

Radiocarbon Production Events and their Potential Relationship with the Schwabe Cycle - *SUPPLEMENTARY INFORMATION*

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S1 – RAW DATA (NEWLY MEASURED)

Sample type	Sample number (GrM)	Calendar age (year CE)	¹⁴ C age (year BP)	Δ ¹⁴ C (‰)	Averaged ¹⁴ C age (year BP)	Averaged Δ ¹⁴ C (‰)
A (Oak)	13331	1853	124 ± 15	-3.70 ± 1.86	126 ± 11	-3.94 ± 1.36
	13404		129 ± 16	-4.32 ± 2.01		
Mapledurham (UK)	13332	1855	137 ± 16	-5.54 ± 2.01	137 ± 16	-5.54 ± 1.98
	13334	1856	169 ± 16	-9.62 ± 2.00	149 ± 11	-7.03 ± 1.36
	16797		131 ± 15	-4.92 ± 1.86		
	12714	1857	119 ± 13	-3.56 ± 1.55	119 ± 12	-3.56 ± 1.49
	12715	1858	111 ± 13	-2.68 ± 1.55	111 ± 12	-2.68 ± 1.49
	12716	1859	142 ± 13	-6.64 ± 1.55	144 ± 8	-6.89 ± 0.99
	16798		153 ± 14	-8.00 ± 1.70		
	18107		138 ± 13	-6.15 ± 1.85		
	12717	1860	114 ± 13	-3.30 ± 1.55	130 ± 10	-5.03 ± 1.24
	13335		153 ± 16	-8.12 ± 2.00		
	12719	1861	145 ± 13	-7.25 ± 1.54	145 ± 12	-7.25 ± 1.48
	12721	1862	127 ± 11	-5.15 ± 1.39	132 ± 8	-5.89 ± 1.11
	12727		140 ± 13	-6.76 ± 1.55		
	12722	1863	158 ± 13	-9.10 ± 1.54	158 ± 12	-9.10 ± 1.48
	13336	1864	146 ± 15	-7.74 ± 1.85	140 ± 11	-7.00 ± 1.36
	13405		134 ± 16	-6.26 ± 2.01		
12725	1865	139 ± 11	-6.99 ± 1.39	137 ± 8	-6.75 ± 1.11	

	12729		135 ± 13	-6.50 ± 1.55		
	12726	1866	119 ± 13	-4.64 ± 1.55	119 ± 12	-4.64 ± 1.48

<i>Sample type</i>	<i>Sample number (GrM)</i>	<i>Calendar age (year CE)</i>	<i>¹⁴C age (year BP)</i>	<i>Δ¹⁴C (‰)</i>	<i>Averaged ¹⁴C age (year BP)</i>	<i>Averaged Δ¹⁴C (‰)</i>
B1 (Juniper)	16801	756	1350 ± 15	-23.35 ± 1.82	1350 ± 15	-23.35 ± 1.82
	16803	758	1344 ± 15	-22.86 ± 1.82	1344 ± 15	-22.86 ± 1.82
	16804	759	1360 ± 25	-24.92 ± 3.03	1360 ± 25	-24.92 ± 3.03
	16805	762-763	1305 ± 16	-18.63 ± 1.95	1305 ± 16	-18.63 ± 1.95
Sierra Nevada (USA)	16806	765	1316 ± 16	-20.27 ± 1.95	1316 ± 16	-20.27 ± 1.95
	16809	766	1311 ± 15	-19.78 ± 1.83	1311 ± 15	-19.78 ± 1.83
	16810	768	1324 ± 16	-21.61 ± 1.95	1324 ± 16	-21.61 ± 1.95
	16811	769	1308 ± 15	-19.77 ± 1.83	1308 ± 15	-19.77 ± 1.83
	16812	771	1326 ± 24	-22.20 ± 2.92	1326 ± 24	-22.20 ± 2.92
	16813	772	1320 ± 18	-21.59 ± 2.19	1320 ± 18	-21.59 ± 2.19
	16814	774	1261 ± 16	-14.62 ± 1.96	1291 ± 12	-18.29 ± 1.47
	17197		1333 ± 19	-23.41 ± 2.31		
	16815	775	1172 ± 16	-3.76 ± 1.98	1172 ± 16	-3.76 ± 1.98
	16816	777	1193 ± 16	-6.60 ± 1.98	1177 ± 11	-4.62 ± 1.36
	17198		1161 ± 16	-2.64 ± 1.98		

