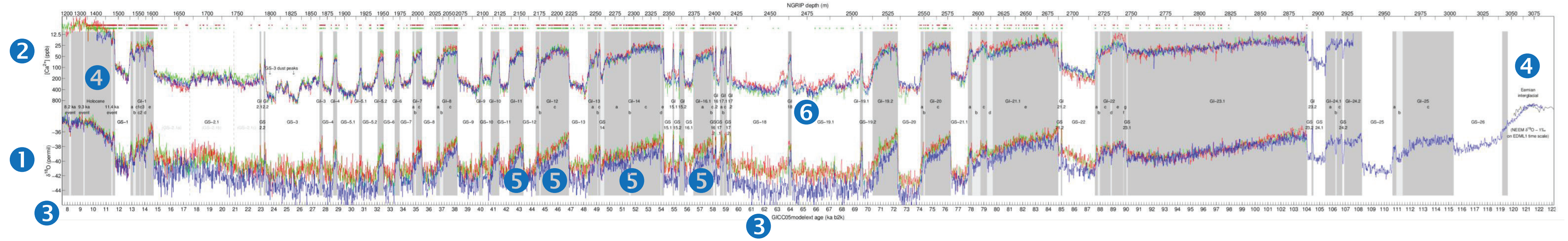
Event	NGRIP depth (m)	Age (a b2k) and definition uncertainty	Maximum counting error (years)	Notes and comments
End of 8.2 ka BP event	1219.47	8140 +50/-10	45	1, 2
Volcanic peak inside 8.2 ka	1228.67	8236 ± 1	47	2, 3
Start of 8.2 ka BP event	1234.78	8300 +10/-40	49	1, 2
End of 9.3 ka BP event	1322.88	9240 +30/-10	68	1, 2
Start of 9.3 ka BP event	1331.65	9350 +10/-20	70	1, 2
End of 11.4 ka BP event	1476.16	11400 [a]	96	13
Start of 11.4 ka BP event	1482.32	11520 [a]	97	13
Start of Holocene	1492.45	11703 ± 4	99	3, 4, 5
Start of GS-1	1526.52	12896 ± 4	138	3, 5
Start of GI-1a	1534.50	13099 [a]	143	6
Start of GI-1b	1542.10	13311 [b]	149	6
Start of GI-1c1	1554.75	13600 [b]	156	13
Start of GI-1c2	1557.08	13660 [b]	158	13
Start of GI-1c3	1570.50	13954 [a]	165	6
Start of GI-1d	1574.80	14075 [a]	169	3
Start of GI-1e	1604.64	14692±4	186	3, 5
Start of GS-2.1a	1669.09	17480 [c]	330	8, 13
Start of GS-2.1b	1745.31	20900 [c]	482	7, 8
Start of GS-2.1c	1783.62	22900 [a]	573	7, 8
Start of GI-2.1	1786.28	23020 [a]	583	8, 13
Start of GS-2.2	1790.26	23220 [a]	590	8, 13
Start of GI-2.2	1793.19	23340 [a]	596	7, 8, 9
Start of GS-3	1861.69	27540 [b]	822	7, 8
Start of GI-3	1869.12	27780 [a]	832	7, 8, 9
Start of GS-4	1882.62	28600 [a]	887	7, 8
Start of GI-4	1891.57	28900 [a]	898	7, 8, 9
Start of GS-5.1	1916.08	30600 [b]	1008	8, 13
Start of GI-5.1	1920.56	30840 [b]	1024	8, 13
Start of GS-5.2	1939.68	32040 [b]	1107	8, 11
Start of GI-5.2	1951.65	32500 [a]	1132	8, 9
Start of GS-6	1964.30	33360 [b]	1191	8, 11
Start of GI-6	1974.55	33740 [a]	1212	8, 9
Start of GS-7	1990.28	34740 [b]	1286	8, 11
Start of GI-7a	1993.79	34880 [b]	1293	8, 13
Start of GI-7b	1997.04	35020 [b]	1299	8, 13
Start of GI-7c	2009.44	35480 [a]	1321	8, 9
Start of GS-8	2026.66	36580 [b]	1397	8, 11
Start of GI-8a	2032.67	36860 [b]	1408	8, 13
Start of GI-8b	2038.23	37120 [b]	1417	8, 13
Start of GI-8c	2070.02	38220 [a]	1449	8, 9
Start of GS-9	2094.64	39900 [b]	1569	8, 11
Start of GI-9	2099.61	40160 [a]	1580	8, 9
Start of GS-10	2109.71	40800 [b]	1615	8, 11
Start of GI-10	2124.03	41460 [a]	1633	8, 9
Start of GS-11	2134.99	42240 [b]	1682	8, 11
Start of GI-11	2157.49	43340 [a]	1736	8, 10
Start of GS-12	2170.00	44280 [b]	1780	8, 11
Start of GI-12a	2174.80	44560 [a]	1791	8, 13
Start of GI-12b	2176.61	44680 [a]	1796	8, 13
Start of GI-12c	2222.30	46860 [a]	1912	8, 10
Start of GS-13	2240.96	48340 [d]	1988	8, 11
Start of GI-13a	2252.80	49060 [a]	2021	8, 13
Start of GI-13b	2253.84	49120 [a]	2023	8, 13
Start of GI-13c	2256.89	49280 [a]	2031	8, 10
Start of GS-14 [QS]	2261.46	49600 [d]	2051	8, 13
Start of GI-14a	2293.25	51500 [b]	2136	8, 13
Start of GI-14b	2295.90	51660 [b]	2144	8, 13
Start of GI-14c	2340.38	53960 [a]	2289	8, 13
