On the similarity and apparent cycles of isotopic variations in East Antarctic snow and ice cores

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Cycles in climatic parameters (?)

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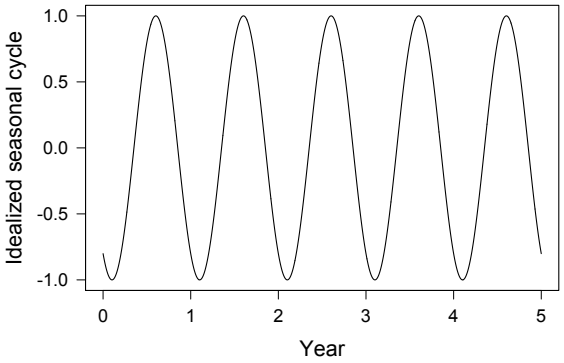
Cycles in climatic parameters (?)

Periodic seasonal cycle (temperature).



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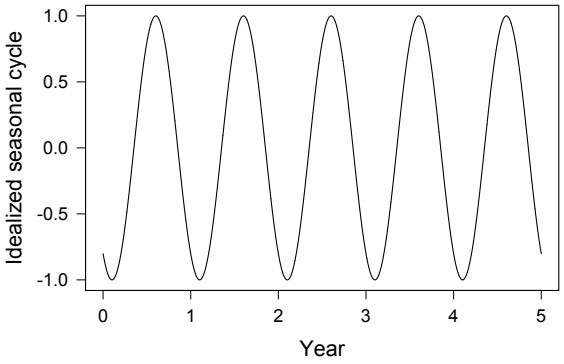
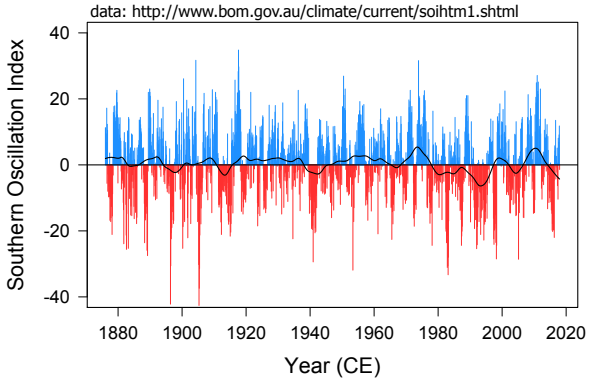


Quasi-periodic oscillations (e.g. ENSO).



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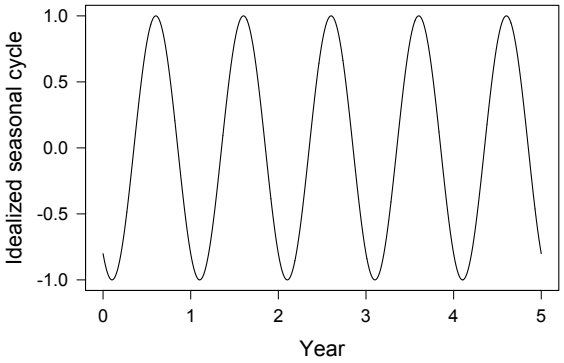

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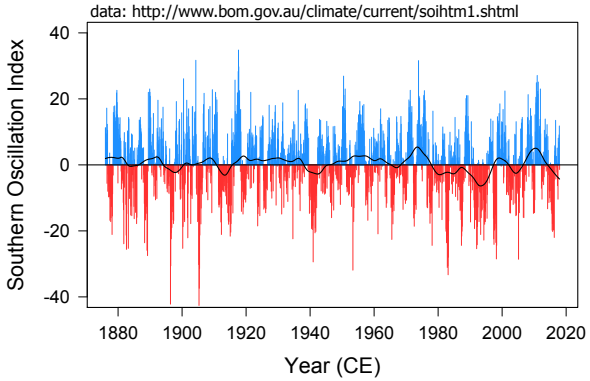
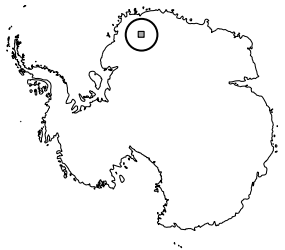
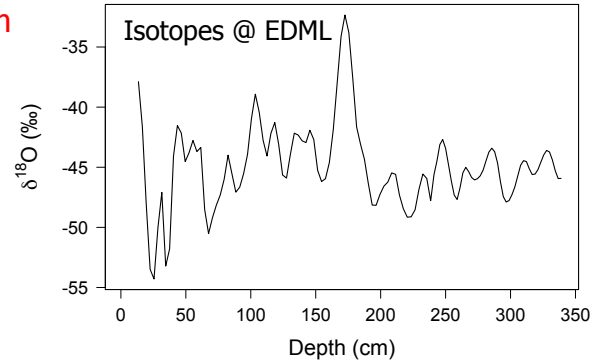




