2
			1054	-5.8	1.2	1334	2.0	1.2	1454	7.8	1.2	1704	16.5	1.2
			1055	-5.6	1.2	1335	1.8	1.2	1455	8.1	1.2	1705	16.3	1.2
			1056	-5.6	1.3	1336	1.5	1.2	1456	8.6	1.2	1706	16.1	1.2
			1057	-5.9	1.2	1337	1.2	1.3	1457	9.1	1.2	1707	16.1	1.2
			1058	-6.2	1.3	1338	1.0	1.3	1458	9.6	1.2	1708	16.1	1.2

1059	-6.5	1.3	1339	0.8	1.3	1459	10.0	1.2	1709	16.2	1.2
1060	-6.8	1.3	1340	0.7	1.3	1460	10.3	1.2	1710	16.3	1.2
1061	-7.1	1.3	1341	0.6	1.3	1461	10.5	1.2	1711	16.5	1.2
1062	-7.3	1.3	1342	0.5	1.3	1462	10.4	1.2	1712	16.5	1.2
1063	-7.5	1.3	1343	0.3	1.2	1463	10.1	1.2	1713	16.6	1.2
1064	-7.6	1.3	1344	0.2	1.3	1464	9.9	1.2	1714	16.6	1.2
1065	-7.7	1.3	1345	0.0	1.3	1465	9.6	1.2	1715	16.6	1.2
1066	-7.8	1.3	1346	-0.2	1.3	1466	9.5	1.2	1716	16.5	1.2
1067	-7.9	1.3	1347	-0.4	1.3	1467	9.4	1.2	1717	16.2	1.2
1068	-7.9	1.3	1348	-0.6	1.3	1468	9.5	1.2	1718	15.8	1.2
1069	-8.0	1.3	1349	-0.7	1.3	1469	9.5	1.2	1719	15.2	1.2
1070	-8.2	1.3	1350	-0.9	1.3	1470	9.4	1.2	1720	14.6	1.2
						1471	9.3	1.2			
						1472	9.3	1.2			
						1473	9.4	1.2			
						1474	9.6	1.2			
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						1484	10.6	1.2			
						1485	10.4	1.2			
						1486	10.3	1.2			
						1487	10.3	1.2			
						1488	10.2	1.2			
						1489	10.2	1.2			
						1490	10.2	1.2			
						1491	10.3	1.2			
						1492	10.3	1.2			
						1493	10.4	1.2			
						1494	10.4	1.2			

1495	10.5	1.2
1496	10.5	1.2
1497	10.5	1.2
1498	10.4	1.2
1499	10.4	1.2
1500	10.3	1.2
1501	10.2	1.2
1502	10.2	1.2
1503	10.2	1.2
1504	10.2	1.2
1505	10.1	1.2
1506	10.1	1.2
1507	10.2	1.2
1508	10.2	1.2
1509	10.3	1.2
1510	10.4	1.2
1511	10.4	1.2
1512	10.5	1.2
1513	10.5	1.2
1514	10.4	1.2
1515	10.2	1.2
1516	10.1	1.2
1517	10.0	1.2
1518	10.0	1.2
1519	10.0	1.2
1520	10.2	1.2
1521	10.4	1.2
1522	10.6	1.2
1523	10.9	1.2
1524	11.2	1.2
1525	11.5	1.2
1526	11.9	1.2
1527	12.3	1.2
1528	12.6	1.2
1529	12.9	1.2
1530	13.1	1.2

			1531	13.3	1.2		
			1532	13.4	1.2		
			1533	13.4	1.2		
			1534	13.3	1.2		
			1535	13.1	1.2		
			1536	12.8	1.2		
			1537	12.4	1.2		
			1538	12.0	1.2		
			1539	11.7	1.2		
			1540	11.3	1.2		
			1541	11.0	1.2		
			1542	10.8	1.2		
			1543	10.6	1.2		
			1544	10.5	1.2		
			1545	10.5	1.2		
			1546	10.6	1.2		
			1547	10.6	1.2		
			1548	10.5	1.2		
			1549	10.3	1.2		
			1550	10.0	1.2		

Table S4. Specifications for ticktack Analysis of New $\Delta^{14}C$ Data

Fitting approach	SingleFitter	
Carbon box-model	Brehm21	
Production model	simple_sinusoid	
Starting parameters	Burn-in	700
	Production	1500
	Rise start lower bound	424 BCE
	Rise start upper bound	404 BCE
	Duration limits	70 to 95 years
	Solar Cycle Phase (phi)	0 to 11 years
	^{14}C Production (Area)	-2 to 24 atoms cm^{-2}