Start of GI-14d	2341.38	54020 [a]	2292	8, 13
Start of GI-14e	2345.52	54220 [a]	2301	8, 10
Start of GS-15.1	2353.65	54900 [a]	2338	8, 13
Start of GI-15.1	2355.34	55000 [a]	2349	8, 13
Start of GS-15.2	2359.64	55400 [a]	2368	8, 13
Start of GI-15.2	2366.32	55800 [a]	2392	8, 10
Start of GS-16.1	2374.41	56500 [b]	2430	8, 13
Start of GI-16.1a	2396.75	57920 [a]	2492	8, 13
Start of GI-16.1b	2397.35	57960 [a]	2494	8, 13
Start of GI-16.1c	2398.78	58040 [a]	2497	8, 13
Start of GS-16.2	2400.34	58160 [a]	2505	8, 13
Start of GI-16.2	2402.55	58280 [a]	2511	8, 10
Start of GS-17.1	2406.01	58560 [b]	2528	8, 13
Start of GI-17.1a	2409.78	58780 [a]	2540	8, 13
Start of GI-17.1b	2410.65	58840 [a]	2542	8, 13
Start of GI-17.1c	2415.01	59080 [a]	2557	8, 13
Start of GS-17.2	2417.66	59300 [a]	2569	8, 13
Start of GI-17.2	2420.44	59440 [a]	2573	8, 10
Start of GS-18	2461.82	63840 [a]	n.a.	8, 13
Start of GI-18	2465.85	64100 [a]	n.a.	8, 13
Start of GS-19.1	2504.86	69400 [b]	n.a.	8, 13
Start of GI-19.1	2507.59	69620 [a]	n.a.	8, 13
Start of GS-19.2	2512.54	70380 [c]	n.a.	8, 13
Start of GI-19.2	2535.96	72340 [a]	n.a.	8, 13
Start of GS-20	2547.52	74100 [b]	n.a.	8, 13
Start of GI-20a	2549.63	74320 [b]	n.a.	8, 13
Start of GI-20b	2550.96	74440 [b]	n.a.	8, 13
Start of GI-20c	2579.13	76440 [a]	n.a.	8, 13
Start of GS-21.1	2590.25	77760 [d]	n.a.	8, 13
Start of GI-21.1a	2594.45	78080 [b]	n.a.	8, 13
Start of GI-21.1b	2602.13	78740 [b]	n.a.	8, 13
Start of GI-21.1c	2609.14	79240 [a]	n.a.	8, 13
Start of GI-21.1d	2614.50	79700 [e]	n.a.	8, 13
Start of GI-21.1e	2687.29	84760 [a]	n.a.	8, 13, 12
Start of GS-21.2	2689.81	84960 [a]	n.a.	8, 13
Start of GI-21.2	2691.13	85060 [a]	n.a.	8, 13, 12
Start of GS-22	2717.11	87600 [b]	n.a.	8, 13
Start of GI-22a	2719.69	87820 [b]	n.a.	8, 13
Start of GI-22b	2721.56	88000 [b]	n.a.	8, 13
Start of GI-22c	2730.94	88800 [b]	n.a.	8, 13
Start of GI-22d	2732.29	88920 [b]	n.a.	8, 13
Start of GI-22e	2743.58	89800 [a]	n.a.	8, 13
Start of GI-22f	2744.08	89840 [a]	n.a.	8, 13
Start of GI-22g	2746.53	90040 [a]	n.a.	8, 13
Start of GS-23.1 [QS]	2747.54	90140 [b]	n.a.	8, 13
Start of GI-23.1	2891.53	104040 [a]	n.a.	8, 13
Start of GS-23.2	2894.99	104380 [a]	n.a.	8, 13
Start of GI-23.2	2896.61	104520 [a]	n.a.	8, 13
Start of GS-24.1	2905.05	105440 [f]	n.a.	8, 13
Start of GI-24.1a	2914.17	106220 [f]	n.a.	8, 13
Start of GI-24.1b	2915.31	106320 [f]	n.a.	8, 13
Start of GI-24.1c	2920.60	106750 [f]	n.a.	8, 13
Start of GS-24.2	2922.06	106900 [f]	n.a.	8, 13
Start of GI-24.2	2938.19	108280 [f]	n.a.	8, 13
Start of GS-25	2954.08	110640 [f]	n.a.	8, 13
Start of GI-25a	2956.85	110940 [f]	n.a.	8, 13
Start of GI-25b	2961.07	111440 [f]	n.a.	8, 13
Start of GI-25c	3003.17	115370 [f]	n.a.	8, 13
Start of GS-26	3040.89	119140 [f]	n.a.	8, 13

