Importance of measurement precision for high frequency water isotope data

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1. Introduction to diffusion and deconvolution

- Diffusion smooths out water isotope record from ice cores
- High frequencies can be restored using deconvolution

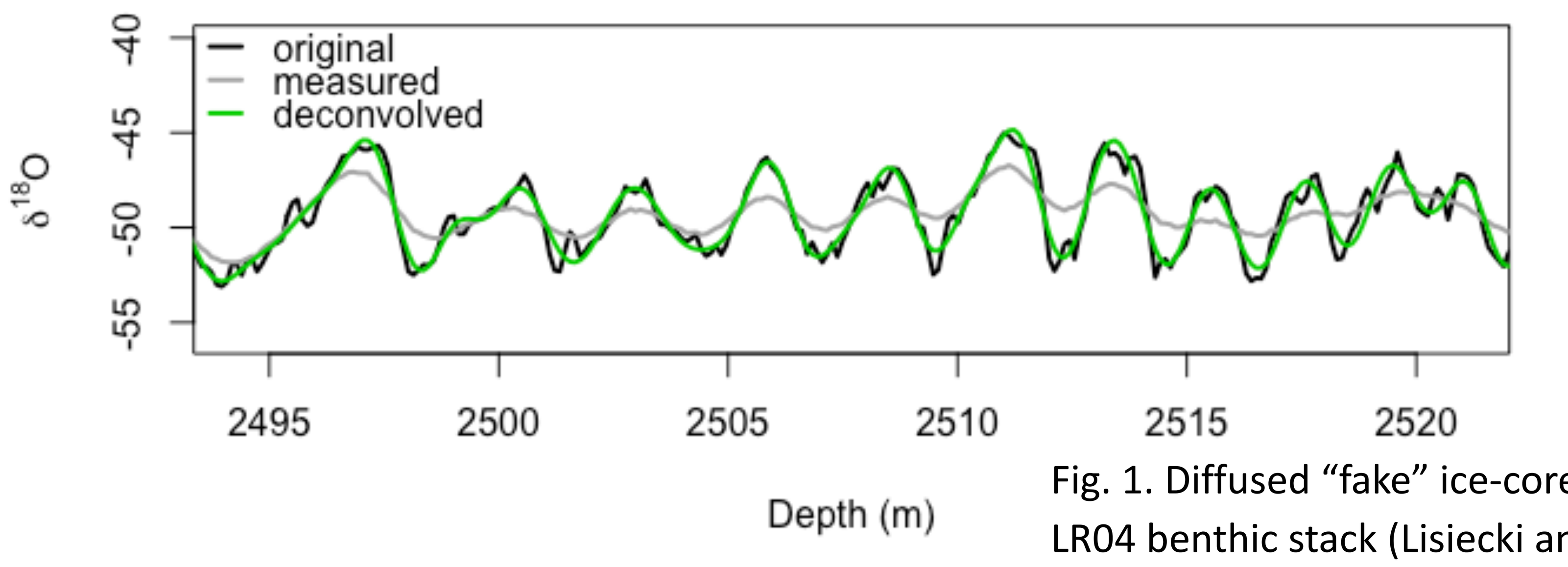

Fig. 1. Diffused “fake” ice-core record created using the LR04 benthic stack (Lisiecki and Raymo, 2005)

- Can represent a diffused timeseries in the frequency domain using Eqn. 1 (Johnsen et al., 2000)

$$P(f) = P_0(f)e^{-(2\pi f\sigma)^2} + N \quad (1)$$

Where
P_0 = power spectral density (PSD) of record before diffusion
f = frequency
σ = diffusion length
N = measurement noise