warm

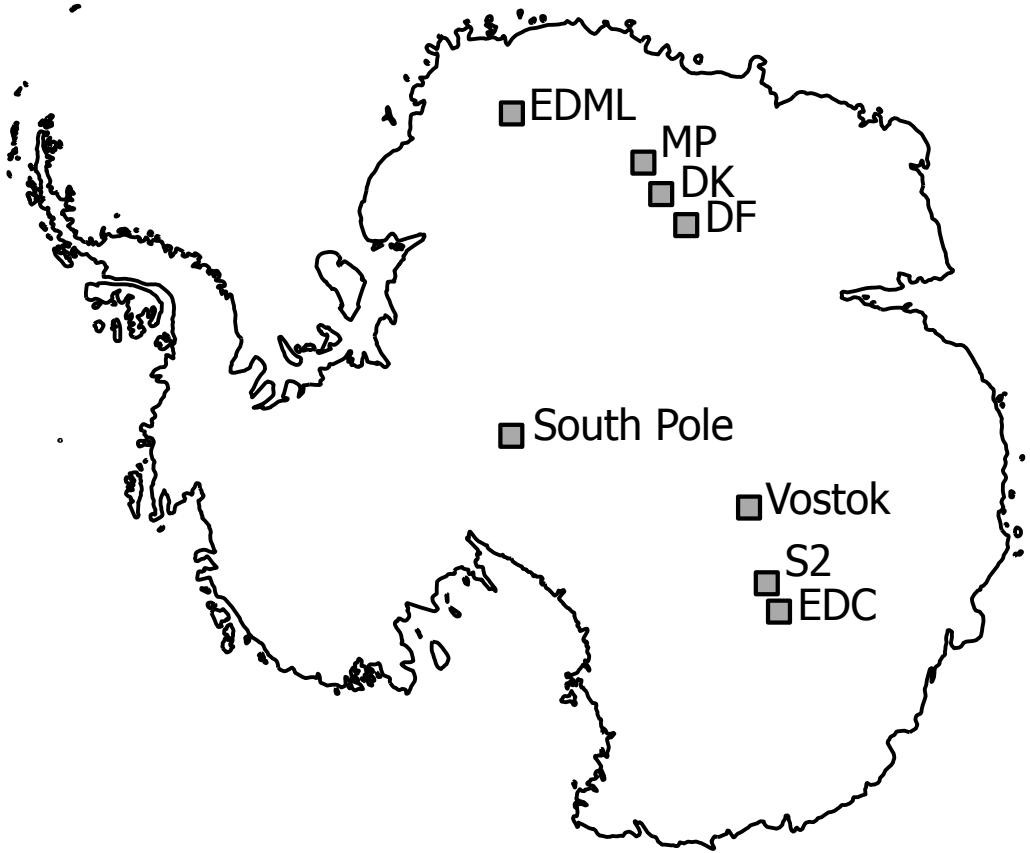
cold



- Stable isotopes from Antarctic snow are interpreted as proxy for temperature.
- What is the **origin of the apparent cycles** in the isotopic time series?

Münch et al. (2017), Cryosphere

Similar “cycles” in East Antarctic isotope profiles



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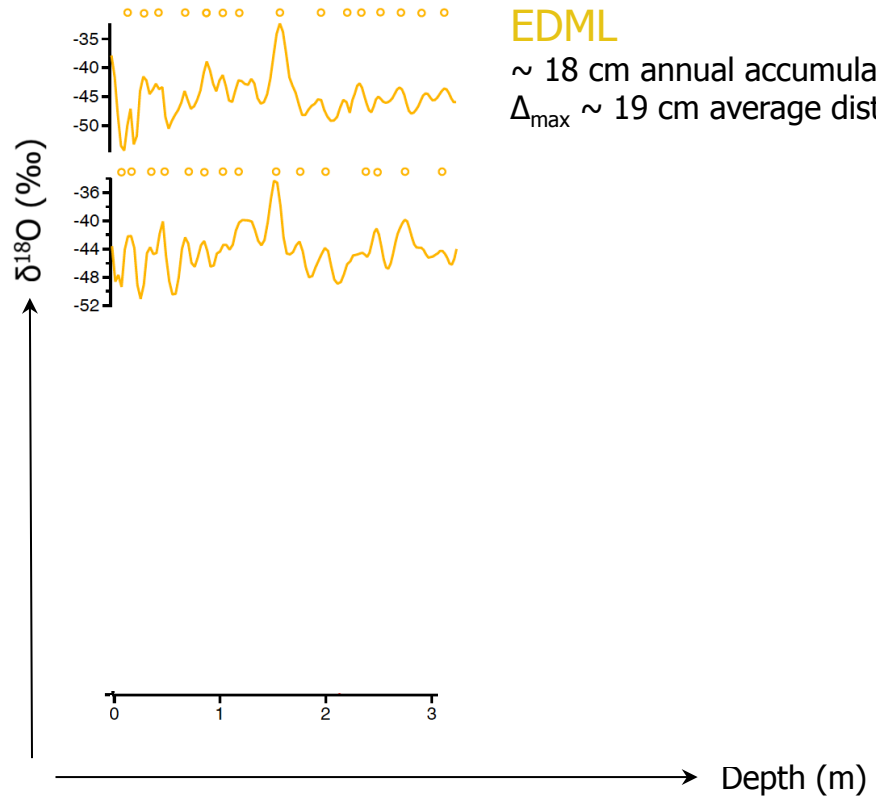
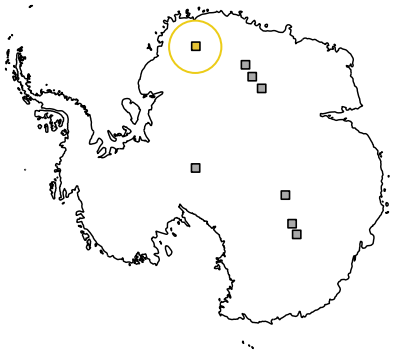


EDML

~ 18 cm annual accumulation of snow

Δ_{max} ~ 19 cm average distance between maxima



Casado et al. (2017), Cryosphere Disc.

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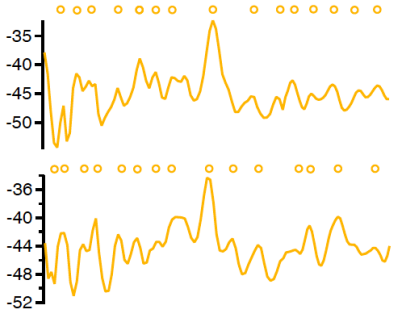

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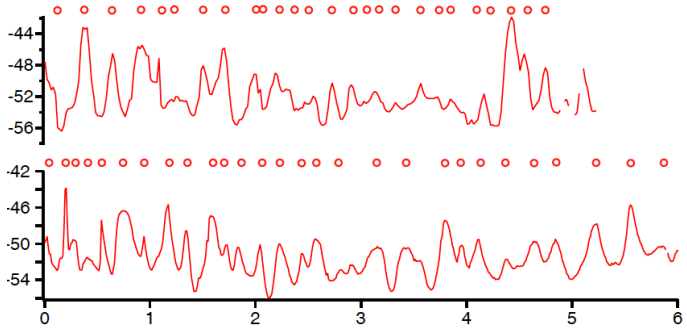

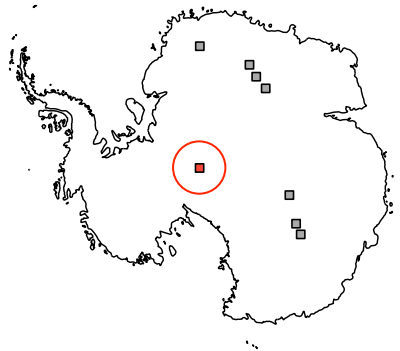

South Pole

accum. ~ 20 cm

Δ_{max} ~ 20 cm

$\delta^{18}O$ (‰)

Depth (m)

Casado et al. (2017), Cryosphere Disc.