<i>Sample type</i>	<i>Sample number (GrM)</i>	<i>Calendar age (year CE)</i>	<i>¹⁴C age (year BP)</i>	<i>Δ¹⁴C (‰)</i>	<i>Averaged ¹⁴C age (year BP)</i>	<i>Averaged Δ¹⁴C (‰)</i>
B2 (Oak)	11849	770	1314 ± 17.5	-20.62 ± 2.13	1290 ± 7	-17.72 ± 0.86
	12731		1286 ± 14	-17.2 ± 1.68		
	12786		1276 ± 16	-15.98 ± 1.99		
	14094		1290 ± 11	-17.69 ± 1.38		
Dorestad (NL)	10567	771	1312 ± 22.5	-20.5 ± 2.74	1278 ± 12	-16.32 ± 1.45
	11774		1267 ± 15	-15 ± 1.84		
	12686		1250 ± 37.5	-12.91 ± 4.61		
	10568	772	1295 ± 22.5	-18.54 ± 2.75	1281 ± 6	-16.87 ± 0.76
	12179		1286 ± 14	-17.44 ± 1.68		
	12737		1266 ± 14	-14.99 ± 1.69		
	12739		1271 ± 14	-15.61 ± 1.68		
	14093	773	1292 ± 11	-18.18 ± 1.38	1308 ± 11	-20.20 ± 1.39
	10569		1315 ± 22.5	-21.1 ± 2.74		
	13095		1312 ± 19	-20.73 ± 2.29		
	13096	774	1298 ± 19	-19.03 ± 2.29	1285 ± 25	-17.56 ± 3.06
	10570		1285 ± 25	-17.56 ± 3.06		
	10572	775	1205 ± 25	-7.84 ± 3.09	1211 ± 15	-8.63 ± 1.85
	17405		1215 ± 19	-9.08 ± 2.31		
	10574	776	1125 ± 25	1.97 ± 3.12	1142 ± 15	-0.19 ± 1.87
	13098		1152 ± 19	-1.4 ± 2.33		
10575	777	1165 ± 25	-3.13 ± 3.1	1153 ± 14	-1.65 ± 1.69	

	14839		1148 ± 16	-1.02 ± 2.02		
	10577	778	1170 ± 25	-3.87 ± 3.1	1168 ± 10	-3.66 ± 1.25
	14440		1173 ± 15	-4.25 ± 1.86		
	15240		1162 ± 16	-2.88 ± 2.02		
	10578	779	1170 ± 25	-3.99 ± 3.1	1176 ± 14	-4.78 ± 1.69
	13460		1179 ± 16	-5.11 ± 2.01		

Sample type	Sample number (GrM)	Calendar age (year CE)	¹⁴ C age (year BP)	Δ ¹⁴ C (‰)	Averaged ¹⁴ C age (year BP)	Averaged Δ ¹⁴ C (‰)
C (Juniper)	16818	976	1136 ± 15	-23.32 ± 1.82	1136 ± 15	-23.32 ± 1.82
	16819	978	1108 ± 15	-20.15 ± 1.82	1108 ± 15	-20.15 ± 1.82
Sierra Nevada (USA)	16820	980	1113 ± 18	-20.99 ± 2.19	1113 ± 18	-20.99 ± 2.19
	16821	982	1143 ± 16	-24.88 ± 1.94	1143 ± 16	-24.88 ± 1.94
	17189	984	1120 ± 16	-22.32 ± 1.94	1120 ± 16	-22.32 ± 1.94
	17190	986	1101 ± 16	-20.24 ± 1.95	1102 ± 11	-20.36 ± 1.34
	17201		1102 ± 16	-20.36 ± 1.95		
	17191	988	1116 ± 18	-22.31 ± 2.19	1116 ± 18	-22.31 ± 2.19
	17192	989-991	1105 ± 19	-21.20 ± 2.31	1096 ± 12	-20.11 ± 1.46
	17202		1089 ± 16	-19.25 ± 1.95		
	17193	993	1047 ± 16	-14.47 ± 1.96	1047 ± 16	-14.47 ± 1.96
	17195	995	1035 ± 16	-13.23 ± 1.96	1035 ± 16	-13.23 ± 1.96
	17196	997	1045 ± 16	-14.70 ± 1.96	1045 ± 16	-14.70 ± 1.96

