Inferring climate variability from replicated Antarctic ice-core water isotope records

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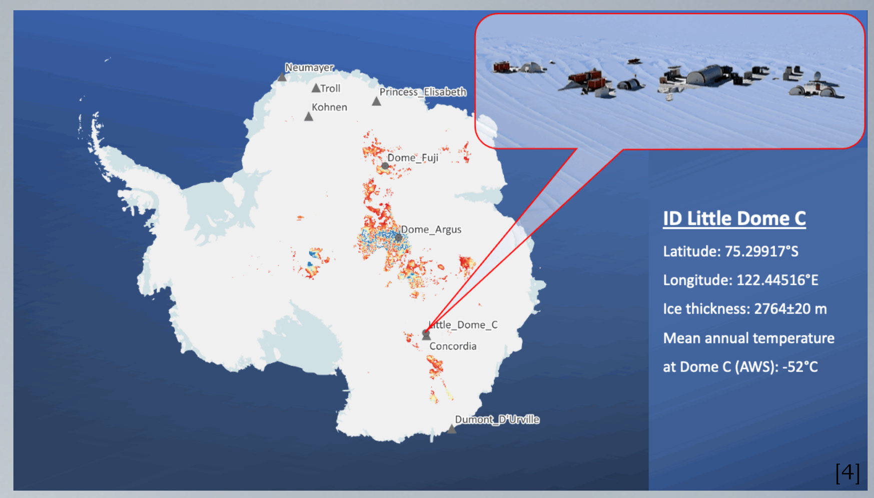
Sharing is encouraged

Motivation

Changes in climate variability are as critical to understand as changes in the mean climate, yet remain difficult to quantify from ice cores because single records are strongly affected by local noise arising from depositional, post-depositional, and diffusive processes. As a result, past changes in climate variability cannot be robustly separated from changes in ice-core noise using individual cores alone. This limitation can be overcome by analysing replicated ice-core records, where the common signal can be interpreted as climate-driven variability. For the first time, such an approach is now feasible for deep Antarctic ice cores through the paired water-isotope records of EPICA Dome C and the new Beyond EPICA Oldest Ice Core (BE-OIC), which together provide a replicated archive extending back 800,000 years. Here, we present first results from the upper ~ 300 m of the BE-OIC ice core focusing on Holocene variability in stable water isotopes, which are used as a proxy for temperature.



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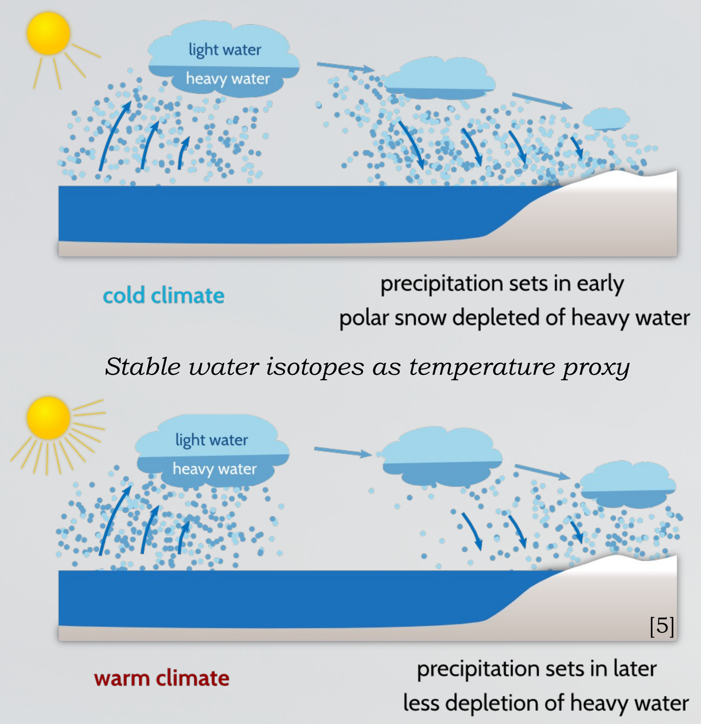
Outstanding Student & PhD candidate Presentation contest

Ice-cores are noisy climate archives (A)

