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Laki to Tambora

Pattern Recognition in High Resolution Volcanic and Isotopic Signals

Thea Quistgaard¹

¹University of Copenhagen

February 9, 2021

Outline of talk

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Diffusion of Water Isotopes

Fick's 2nd law:

$$\frac{\partial \delta}{\partial t} = D(t) \frac{\partial^2 \delta}{\partial z^2} - \dot{\epsilon}_z(t) z \frac{\partial \delta}{\partial z} \tag{1}$$

$$\delta_{\mathsf{meas}}(z) = S(z)[\delta_{\mathsf{init}}(z) * \mathcal{G}(z)]$$
 (2)

$$\mathcal{G}(z) = \frac{1}{\sigma(z)\sqrt{2\pi}}e^{-\frac{z^2}{2\sigma(z)^2}}, \quad \text{a Gaussian filter,} \quad (3)$$

$$S(z) = e^{\int_0^z \dot{\epsilon_z}(z')dz'},$$
 the thinning function (4)

Diffusion in Firn

Diffusion of Water

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$$\delta_{\text{meas}}(z) = S(z)[\delta_{\text{init}}(z) * \mathcal{G}(z)] \tag{2}$$

where $\delta_{\rm meas}(z)$ is the measured signal, $\delta_{\rm init}(z)$ is the initial isotopic signal

$$\mathcal{G}(z) = \frac{1}{\sigma(z)\sqrt{2\pi}}e^{-\frac{z^2}{2\sigma(z)^2}}, \quad \text{a Gaussian filter,} \quad (3)$$

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Example Data: Site A

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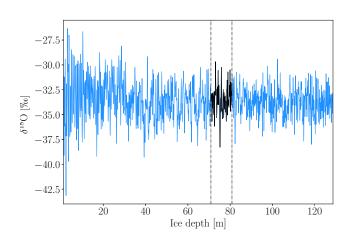


Figure: Example data from Alphabet Core drilled at site A near Crête.

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Unevenly Sampled Data: Spline Interpolation

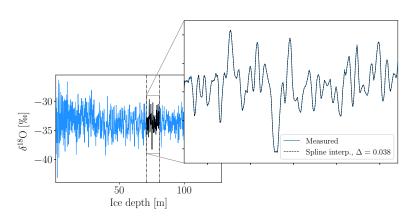


Figure: Example data from Alphabet Core drilled at site A near Crête. Shows zoom in of data from Laki to Tambora along with spline interpolated data.



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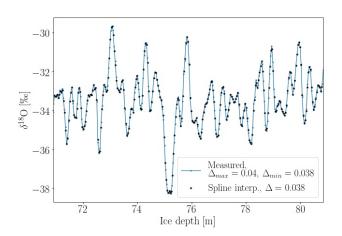


Figure: Site A, raw and cubic spline interpolated data.

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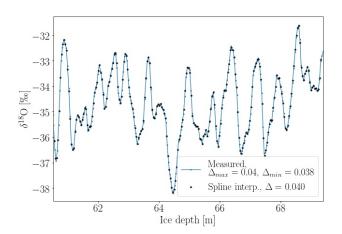


Figure: Site G, raw and cubic spline interpolated data.

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Site A: Density and Diffusion Profiles

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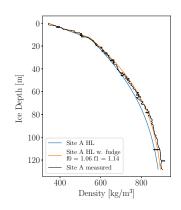
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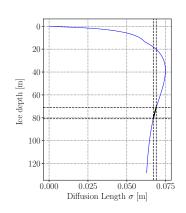
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- (a) Density-depth profiles based on analytical Herron-Langway model. Black is empirical data, blue is purely analytical fit and orange is fudged analytical fit
- (b) Modeled diffusion length profile based on empirically computed density profile. Black dashed lines indicate ice depth corresponding to date Laki and Tambora eruptions.



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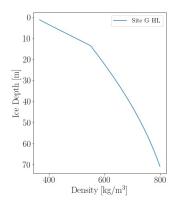
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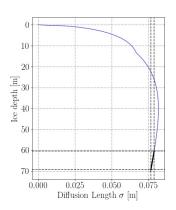
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Site G: Density and Diffusion Profiles





- (a) Density-depth profiles based on analytical Herron-Langway model. Black is empirical data, blue is purely analytical fit and orange is fudged analytical fit
- (b) Modelled diffusion length profile based on empirically computed density profile. Black dashed lines indicate ice depth corresponding to date Laki and Tambora eruptions.