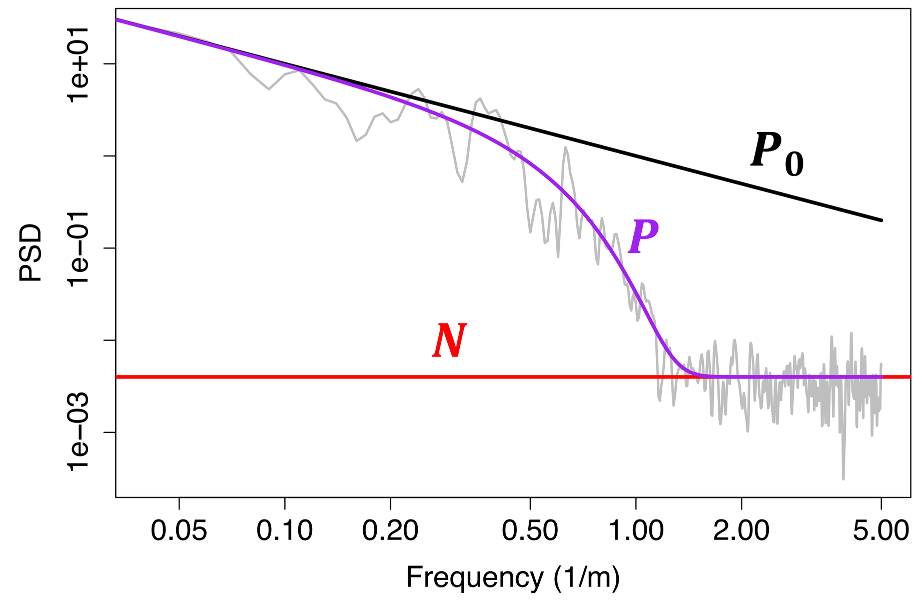

Fig. 2. Spectral representation of diffusion

2. How to recover higher frequencies?

- Higher measurement precision enables higher frequencies to be recovered through deconvolution
- Want to quantify how much frequency information is gained for a given drop in measurement noise

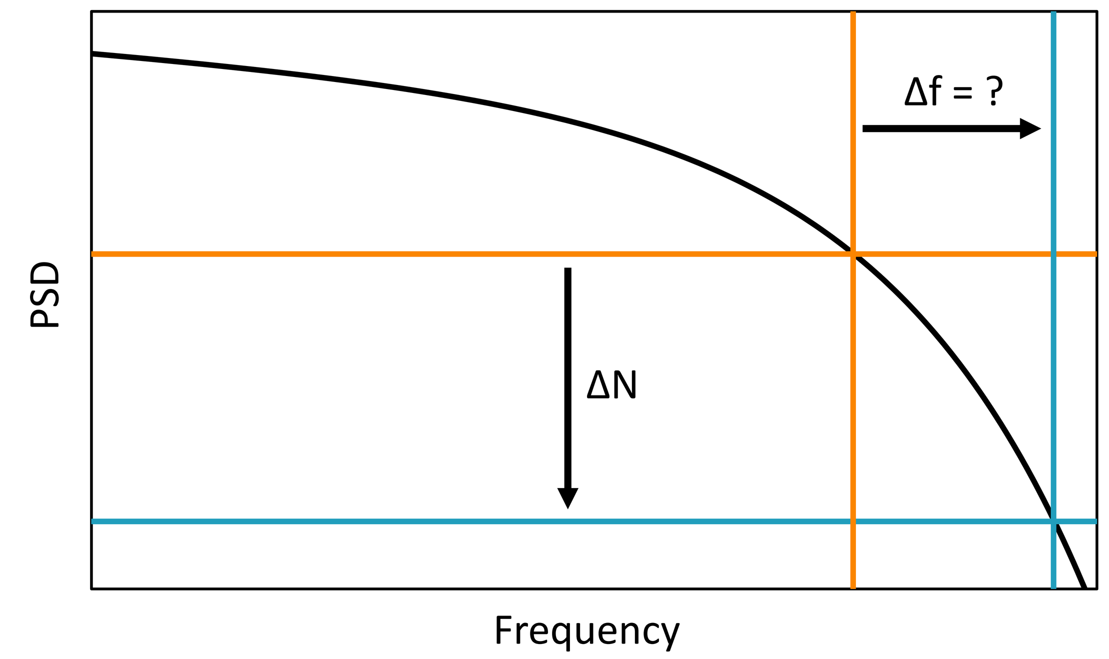

Fig. 3. Lowering the measurement noise increases the resolvable frequencies

3. What is gained by reducing measurement noise?

Taking the first RHS term from Eqn. 1 and dividing by the measurement noise gives us the signal to noise ratio S

