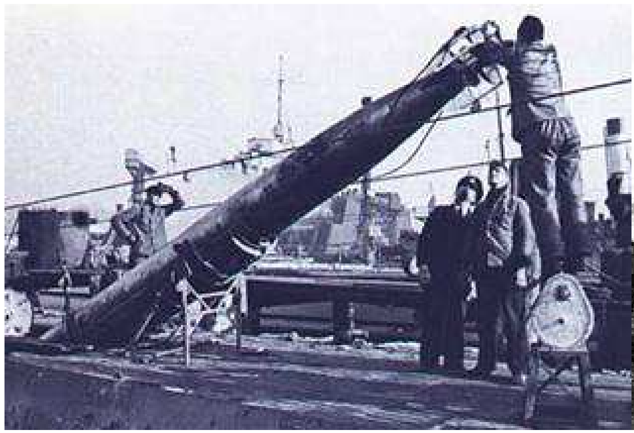
Detection of Density Fluctuations Using Density Sensitive Backscatter for an Active Sensor

Dr Ron Larham
BAE Systems Maritime Services



Overview

In this presentation I wish to talk about the detection of localised regions of turbulence in a stratified medium using the variation in backscatter from the medium due to the density fluctuations within the turbulent region.

- Examples of stratified media are the atmosphere and the seas.
- Generators of turbulence: aircraft, birds, underwater vehicles, marine mammals and fish, static objects in a flow field.

Active sensors

EM (Radar, Lidar),

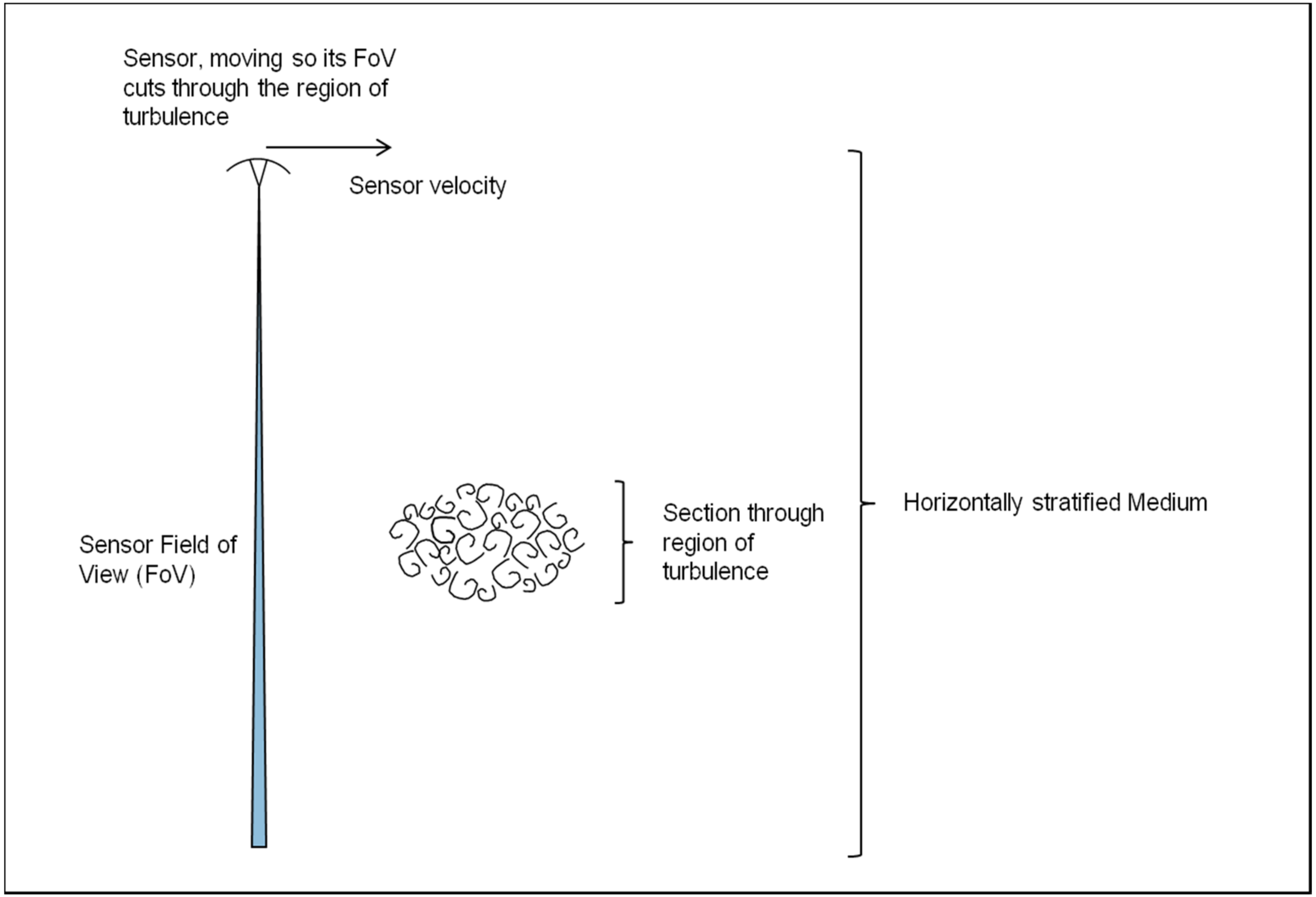
- Both usable at considerable ranges in air. Though as we need resolution comparable to the size scale of the turbulence we need tight beams so Lidar is preferable.
- EM not so suitable in water due to high attenuation, though propagation through water is possibly usable in parts of the optical spectrum.