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Laki and Tambora

- Electrical Conductivity Measurements (ECM)
- (Dielectric Profiling (DEP))

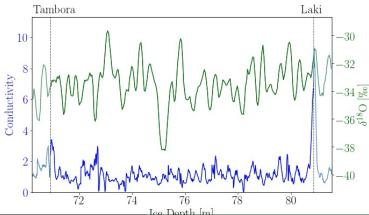


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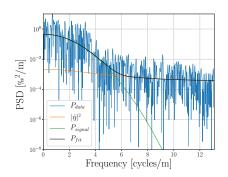
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$$P_{\rm tot} = P_{\rm signal} + |\hat{\eta}|^2$$

$$|\hat{\eta}|^2 = \frac{\sigma_{\eta}^2 \Delta}{|1 - a_1 e^{-ik\Delta}|^2}$$

$$P_{\rm signal} = P_0 e^{-k^2 \sigma^2}$$

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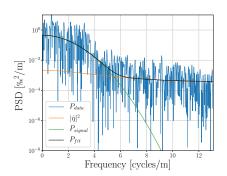
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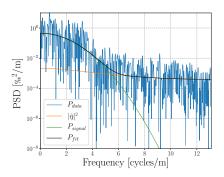
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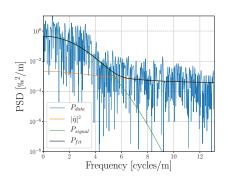
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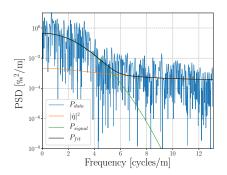
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Diffusion Lengths and Transfer Functions

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$$\hat{\delta}_{\text{meas}} = \hat{\delta}_{\text{init}} \cdot \hat{M} \Leftrightarrow \hat{\delta}_{\text{init}} = \hat{\delta}_{\text{meas}} \cdot \hat{M}^{-1} \tag{5}$$

Add an optimal Wiener filter to enhance signal and minimize noise:

$$\hat{F} = \frac{P_{\text{signal}}}{P_{\text{signal}} + |\hat{\eta}|^2} \tag{6}$$

$$\hat{\delta}_{\text{init}} = \hat{\delta}_{\text{meas}} \cdot \hat{F} \cdot \hat{M}^{-1} = \hat{\delta}_{\text{meas}} \cdot \hat{R} \tag{7}$$

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Diffusion Lengths and Transfer Functions

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Filtering

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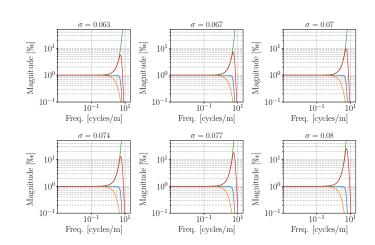


Figure: Frequency filters: The optimal filter found from the PSD (blue), the transfer function (orange), the inverse of the transfer function (green) and the combined signal restoration filter (red).

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- SciPy.signal.find_peaks
- N = 32 years btw Tambora and Laki Eruptions
- Best diffusion length estimate algorithm
- Interpolations and resampling

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Diffusion Length Estimate Algorithm

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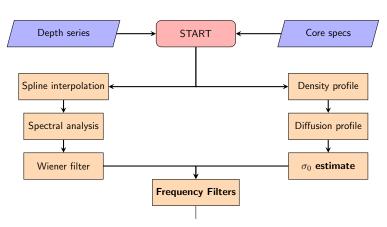


Figure: Flowchart of method for diffusion length computation, preliminary analysis steps.

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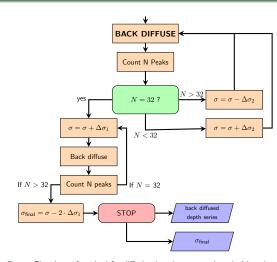


Figure: Flowchart of method for diffusion length computation, decision chart.

Diffusion Length V. Peaks - No Limit

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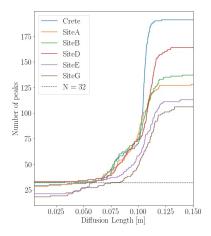


Figure: Diffusion length used in back diffusion versus counted number of peaks in data series for all cores.



