Evaluating the accuracy of the Greenland Ice-Core Chronology (GICC)

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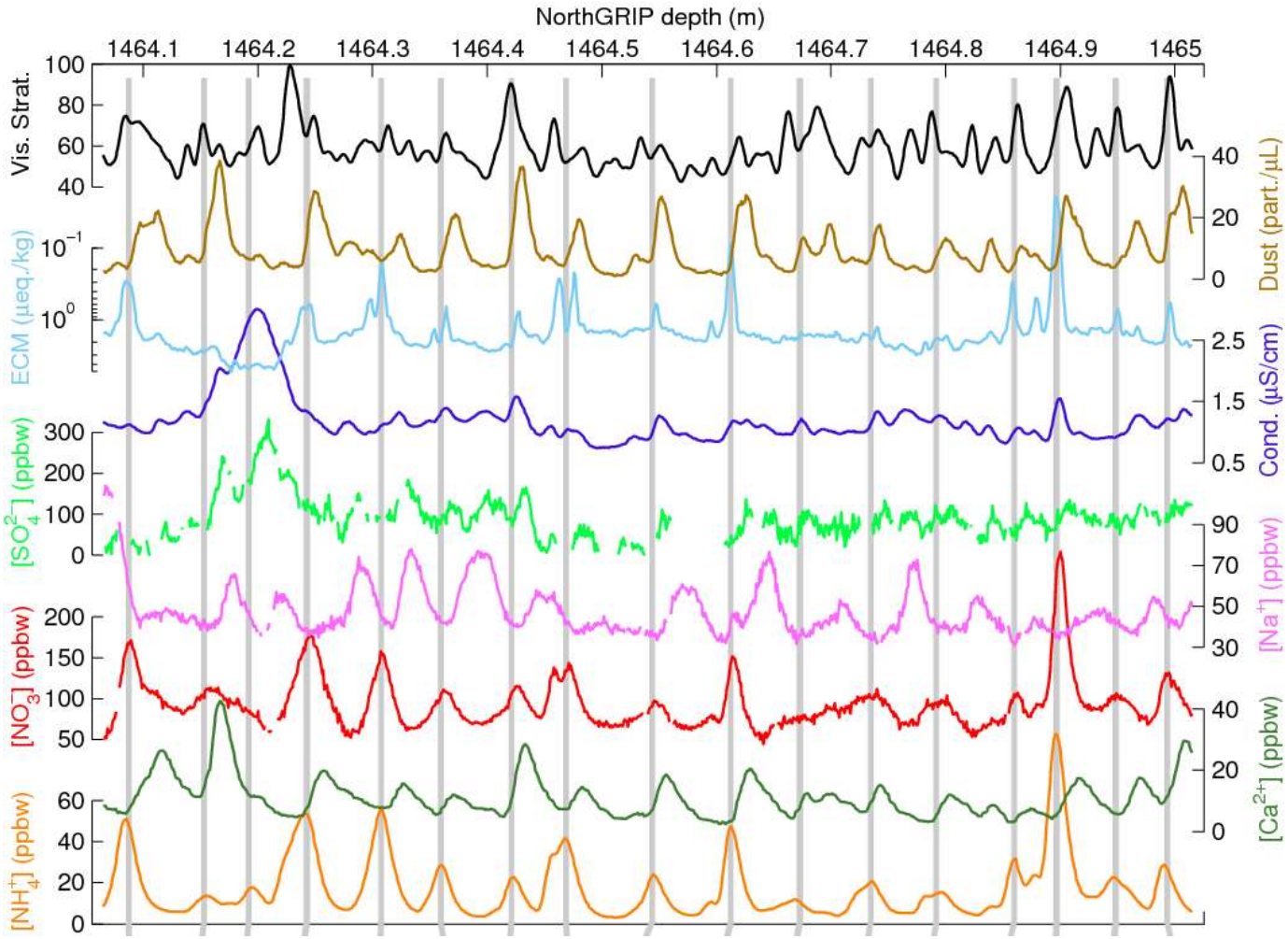
Ice-core annual-layer counting: A typical Holocene sequence



More examples of annual-layer identification in Rasmussen et al., 2006, doi:10.1029/2005JD006079

Annual variations can be seen in many data series:

Winter

high $[Na^+]$

Spring

high $[Ca^{2+}]$ and dust content

Summer

high $[NH_4^+]$ ($\Rightarrow$ dip in ECM), $[NO_3^-]$, and often $[SO_4^{2-}]$

No clear annual signal

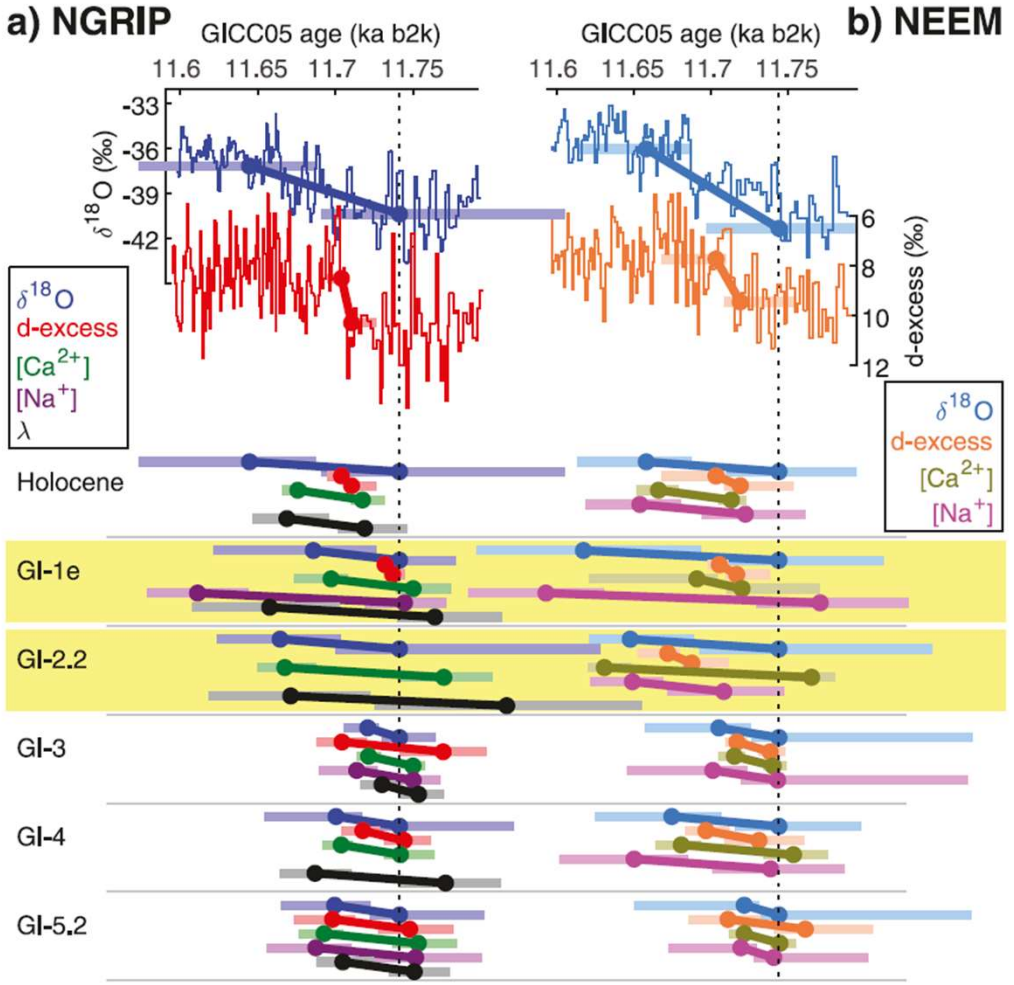
Visual stratigraphy and conductivity

Within ice cores, dating is often not the limitation when mapping out leads and lags

Two recent papers addressing leads and lags between different proxies in well-dated ice-core records:

T. Erhardt et al., 2019,
https://doi.org/10.5194/cp-15-811-2019
Stacking data from many transitions, establishing the average order of events.

E. Capron et al., 2021,
https://doi.org/10.1038/s41467-021-22241-w
Illustrates that while the results from the two parallel NGRIP and NEEM records agree, there is large variability between individual events.
There is no obvious relation between the variability and variations in background climate.



