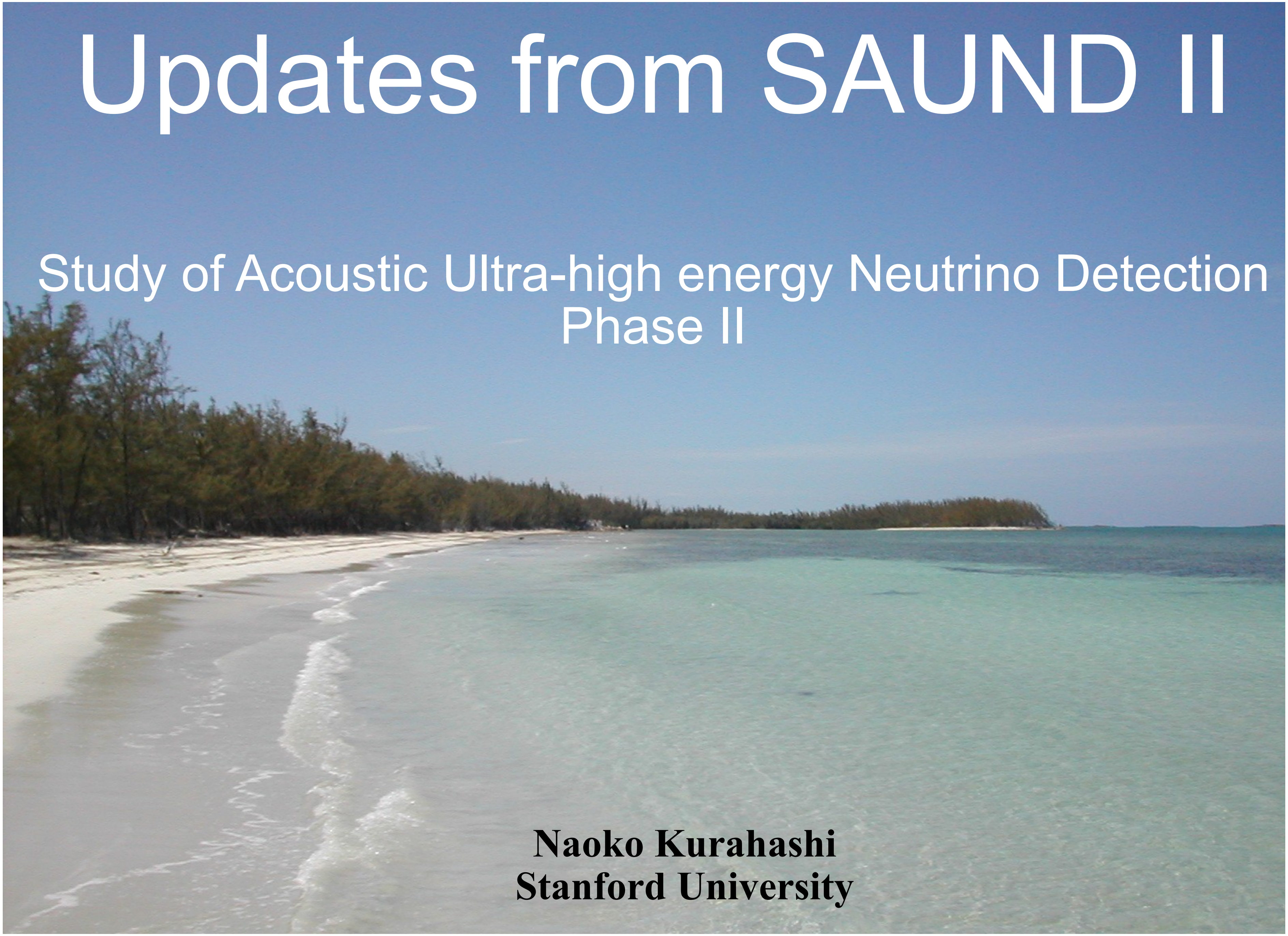


Updates from SAUND II

Study of Acoustic Ultra-high energy Neutrino Detection
Phase II

Naoko Kurahashi
Stanford University

ARENA 2008 University of Roma “Sapienza”, June 26th 2008

Outline

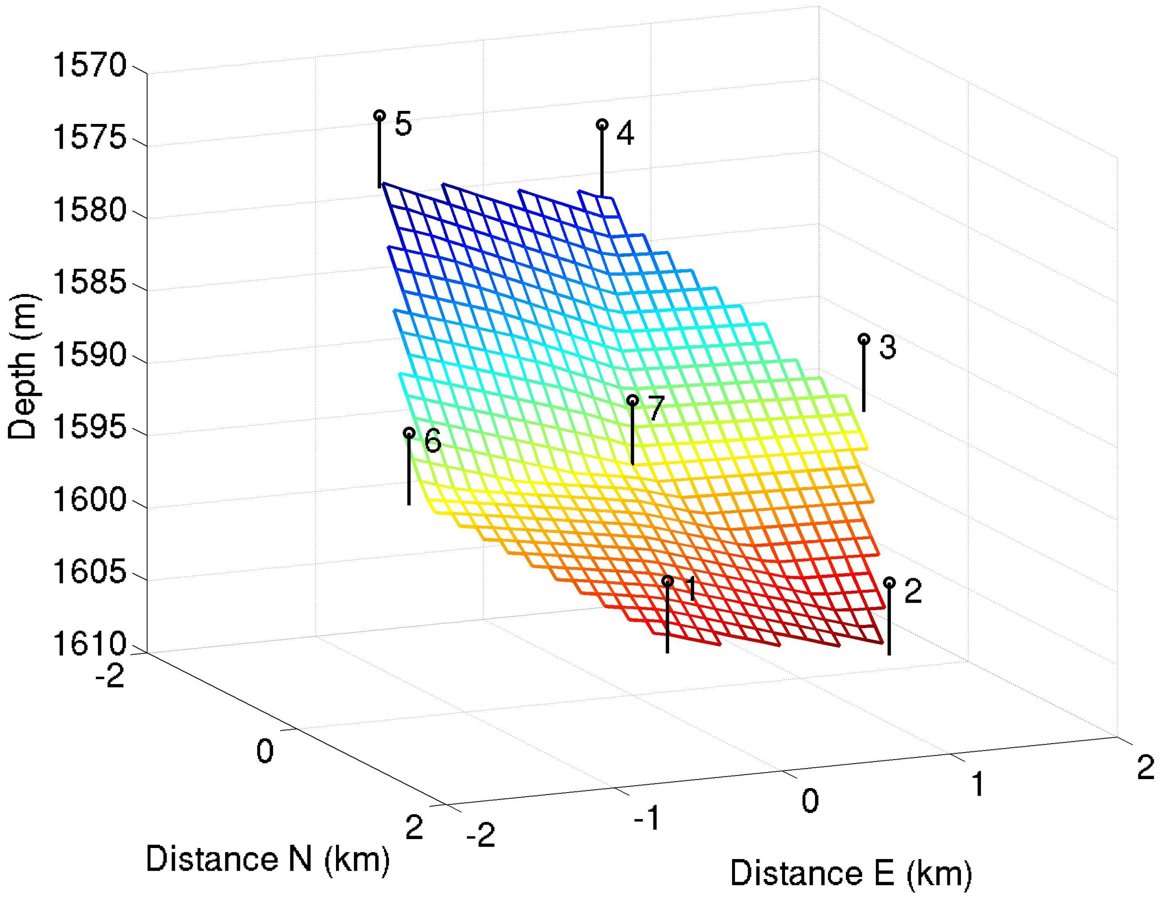
- Overview of the SAUND Experiment
  - ➔ SAUND II DAQ Structure
- Background Data
  - ➔ Ocean Ambient Noise Study
- Neutrino Signal Analysis
- Ongoing Studies and Future Plans

SAUND and AUTEC

History of SAUND

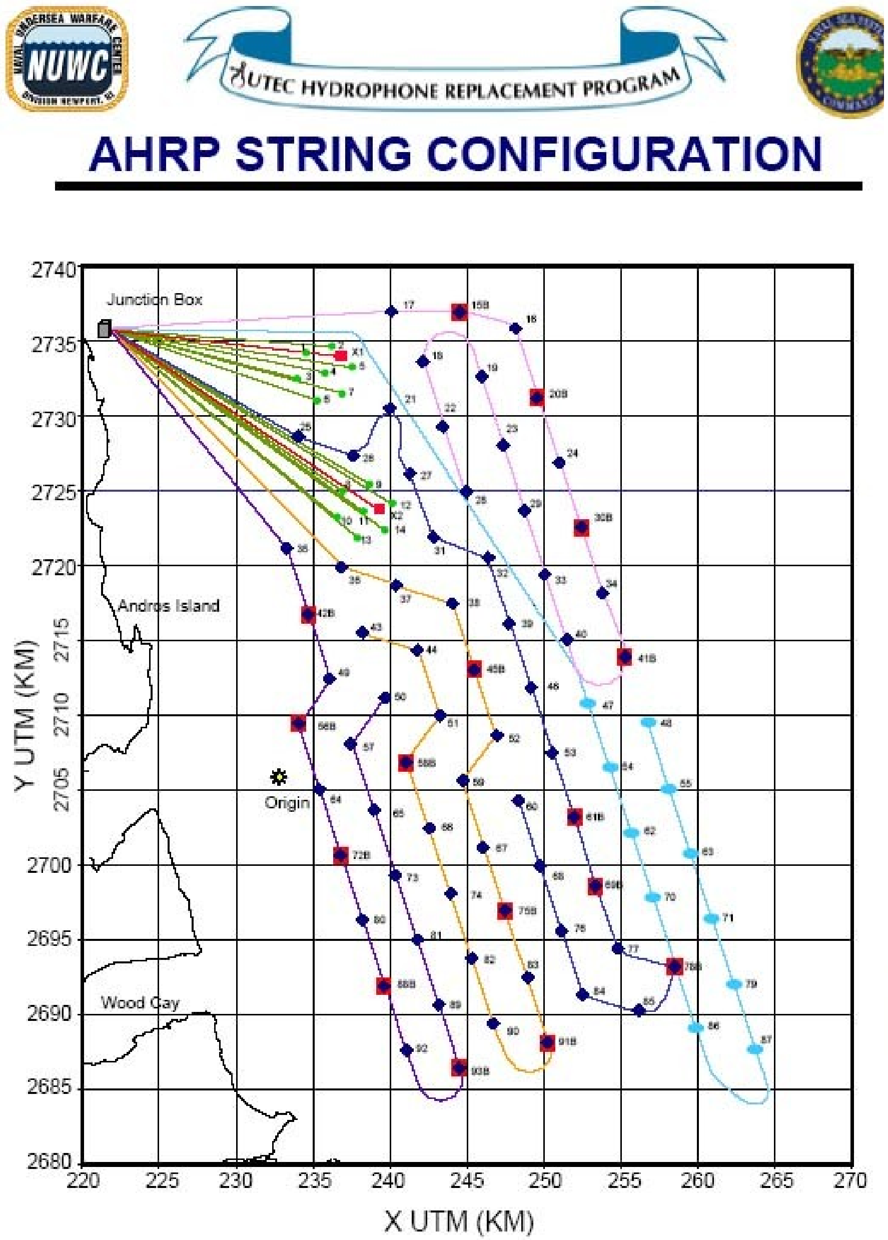
SAUND II based on....
Feasibility and Sensitivity Study
N.G. Lehtinen et al., Astroparticle Physics 17 (2002) 279-292
SAUND I Experiment
J. Vandenbroucke et al., Astrophysical Journal 621 (2005) 301-312