Table S1a, S1b, S1c, S1d. Raw radiocarbon measurements, expressed as ¹⁴C age and Δ¹⁴C

S2 – RAW DATA (PREVIOUSLY PUBLISHED)

Event-775 (Miyake et al., 2013)		
Calendar age (year CE)	Δ ¹⁴ C (‰)	± (‰)
730	-11.8	2.1
732	-14.5	2.1
734	-10.4	2.1
736	-10.6	2.6
738	-13.2	2.1

740	-12.8	2.1
742	-17.9	2.1
744	-13.6	2.2
746	-15.3	2.1
748	-15.9	2.6
750	-16.0	1.8
752	-17.5	2.0
754	-20.4	2.0
756	-20.9	2.0
758	-18.0	2.0
760	-17.9	2.0

Event-994 (Miyake et al., 2013)		
<i>Calendar age (year CE)</i>	$\Delta^{14}\text{C}$ (‰)	\pm (‰)
988	-21.9	1.8
989	-20.2	1.9
989	-21.3	1.8
990	-25.3	2.9
990	-22.5	1.7
991	-21.5	1.5
991	-23.1	1.9
992	-22.8	2.0
992	-24.4	1.9
993	-20.7	1.6
993	-25.3	1.7
994	-11.5	2.0
994	-14.0	1.8
995	-12.9	1.5
995	-18.1	1.7
996	-11.3	2.0
996	-16.7	1.7
997	-14.2	2.0
997	-16.4	1.7
998	-15.3	2.0
999	-13.3	1.6
1001	-15.0	2.9
1003	-17.0	2.6
1005	-13.8	2.6
1007	-21.1	2.6
1009	-20.1	2.6
1011	-23.0	2.6
1013	-20.5	2.6
1015	-17.9	2.6
1017	-20.8	2.1
1019	-22.0	2.1

1021	-19.2	3.6
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Event-994 (Menjo et al., 2005)		
<i>Calendar age (year CE)</i>	$\Delta^{14}\text{C}$ (‰)	\pm (‰)
996	-14.35	2.55
998	-16.59	2.55
1000	-15.90	2.55
1001	-15.33	2.55
1002	-15.35	2.55
1003	-18.36	2.55
1004	-16.78	2.55
1005	-19.28	2.55
1006	-18.96	2.55
1007	-18.64	2.55
1008	-20.42	1.90
1009	-20.47	1.88
1010	-16.98	1.99
1011	-19.69	1.98
1012	-16.50	1.98
1013	-15.27	1.99
1014	-18.54	2.82
1015	-12.13	2.82
1016	-16.98	2.82
1017	-14.19	2.82
1018	-19.03	2.55
1019	-14.35	3.20
1020	-22.97	3.20
1022	-20.79	3.20
1024	-14.28	2.14

Event-994 (Damon et al., 1995)		
<i>Calendar age (year CE)</i>	$\Delta^{14}\text{C}$ (‰)	\pm (‰)
1004	-14.6	3.9
1005	-18.7	4.0
1006	-21.8	4.0
1007	-19.3	3.7
1008	-21.1	3.4
1009	-22.2	3.8
1010	-15.2	3.3
1011	-10.00	3.5
1012	-17.1	3.3
1013	-11.1	3.2