Acoustic,

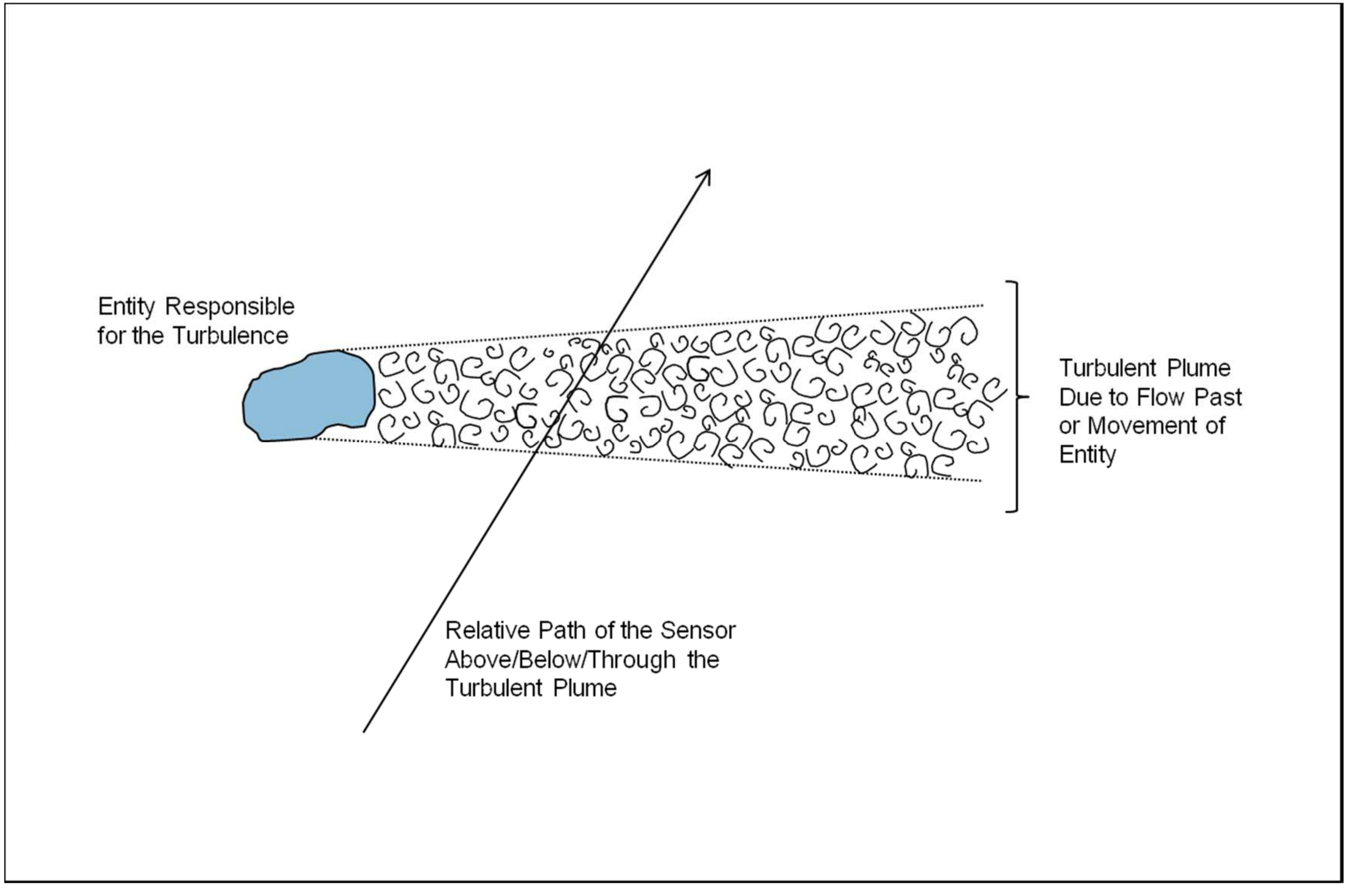
- Sound propagates well in water and air, and at high frequencies tight beams are achievable. Limited data rate due to low speed of sound could be an issue.