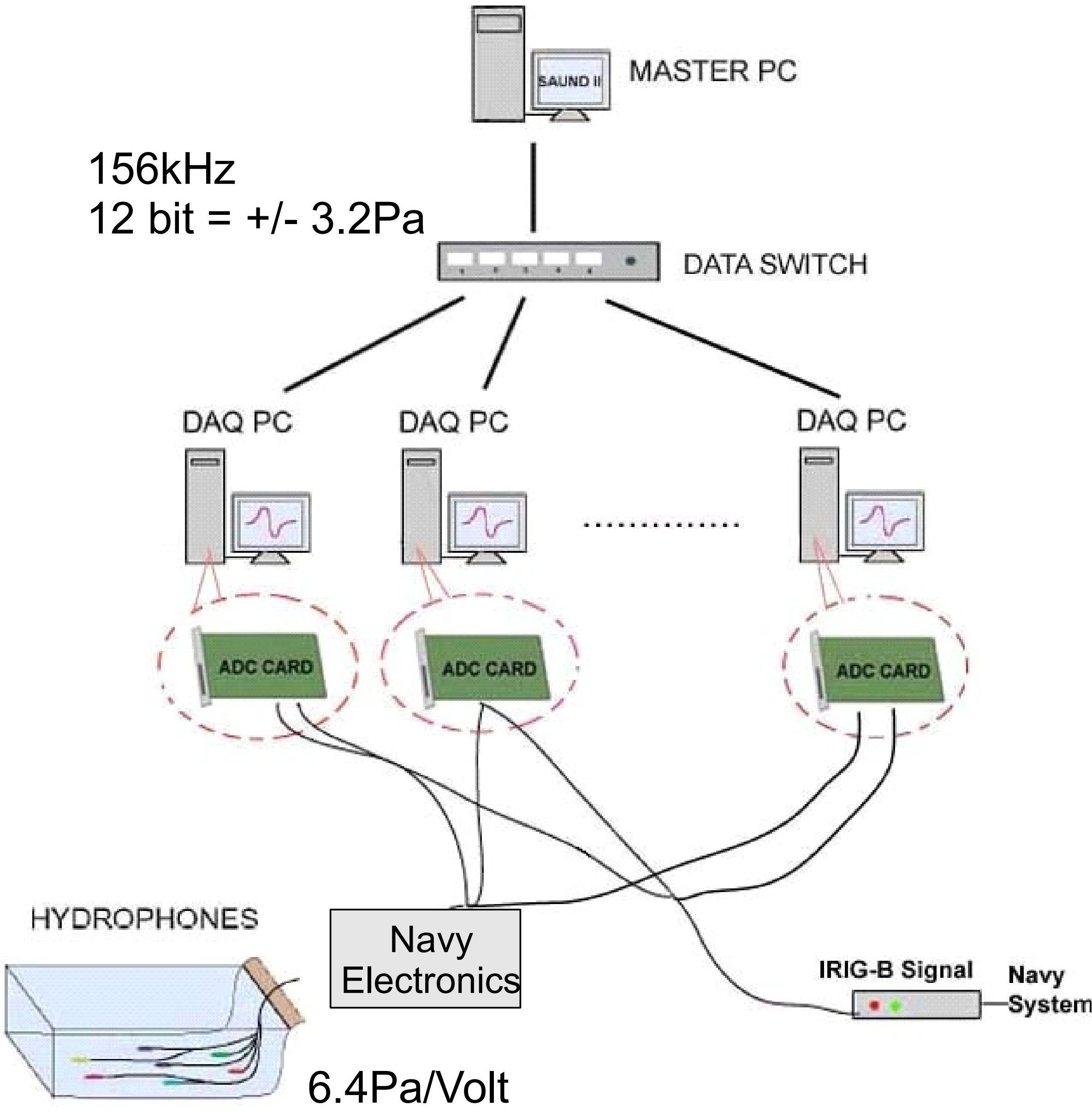
7 hydrophones were used at the same site but with different hydrophones and cables