Notes:
QS: Quasi-stadial (see paper for explanation)
a: Definition uncertainty estimated to 1 data points / 20 years (1σ).
b: Definition uncertainty estimated to 2-3 data points / 40-60 years (1σ).
c: Definition uncertainty estimated to 200 years (1σ).
d: Definition uncertainty estimated to 100 years (1σ).
e: Definition uncertain as the sub-event starts by a long soft slope.
f: Definition uncertainty estimated to 1-2 data points / 20-40 years (1σ) but is based on one data series only (NGRIP $\delta^{18}O$).
1: Rasmussen et al. (2007).
2: NGRIP1 depths used for 8.2 and 9.3 ka events. NGRIP2 depths used elsewhere. To convert these NGRIP1 depths to NGRIP2 depths, subtract 0.43 m.
3: Rasmussen et al. (2006).
4: Walker et al. (2009).
5: Steffensen et al. (2008).
6: Original Björck et al. (1998) definition transferred from GRIP to NGRIP depths using the volcanic markers of Rasmussen et al. (2006).
7: Lowe et al. (2008). NGRIP depth of start of GI-2 changed from the previous erroneous value.
8: NGRIP depths derived from the definitions based on 20-year resolution data on GICC05 or GICC05modelext (below 60 ka b2k) ages.
9: Andersen et al. (2006).
10: Svensson et al. (2008).
11: Blockley et al. (2012).
12: Vallelonga et al. (2012).
13: This work.