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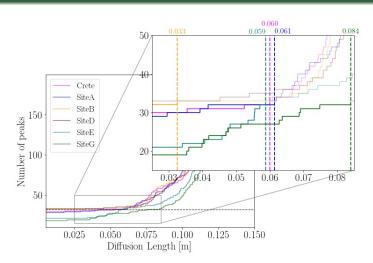
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 $\label{eq:figure:Zoom-in} \textit{Figure: Zoom-in around N} = 32 \; \textit{peaks and corresponding diffusion length used in back diffusion}.$

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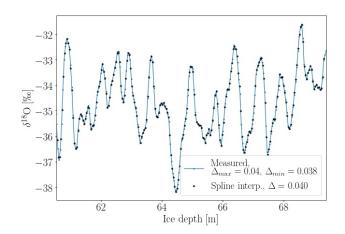


Figure: Cubic spline resampling of raw data.

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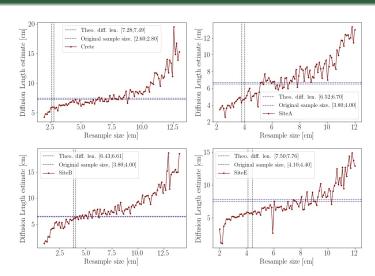


Figure: Resampling size versus diffusion length estimate_to_result; in N = 32 peaks. \equiv \mid = \checkmark 0 \triangleleft 0

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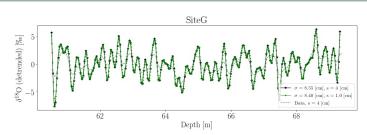
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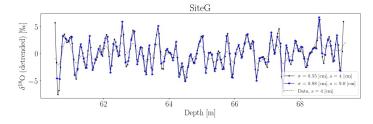


Figure: Deconvoluted data with resampling of 1 and 9 cm intervals after deconvolution, but before peak



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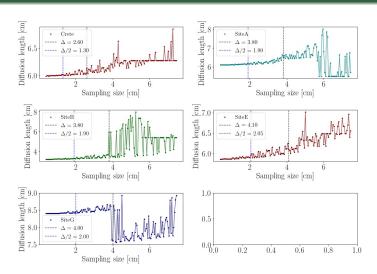


Figure: Resampling size after deconvolution versus diffusion length estimate to result in N = 32 peaks. \sim 0 0

Site A: Theoretical V. Estimated Diffusion Length

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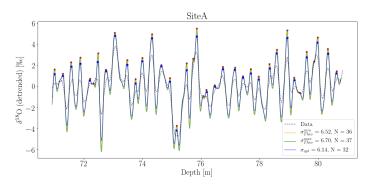


Figure: Data and back diffused signal, using theoretically predicted diffusion lengths and diffusion length estimated through analysis, Site A.

Site G: Theoretical V. Estimated Diffusion Length

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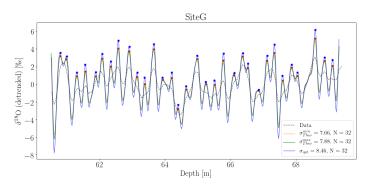


Figure: Data and back diffused signal, using theoretically predicted diffusion lengths and diffusion length estimated through analysis, Site G.

Diffusion Lengths, All Cores

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	Crete	Site A	Site B	Site E	Site G
σ_{Theo}^{min} [cm]	7.28	6.52	6.43	7.50	7.66
σ_{Theo}^{max} [cm]	7.49	6.70	6.61	7.76	7.88
σ_{est} [cm]	6.02	6.14	3.27 (N = 32)	5.95	8.46
			5.85 (N = 33)		

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Linear Interpolation, 50 and 100 cm gaps

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Diffusion of Wate Isotopes

Volcanic Horizo

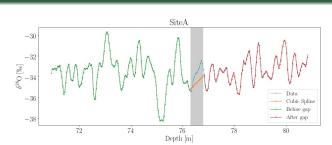
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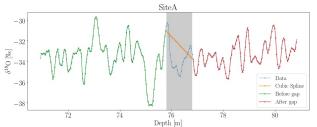
Analysis