SAUND II Schematics

49 Uni-directional Hydrophone readout
20 x 50 km array



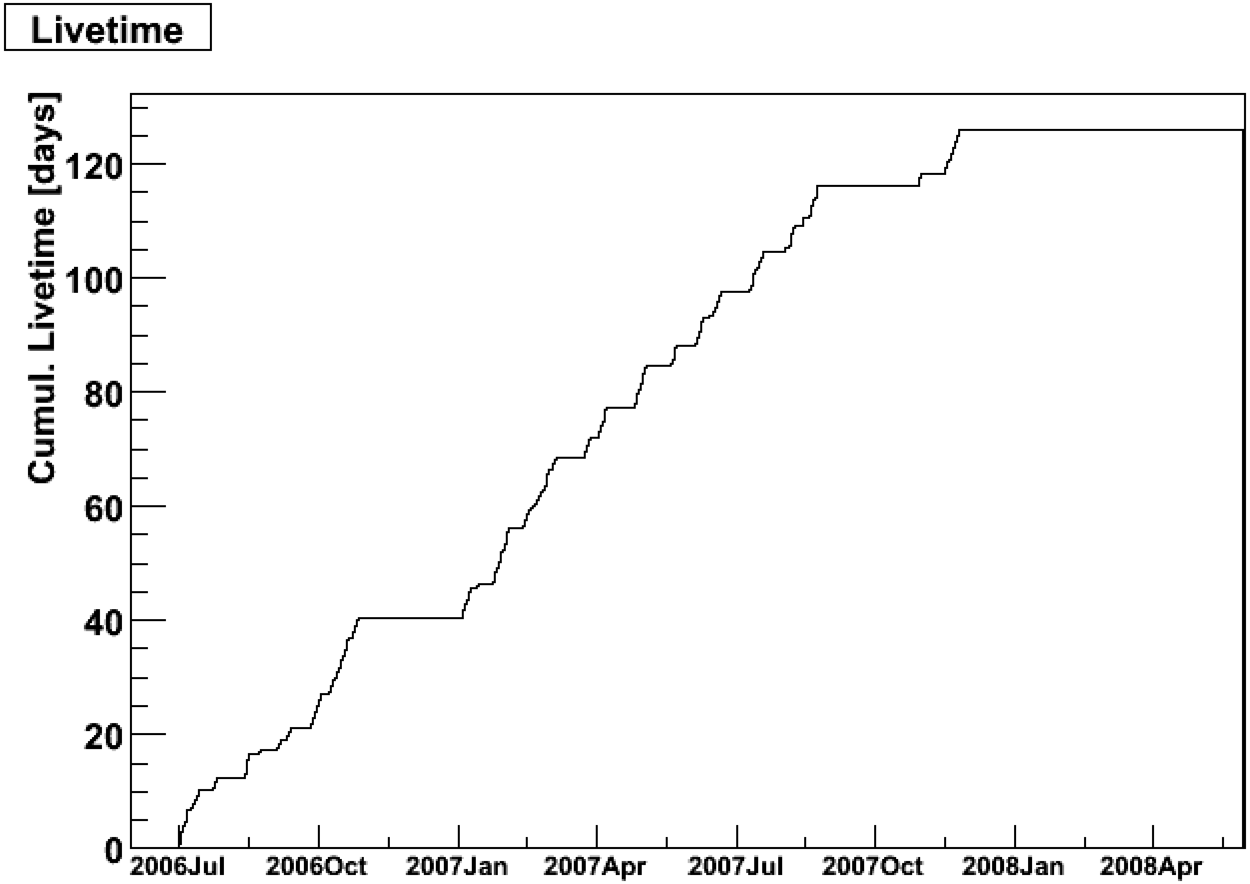


156kHz
12 bit = +/- 3.2Pa

6.4Pa/Volt

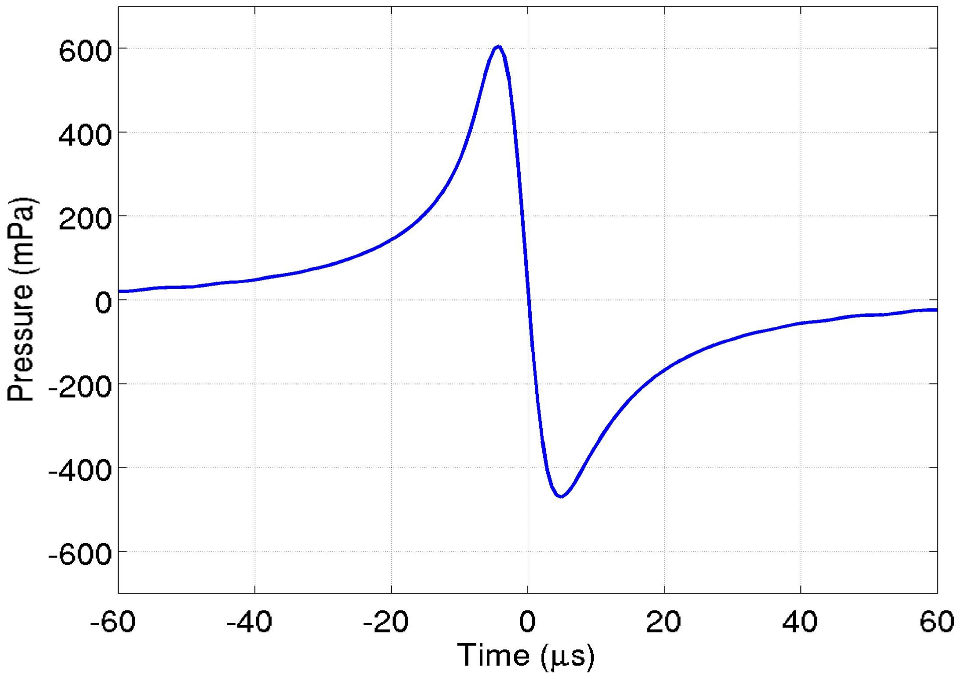
SAUND II Accumulating Data

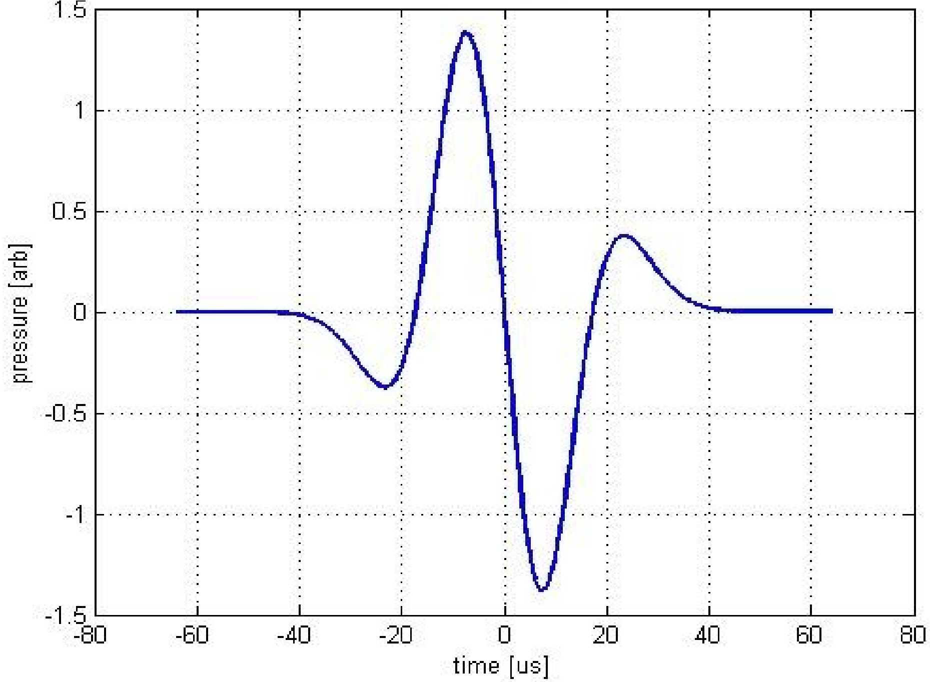
“Physics Run” started Summer 2006



~120 days data accumulation over 14 months
on all 49 hydrophones

Recorded Data





On each Hydrophone

Neutrino-like Waveforms

Triggering Mechanism
Stream data in and match filter shifting 1 datapoint (6.7us) at a time. If convolution is above threshold, record 1ms around event

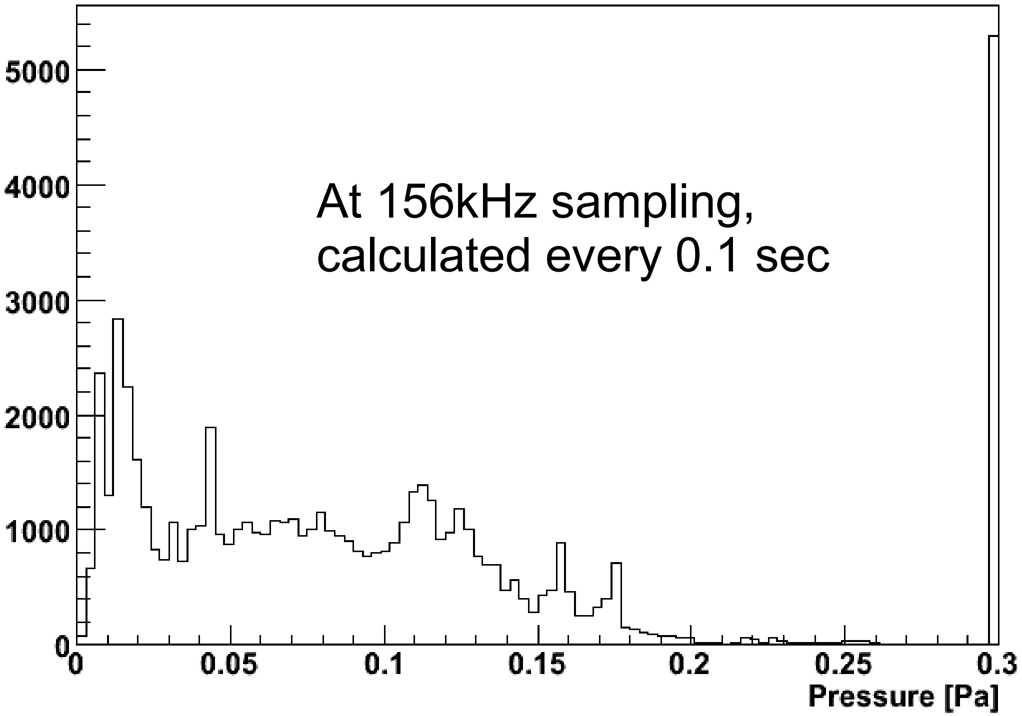
Noise Adaptive Threshold Setting
- Target trigger rate 10 triggers/chan/min
- channel by channel, minute by minute

Background Parameters

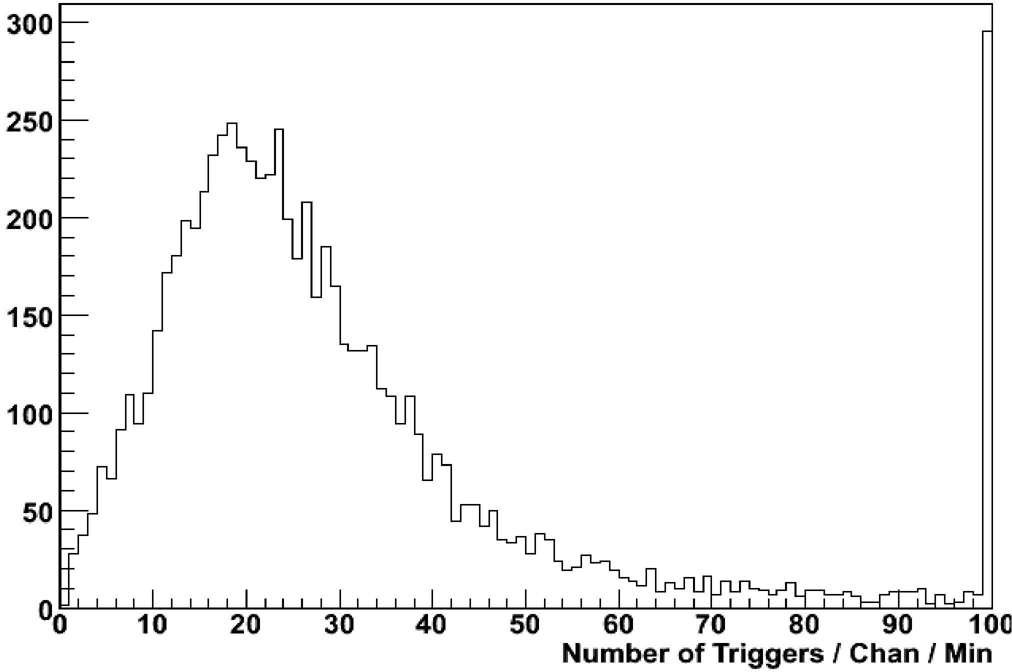
FFT spectrum of 0.1sec every 5sec
RMS value every 0.1sec
adaptive threshold
number of triggers every min