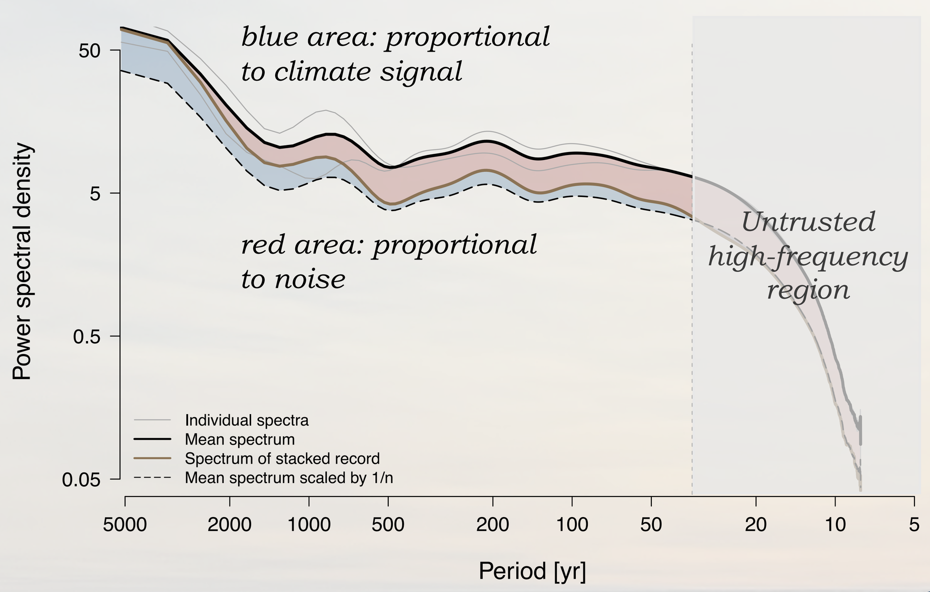


Wind-induced surface erosion and redistribution of snow, ice flow and variability in topography and precipitation intermittancy introduce noise into the single ice-core records.

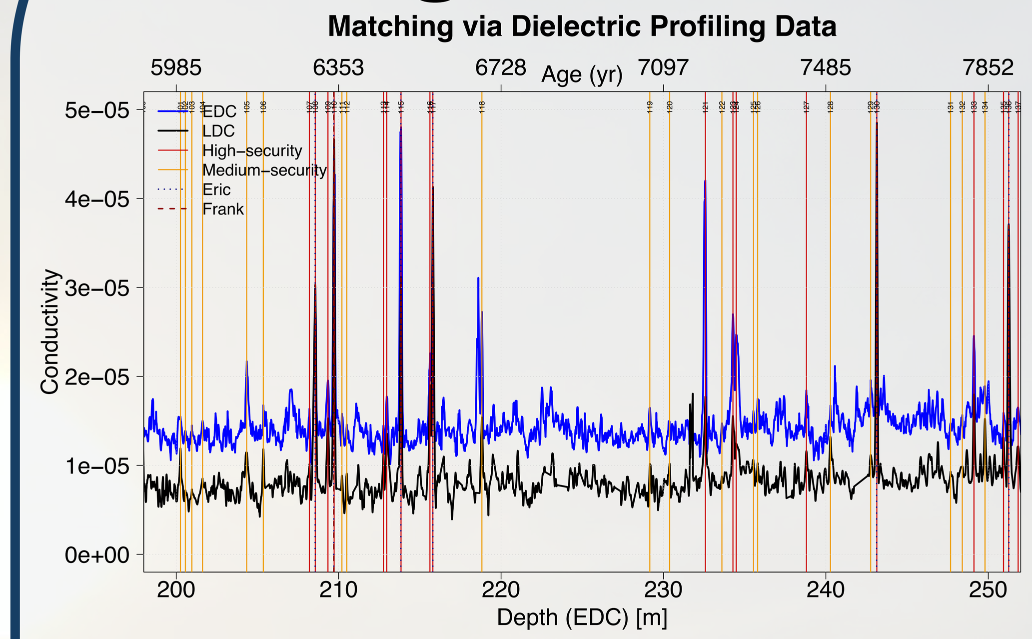
- **Single proxy spectra**: $X_i(f) = C(f) + N_i(f)$
  Common (Climate) signal plus Noise
- **Mean spectrum** for n records: $M(f) = \frac{1}{n}\sum_{i=1}^{n} X_i(f) = C(f) + N(f)$
  assuming independent noise with equal statistical properties
- **Spectrum of "stacked"/mean record**: $S(f) = \Phi(f)C(f) + \frac{1}{n}N(f)$
  Averaging in the time domain reduces noise by number of records
  $\Phi(f)$: linear transfer function accounting for time uncertainty