Tables S5 & S6: $\Delta^{14}C$ Data from IntCal20 (Reimer et al. 2020) for 8.2 ka Event and Younger Dryas (Main Figure 3)

Table S5: 8.2 ka Event

Rise in $\Delta^{14}C$ starts in 6726 BCE

Year (BCE)	$\Delta^{14}C$	±
6276	68.0	3.1
6271	68.4	2.8
6266	69.0	2.8
6261	69.4	3.0
6256	69.5	2.9
6251	69.6	2.8
6246	70.0	2.9
6241	71.0	3.1
6236	72.9	3.0
6231	75.3	2.8
6226	77.8	2.8
6221	80.2	2.9
6216	81.9	3.0
6211	82.6	2.9
6206	82.5	2.7

Table S6: Younger Dryas

Start of YD is defined by Reinig *et al*. (2021) to be 12,807 ± 12 cal BP (10,858 BCE); however, rise in $\Delta^{14}C$ does not start for ~37 years. Thus rise taken to start 12,770 cal BP (10,821 BCE)

Year (BCE)	$\Delta^{14}C$	±
10821	205.3	3.1
10816	206.5	3.8
10811	209.4	4.1
10806	212.6	3.9
10801	215.3	3.7

10796	217.6	3.6
10791	219.8	3.6
10786	222.1	3.7
10781	224.6	4.0
10776	227.7	4.0
10771	230.2	3.3
10766	231.2	2.9
10761	231.6	3.0
10756	232.6	3.1
10751	233.3	2.8
10746	233.4	2.8
10741	233.6	2.9
10736	234.4	3.1
10731	235.6	3.1
10726	236.7	3.0
10721	237.6	2.9
10716	238.1	2.7
10711	238.1	2.7

Tables S7 & S8: $\Delta^{14}C$ Data for Peturbations at 5480 BCE and 800 BCE (Main Figure 3)

These data are reproduced in the entirety from Miyake *et al*. (2017) and Jull *et al*. (2018).

Table S7: 5480 BCE Event

Year (BCE)	$\Delta^{14}C$	±
5485	78.3	1.5
5484	82.5	1.9
5483	83.6	1.6
5482	82.0	1.9
5481	84.2	2.0
5480	88.8	1.9
5479	88.8	1.7
5478	90.1	1.8
5477	90.2	1.5
5476	89.9	1.9
5475	94.8	1.7
5474	96.4	2.3
5473	101.2	1.7
5472	99.8	2.3
5471	104.5	2.5
5470	101.3	2.2
5469	98.5	1.8
5468	102.1	2.3
5467	100.2	1.7

Table S8: 800 BCE Event

Year (BCE)	$\Delta^{14}C$	±
814	-6.5	2.5
813	-1.6	2.0
812	-0.9	2.5
811	0.4	1.7
810	-1.4	2.5
809	-0.5	1.8
808	0.5	2.3
807	2.6	1.7
806	4.9	2.3
805	0.3	1.7
804	8.6	2.2
803	4.1	1.7
802	8	2.4
801	-0.1	2.2
800	6.8	3.7
799	5	2.2
798	7.4	1.9
797	5.3	1.7
796	7.8	2.4
795	5.2	1.7

794	5.8	2.3
793	5.9	1.7
792	6.1	2.4
791	6.2	1.7
790	6	2.4
789	5.6	1.7
788	6.4	2.4
787	6.4	2.0
786	9.2	2.5
785	6.6	1.8
784	7.8	2.5
783	8.9	1.8
782	8.2	2.7
781	7.9	1.8
780	3.7	2.0
779	10.3	1.8
778	10.6	2.1
777	11.1	2.6

Reinig, F., Wacker, L., Jöris, O., Oppenheimer, C., Guidobaldi, G., Nievergelt, D., Adolphi, F., Cherubini, P., Engels, S., Esper, J., Land, A., Lane, C., Pfanz, H., Remmele, S., Sigl, M., Sookdeo, A. & Büntgen, U. 2021. Precise date for the Laacher See eruption synchronizes the Younger Dryas. *Nature* 595: 66–69. https://doi.org/10.1038/s41586-021-03608-x