SAUND II Statistics/Distributions

Taken from a 1% data subset with
randomly chosen time periods

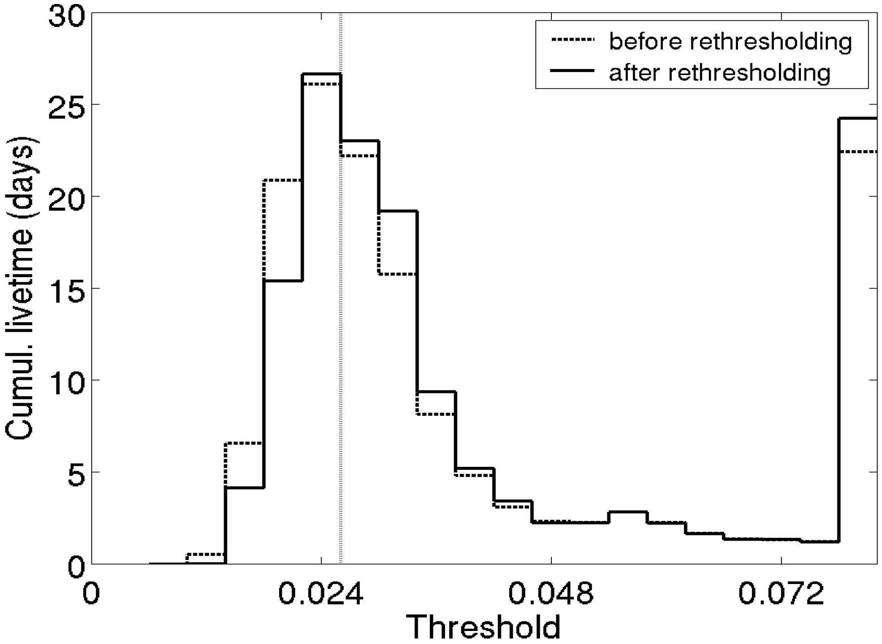

RMS distribution

At 156kHz sampling,
calculated every 0.1 sec


Trigger Rate Distribution

SAUND I as a Benchmark

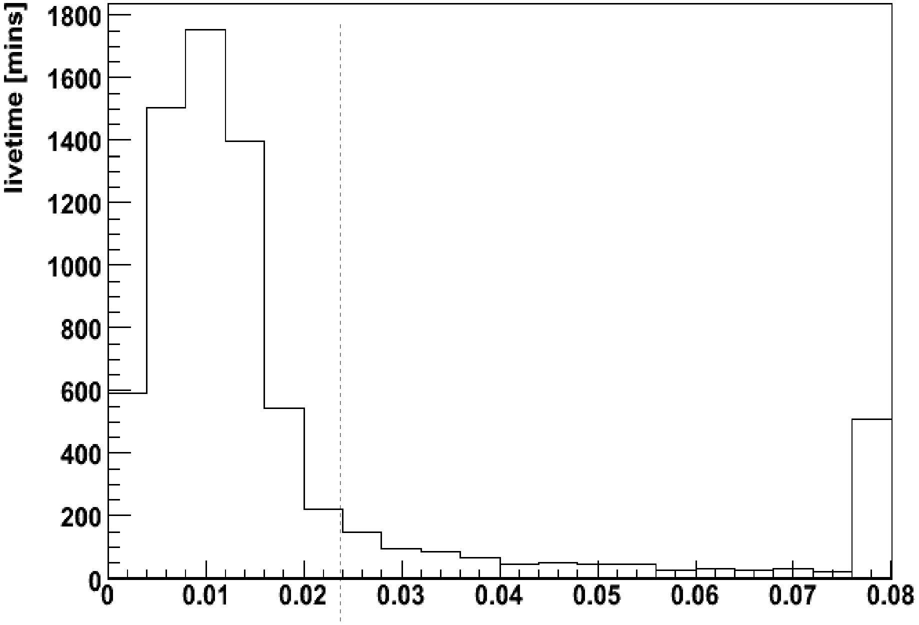
SAUND I



Adaptive Threshold

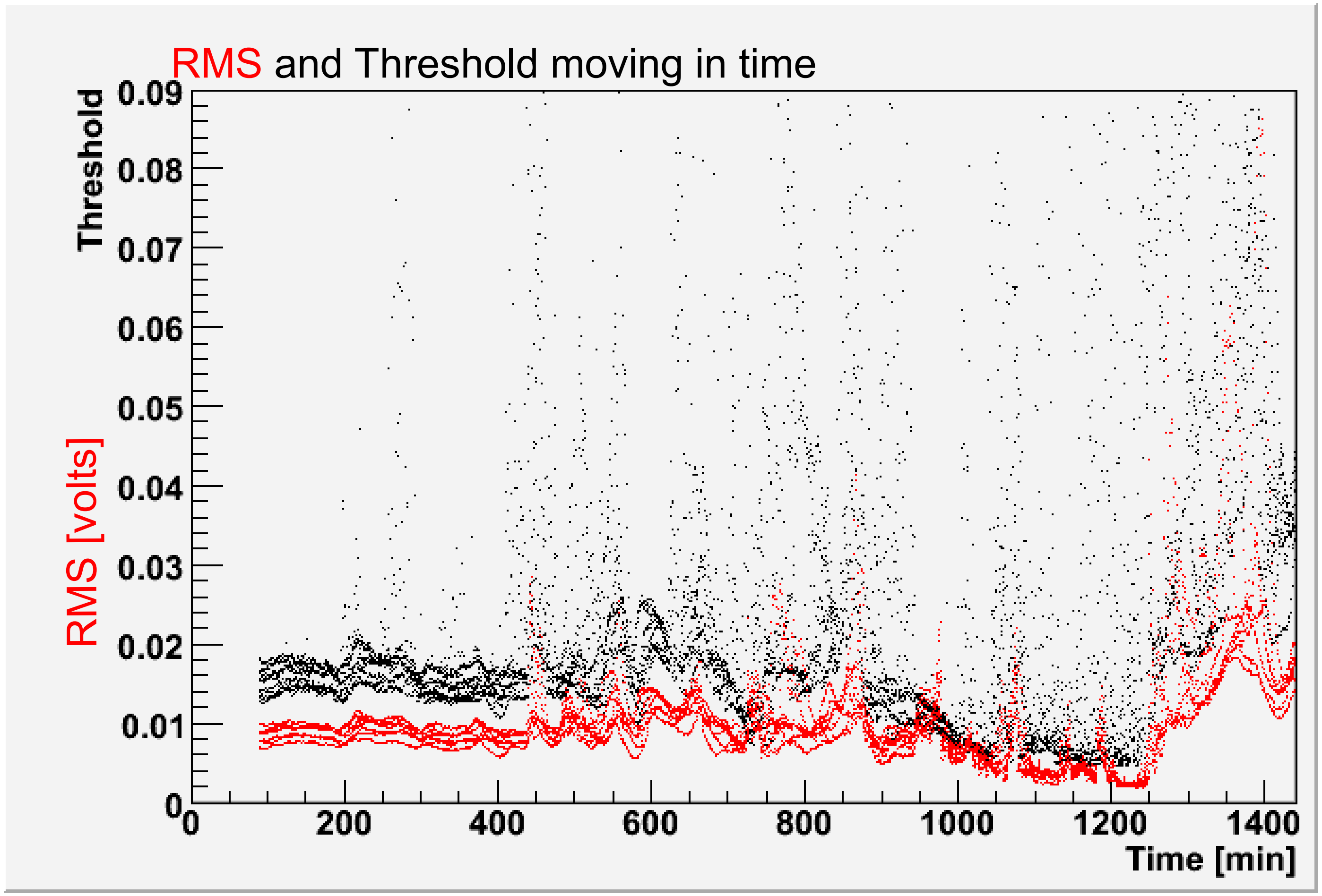
every minute
every hydrophone

SAUND II



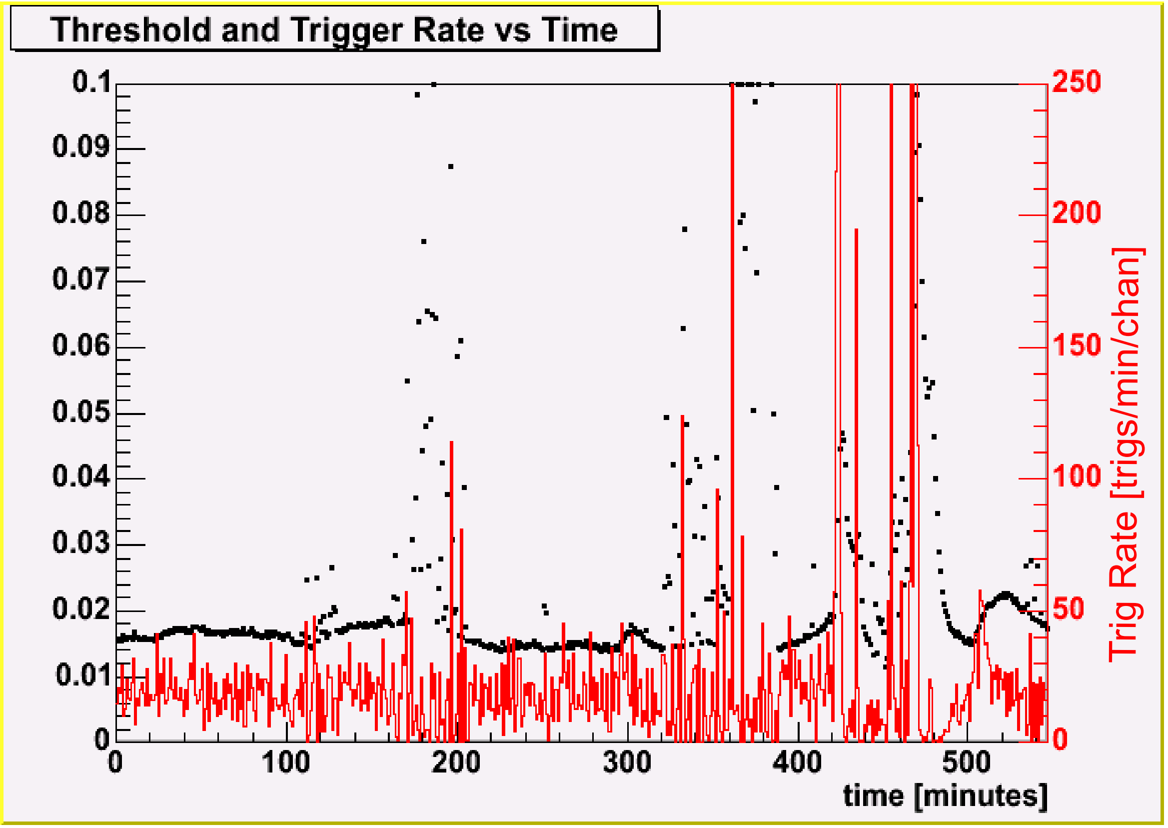
Understanding Trigger Rate Fluctuations

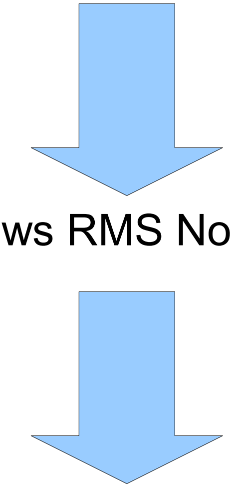
Does noise adaptive thresholding work?