1014	-16.7	3.0
1015	-11.8	4.1
1016	-18.3	3.4

Event-994 (Dee et al., 2016)		
Calendar age (year CE)	$\Delta^{14}\text{C}$ (‰)	\pm (‰)
1004	-13.20	3.45
1005	-23.59	3.41
1006	-12.46	3.20
1007	-17.48	3.80
1008	-23.58	3.41
1009	-24.55	3.53
1010	-16.25	3.80

Table S2a, S2b, S2c, S2d, S2e. Previously published ^{14}C measurements, expressed in $\Delta^{14}\text{C}$, utilized for the study of Event-775 and Event-994.

S3 – DUPLICATES AND CHI SQUARED TEST

Calendar year (year CE)	Sample name	^{14}C age (year BP)	Uncertainty (year BP)	T-Statistic	Chi-Square Test
Sample A					
1853	GrM-13331	124	15	0.024	Pass
	GrM-13404	129	16	0.028	
	Weighted Average	126	11	0.052	
1856	GrM-13334	169	16	1.598	Pass
	GrM-16797	131	15	1.404	
	Weighted Average	149	11	3.002	
1859	GrM-12716	142	13	0.022	Pass
	GrM-16798	153	14	0.421	
	GrM-18107	138	13	0.207	
	Weighted Average	147	10	0.650	
1860	GrM-12717	114	13	1.423	Pass
	GrM-13335	153	16	2.156	
	Weighted Average	130	10	3.579	
1862	GrM-12721	127	11	0.243	Pass
	GrM-12727	140	13	0.340	
	Weighted Average	132	8	0.583	
1864	GrM-13336	146	15	0.140	Pass
	GrM-13405	134	16	0.159	
	Weighted Average	140	11	0.299	
1865	GrM-12725	139	11	0.023	Pass
	GrM-12729	135	13	0.032	
	Weighted Average	137	8	0.055	
Sample B1					
774	GrM-16814	1261	16	3.486	Fail
	GrM-17197	1333	19	4.916	
	Weighted Average	1291	12	8.402	

777	GrM-16816	1193	16	1.000	Pass
	GrM-17198	1161	16	1.000	
	Weighted Average	1177	11	2.000	
Sample B2					
770	GrM-11849	1314	17.5	1.9	Pass
	GrM-12731	1286	14	0.1	
	GrM-12786	1276	16	0.8	
	GrM-14094	1290	11	0.0	
	Weighted Average	1290	7	2.7	
771	GrM-10567	1312	22.5	2.314	Pass
	GrM-11774	1267	15	0.516	
	GrM-12686	1250	37.5	0.548	
	Weighted Average	1278	12	3.378	
772	GrM-10568	1295	22.5	0.4	Pass
	GrM-12179	1286	14	0.1	
	GrM-12737	1266	14	1.2	
	GrM-12739	1271	14	0.6	
	GrM-14093	1292	11	0.9	
	Weighted Average	1282	6	3.2	
773	GrM-10569	1315	22.5	0.107	Pass
	GrM-13095	1312	19	0.053	
	GrM-13096	1298	19	0.257	
	Weighted Average	1308	12	0.417	
775	GrM-10572	1205	25	0.064	Pass
	GrM-17405	1215	19	0.037	
	Weighted Average	1211	15	0.101	
776	GrM-10574	1125	25	0.469	Pass
	GrM-13098	1152	19	0.271	
	Weighted Average	1142	15	0.739	
777	GrM-10575	1165	25	0.233	Pass
	GrM-14839	1148	16	0.095	
	Weighted Average	1153	13	0.328	
778	GrM-10577	1170	25	0.005	Pass
	GrM-14440	1173	15	0.102	
	GrM-15240	1162	16	0.150	
	Weighted Average	1168	10	0.258	
779	GrM-10578	1170	25	0.065	Pass
	GrM-13460	1179	16	0.027	
	Weighted Average	1176	13	0.092	
Sample C					
986	GrM-17190	1101	16	0.001	Pass
	GrM-17201	1102	16	0.001	
	Weighted Average	1102	11	0.002	
989-991	GrM-17192	1105	19	0.243	Pass
	GrM-17202	1089	16	0.172	
	Weighted Average	1096	12	0.415	

