Vertical velocity spectra measured by gliders

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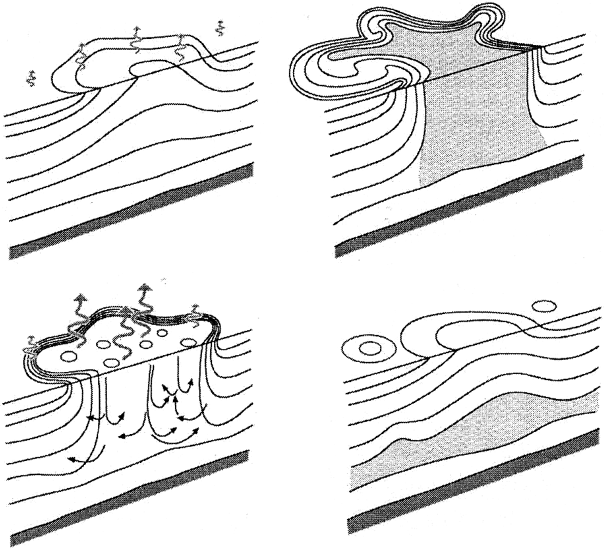
Outline

Introduction

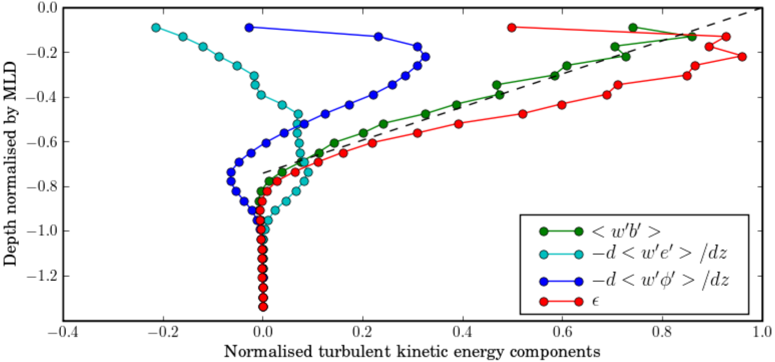


Introduction

Turbulent kinetic energy:

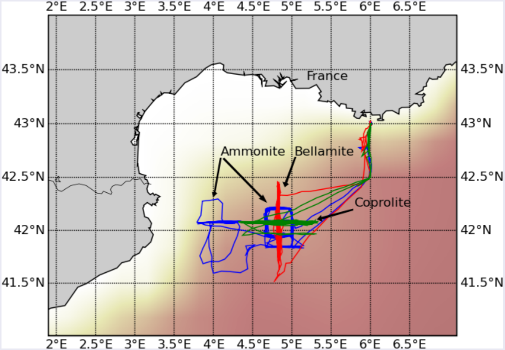
$$< w'b' > - \frac{d}{dz}\left\{ < w'e' > + \frac{1}{\rho} < p'w' > \right\} - \epsilon = 0$$

buoy. prod. -deformation -dissipation=0



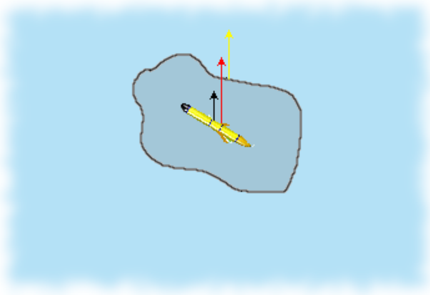
Gulf of Lions Experiment 2008

Glider trajectories



- Three 1000m gliders
- CTD only
- 3 Month mission: mid January - mid April 2008

Vertical velocity – Summary



vertical velocity from pressure sensor
vertical velocity modelled assuming still water conditions
vertical velocity of water patch