SAUND II Sensitivity = 6.4Pa/V

Understanding Trigger Rate Fluctuations





The threshold controls the trigger rate

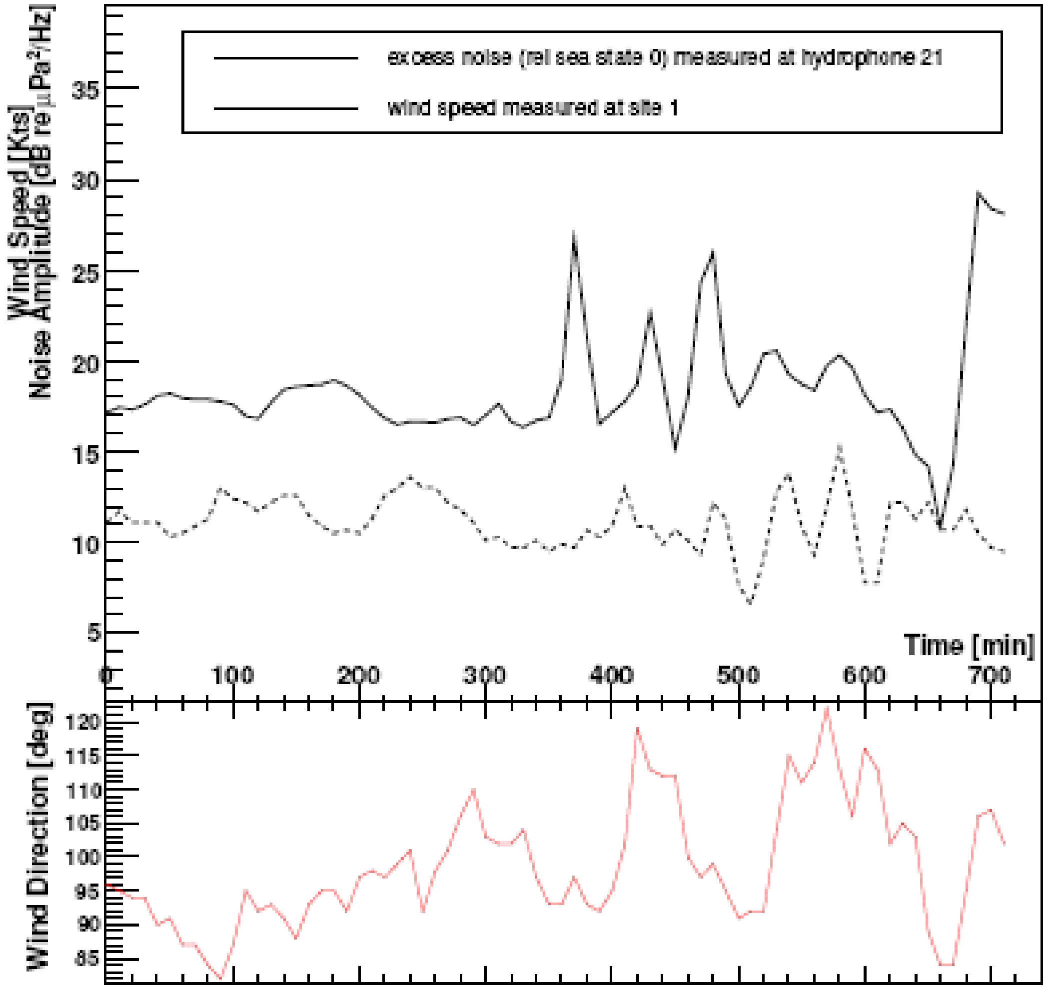
Threshold follows RMS Noise

Noise condition correlates (to some extent) to wind speed

Some Correlation with Wind

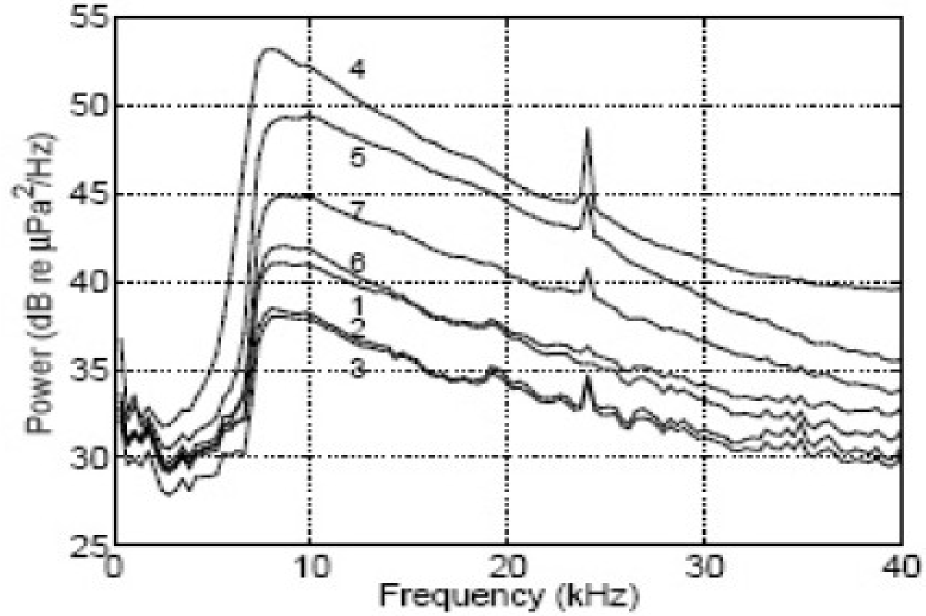
Not a great setup
- Wind measured 21 km away
- Direction of wind is volatile

12 hour period with Pearson product-moment correlation coefficient 0.85 at ~80 min offset (<1% for random time offsets)