In what follows I will focus on Lidar in water

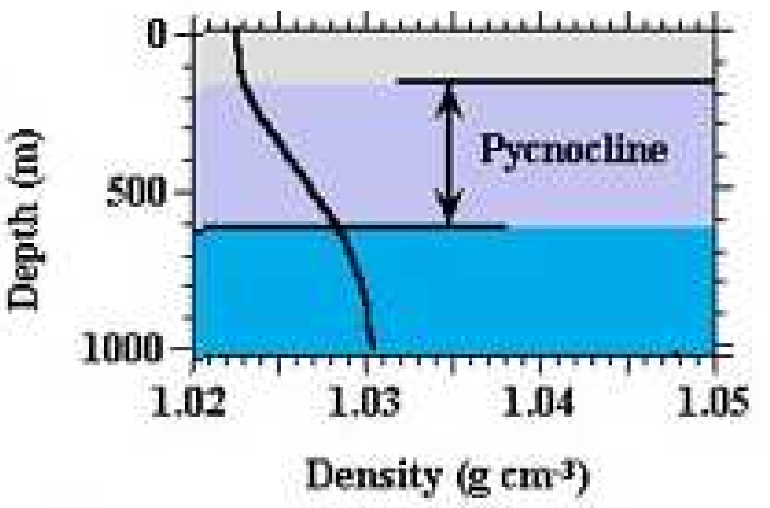
Geometry: Vertical Slice

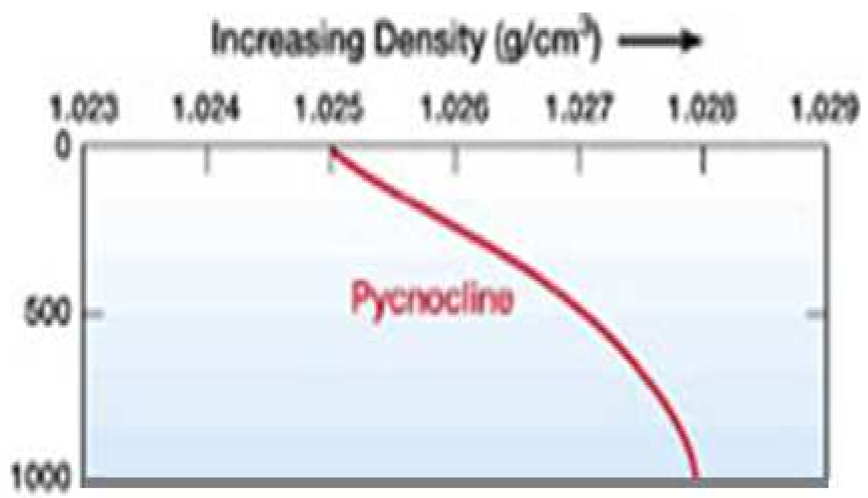


Geometry: Plan View