Table S3a. Details about averaging of duplicate measurements: T-statistics and Chi-Squared test

S4 – ADDITIONAL FIGURES

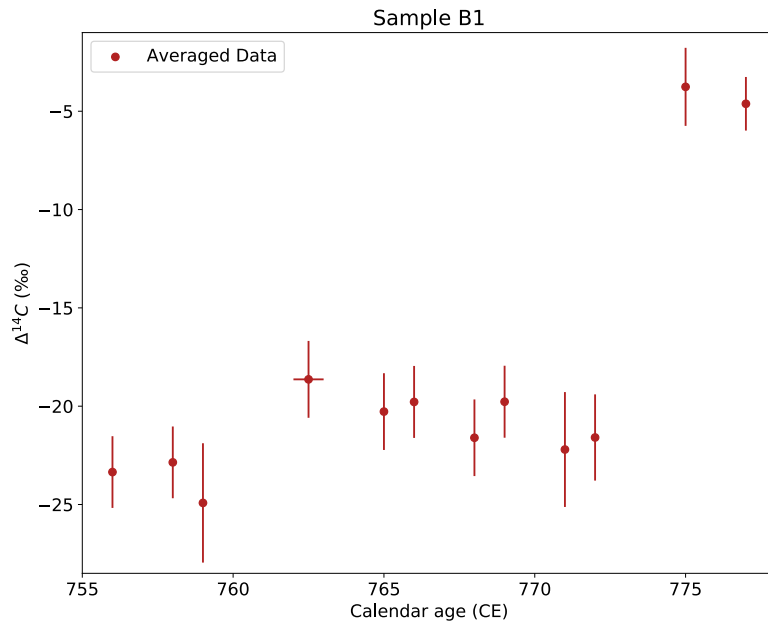


Figure S4a. Results of the radiocarbon measurements over sample B1, concerning Event-775. Multiple measurements over the same calendar year have been averaged (see S3), and data points are shown with 1-sigma error bars.

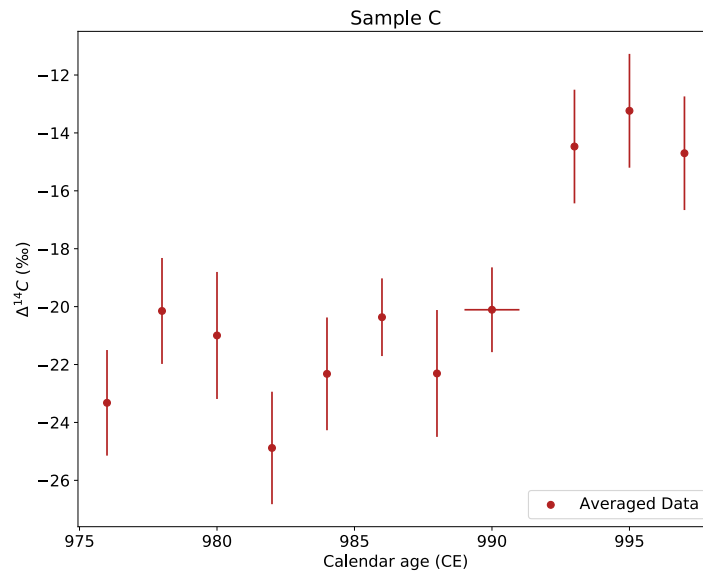


Figure S4b. Results of the radiocarbon measurements over sample C, concerning Event-994. Multiple measurements over the same calendar year have been averaged (see S3), and data points are shown with 1-sigma error bars.