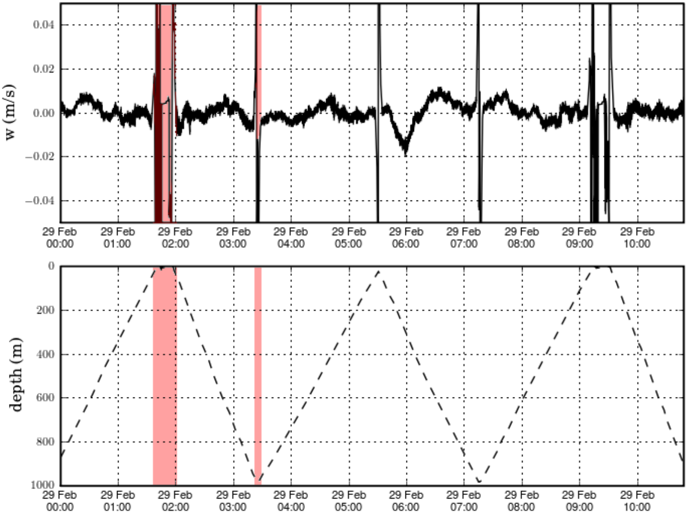
Vertical velocity – Summary

Result:

- Two equations
  - U: glider speed (through water)
  - α': angle of attack
- $w_g = U \sin(\text{pitch} + \alpha')$
- $w = w_{\text{press.}} - w_g$
- Model input:
  - CTD (density)
  - oil volume change buoyancy engine
  - attitude (pitch, heading)
- calibration parameters: drag coefficient, compressibility and hull volume

Paper: L. Merckelbach, D. Smeed and G. Griffiths (2009), *Vertical velocities from underwater gliders*, Journal of Atmospheric and Oceanic Technology. *In press, available online.*

Example of measured time series (29 Feb. 2008)



Time series

- Based on navigation pressure sensor (1/4 Hz)
- Nyquist frequency 1/8 Hz
- Time of single yo $\approx$ 1.5 - 2 hours
- Per profile: $f = [1.25 \times 10^{-4}, 1.25 \times 10^{-1}]$ Hz

But first: consider one long time series, cut in segments of about 4 hours (2 yo cycles).

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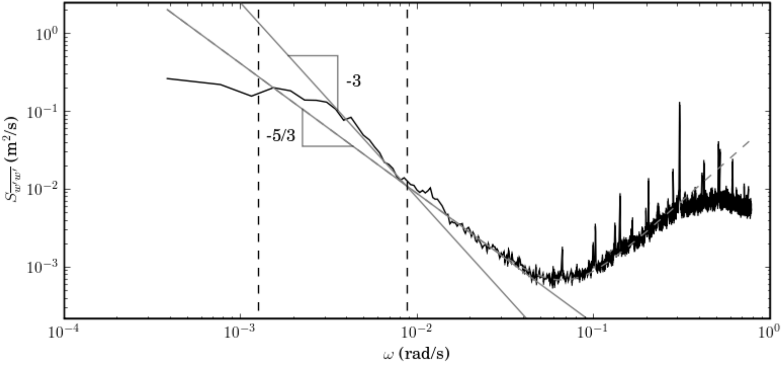
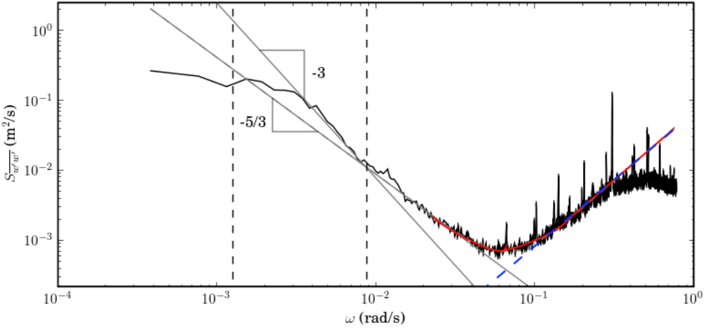
Vertical velocity spectra (calm period)

A vertical velocity spectrum in ω-space of a 10 days time series (about 100 segments).