Extract of figure from E. Capron et al., 2021,
https://doi.org/10.1038/s41467-021-22241-w
Yellow shades mark D-O-event onsets following a Heinrich stadial

Ice-core dating uncertainty

The **Maximum Counting Error** (MCE) is the result of all ”uncertain annual layers” being counted as ½ ± ½ year, summed up linearly (a conservative assumption).

Some examples of reasons for this uncertainty:

- Marginal data resolution, masking thin layers.
- Unusual seasonal snow distribution, obscuring the normal seasonal sequenze of when different impurities peak
- Snow redistribution by wind, removing a season’s snow or adding a false ‘extra season’ to the normal seasonal sequenze

Example values of the MCE:

- At the onset of Holocene: 99 years,
- At the onset og the Bølling interstadial, GI-1e: 186 years
- 20,000 years ago: 444 years

Holocene dating progress

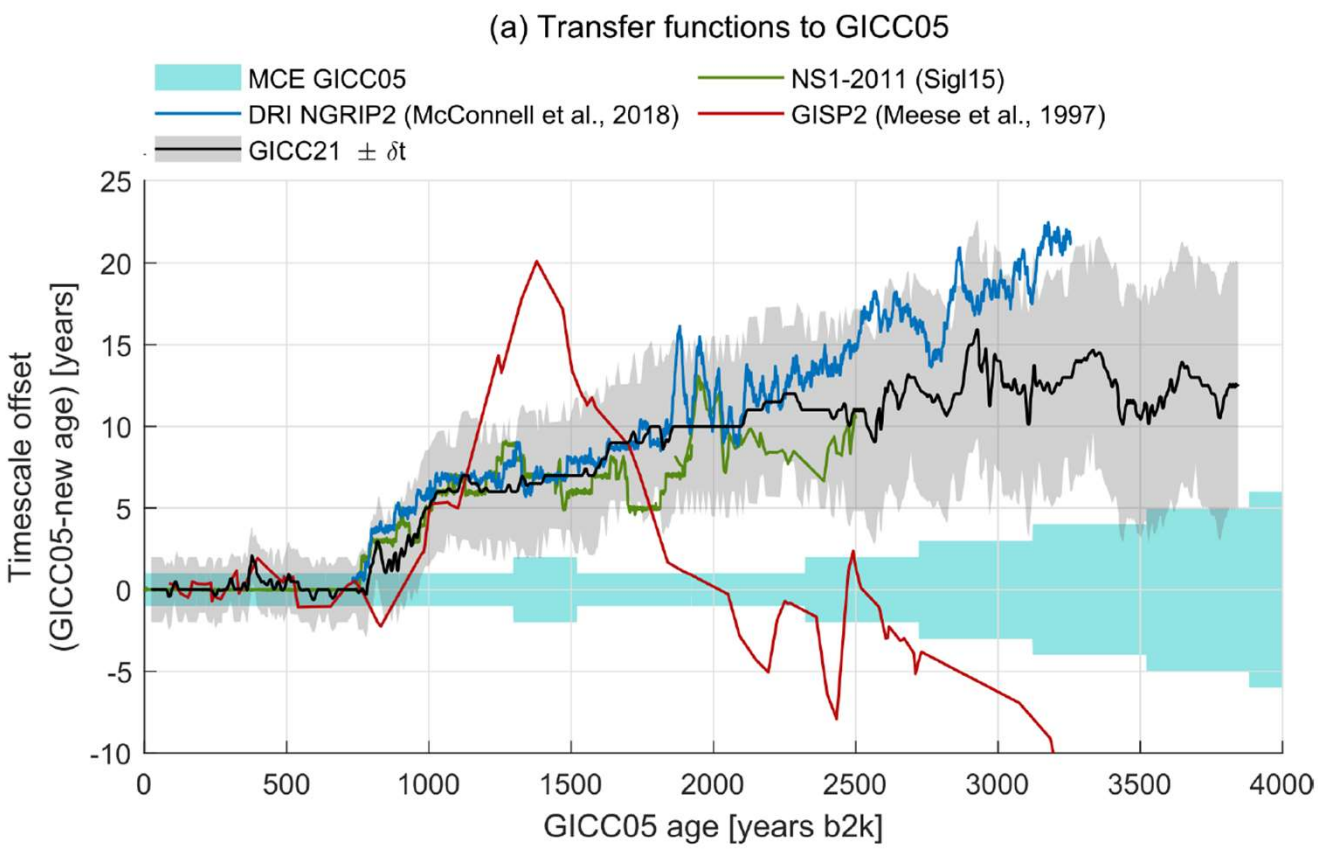


Figure from Sinnl et al., 2022, "A multi-ice-core, annual-layer-counted Greenland ice-core chronology for the last 3800 years: GICC21", Clim. Past, 18, 1125–1150, 2022. https://doi.org/10.5194/cp-18-1125-2022