Random Gaps/Missing Data

Linear Timesca

O...blool





Laki to Tambora

Linear Interpolation, 50 and 100 cm gaps

T. Quistgaar

Readying th Signals

Diffusion of Wate Isotopes

Volcanic Horizo

Continue

Analysis

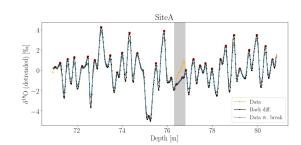
Peak Detect

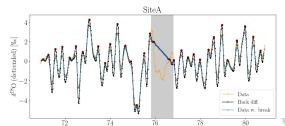
Random

Gaps/Missing Data

Linear Timesca







Laki to Tambora

Cubic Spline Interpolation

T. Quistgaaı

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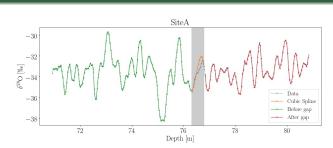
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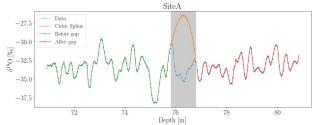
Allalysis

Random Gaps/Missing Data

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Laki to Tambora

Cubic Spline Interpolation

i. Quistguard

Readying th Signals

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Back Diffusion

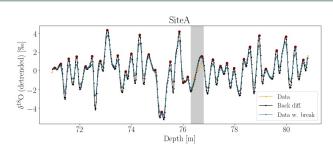
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D--!- D-+--

Random

Gaps/Missing Data

Linear Timesc



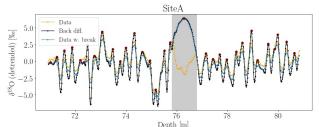




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Linear Timescale

Laki to Tambora

Crete

T. Quistgaard

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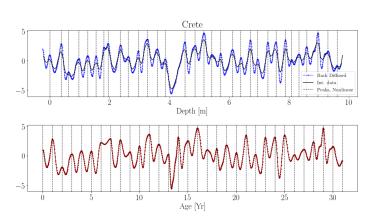


Figure: Data series on nonlinear and linearized timescales, Crete.

Site A

T. Quistgaar

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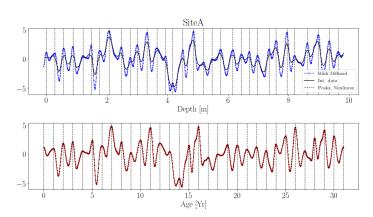


Figure: Data series on nonlinear and linearized timescales, Site A.

Site G

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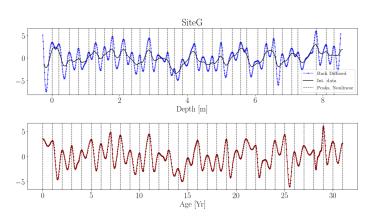


Figure: Data series on nonlinear and linearized timescales, Site G.

Further Work

I. Quistgaai

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Analysis Peak Detection

Random Gaps/Missing Data Linear Timescale

- Peaks and troughs
- Accumulation seasonality
- ECM data back diffusion
- Missing data reconstruction
- Peak/cycle detection through standardization and classification

Thank you!

I. Quistgaai

Readying the Signals

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Any questions?

Actual Total Diffusion

Γ. Quistgaar

Total diffusion in ice and firn

$$\sigma_{\rm tot}(z)^2 = [S(z)\sigma_{\rm firm}(z)]^2 + \sigma_{\rm ice}(z)^2 \tag{8} \label{eq:sigma}$$

Giving an actual measured diffusion length at z_i of

$$\sigma(z_i)^2 = \sigma_{\mathsf{firn}}(z_i)^2 S(z_i) + \sigma_{\mathsf{ice}}(z_i)^2 + \sigma_{\mathsf{dis}}(z_i)^2$$
 (9)

with

$$\sigma_{\mathsf{dis}}(z_i)^2 = \frac{2\Delta(z_i)^2}{\pi^2} \ln\left(\frac{\pi}{2}\right) \tag{10}$$

Actual Total Diffusion

Γ. Quistgaard

Total diffusion in ice and firn

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Laki and Tambora

Γ. Quistgaard

- Electrical Conductivity Measurements (ECM)
- Dielectric Profiling (DEP)