SAUND I as a Benchmark

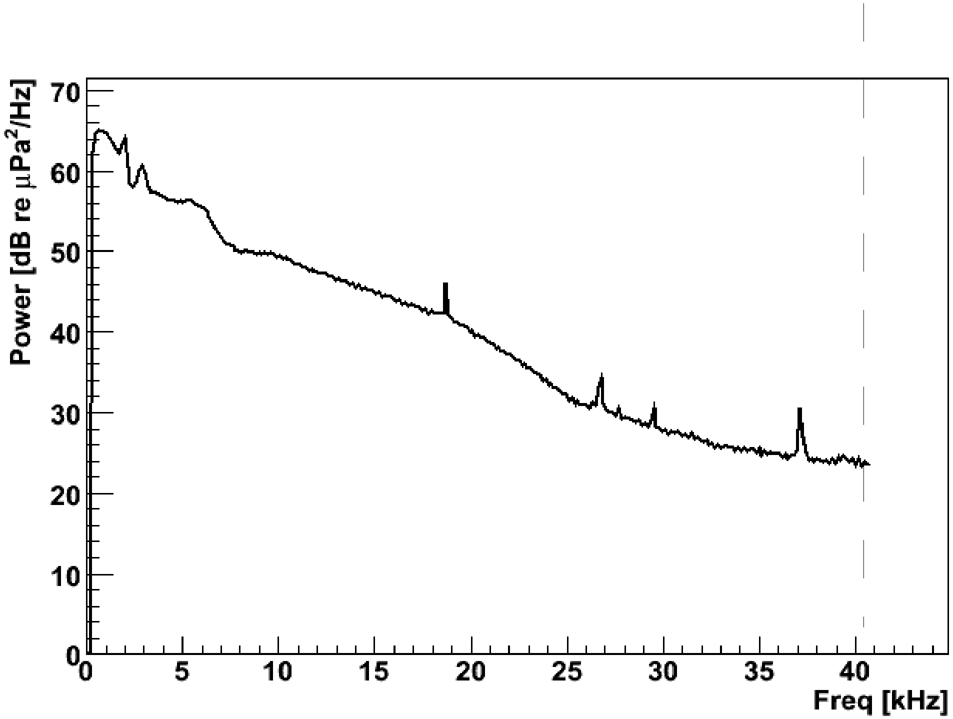
SAUND I



Ambient Noise
Measurements

6.5 ms integrated
every 5 s

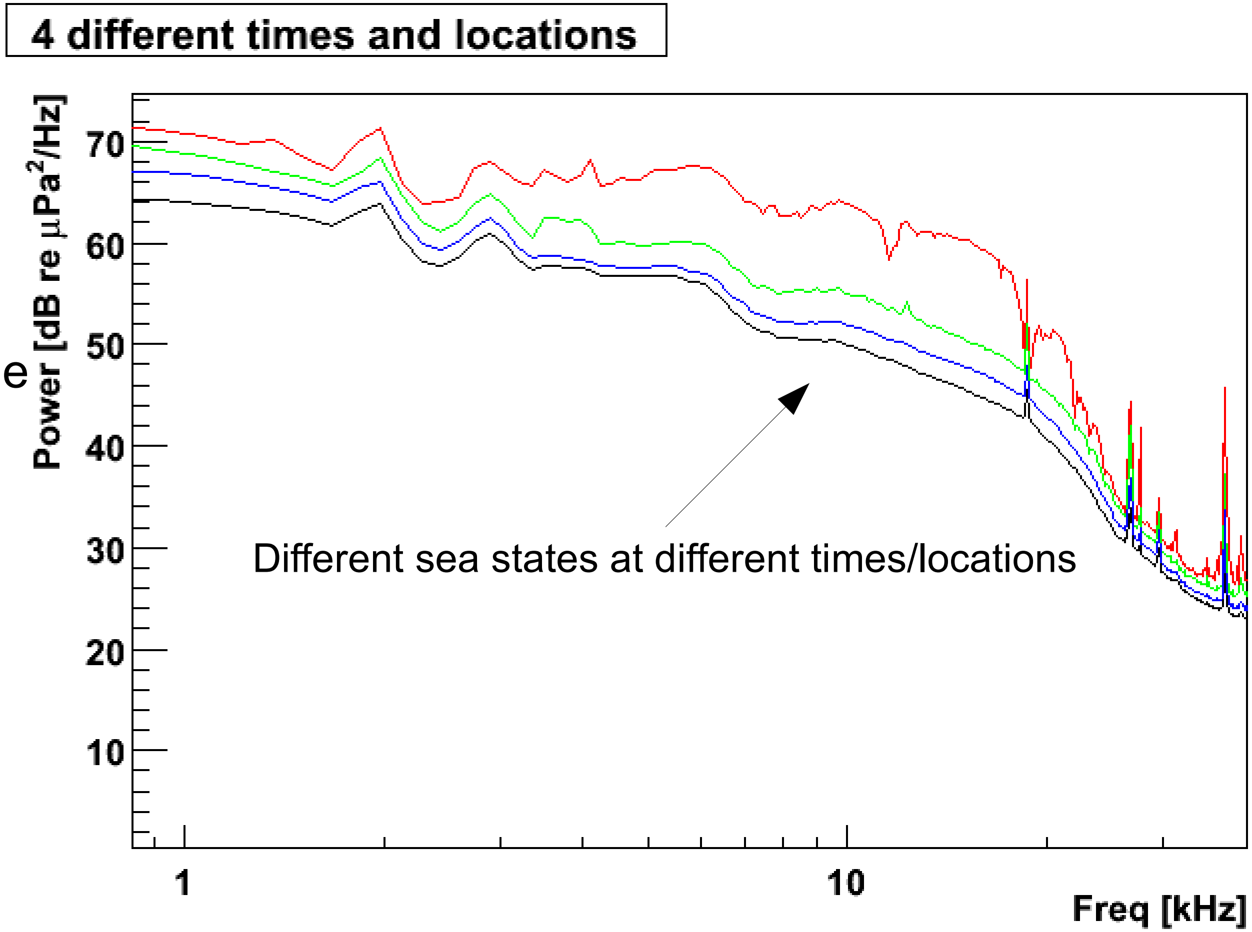
SAUND II



Consistency of the Spectral Shape

Is the spectral shape
- •non-intermittent
- •non-transient
- •Non-local

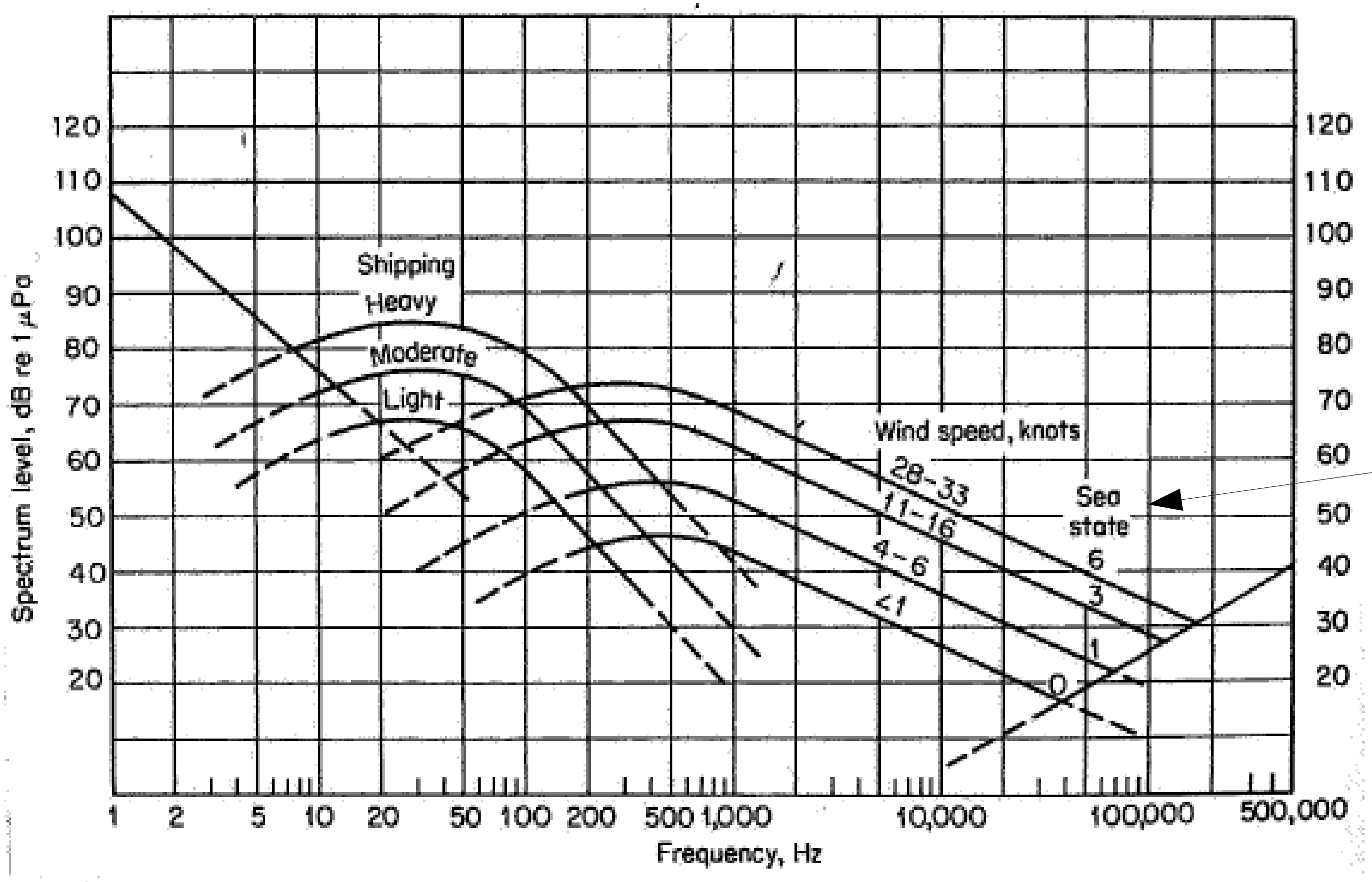
Very similar shape except for the "offset"



Different sea states at different times/locations

The Ambient Noise Spectrum

Urick, “Principles of Underwater Sound” (1967)



“Sea State”
a measure of how “rough” the ocean is. Correlates mainly with wind (also wave height, whitecaps, etc)

“Knudsen Noise Region” 1kHz - 50 kHz
-5to-6 dB per octave, absolute level depends on wind

Consistency of the Spectral Shape

11 twenty-four hour data periods
randomly from
July to November 2006
x
49 hydrophones
=
539 noise spectra

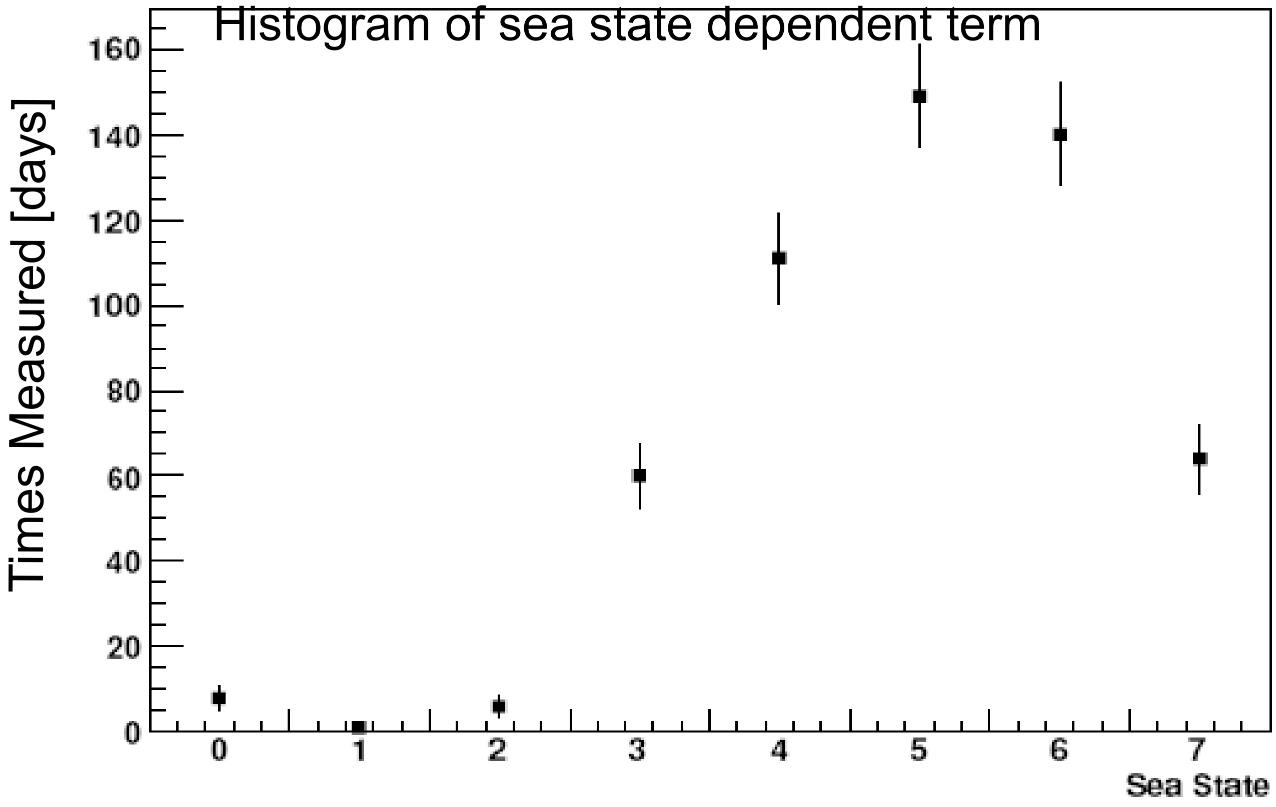
$$P(f, n_s) = 10\underbrace{\log(f^{-5/3}) + 94.5}_{\text{sea state zero Knudsen power law}} + \underset{\uparrow}{P_{ss}}(n_s)$$

sea state dependent term

$$P_{ss} = 30\log(n_s + 1)$$

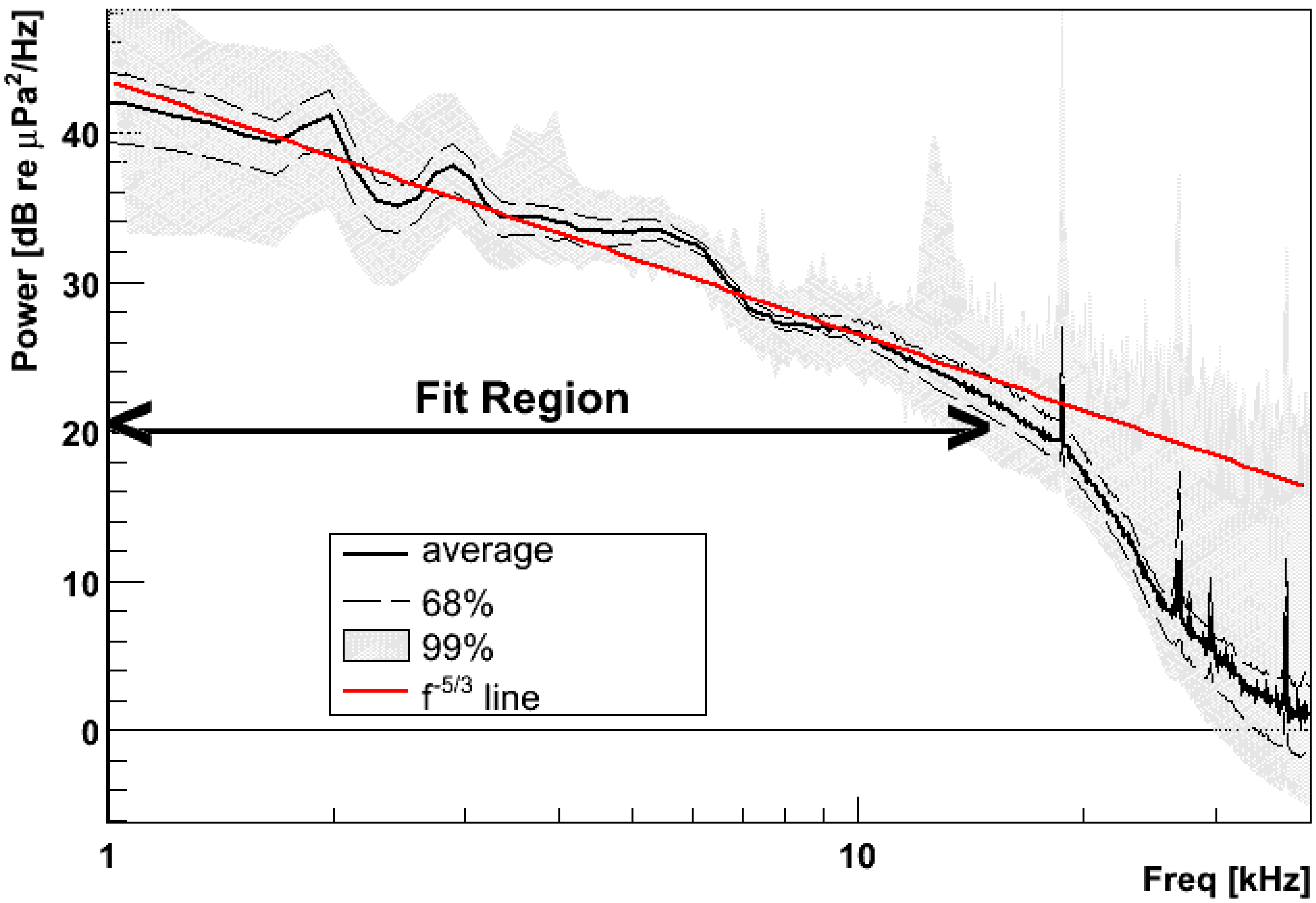
Least square fit 1kHz – 15kHz
to determine Pss