Sigl et al., 2015:
Timing and climate forcing of volcanic eruptions for the past 2,500 years,
doi:10.1038/nature14565

Sinnl et al., 2022
New GICC21 time scale for the last 3,800 years

See paper or visit Giulia Sinnl's poster
EGU23-289,
Hall X3 position 66,
Thursday 14:00-15:45

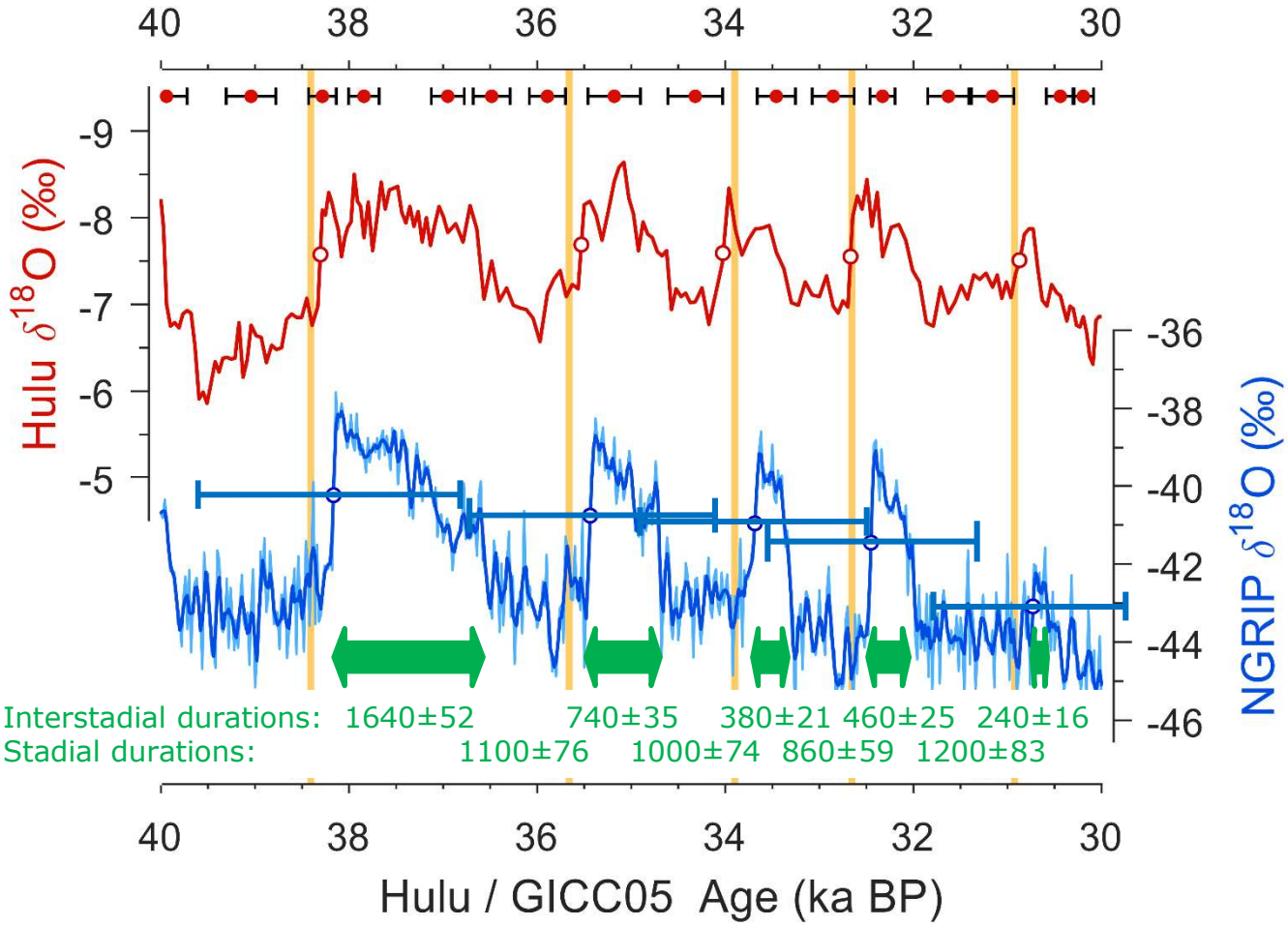
Also supported by data on solar storms, Paleari et al., 2022, https://doi.org/10.1038/s41467-021-27891-4