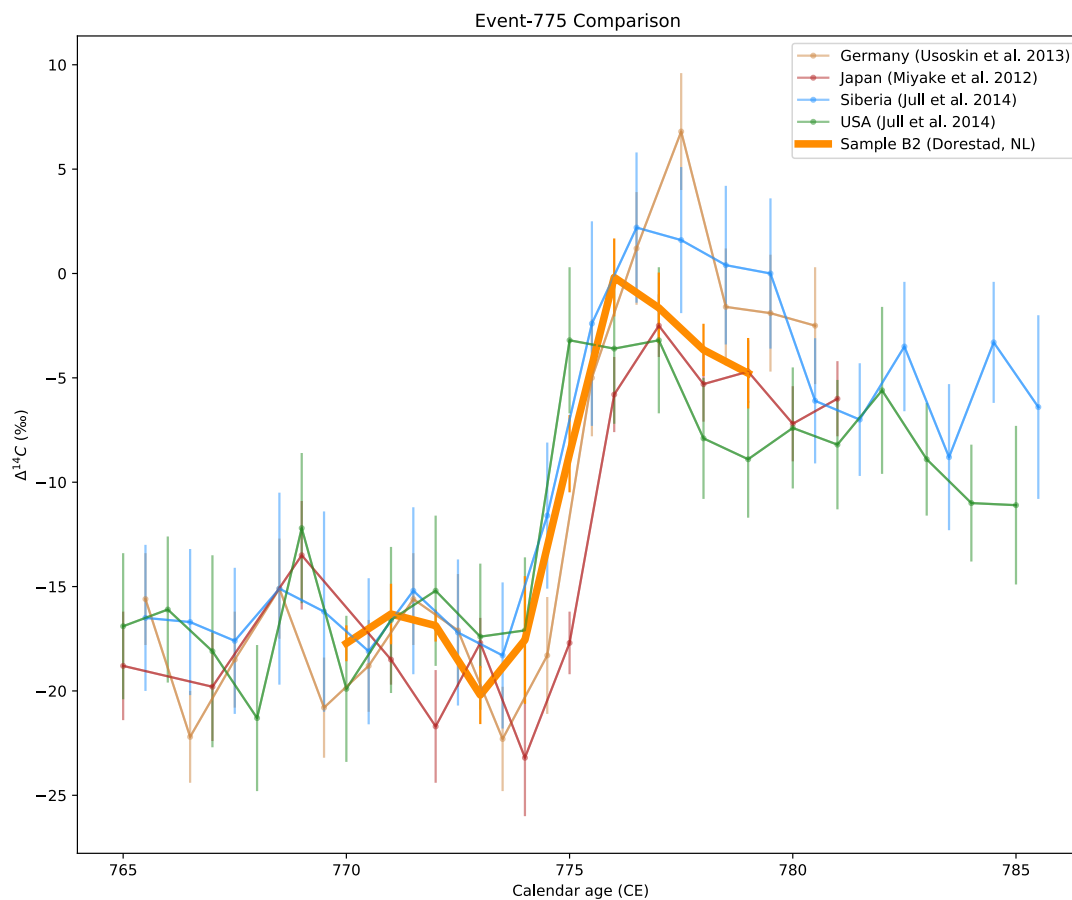


Figure S4c. In orange, results of the radiocarbon measurements over sample B2, concerning Event-775. Multiple measurements over the same calendar year have been averaged (see S3), and data points are shown with 1-sigma error bars. In other colors, radiocarbon measurements over the same event, previously published in other studies. Our measurements (in orange) sit perfectly in between the measurements of earlier analysis of other laboratories.

S5 – INFO ABOUT SUNSPOT RECORD

All the data used for the study of the Sunspot Record in conjunction with the Carrington Event, were downloaded, as freely available, from the website of SILSO (Sunspot Index and Long-term Solar Observation) (<http://www.sidc.be/silso/>). SILSO is part of the Solar Influences Data Analysis Center (SIDC), which in turn is part of the Royal Observatory of Belgium and a partner in the Solar Terrestrial Center of Excellence (STCE). The data downloaded and used is the 'daily total sunspot number'.