$$S = \frac{P_0}{N}e^{-(2\pi f\sigma)^2} \quad (2)$$

S will equal 1 at some specific frequency f_1

$$f_1 = \frac{1}{2\pi\sigma}\sqrt{\ln\frac{P_0}{N}}$$

Reducing the noise by a factor η gives a new frequency f_2 where S is again equal to 1

$$f_2 = \frac{1}{2\pi\sigma}\sqrt{\ln\frac{\eta P_0}{N}}$$

The relative gain in frequency, ‘α’, from a noise reduction of η is given by the ratio of these two frequencies

$$\alpha = \frac{f_2}{f_1} = \sqrt{1 + \frac{\ln\eta}{\ln\frac{P_0}{N}}} \quad (3)$$

Entering expected values of deep ice records for P_0 and N produces a plot of α against η, shown in Fig. 4.

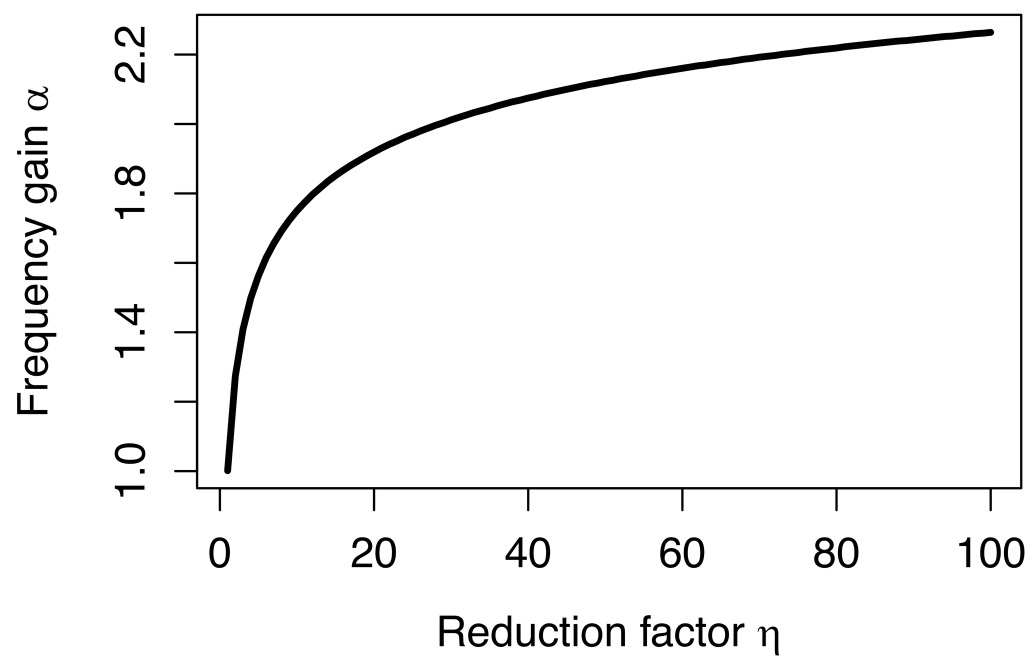

Fig. 4. Effect of reducing measurement noise on the recoverable frequency. A drop in measurement noise of a factor of 10 (η = 100) more than doubles the frequency at which S = 1

4. Visual effect on timeseries

- We simulate timeseries with the same deep ice parameters
- Numerically estimating α for a range of η gives the same solution as Fig. 4, validating our result
- To visualise the effect of measurement noise on deconvolution, we deconvolve the timeseries with $\eta = 1$ and $\eta = 100$