Density Gradients





Density gradient in top 200m for these plots is

$$\sim 0.0025 - 0.005\,\mathrm{kg/m^3}\,/\mathrm{m}$$

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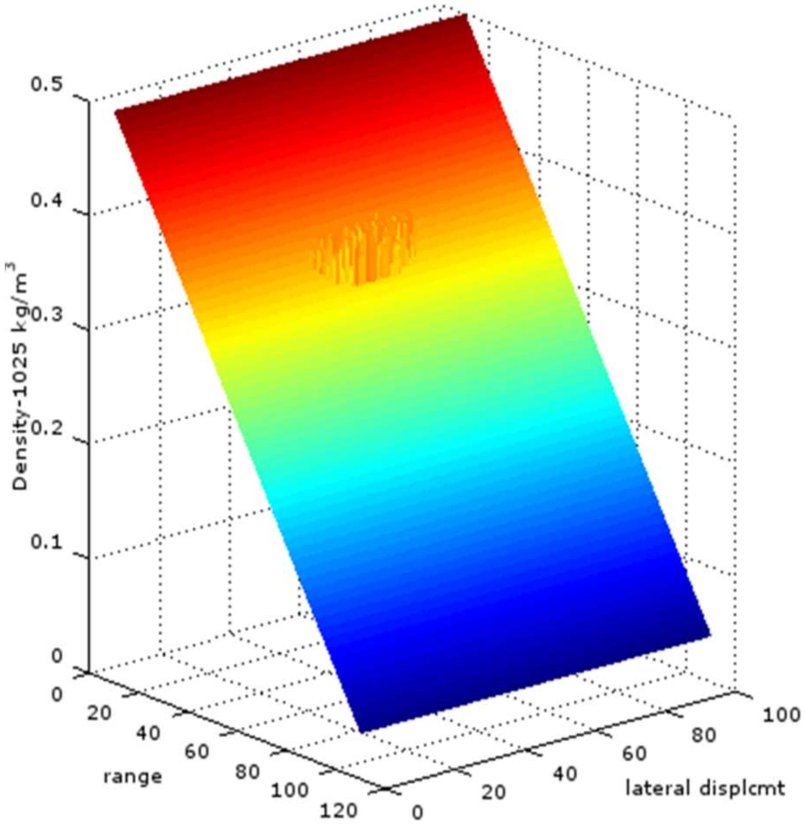
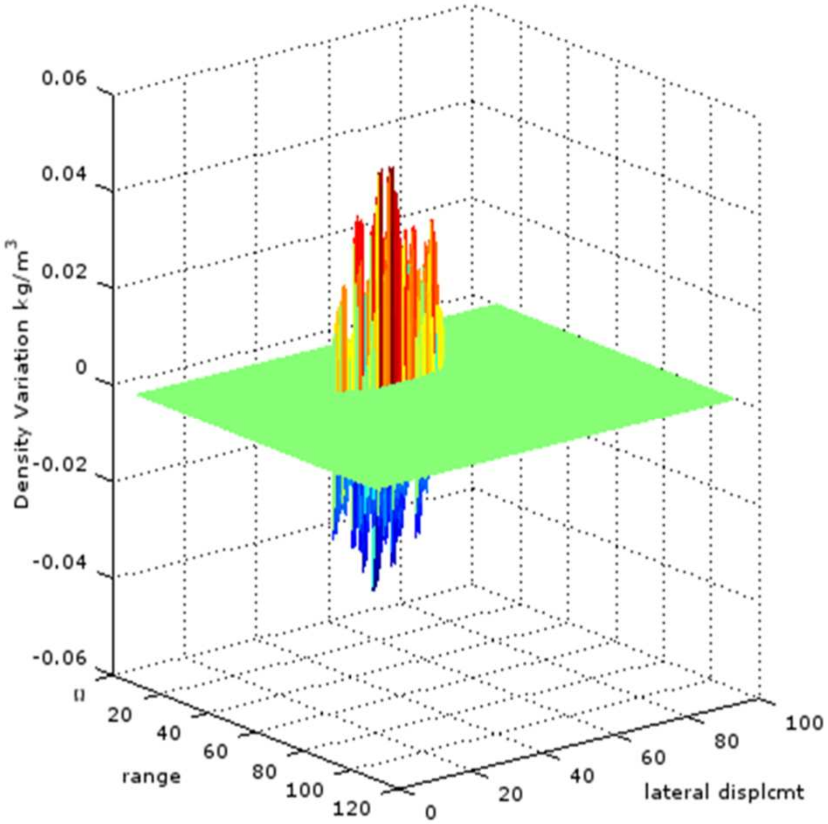
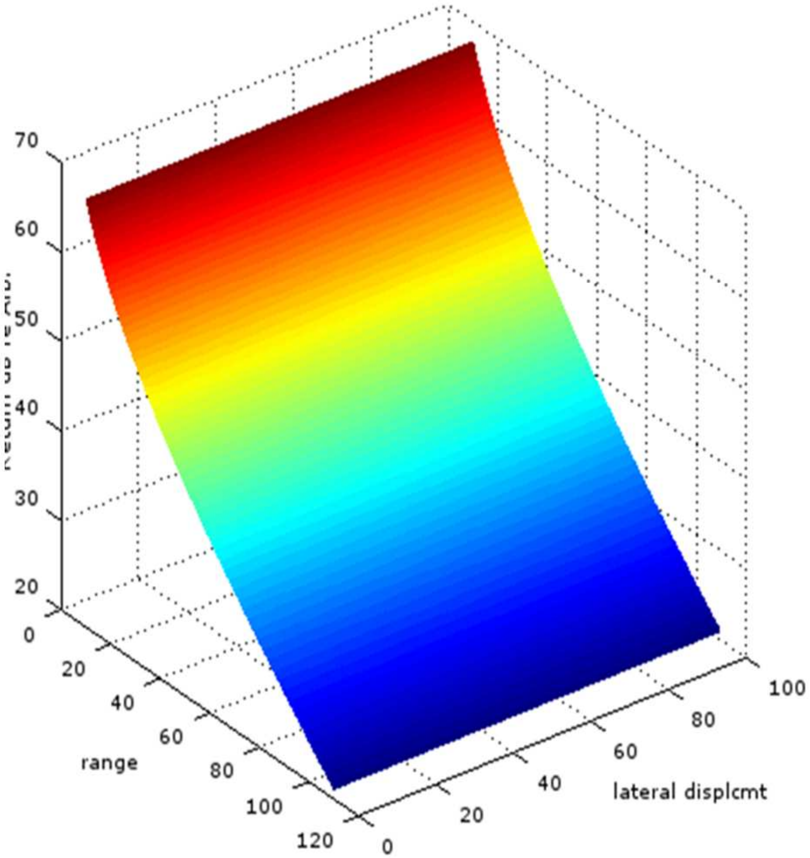
Example Density Variation