Pressure sensor noise

Blue: pressure sensor noise
Red: pressure sensor noise + fitted $\omega^{-5/3}$



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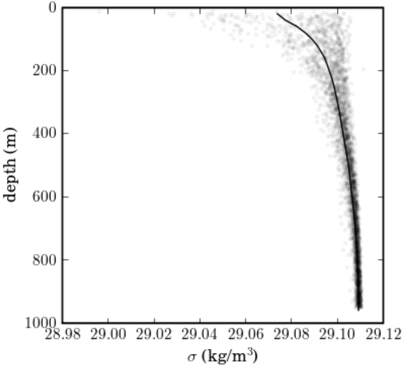
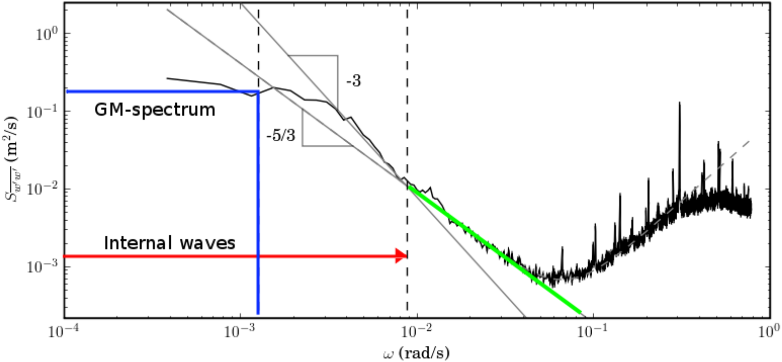


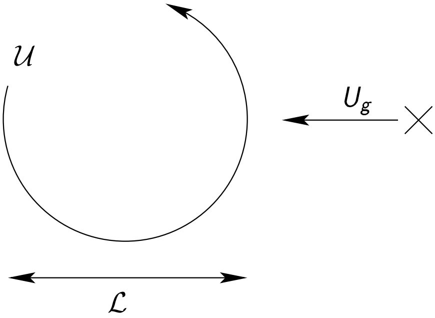
$$N^2 = \frac{g}{\rho}\frac{d\rho}{dz}$$

Vertical velocity spectra (calm period)

A 10-day vertical velocity spectrum in ω-space.



Taylor's frozen turbulence hypothesis:



$\mathcal{U}$: turbulent velocity scale
$\mathcal{L}$: turbulent length scale
U_g: glider speed

$$k = \frac{\omega}{U_g} \text{ if } \mathcal{U} \ll U_g.$$

$\mathcal{U} \approx 0.01$ m/s; $U_g \approx 0.4$ m/s.

-5/3: $\omega = 0.01..0.1$ rad/s $\Rightarrow$
$L = 350..35$ m
Length scales too large for inertial subrange.

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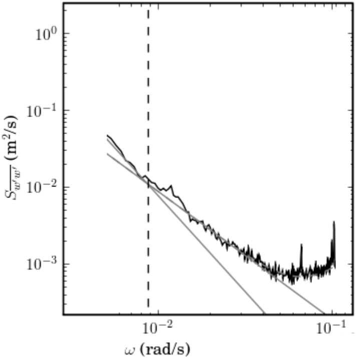

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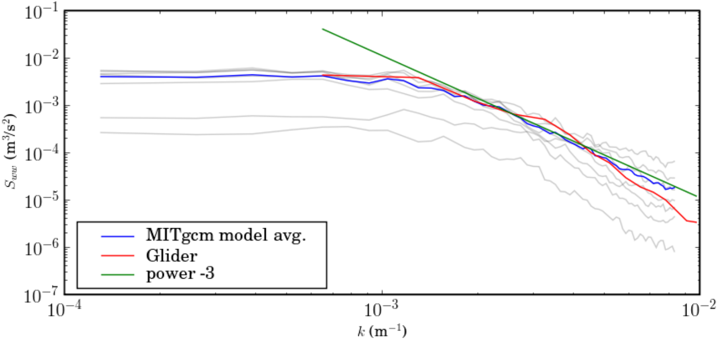
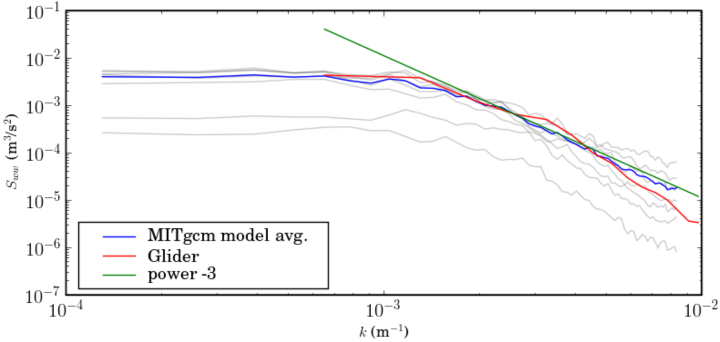
Model glider in model ocean

Comparison model simulation of convection MITgcm (400 W/m^2, completely mixed over depth (1000 m)), and a simulated glider.