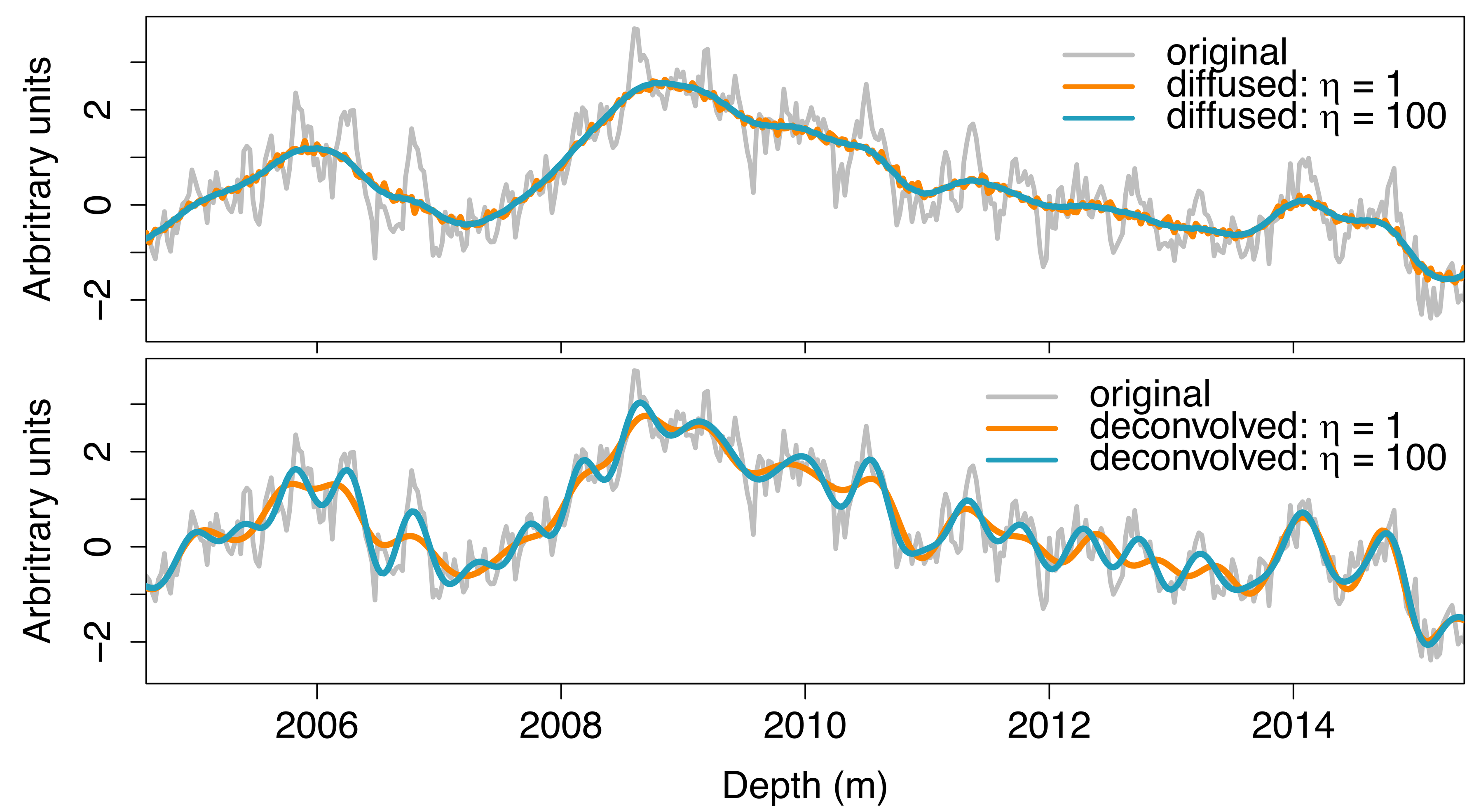

Fig. 5. Less noisy timeseries (blue) shows visible improvement in deconvolution compared to timeseries with more noise (orange)

5. How to achieve such high precision?

- Proposed method using long integration time measurements
- Involves continuous measuring of discrete water isotope samples for 30+ minutes per sample
- Early results suggest measurement noise can be decreased by more than a factor of 10
- While time consuming, could be very beneficial in valuable intervals with limited samples, such as deep, thinned ice

6. Conclusion

- Reducing measurement noise by a factor of 10 more than doubles the maximum effective resolution recoverable
- Long integration measurements offer a way to achieve such significant improvements in precision
- High precision measurements are especially crucial for very deep, thinned ice in attempts to recover millennial-scale variability

References

1) Lisiecki L. E., Raymo M. E., Paleoceanography, (2005), 20
2) Johnsen S. et al., Physics of Ice Core Records, (2000), pg. 121 – 140

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