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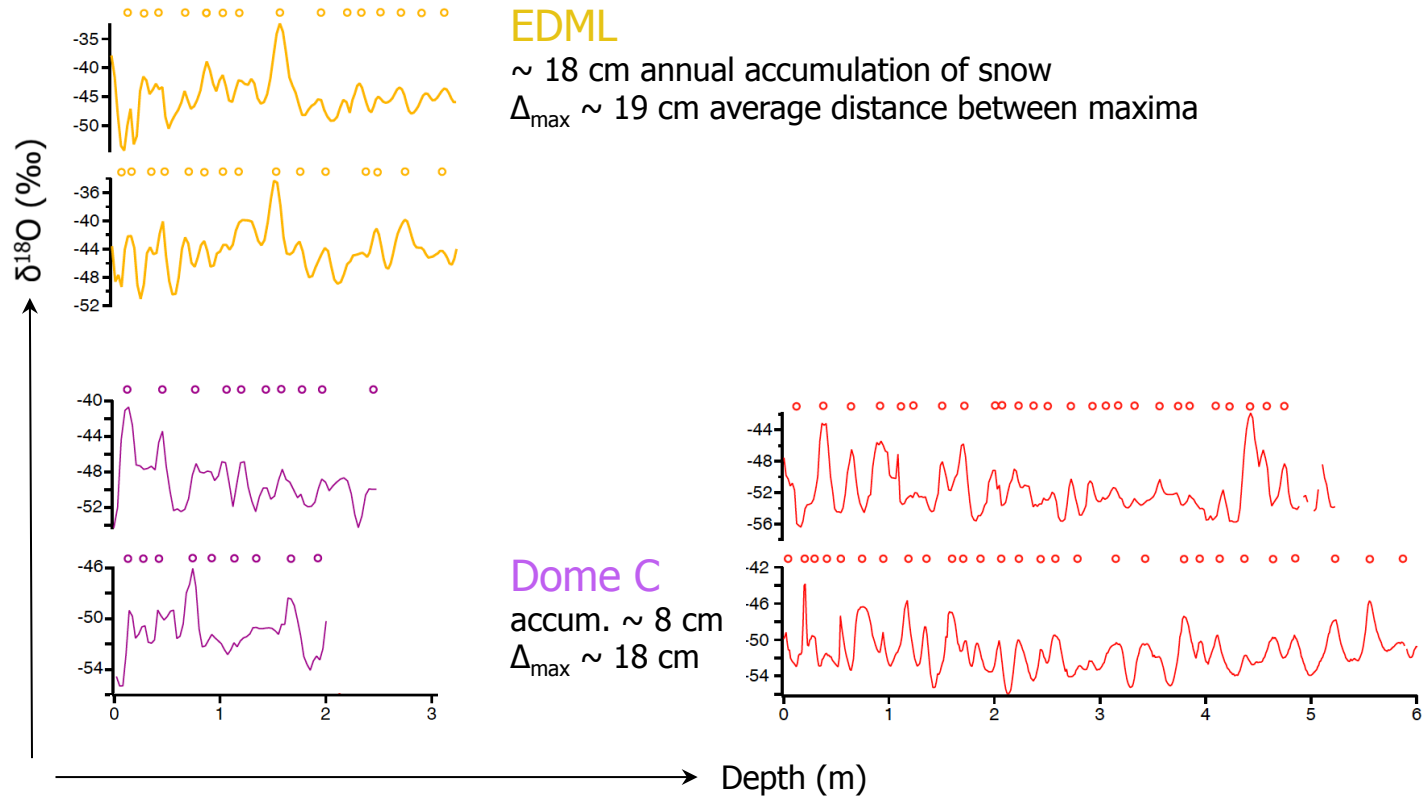
Similar “cycles” in East Antarctic isotope profiles