Stratigraphic Noise

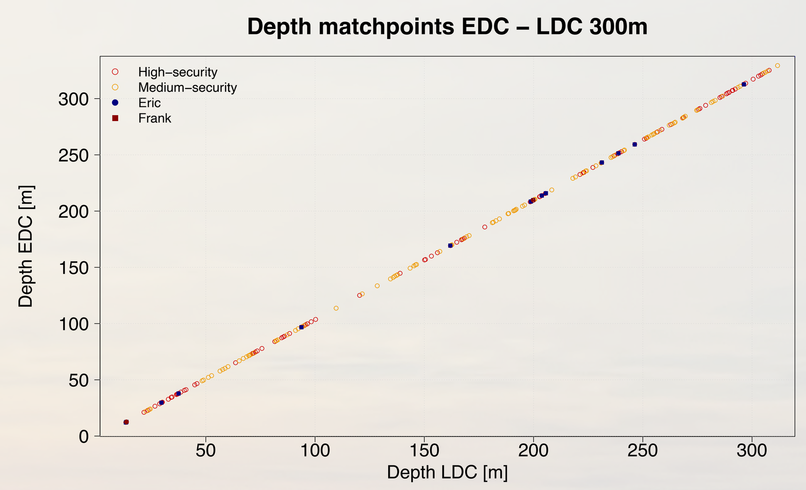
T. Laepple

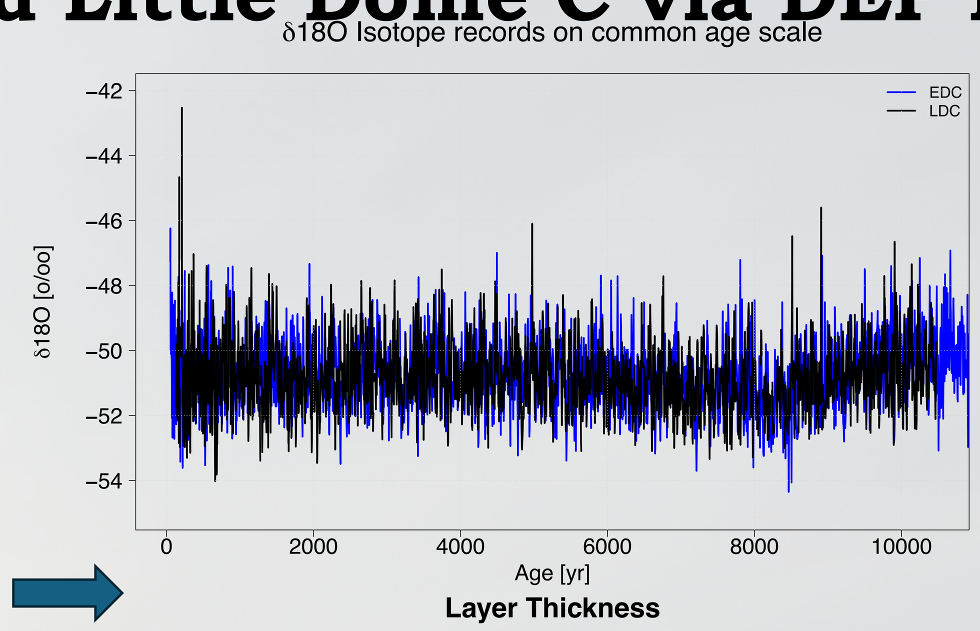


Matching of Dome C and Little Dome C via DEP Data (B)