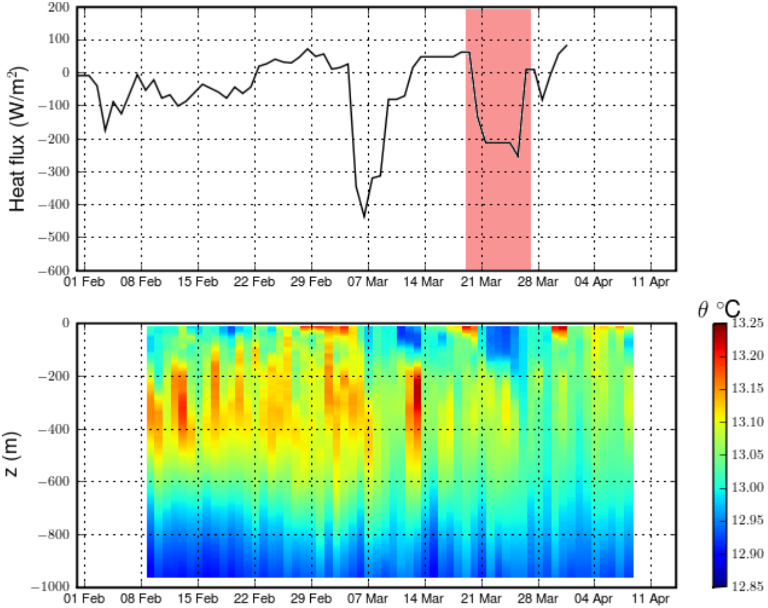


Model glider in model ocean



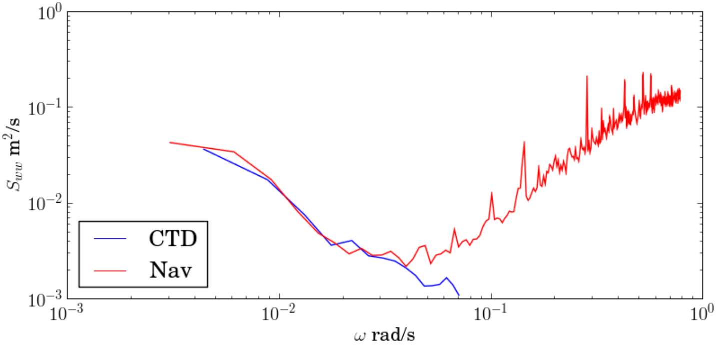
- glider spectrum $\omega \longrightarrow k$ matches model spectrum in k;
- glider spectrum approximately depth averaged spectrum;
- suggests Taylor's hypothesis to be applicable.

Second convection event

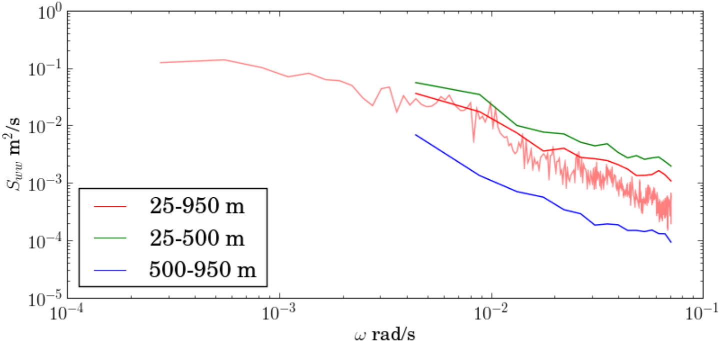


Using CTD data instead?

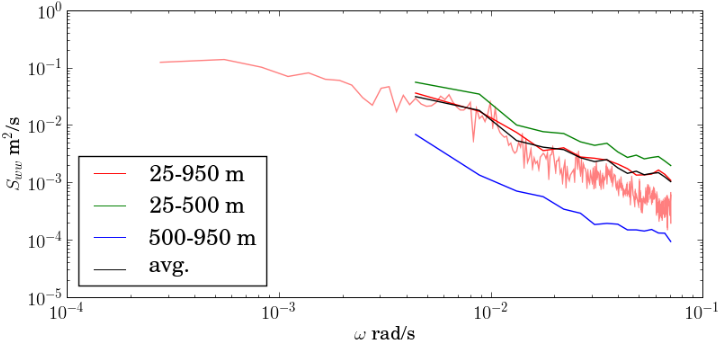
CTD about 10 times more accurate ⇒ 2 decades gain.
Sample interval CTD: 44.4 seconds.
Time series per profile.