Abrupt climate change as seen in three Greenland ice cores

Greenland ice-core records (GRIP in red, GISP2 in green, and NGRIP in blue) show how Greenland temperature (lower curves) and the dustiness of the Arctic atmosphere (upper curves) changed abruptly and repeatedly during the glacial period. Time goes from right to left, and each step in the curve represents 20 years of data. The glacial period consists of a series of periods of full glacial conditions called *stadials* interrupted by milder *interstadials* (grey shaded intervals). The sharpest jumps of the curve correspond to warmings in Greenland of more than 20°C (36°F) in a few decades. Together with the abrupt warmings, the ice-core dust content drops to a tenth, reflecting synchronous changes in the Northern Hemisphere atmospheric circulation.



❶ Reconstructing past temperatures from ice cores

The lower set of curves show so-called *delta-O-eighteen* ($\delta^{18}O$) data which indirectly measures the temperature at the time of snowfall. Technically, $\delta^{18}O$ is the level of depletion of the heavy oxygen isotope ^{18}O relative to the more common ^{16}O isotope in the water molecules in the ice. Low values correspond to cold conditions. A change in $\delta^{18}O$ by 1‰ (1 per mille) corresponds to a temperature change of about 3°C on the time scales considered here. $\delta^{18}O$ reflects temperature because the amount of ^{18}O left in the vapour in a cloud depends on how much cooling the cloud has experienced since the vapour originally evaporated from the ocean, which again varies with climate. The GRIP and GISP2 cores were drilled 30 km from each other, while NGRIP is further North, resulting in lower $\delta^{18}O$ values.

❷ The dust content of the ice cores

The upper curves show the concentration of Calcium ions ($[Ca^{2+}]$) in the ice. The main source of Calcium is terrestrial dust, and $[Ca^{2+}]$ has been chosen as an indicator for dust because it is the only dust component, which has been measured in a similar way in all three cores. Note the reversed scale so that the shifts follow those of $\delta^{18}O$ below. The $[Ca^{2+}]$ scale on the axis is logarithmic: each axis tick-mark represents a doubling of the concentration.

From geochemistry measurements, we know that the dust that ends up in Greenland ice cores mainly comes from Central Asia. The variable dust content in the ice cores is a result of changing conditions at the source (colder and drier conditions allow easier mobilization of dust into the atmosphere) and changed efficiency of the atmospheric transport from Asia to Greenland and changes in wash-out en route (it is generally more windy during the cold phases and the colder/drier conditions means less dust wash-out along the way).

Comparing the two sets of curves

The $[Ca^{2+}]$ and $\delta^{18}O$ curves change almost simultaneously between the cold stadials and milder interstadials (see text ❺). $\delta^{18}O$ reflects conditions along the trajectory from the moisture source to the snow deposition location, while the $[Ca^{2+}]$ reflects changes on a larger geographical scale. This illustrates that the temperature changes in Greenland, which are likely linked to changes in the oceanic heat transport from mid-latitudes to the Arctic (also known as the Atlantic Meridional Overturning Circulation, or the AMOC), are manifestations of climate change that affected a larger geographical region.

❸ The time scale

The records are presented on a time scale where each step in the curves represents the average of 20 years of data. The axis unit is thousands of years before the year 2000 CE, denoted "ka b2k".

The seasonal cycle can be recognized in both the $\delta^{18}O$ and the impurity records, and the ice can therefore be dated by identifying and counting the annual layers, starting at present at the top of the core. The annual layers are not clearly visible like tree rings, but the concept is similar. The flow of ice slowly squeezes the layers, and they therefore gradually get thinner with depth. The time scale presented here was created by counting annual layers in the ice-core records more than 60 thousand years back; as far as they could be resolved by the impurity measurements. Beyond this, the depth-time relationship was extended by mathematical modelling of the flow of ice. The annual-layer-counted time scale is called the Greenland Ice Core Chronology 2005, or GICC05, and the time scale used here is GICC05modelext. It is based on NGRIP data for almost the entire section shown here. In order to be able to present all curves on the same time scale, the time scale has been applied to the GRIP and GISP2 ice cores using reference horizons: layers found in several cores known to represent the same point in time. The dots just below the upper NGRIP depth axis (which illustrates how the annuals layers get thinner with increasing depth or age) show the position of the reference horizons used to transfer the GICC05modelext time scale from NGRIP to the GRIP (red dots) and GISP2 (green dots) records.

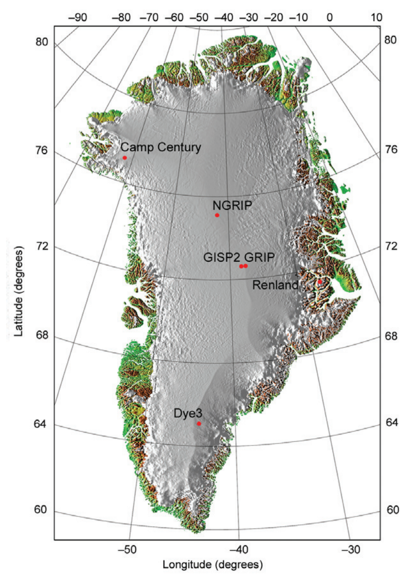
❹ The time span

The curve starts to the right during the previous interglacial, the Eemian interglacial, which ended about 119 thousand years ago. No undisturbed ice-core records that go beyond the Eemian period have been retrieved from the Greenland ice sheet. The curves continue throughout the glacial period, which formally ended 11.7 thousand years ago, and end just after the so-called *8.2 ka event*, which can be considered the last tremble from the glacial period. This event, which is named from its age of approx. 8,200 years, most likely represents the sudden drainage of a large volume of meltwater from the lakes formed during the melting of the Laurentide ice sheet, which during the glacial period covered the northern part of North America. The meltwater disrupted the ocean circulation in the North Atlantic, leading to cooling for a period up to a few centuries.