EDML

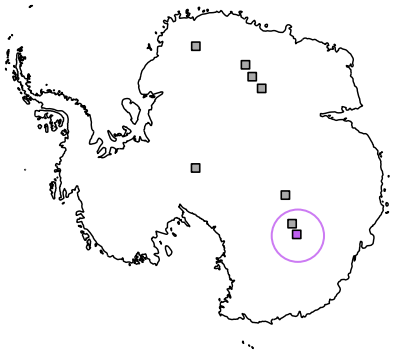
~ 18 cm annual accumulation of snow

Δ_{max} ~ 19 cm average distance between maxima

Dome C

accum. ~ 8 cm

Δ_{max} ~ 18 cm



South Pole

accum. ~ 20 cm

Δ_{max} ~ 20 cm

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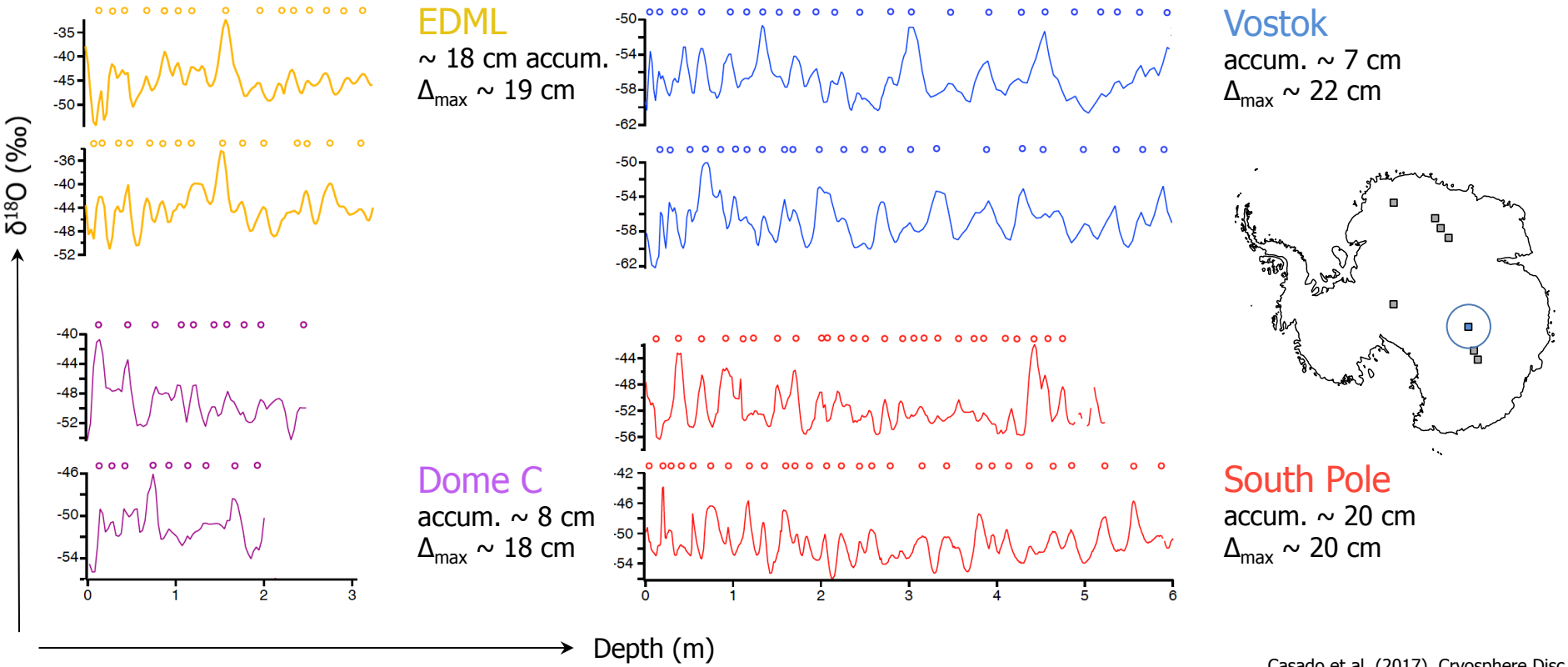

EDML
~ 18 cm accum.
Δ_{max} ~ 19 cm

Vostok
accum. ~ 7 cm
Δ_{max} ~ 22 cm

Dome C
accum. ~ 8 cm
Δ_{max} ~ 18 cm

South Pole
accum. ~ 20 cm
Δ_{max} ~ 20 cm

Casado et al. (2017), Cryosphere Disc.

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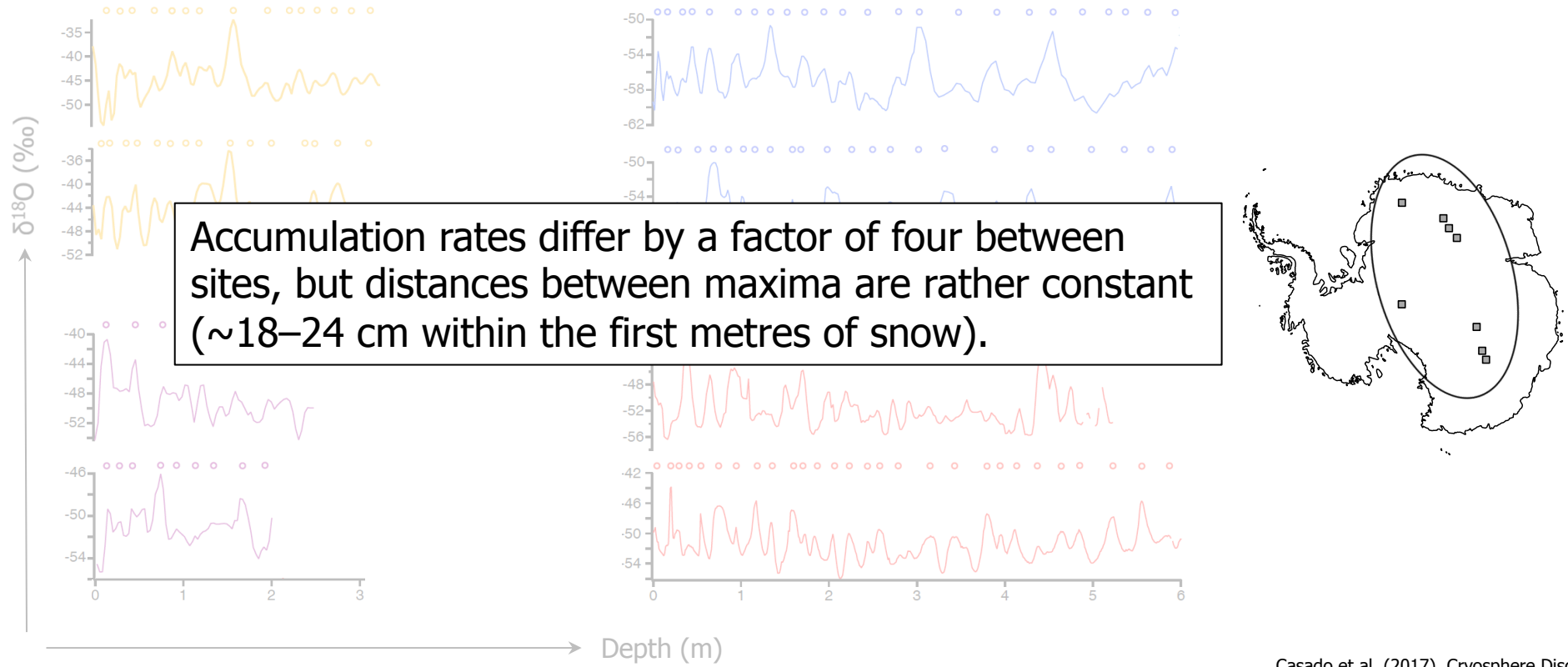
Similar “cycles” in East Antarctic isotope profiles



Accumulation rates differ by a factor of four between sites, but distances between maxima are rather constant (~18–24 cm within the first metres of snow).

Casado et al. (2017), Cryosphere Disc.

