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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Periodic seasonal cycle (temperature).

Similarity and apparent cycles of East Antarctic isotope variations

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Cycles in climatic parameters (?)

- Periodic seasonal cycle (temperature).
- Quasi-periodic oscillations (e.g. ENSO).

Idealized seasonal cycle

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

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Cycles in climatic parameters (?)

Periodic seasonal cycle (temperature).

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

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

South Pole

EDML

Vostok

S2

EDC

DK

DF

MP
Similar “cycles” in East Antarctic isotope profiles

EDML

$\sim 18$ cm annual accumulation of snow
$\Delta_{\text{max}} \sim 19$ cm average distance between maxima

Casado et al. (2017), Cryosphere Disc.
Similar “cycles” in East Antarctic isotope profiles

**EDML**
- ~ 18 cm annual accumulation of snow
- $\Delta_{\text{max}}$ ~ 19 cm average distance between maxima

**South Pole**
- accum. ~ 20 cm
- $\Delta_{\text{max}}$ ~ 20 cm

Casado et al. (2017), Cryosphere Disc.
Similar “cycles” in East Antarctic isotope profiles

EDML
- ~ 18 cm annual accumulation of snow
- $\Delta_{\text{max}} \sim 19$ cm average distance between maxima

Dome C
- accum. ~ 8 cm
- $\Delta_{\text{max}} \sim 18$ cm

South Pole
- accum. ~ 20 cm
- $\Delta_{\text{max}} \sim 20$ cm

Casado et al. (2017), Cryosphere Disc.
Similar “cycles” in East Antarctic isotope profiles

EDML
- Accumulation: ≈ 18 cm
- $\Delta_{\text{max}}$: ≈ 19 cm

Dome C
- Accumulation: ≈ 8 cm
- $\Delta_{\text{max}}$: ≈ 18 cm

Vostok
- Accumulation: ≈ 7 cm
- $\Delta_{\text{max}}$: ≈ 22 cm

South Pole
- Accumulation: ≈ 20 cm
- $\Delta_{\text{max}}$: ≈ 20 cm

Casado et al. (2017), Cryosphere Disc.
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).
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?

White noise of variance 1

Power-law noise (slope 1.5) of variance 1
Rice’s formula

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

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

**Expected distance between upward crossings:**

\[
\Delta^+ = 2\pi \sqrt{\frac{\Omega_0}{\Omega_2}} \propto \sqrt{\frac{\text{var}(X)}{\text{var}(X')}}
\]

**Expected distance between maxima:**

\[
\Delta_{\text{max}} = 2\pi \sqrt{\frac{\Omega_2}{\Omega_4}} \propto \sqrt{\frac{\text{var}(X')}{\text{var}(X'')}}
\]
Isotope profiles qualitatively

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

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

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

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

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

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

Null hypothesis: Rice’s formula for diffused white noise:

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

Diffusion length ~ similar across sites.

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

Adapted from: Centre for Ice and Climate, University of Copenhagen
(More realistic) Forward model for isotope profiles

1. Isotopic seasonal cycle driven by local temperatures.

2. Part of variance (fraction $\xi$) transferred to noise in depositional process.

3. Diffusion and densification of signal.
Structure of isotopic signal & cycle length

Structure of isotopic signal & cycle length

\[ \xi = 0, \text{periodic input signal} \]

\[ \xi = 1, \text{white noise} \]

\[ \xi = 0.5, \text{mixed input signal} \]

\[ \text{densification only} \]

\[ \text{densification & diffusion} \]

\[ \text{cycle length (m)} \]

\[ \text{snow depth (m)} \]

Laeppele et al. (2018), Cryosphere
Structure of isotopic signal & cycle length

Similarity and apparent cycles of East Antarctic isotope variations

Laepple et al. (2018), Cryosphere
Structure of isotopic signal & cycle length

\[ \xi = 0, \text{periodic input signal} \quad \xi = 1, \text{white noise} \quad \xi = 0.5, \text{mixed input signal} \]

Density only

Density & diffusion

Depth dependency of “cycle length” informs about nature of signal.

Laeppele et al. (2018), Cryosphere
Observed vs. theoretical “cycle lengths”

Laepple et al. (2018), Cryosphere

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Laeppele et al. (2018), Cryosphere
Observed vs. theoretical “cycle lengths”

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

Laeppele 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.

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.

Laeppe et al. (2018), Cryosphere