P_{ss} for 539 spectra
(spans 11 days, 49 locations)


Histogram of sea state dependent term

Consistency of the Spectral Shape

539 “sea state subtracted” spectra
(spans 11 days spread out over 6 months and 49 locations)

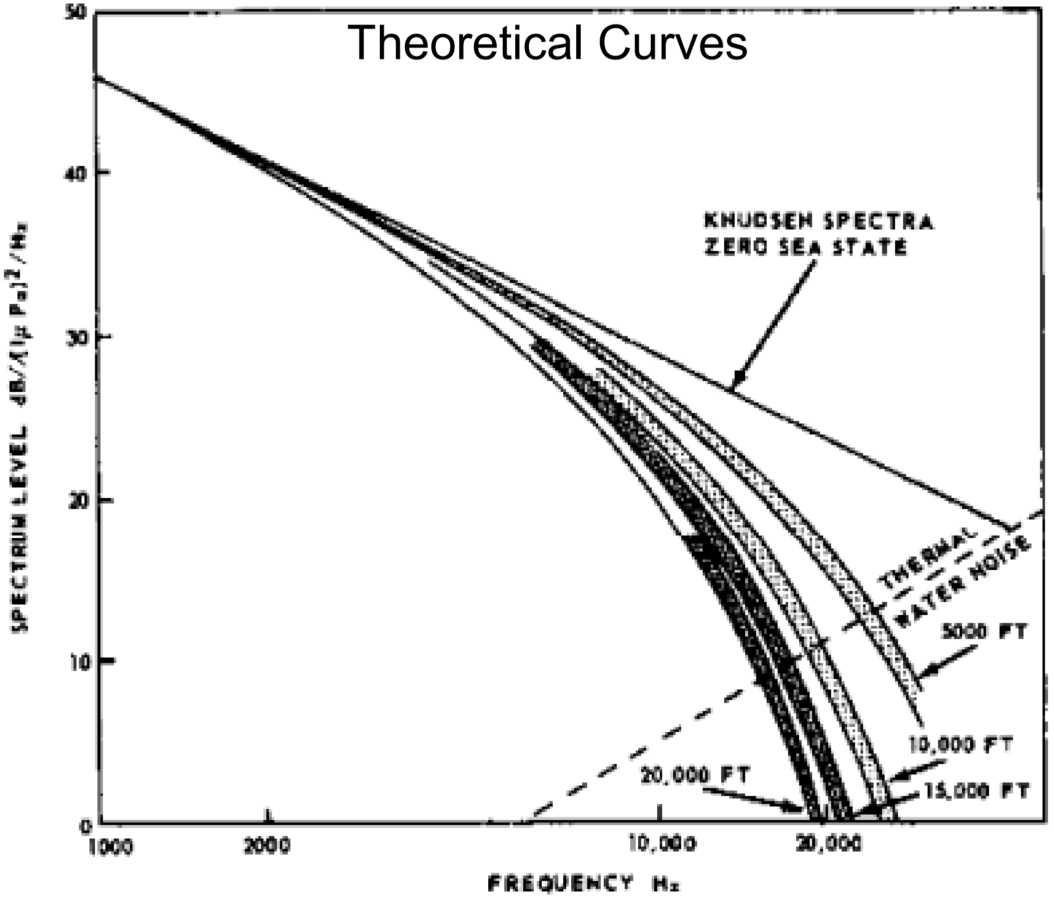


Faster falloff of slope after 15 kHz is a CONSISTENT feature

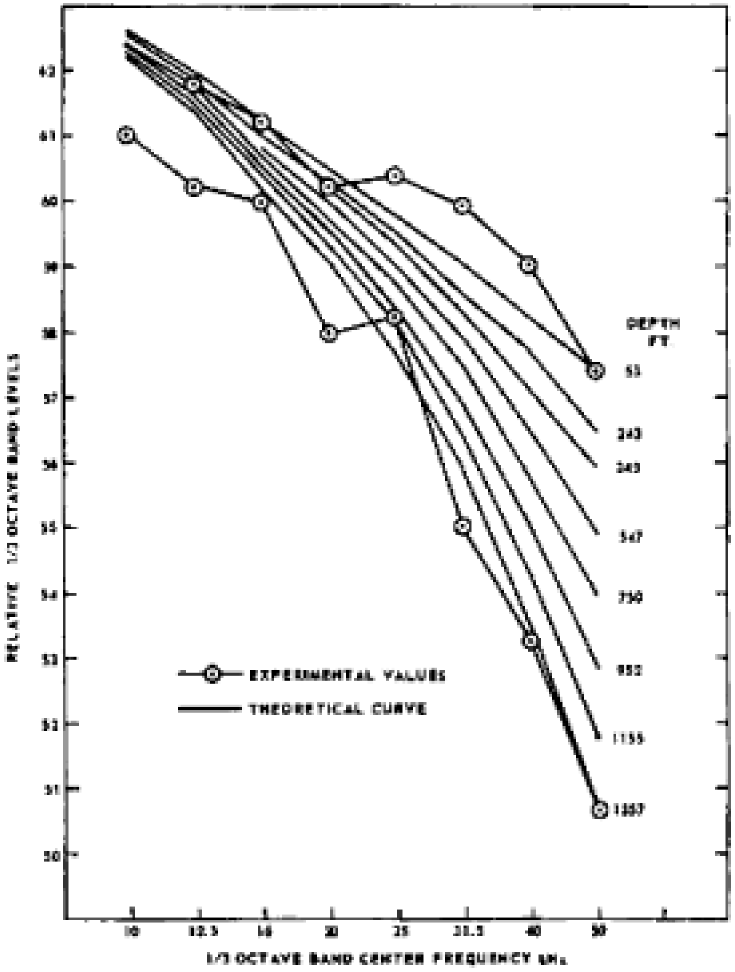
J. R. Short, “High-Frequency Ambient Noise and Its Impact on Underwater Tracking Ranges”, IEEE Journal of Oceanic Engineering, vol 30, no 2, April 2005

*Originally published in the United States Navy Journal of Underwater Acoustics, April 1972

Because of absorption, “at deep depths and high frequencies, the noise spectrum rolls off at a much faster rate than the -5 to -6 dB/octave assumed”


Theoretical Curves

Knudsen spectra, zero sea state, as observed by an omnidirectional hydrophone



Data compared to theory

Attenuation Effect

effective noise intensity per unit band received by an omnidirectional hydrophone located at depth h

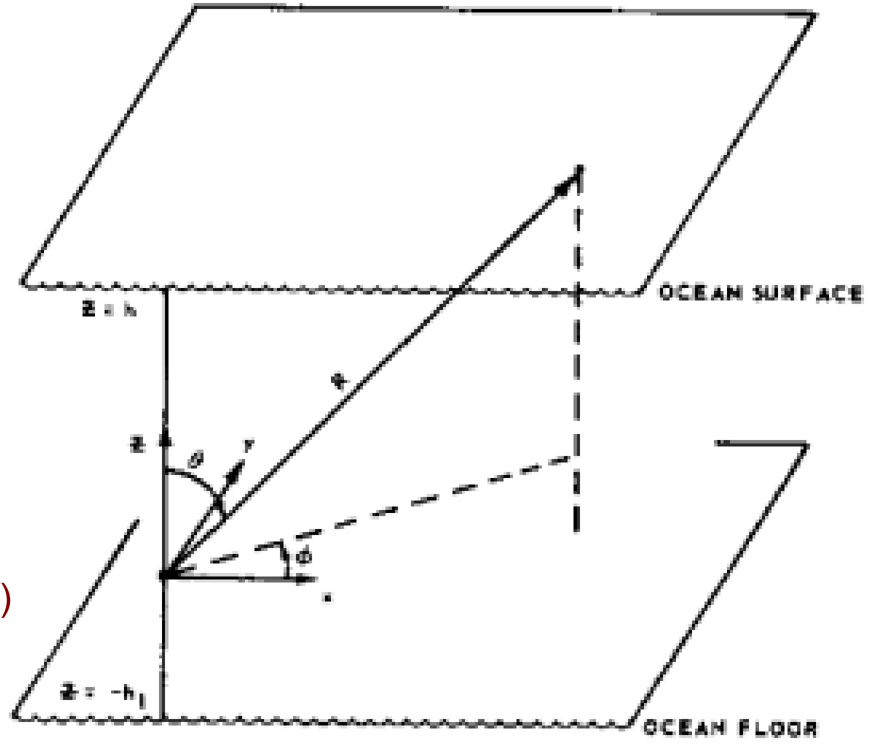
$$\boxed{J_0(ah) = 2\pi J_\infty \int_0^{\pi/2} \underline{\cos^{n-1}\theta}\, \underline{e^{-ah\sec\theta}} \sin\theta\, d\theta}$$

Average intensity per unit solid angle per unit band radiated by an unit surface area (freq dependent)

Surface sources
n=1 monopole
n=2 dipole

Relates to the sound absorption coefficient α(f)

$$\alpha h = -10\log(e^{-ah})$$

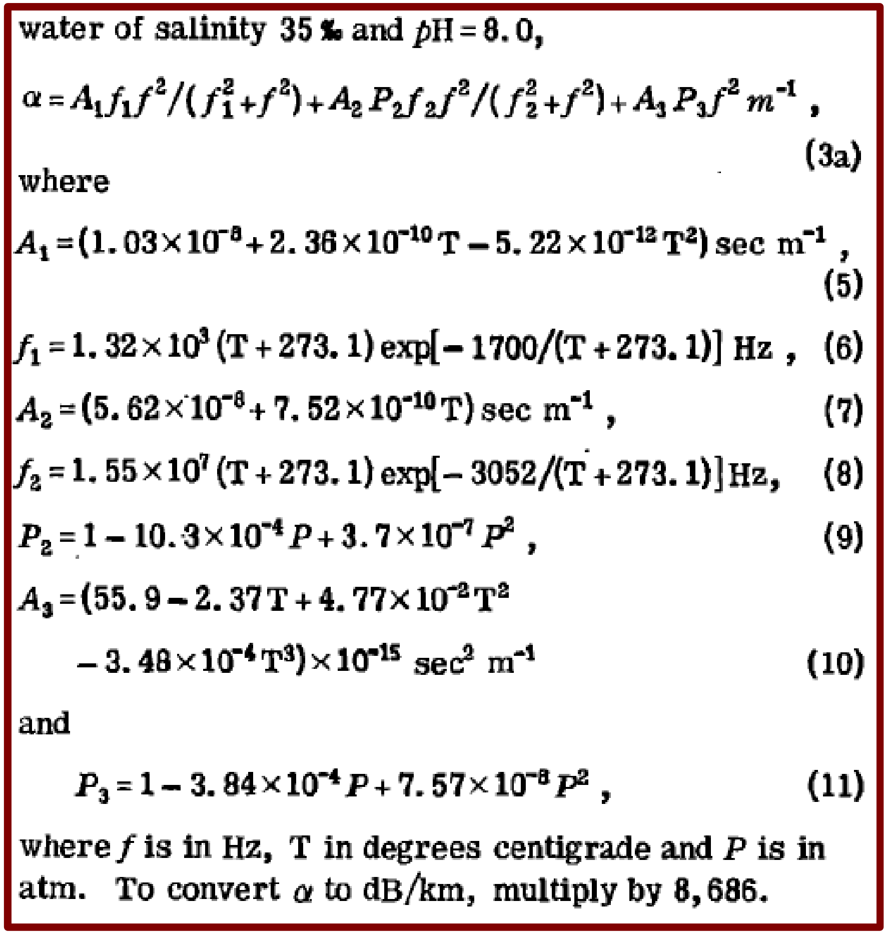


Geometry of the problem.