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Understanding observed cycles

1. Mathematics for crossing statistics of random noise: Rice's formula

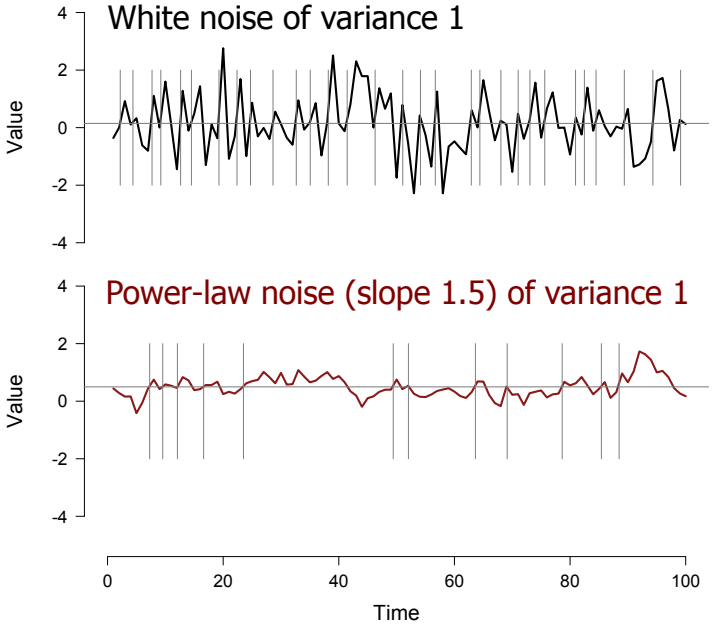
2. Model for signal formation of isotope profiles

Rice’s formula

How often does a random time series cross the zero line / have maxima?

Rice's formula

How often does a random time series cross the zero line / have maxima?



Rice's formula

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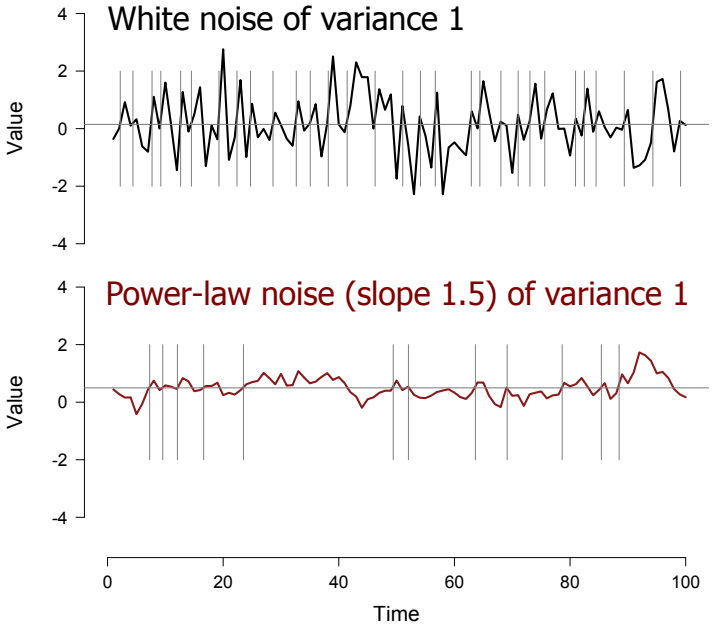

- Formula by S. O. Rice (Rice, 1944, 1945):

Expected distance between upward crossings:

$$\Delta^{+} = 2\pi\sqrt{\frac{\Omega_0}{\Omega_2}} \propto \sqrt{\frac{\mathrm{var}(X)}{\mathrm{var}(X')}}$$

Expected distance between maxima:

$$\Delta_{\max} = 2\pi\sqrt{\frac{\Omega_2}{\Omega_4}} \propto \sqrt{\frac{\mathrm{var}(X')}{\mathrm{var}(X'')}}$$

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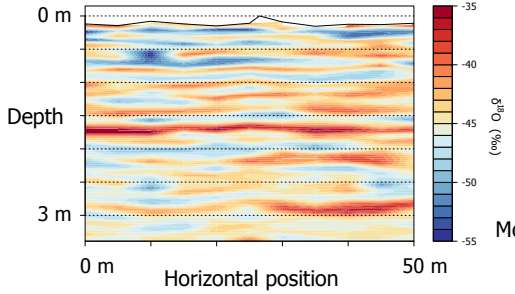
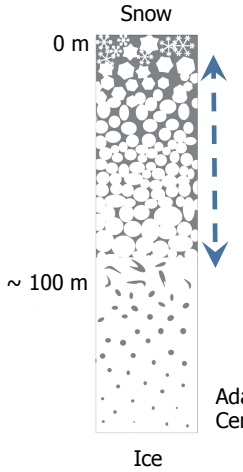
Isotope profiles qualitatively



On local scale: large spatial variability created in depositional process.

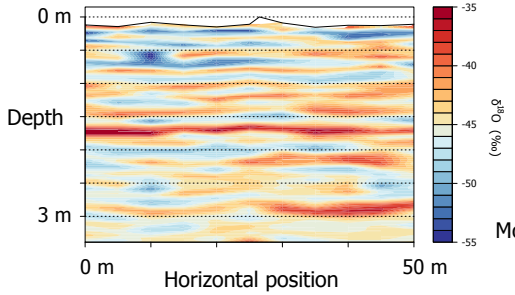
Modified from: Münch et al. (2018), Cryosphere



With depth: smoothing due to diffusional mixing of vapour within the snow and firn column.

Adapted from:
Centre for Ice and Climate, University of Copenhagen

Isotope profiles qualitatively



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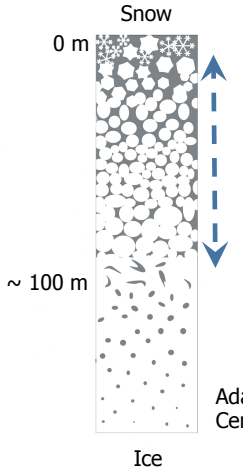

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➢ Null hypothesis:
Rice's formula for diffused white noise:

$$\Delta_{\max} = 2\pi\sqrt{\frac{2}{3}}\sigma$$

Diffusion length
~ similar across sites.