Issues when making common time-scales

Speleothem dates have excellent accuracy. Uncertainties are small and uncorrelated

Annual-layer counted ice-core chronologies suffer from accumulation of errors leading to low accuracy

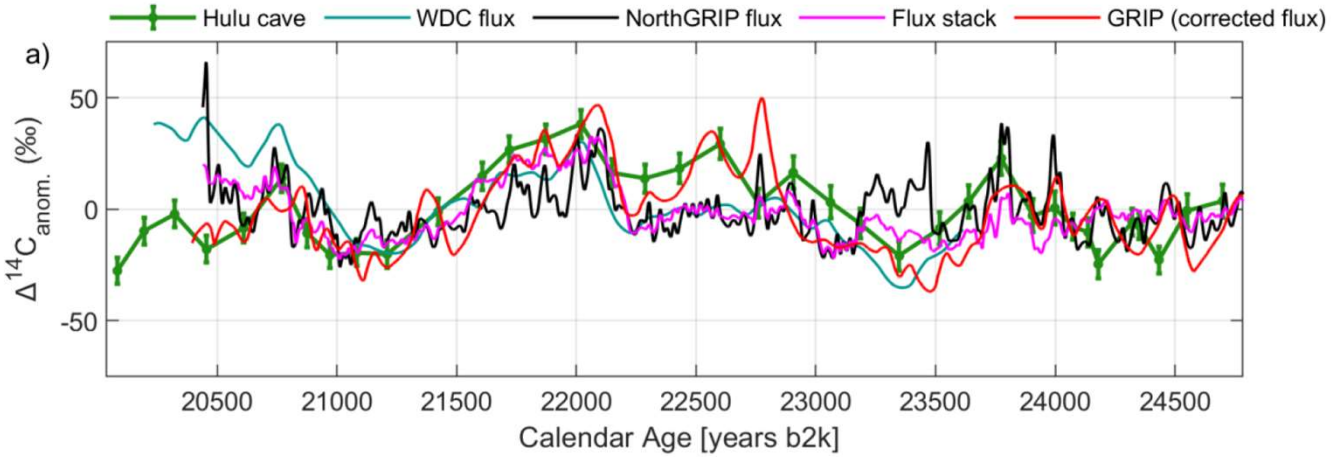
… but have outstanding precision



Hulu cave: 2σ dating uncertainties.
GICC05: Maximum Counting Error ranges.
Graph based on original kindly provided by Christo Buizert following Buizert et al., Clim. Past vol. 11, 2015.

Aligning ^{10}Be and IntCal / Δ^{14}C

- **Holocene**: Muscheler, Adolphi, Knudsen, QSR, 2014,
  GICC has ~65 years too many at the onset of the Holocene
- **LGM and Laschamp**: Adolphi et al., Clim. Past, 2018,
  GICC roughly right at 13-15 ka b2k
  GICC has 550 years too few years at 22 ka b2k (assym. uncertainty)
  GICC has ~250 years too few years at 42 ka b2k (0-500 years with 68.2% confidence)
- **Refining the LGM match** with more data: Sinnl et al., Clim. Past, accepted
  GICC has 375 years too few years at 22 ka b2k (75–625 years at 68% confidence):



Another constraint:
Dating the Z2 ash layer by ^{40}Ar/^{39}Ar: Groen & Storey, QSR, 2022, https://doi.org/10.1016/j.quascirev.2022.107526:
GICC has 740 years too few years at 22 ka b2k (2σ:±440 y) at 56 ka b2k.