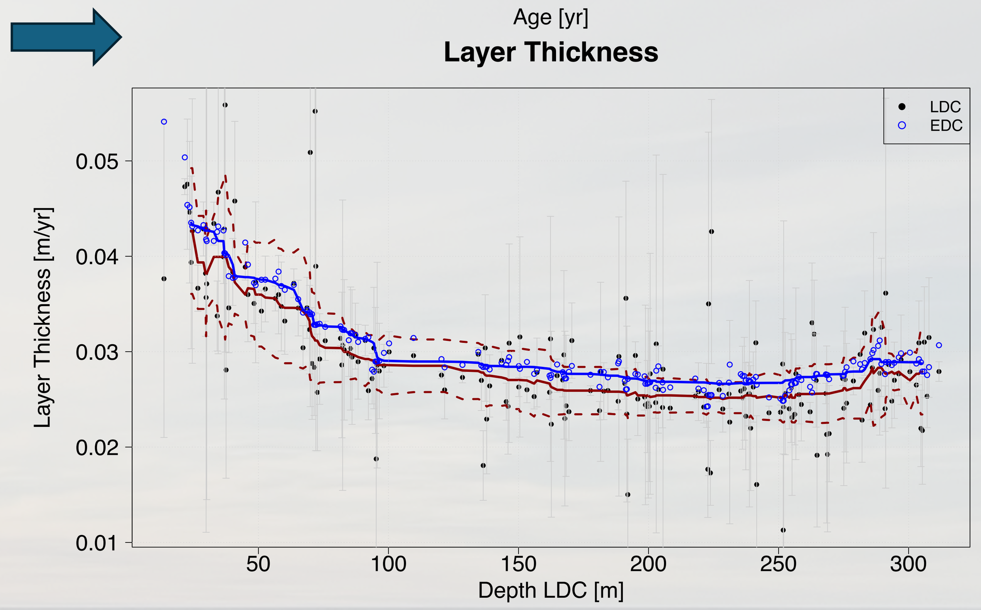


Matchpoints by Frank Wilhelms and Eric Wolff included in figures



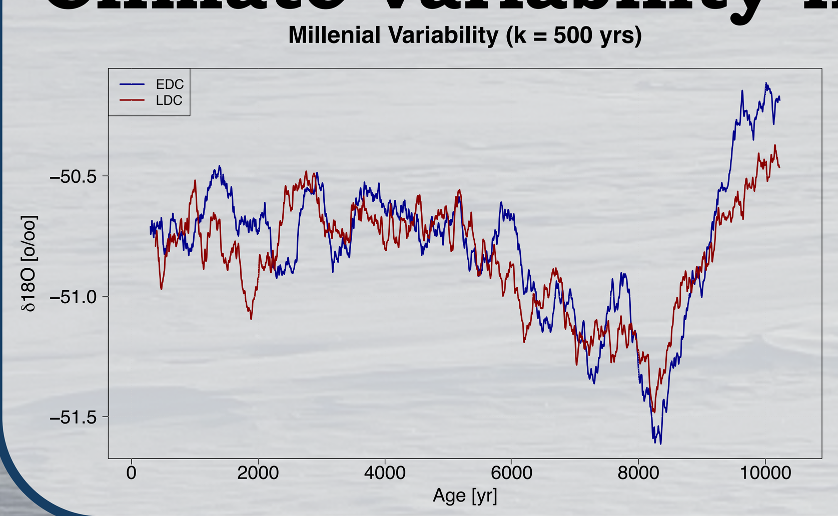


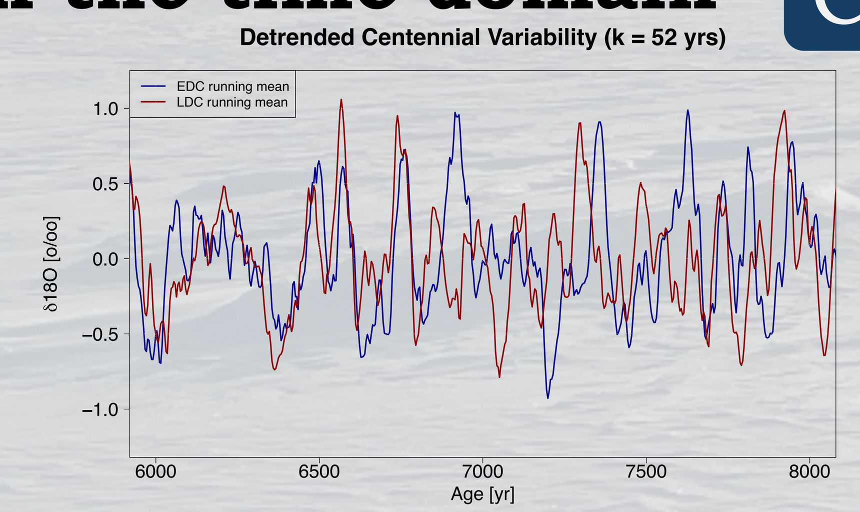
Dielectric Profiling measures the conductivity across the ice core which is altered by e.g. volcanic ash layers and therefore provides independent age markers.