S6 – DENDROCHRONOLOGY

Sample A

Wood: Oak
Site: Mapledurham, England
Dendro-code: MAP71x
Laboratory: Oxford Dendrochronology Laboratory,
Daniel Miles, daniel.miles@arch.ox.ac.uk

Sample B1

Wood: Juniper
Site: Sierra Nevada Mountains, California
Dendro-code: CS9d1
Laboratory: Oxford Dendrochronology Laboratory,
Daniel Miles, daniel.miles@arch.ox.ac.uk

Sample B2

Wood: Oak
Site: Dorestad Haven, The Netherlands
Project ID: P2016003
Arch. number: 357-8-38
Dendro-code: D1600030
Laboratory: Netherlands Cultural Heritage Agency (Rijksdienst voor het Cultureel Erfgoed),
Esther Jansma, E.Jansma@cultureelerfgoed.nl
Petra Doeve, P.Doeve@cultureelerfgoed.nl

Sample C

Wood: Juniper
Site: Sierra Nevada Mountains, California
Dendro-code: CS9d2
Laboratory: Oxford Dendrochronology Laboratory,
Daniel Miles, daniel.miles@arch.ox.ac.uk

S7 – CUBIC SPLINE INTERPOLATION AND RESIDUALS

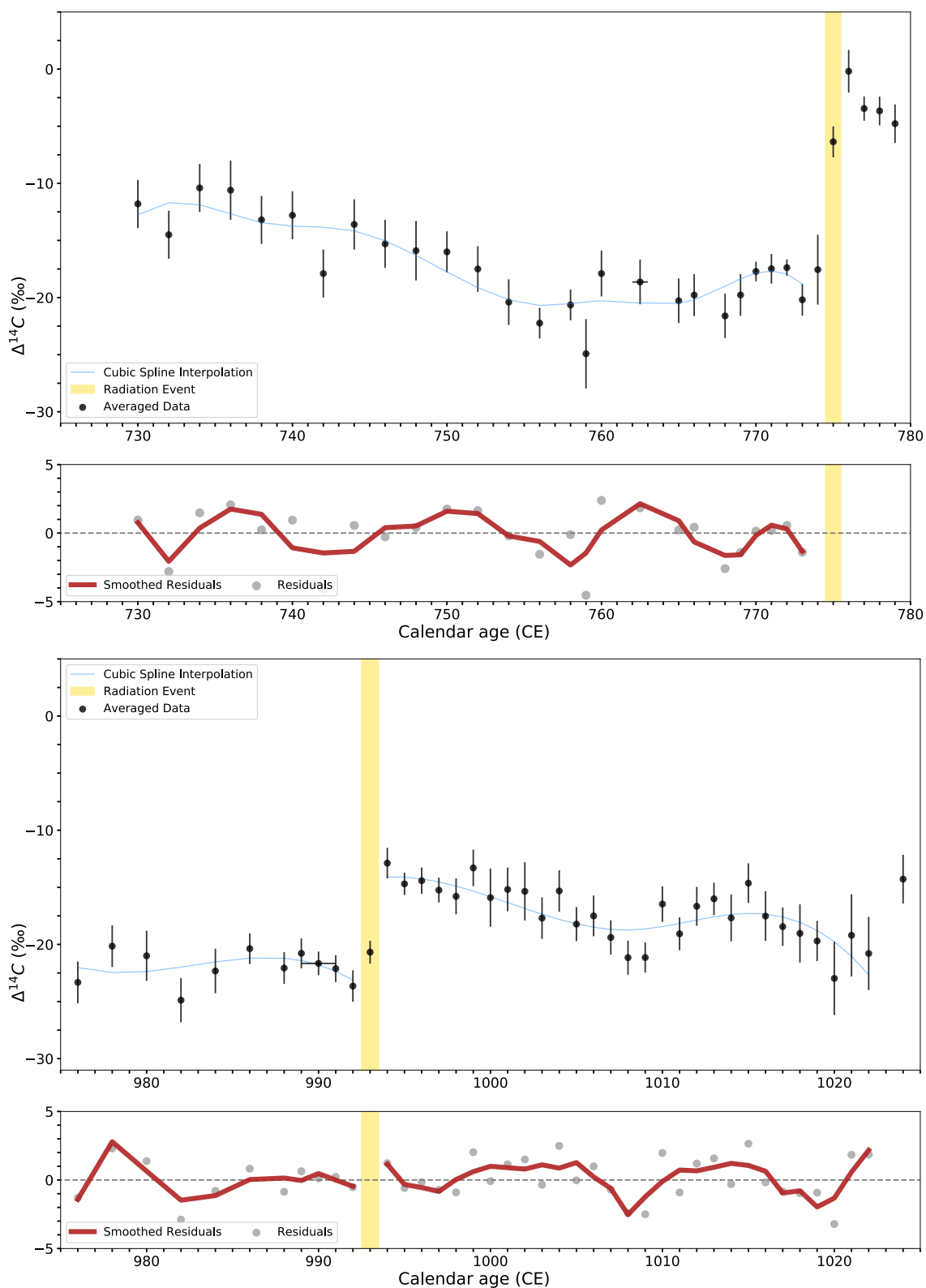