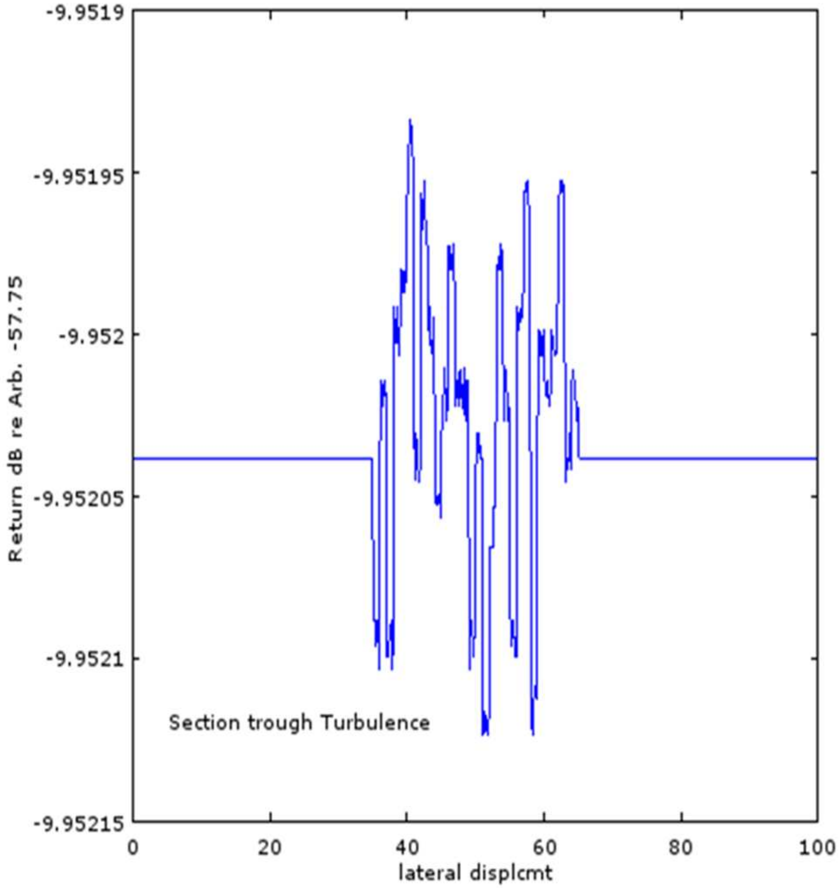
Here Using a Constant Density Gradient $\sim 0.0045\ \mathrm{kg/m^3/m}$