Laepple et al. (2018), Cryosphere

(More realistic) Forward model for isotope profiles

1. Isotopic seasonal cycle driven by local temperatures.

2. Part of variance (fraction ξ) transferred to noise in depositional process.

3. Diffusion and densification of signal.

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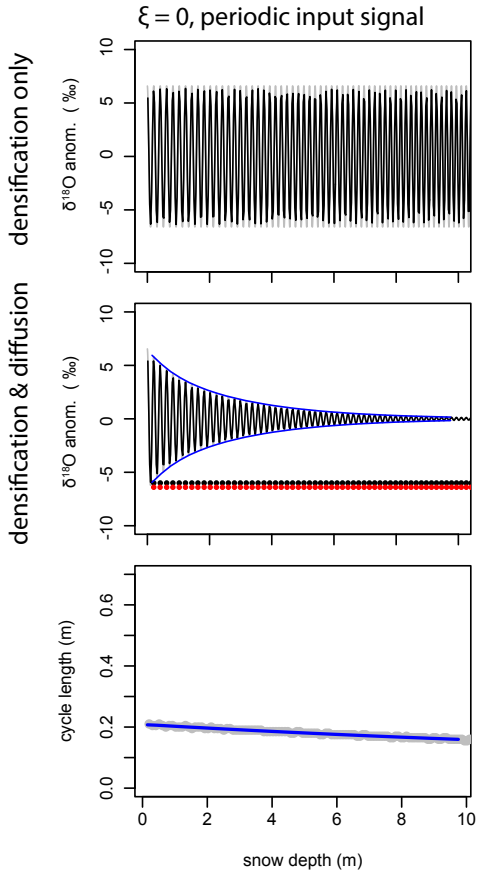
Structure of isotopic signal & cycle length



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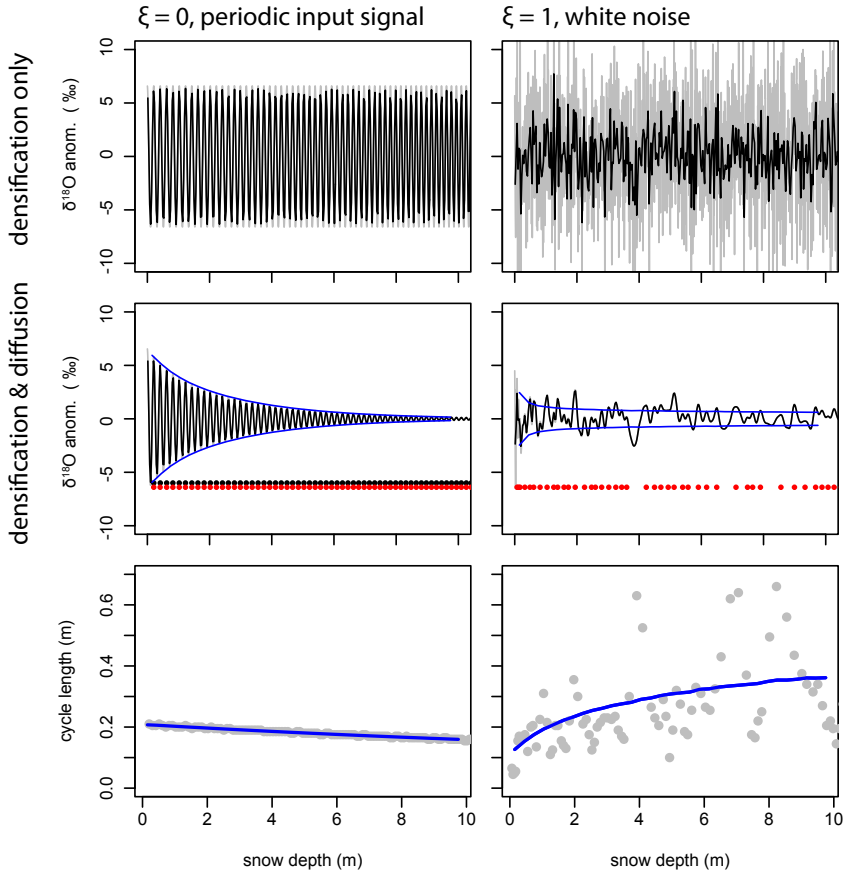