The shift in isotope values as well as layer thickness at the end of the analysed section reveals a temperature change going along with a change in accumulation rate (8.2 ka cooling event).

Climate variability in the time domain (C)

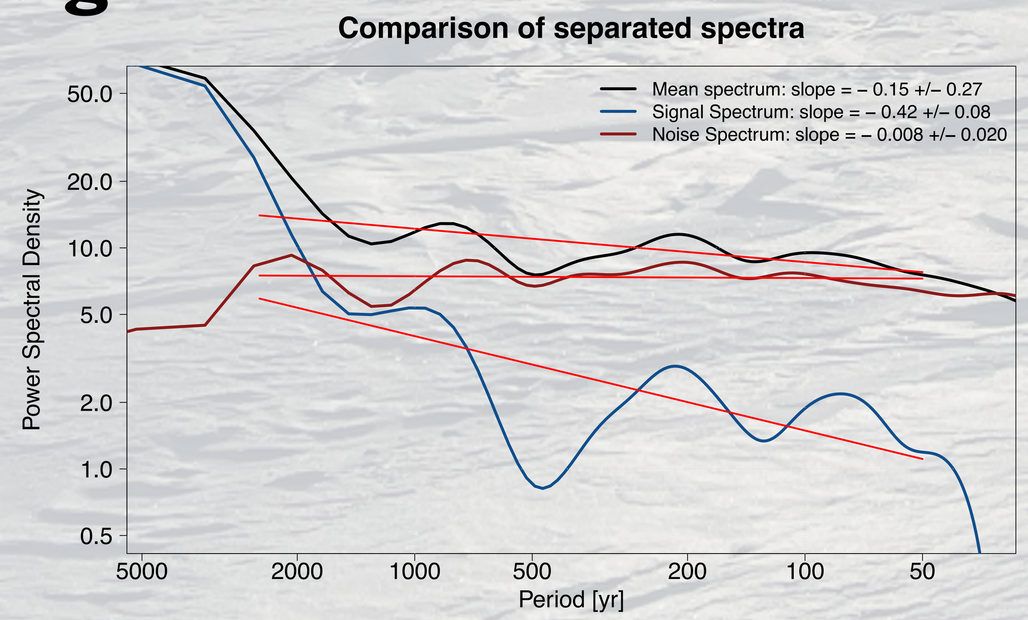




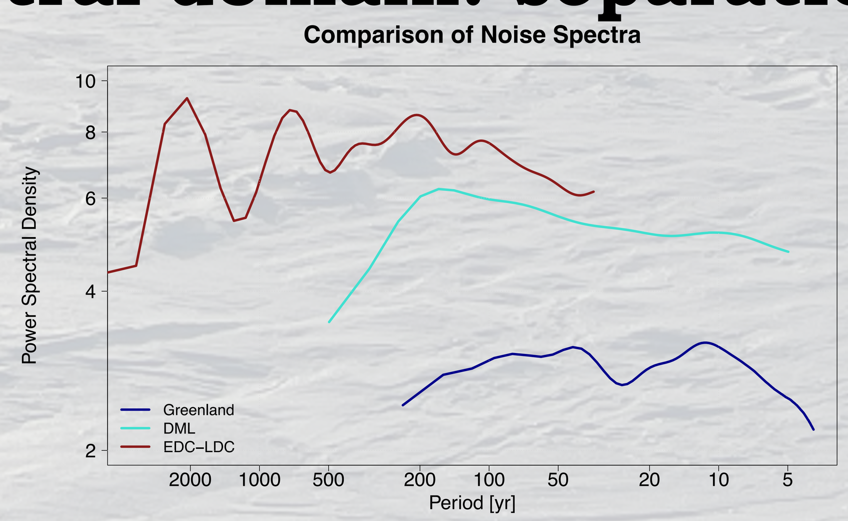
Take-home

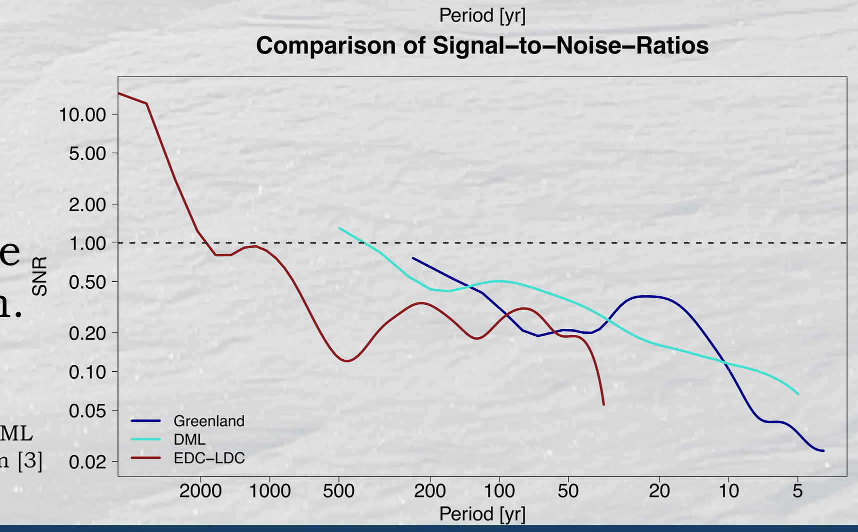
With the help of spectral analysis it is possible to separate the common climate signal from local noise for this unique pair of replicated Antarctic ice-core records, with the climate signal dominating on the millenial-scale, and noise being dominant in the centennial and sub-centennial high-frequency domain.

Climate variability in the spectral domain: separation of climate signal and local noise (D)



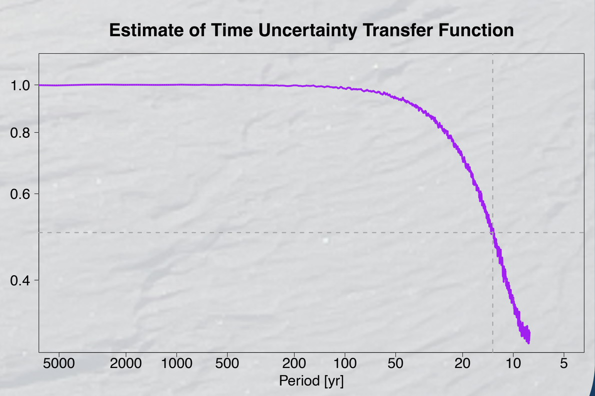
Separating the climate signal increases the slope of the power-law fit, while the noise follows a white spectrum. The comparison to Greenland and DML reveals an increase of noise with decreased resolution/accumulation rate.





Greenland & DML data taken from [3]

The high-frequency part of the spectra is influenced by diffusion, **time uncertainty** and numerical effects.