Estimating time-scale differences by aligning climatic events

CENTRE FOR ICE AND CLIMATE

Clim. Past, 14, 1755–1781, 2018
https://doi.org/10.5194/cp-14-1755-2018

Climate of the Past Open Access EGU

Connecting the Greenland ice-core and U/Th timescales via cosmogenic radionuclides: testing the synchroneity of Dansgaard–Oeschger events

Florian Adolphi[1,2], Christopher Bronk Ramsey[3], Tobias Erhardt[1], R. Lawrence Edwards[4], Hai Cheng[4,5], Chris S. M. Turney[6], Alan Cooper[7], Anders Svensson[8], Sune O. Rasmussen[8], Hubertus Fischer[1], and Raimund Muscheler[2]

nature communications

Coupled atmosphere-ice-ocean dynamics during Heinrich Stadial 2

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Xiyu Dong[1], Gayatri Kathayat[1], Sune O. Rasmussen[2], Anders Svensson[2], Jeffrey P. Severinghaus[3], Hanying Li[1], Ashish Sinha[1,4], Yao Xu[1], Haiwei Zhang[1], Zhengguo Shi[1,5,6], Yanjun Cai[1], Carlos Pérez-Mejías[1], Jonathan Baker[1], Jingyao Zhao[1], Christoph Spötl[7], Andrea Columbu[8], Youfeng Ning[1], Nicolas M. Strikis[9], Shitao Chen[10,11,12], Xianfeng Wang[13], Anil K. Gupta[14], Som Dutt[15], Fan Zhang[1], Francisco W. Cruz[16], Zhisheng An[5], R. Lawrence Edwards[17] & Hai Cheng[1,5,18]

Climate of the Past Open Access

Clim. Past, 11, 153–173, 2015
www.clim-past.net/11/153/2015/
doi:10.5194/cp-11-153-2015

The WAIS Divide deep ice core WD2014 chronology – Part 1: Methane synchronization (68–31 ka BP) and the gas age–ice age difference

C. Buizert[1], K. M. Cuffey[2], J. P. Severinghaus[3], D. Baggenstos[3], T. J. Fudge[4], E. J. St[illegible] B. R. Markle[4], [illegible]wards[8], M. Sigl[9], M. Winstrup[4], R. H. Rhodes[1], E. J. Brook[1], T. A. Sowers[5], G. D. Clow[6], H. Cheng[7,8], J. R. McConnell[9], and K. C. Taylor[9]

Clim. Past, 16, 29–50, 2020
https://doi.org/10.5194/cp-16-29-2020

NALPS19: sub-orbital-scale climate variability recorded in northern Alpine speleothems during the last glacial period

Gina E. Moseley[1], Christoph Spötl[1], Susanne Brandstätter[1], Tobias Erhardt[2], Marc Luetscher[1,4], and R. Lawrence Edwards[3]

Climate of the Past Open Access EG

Science **369**, 963–969 (2020) 21 August 2020

GLOBAL CLIMATE CHANGE

Synchronous timing of abrupt climate changes during the last glacial period

Ellen C. Corrick[1,2]*, Russell N. Drysdale[1,2], John C. Hellstrom[3], Emilie Capron[4,5], Sune Olander Rasmussen[5], Xu Zhang[6,7,8], Dominik Fleitmann[9], Isabelle Couchoud[2,1], Eric Wolff[10]

Conclusions

- Holocene: time scales are converging although a lot of tedious work remains.
- In the glacial, GICC seems to have a problem in the LGM which is only barely accounted for in the quoted uncertainty
- Further back in MIS 3, we again come closer to good alignment with IntCal (U/Th).
- In MIS 3 GICC is much more accurate than estimated from annual-layer counting uncertainties.
  Estimate: GICC likely lacks no more than 500 years, or have no more than 200 years too much anywhere
  (while the quoted uncertainty, the MCE, is 800-2600 years).
- Below this, both absolute and relative uncertainties are larger because the annual layers can't be resolved, but GICC is likely accurate within a millenium.
- Questions, opinions or more constraints?
  Find me at Giulia Sinnl's poster:
  EGU23-289, Hall X3 position 66, Thursday 14:00-15:45