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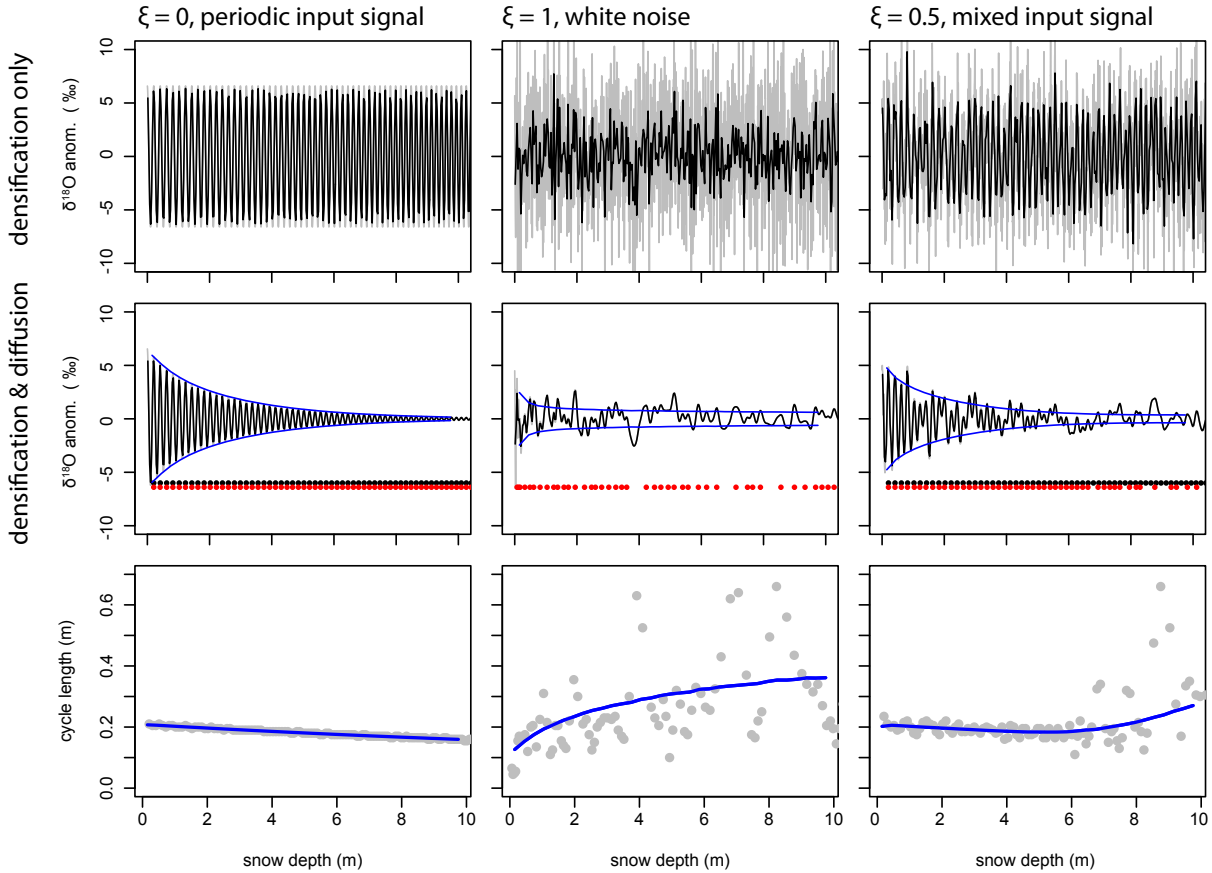
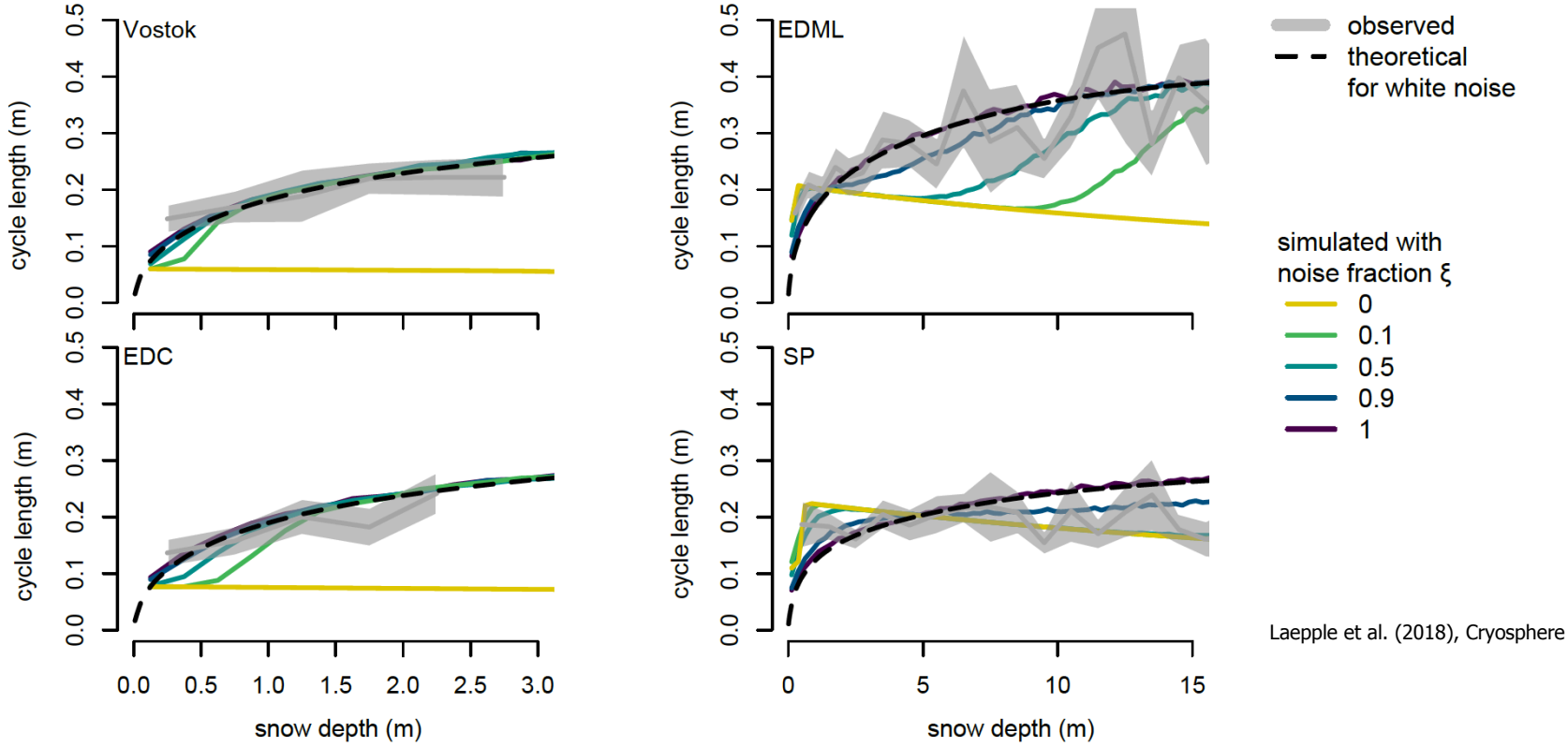


Depth dependency of "cycle length" informs about nature of signal.

Laepple et al. (2018), Cryosphere

Observed vs. theoretical “cycle lengths”