Sources

[1] *Münch, T., Laepple, T. (2018). What climate signal is contained in decadal- to centennial-scale isotope variations from Antarctic ice cores? Clim. Past, 14, 2053–2070, 2018, https://doi.org/10.5194/cp-14-2053-2018*

[2] *Hirsch, N., Dolman, A. M., Münch, T., & Laepple, T. (2025). Greenland ice core isotope variability strongly influenced by systematic changes in depositional noise. Geophysical Research Letters, 52, e2025GL116529. https://doi.org/10.1029/2025GL116529*

[3] *McPartland, M., Münch, T., Dolman A., Hébert, R., Laepple, T. (2025). The colors of proxy noise. Clim. Past, 21, 1917-1931, 2025, https://doi.org/10.5194/cp-21-1917-2025*

[4] *https://www.beyondepica.eu/en/*

[5] *https://www.physics-in-a-nutshell.com/article/16/evidence-for-the-earths-climate-history*

[6] *Gkinis, V., Dahl-Jensen, D., Steffensen, J., Vinther, B., Landais, A., Jouzel, J., Masson-Delmotte, V., Cattani, O., Minster, B., Grisart, A., Hörhold, M., Stenni, B., Selmo, E. (2021). Oxygen-18 isotope ratios from the EPICA Dome C ice core at 11 cm resolution [dataset]. PANGAEA, https://doi.org/10.1594/PANGAEA.939445*