Mean Backscatter





Other Scatters

From the plots we can see that the density and expected returns fluctuations can be very small, so we might expect that other unrelated things going on in the medium would obscure the sort of fluctuations we are looking for.

At a cost in the amplitude of the returns we can counter this by looking at non-linear backscatter, in the case light in water the Raman backscatter could be used, which is frequency shifted from the TX wavelength.

The plots in the previous slide were produced using the backscatter coefficient for Stokes-Raman backscatter.

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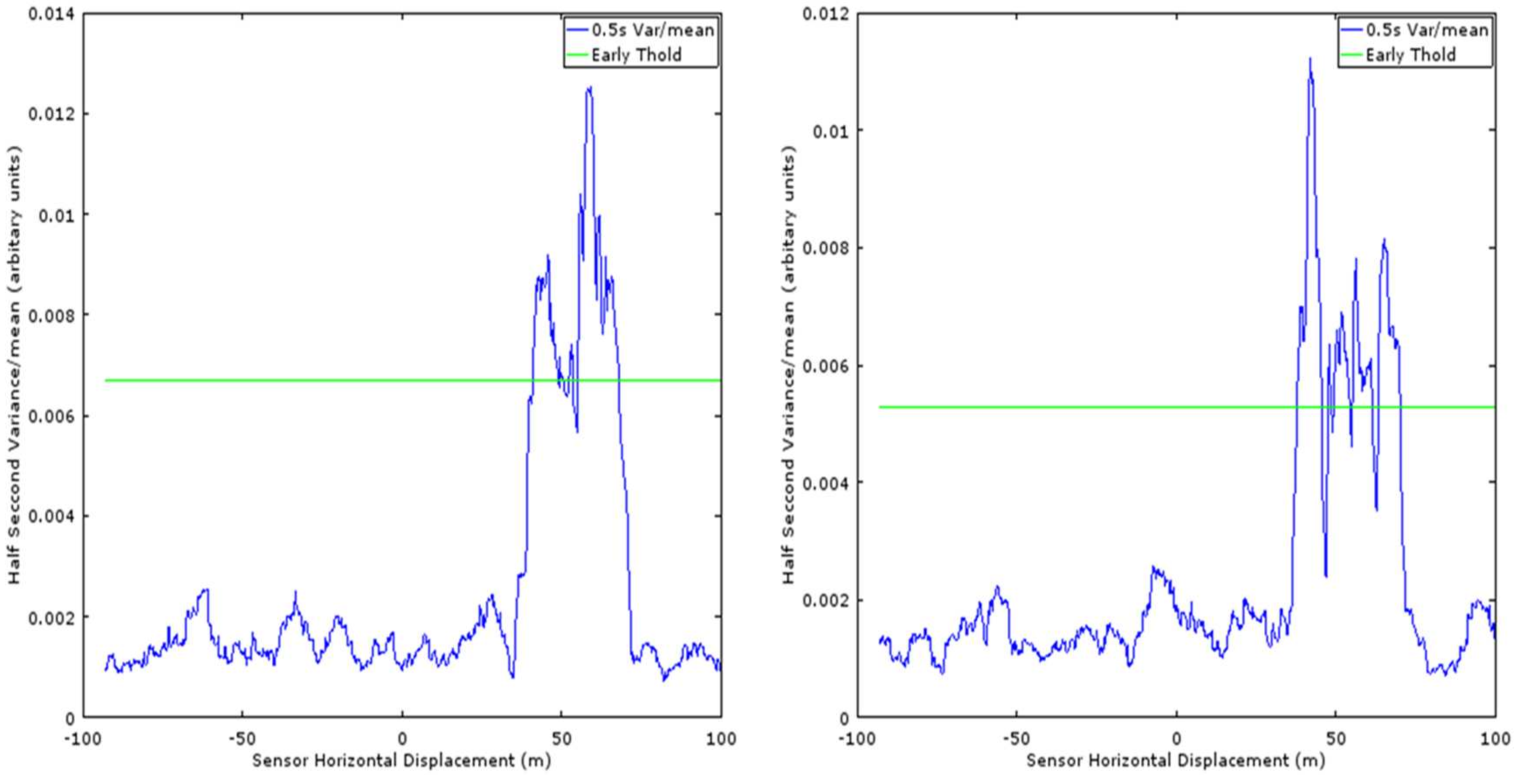
Noise

For light in water, if we have a large enough backscatter return we are essentially counting photons, and so the measured return will contaminated by photon or shot noise.

Summing N returns from the same volume will in effect give us independent samples of the photon noise and so the relative size of the noise will be reduced by a factor of $\sqrt{N}$ (or the sum will have the appropriate mean and be contaminated by photon noise)