Figure S7a. Results of the analysis over the Event-775 (above) and Event-994 (below). In the top row, averaged data points with 1-sigma error bars (black) and time location of the radiation event (yellow). In the bottom row, residuals of the spline fit (gray dots) and smoothed residuals obtained through a Savitzky-Golay filter (red line).

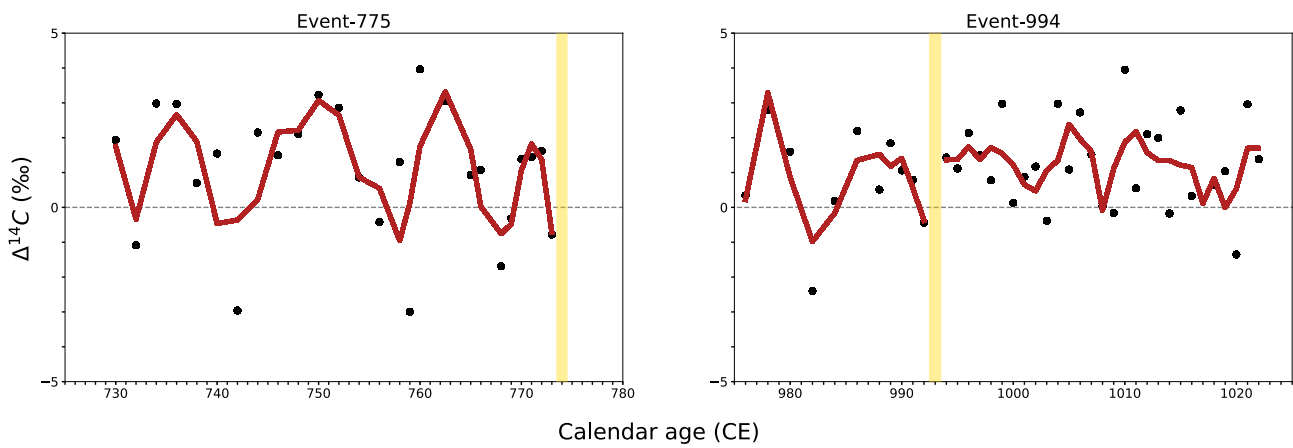


Figure S7b. Residuals of the cubic spline interpolation (gray dots) and smoothed residuals (red line) over 1,000 times Monte Carlo resampling of the normally distributed experimental data analyzed in Figure 3 and 4. The results over Event-775 is in accordance with the result of the band-pass filter over the same event. The result over Event-994 also coincides with the result of the band-pass filter over the same event, but only in the period before the spike. After the spike, the data is affected by the radiation event and the random resampling disrupts any periodicity.