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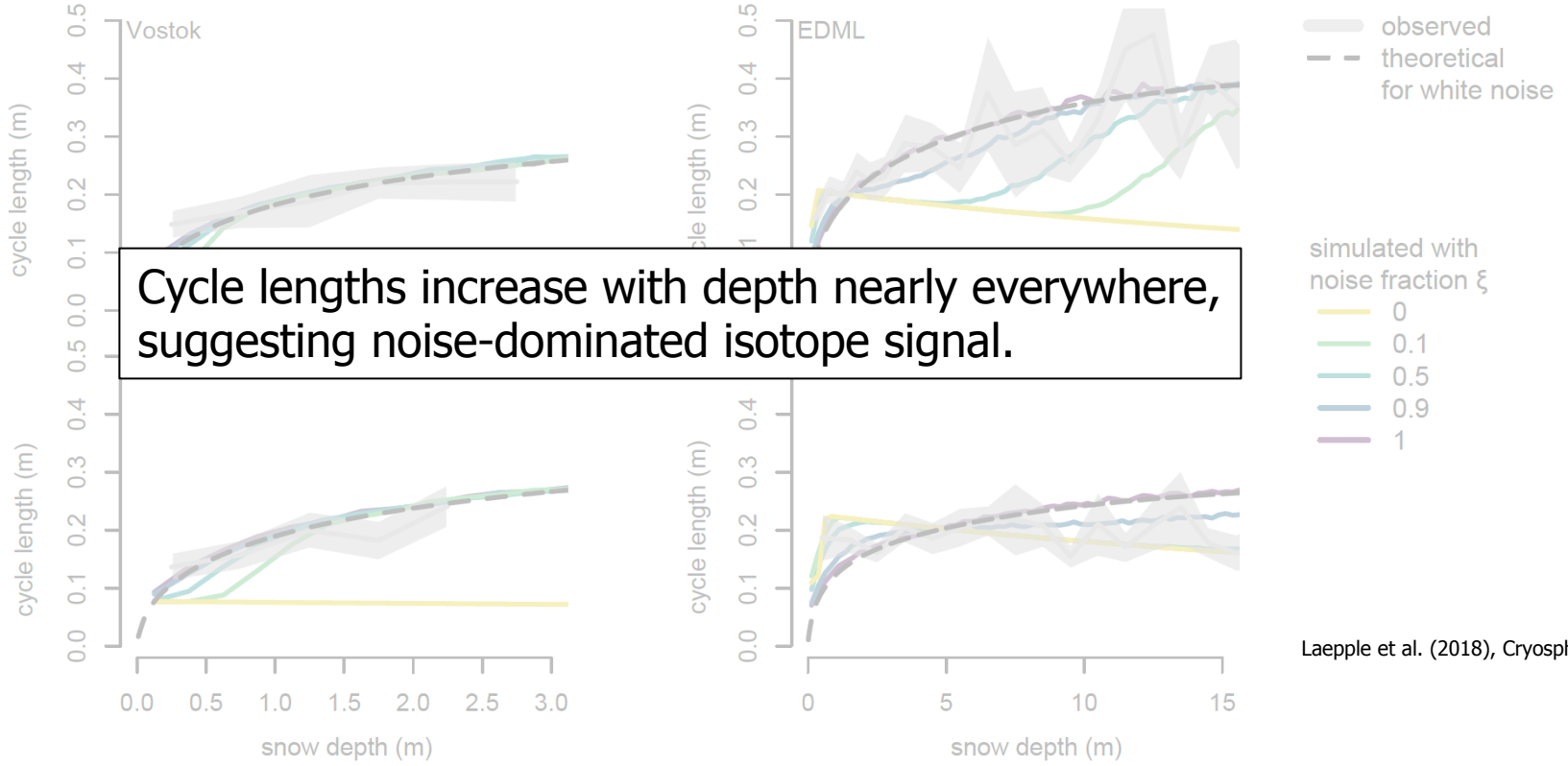
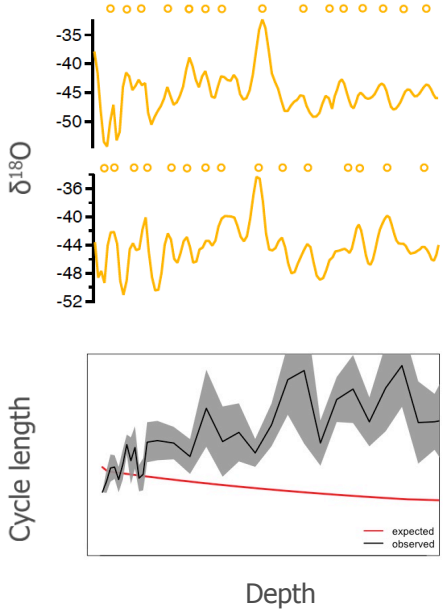


Cycle lengths increase with depth nearly everywhere, suggesting noise-dominated isotope signal.

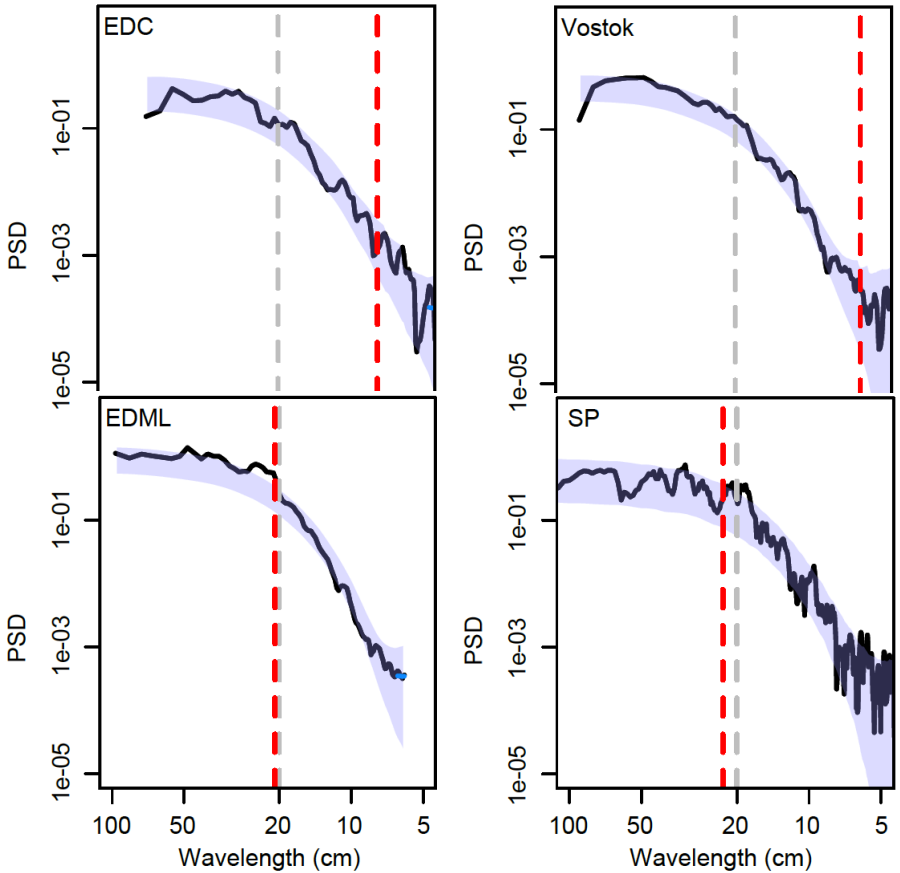
Laepple et al. (2018), Cryosphere

Summary

- Similar “cycle lengths” across East Antarctic are no direct climatic features but effect of diffusional smoothing.
- This suggests a mostly noise-dominated isotope signal.
- Similar smoothing effects could be important for other proxies, e.g. bioturbation in marine sediments.
- for more details:
  Laepple, Münch, et al. (2018), The Cryosphere, 12(1), 169–187.



Similar power spectra across Antarctic sites



No significant spectral power around the wavelengths corresponding to either the annual accumulation rate or the average "cycle" length.

Laepple et al. (2018), Cryosphere