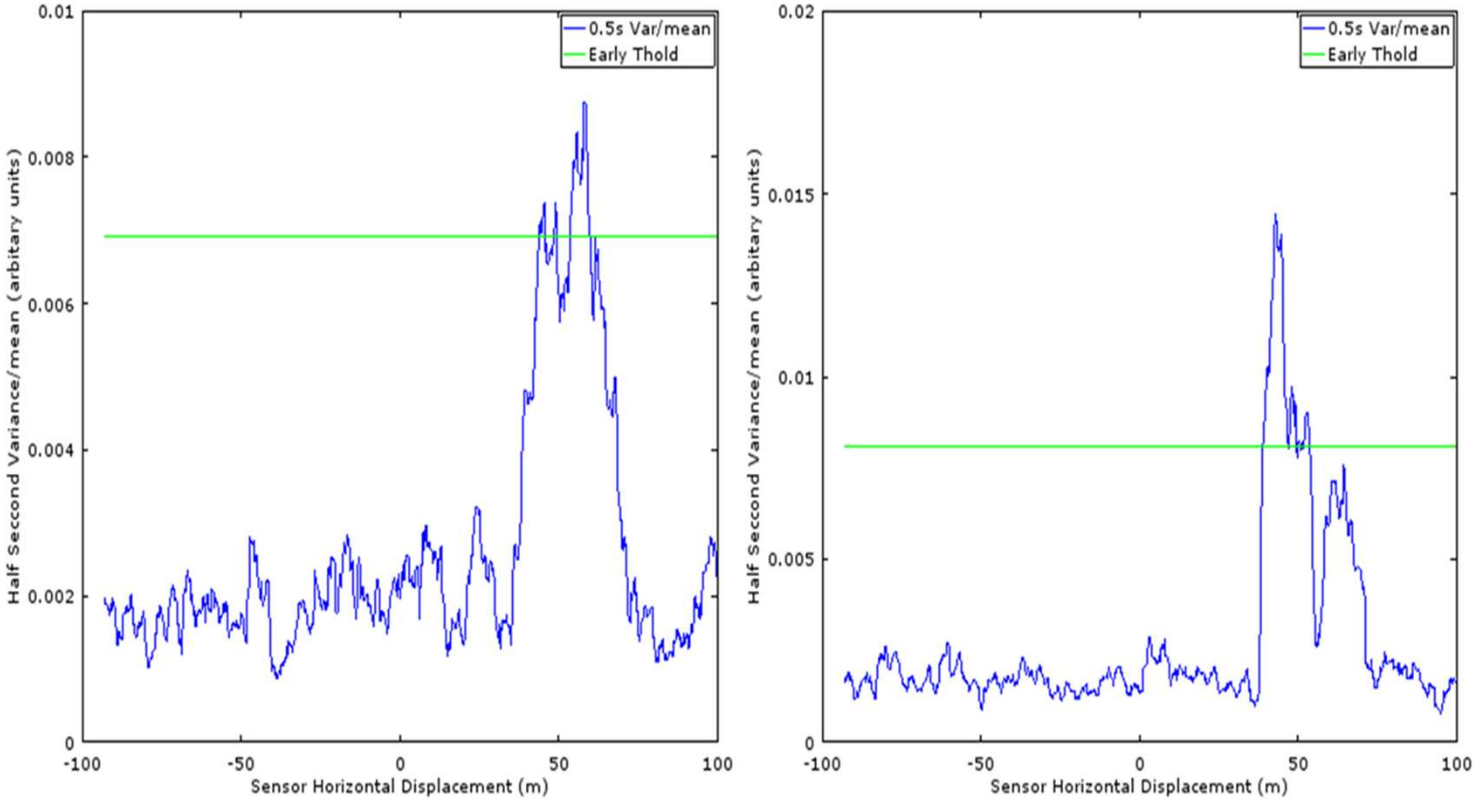
So we can in effect integrate the returns from multiple TX's from the same volume element with an effect comparable to having increased the TX power by a factor of the number of returns. So we want to use a prf as high as possible consistent with the unambiguous range constraints to which we may be subject.

Constant Range Return Slice Through Turbulence I



Plots of slices of two instantiation of return variances/mean for the default configuration through the approximate centre line of the turbulence. The threshold shown is the $m + 3s$ from a 2s learning period remote from the turbulence, shown only for illustrative purposes.

Constant Range Return Slice Through Turbulence II



Plots of slices of two instantiation of return variances/mean for the default configuration with a superimposed sinusoidal variation in the background, of amplitude equivalent to a 1m depth variation, through the approximate centre line of the turbulence. The threshold shown is the $m + 3s$ from a 2s learning period remote from the turbulence, shown only for illustrative purposes.

Discussion

- Here I have been mainly talking about the detection of fluctuation in the returns from the turbulent region. This implicitly assumes a particular model of the fluctuations, but we are not restricted to such processing schemes depending on a single assumption of this kind.
- For instance in the case of a well mixed region where significant density variations occur on scales small compared to the sensor resolution as far as the sensor is concerned the region of turbulence is a region of constant density. So we can instead look for the signature of a region were the average density appears more nearly constant than that of the medium remote from the turbulence.
- In a practical system one could employ multiple detection schemes in parallel.
- I have skated over 1D processing in the preceding slide. This will not be the case in an operational system, we would use 2D processing (range and lateral displacement of the sensor)

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Discussion (cont)

- One concern is that the average power density in the beam needed to make such a system work may be high enough to trigger secondary effects that would degrade performance.

  Some of these effects would be of a minor consequence as we are not relying on a theoretical model of the backscatter remote from the turbulence, but learn its behavior.

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Thank you