Does the glider measure a depth-averaged spectrum?



Does the glider measure a depth-averaged spectrum?



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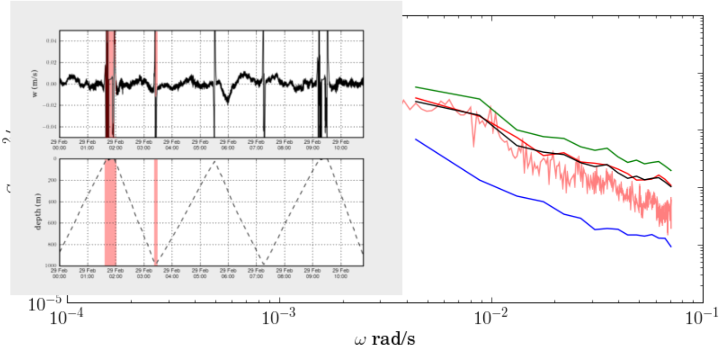


GM-spectrum

Below mixed layer: $N \approx 3 \times 10^{-4}\ \mathrm{s}^{-1}$.

$$S_{ww}(\omega) = S_{ww}^{GM} = 1.5\varepsilon N^{-2}\ \forall\ \omega < 2\pi N$$
$$S_{ww}(\omega) = 0\ \forall\ \omega >= 2\pi N$$
$$\frac{1}{2\pi}\int_0^\infty S_{ww}\,d\omega = S_{ww}^{GM} N = Var(w) = 2.6 \times 10^{-5}\ \mathrm{m}^2/\mathrm{s}^2$$

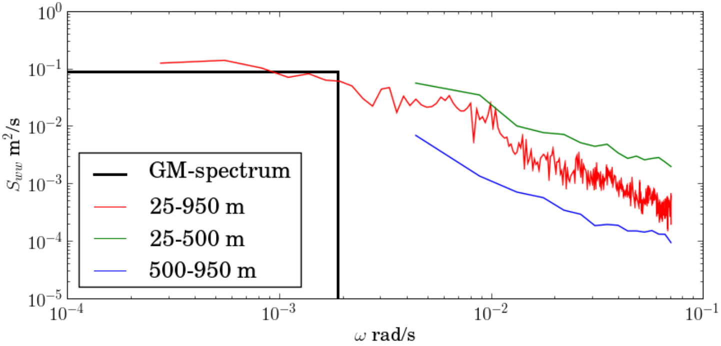
↑

from CTD derived velocity data

So that:

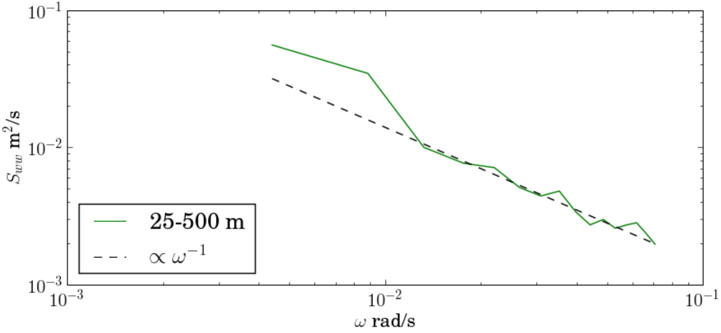
$S_{ww}^{GM} \approx 0.09\ \mathrm{m}^2/\mathrm{s}$ and $\varepsilon \approx 5 \times 10^{-9}\ \mathrm{m}^2/\mathrm{s}^3$.

GM-spectrum

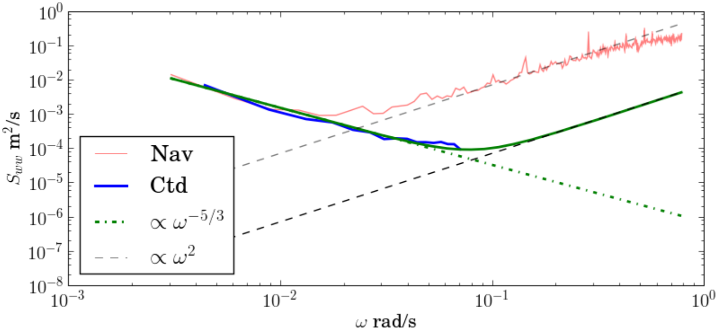


GM spectrum estimated from variance of w below the mixed layer.