❺ Cold and mild periods in the Arctic

The glacial period (the time interval from 119.1 to 11.7 ka b2k) was both much colder and much more variable than the climate in the present and past interglacials. In analogy with glacials and interglacials, the different phases of the glacial are called *stadials* and *interstadials*. The relatively mild interstadials (grey shaded intervals) are periods where the thermohaline circulation in the North Atlantic (or the Atlantic Meridional Overturning Circulation, the AMOC) was strong, bringing heat to the Arctic area and maintaining rather warm ocean conditions around Greenland. In contrast, during the full-glacial stadials, the AMOC was weaker. We do not fully understand what caused the AMOC to change strength and cannot confidently say whether similar abrupt changes are likely to happen in the coming centuries.

Map of Greenland with the locations of the three ice-cores used here, GRIP and GISP2 near the highest point on the ice, Summit, and NGRIP further North along the ice divide. Also shown are the historical Camp Century, DYE-3, and Renland drill sites.



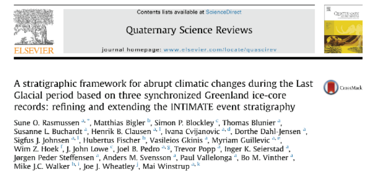
❻ The INTIMATE event stratigraphy:

Also known by the more generic term *Dansgaard-Oeschger Events* to honour the ice-core-science pioneers Willi Dansgaard and Hans Oeschger, the sequence of interstadials and stadials as seen in the Greenland ice cores is often used as a template for Arctic climate change during the glacial period because the ice-core records are very well-resolved and well-dated. The project *Integrating Ice-core, Marine, and Terrestrial Records (INTIMATE)* created the event stratigraphy, which defines the Greenland Stadials (GS) and Greenland Interstadials (GI) based on the Greenland ice-core records alone and provides a unique label for all phases of glacial climate change. The final product, which is what the graph here presents, constitutes a Greenland stratotype sequence, against which other climate records can be compared and correlated. It also provides a more secure basis for investigating the dynamics and fundamental causes of these climatic perturbations.

The INTIMATE event stratigraphy scheme is shown with interstadials illustrated by grey shading and the corresponding GI and GS labels. The intricate numbering system has been developed because new details have appeared in the curves since Willi Dansgaard introduced the original numbering in 1993. The numbering both respects the original numbering and assigns a number to all phases of glacial climate. The light grey intervals indicates slightly colder sub-events within the intestadials, further discussed in the paper.

Learn more

The graph comes from the following paper, which focuses on the numbering and nature of the stadial–interstadial shifts:



The paper is openly accessible from Quaternary Science Reviews and from http://dx.doi.org/doi:10.1016/j.quascirev.2014.09.007

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INTIMATE
Integrating ice core, marine and terrestrial records

A stratigraphic framework for abrupt climatic changes during the Last Glacial period based on three synchronized Greenland ice-core records: Refining and extending the INTIMATE event stratigraphy

Rasmussen *et al.*, Quaternary Science Reviews 106 (2014), p. 14-28

CENTRE FOR ICE AND CLIMATE

20-year average values of δ^{18}O and [Ca^{2+}] (note the reversed logarithmic [Ca^{2+}] scale; see paper for data sources) from GRIP (red), GISP2 (green), and NGRIP (blue) on the GICC05modelext time scale. Ages are given in b2k, denoting years before AD 2000. The dots just below the upper NGRIP depth axis show the position of the match points used to transfer the GICC05modelext time scale from NGRIP to the GRIP (red dots) and GISP2 (green dots) records.

The proposed extension of the INTIMATE event stratigraphy scheme is shown with interstadials illustrated by grey shading (light grey indicates cold sub-events). In the Eemian interglacial, NGRIP data are extended by NEEM δ^{18}O data offset by 1‰. See the paper for details on the numbering of stadial and interstadial events.