-1 spectrum: $z = 25..500$ m



-5/3 spectrum: $z = 500..950$ m



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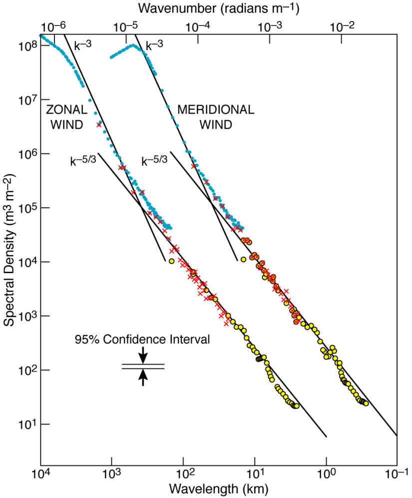
Nagstrom and Gage spectrum (1986) (from: P. Lynch)



Conclusions

- We can deduce vertical velocity measurements from glider observations
- Useful spectra for $f = [1 \times 10^{-4}, 2 \times 10^{-2}]$ Hz
- Glider spectrum $\approx$ depth-averaged spectrum
- Internal subrange is out of reach
- Garret-Munk spectrum recoverable
- Glider data also show -5/3 range for length scales larger than expected for inertial subrange

To resolve higher frequencies/wavenumbers:

- use of dedicated device to measure turbulence (for example *microrider*)
- more sensitive depth sensor (reducing the full-scale)
- glider in drift mode (Langrangian spectrum as done with floats)

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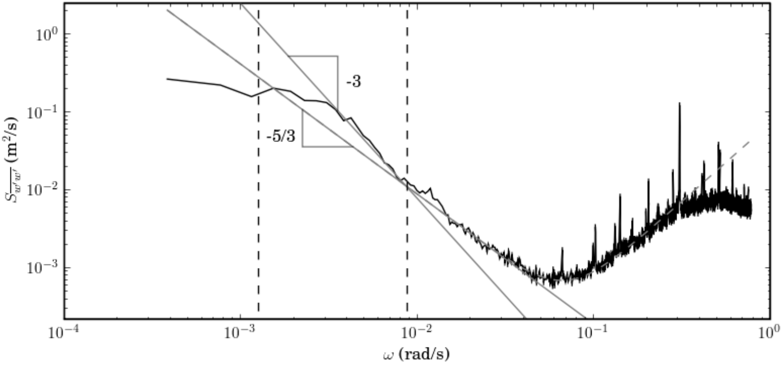

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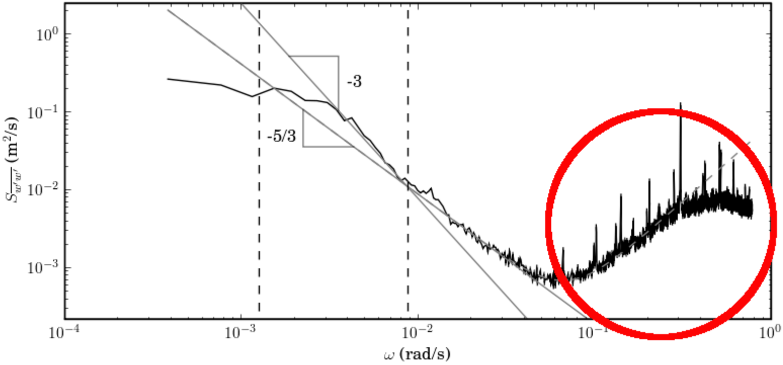

Pressure sensor noise

Assume noise in depth signal, h_ε, to be white:

$$h_m = h + h_\varepsilon \stackrel{\text{FFT}}{\Longrightarrow} H_m = H + H_\varepsilon$$

$$w = \frac{dh}{dt} \Rightarrow W_\varepsilon = i\omega H_\varepsilon$$

So that $W_\varepsilon W_\varepsilon^* = \omega^2 H_\varepsilon H_\varepsilon^*$.

Pressure sensor noise

Blue: pressure sensor noise
Red: pressure sensor noise + fitted $\omega^{-5/3}$