The Absorption Term: $e^{-ahsec\theta}$

Relaxation of Boric Acid, Magnesium Sulfate, & Water

F. H. Fisher and V. P. Simmons, “Sound absorption in sea water,” JASA, vol 62, no 3, (1977)



water of salinity 35 ‰ and pH = 8.0,

$$\alpha = A_1 f_1 f^2/(f_1^2+f^2) + A_2 P_2 f_2 f^2/(f_2^2+f^2) + A_3 P_3 f^2 \ m^{-1}, \quad (3a)$$

where

$$A_1 = (1.03\times10^{-8} + 2.36\times10^{-10}\,\mathrm{T} - 5.22\times10^{-12}\,\mathrm{T}^2)\ \mathrm{sec\ m^{-1}}, \quad (5)$$

$$f_1 = 1.32\times10^{3}\,(\mathrm{T}+273.1)\exp[-1700/(\mathrm{T}+273.1)]\ \mathrm{Hz}, \quad (6)$$

$$A_2 = (5.62\times10^{-8} + 7.52\times10^{-10}\,\mathrm{T})\ \mathrm{sec\ m^{-1}}, \quad (7)$$

$$f_2 = 1.55\times10^{7}\,(\mathrm{T}+273.1)\exp[-3052/(\mathrm{T}+273.1)]\ \mathrm{Hz}, \quad (8)$$

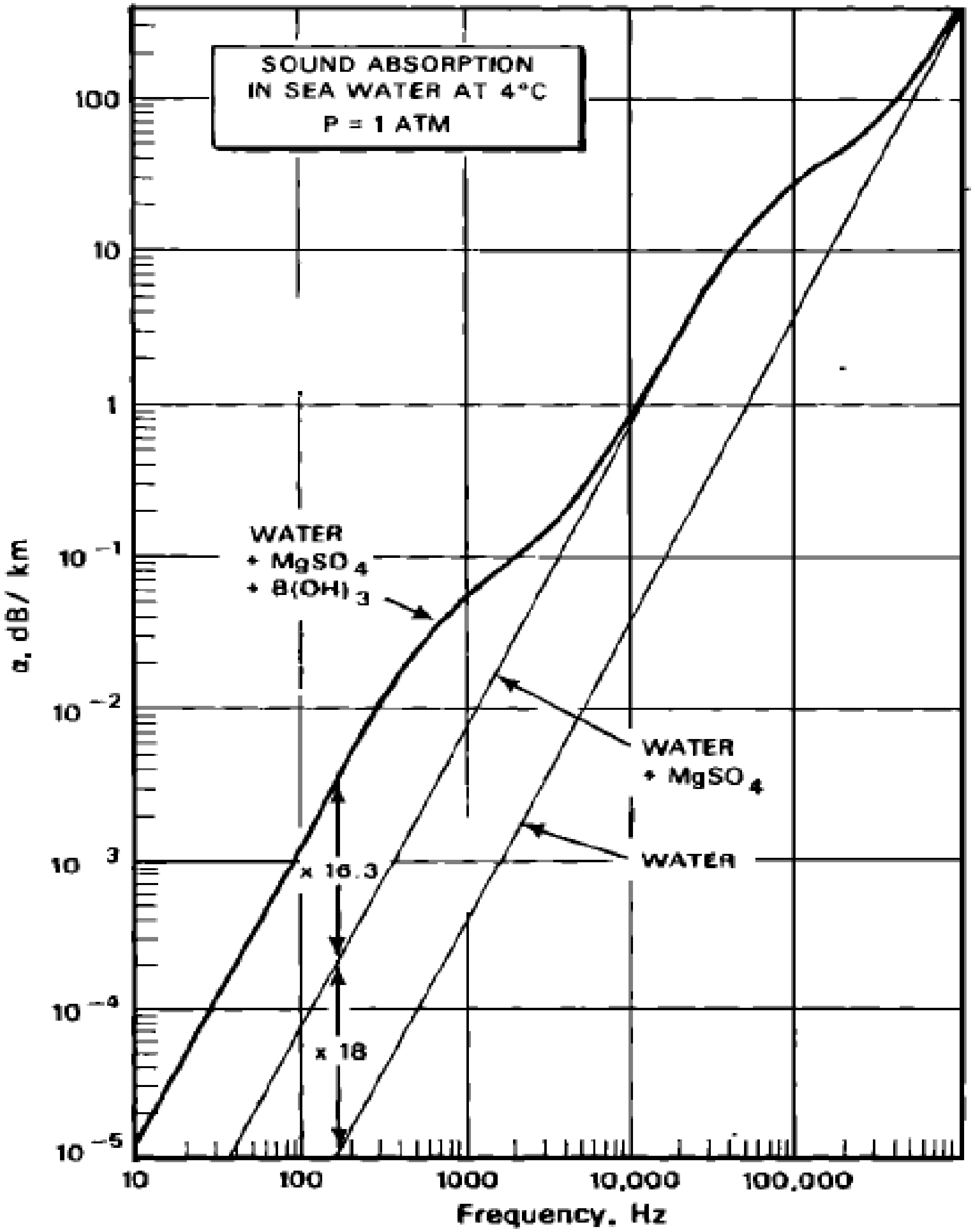
$$P_2 = 1 - 10.3\times10^{-4} P + 3.7\times10^{-7} P^2, \quad (9)$$

$$A_3 = (55.9 - 2.37\,\mathrm{T} + 4.77\times10^{-2}\,\mathrm{T}^2 - 3.48\times10^{-4}\,\mathrm{T}^3)\times10^{-15}\ \mathrm{sec^2\ m^{-1}} \quad (10)$$

and

$$P_3 = 1 - 3.84\times10^{-4} P + 7.57\times10^{-8} P^2, \quad (11)$$

where f is in Hz, T in degrees centigrade and P is in atm. To convert α to dB/km, multiply by 8,686.

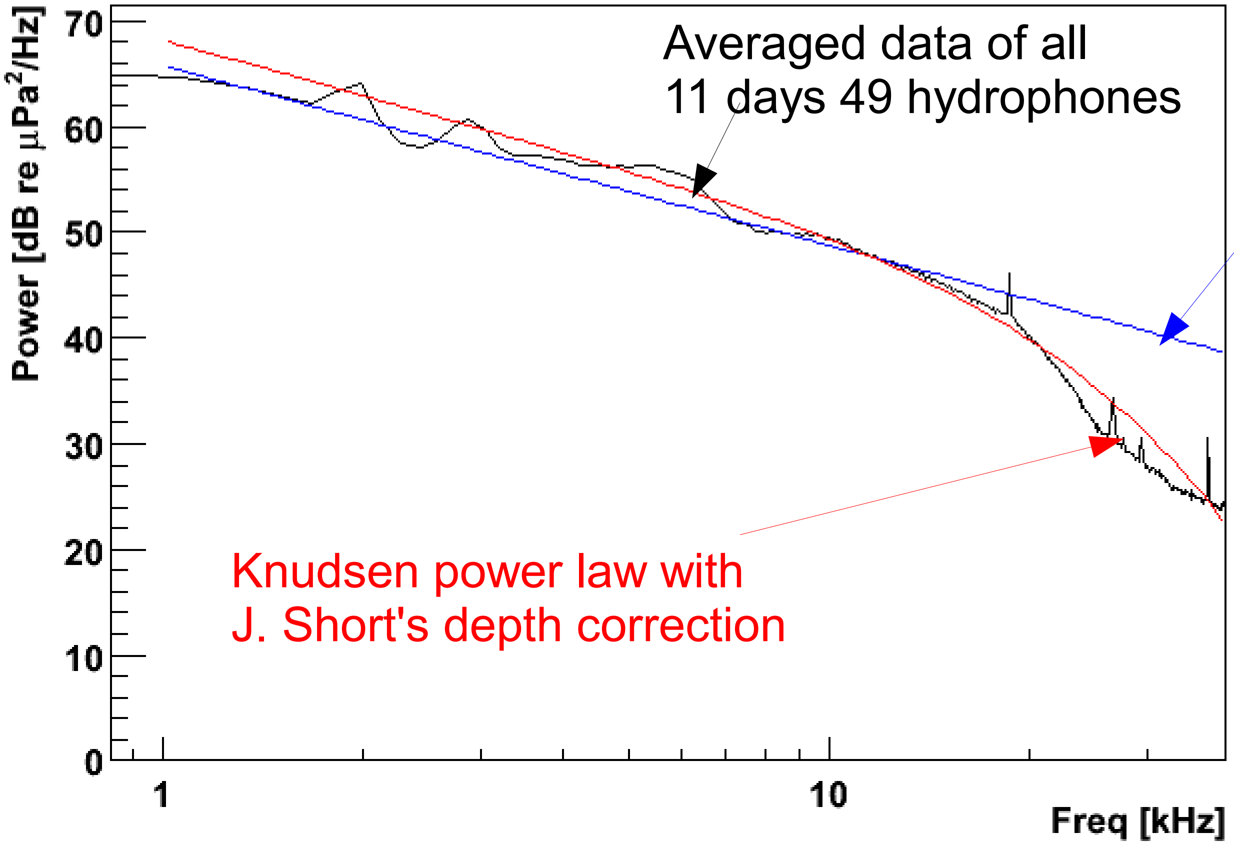


Integrate to get $\alpha h = -10\log(e^{-ah})$

Comparing Data to Theory

$$\underbrace{10 \log \{J_0(0) / 1\mu Pa^2\}}_{\text{Knudsen Spectra power law} + P_{ss}\,^*} + \underbrace{10 \log \{J_0(ah) / J_0(0)\}}_{\text{Term to Calculate}}$$

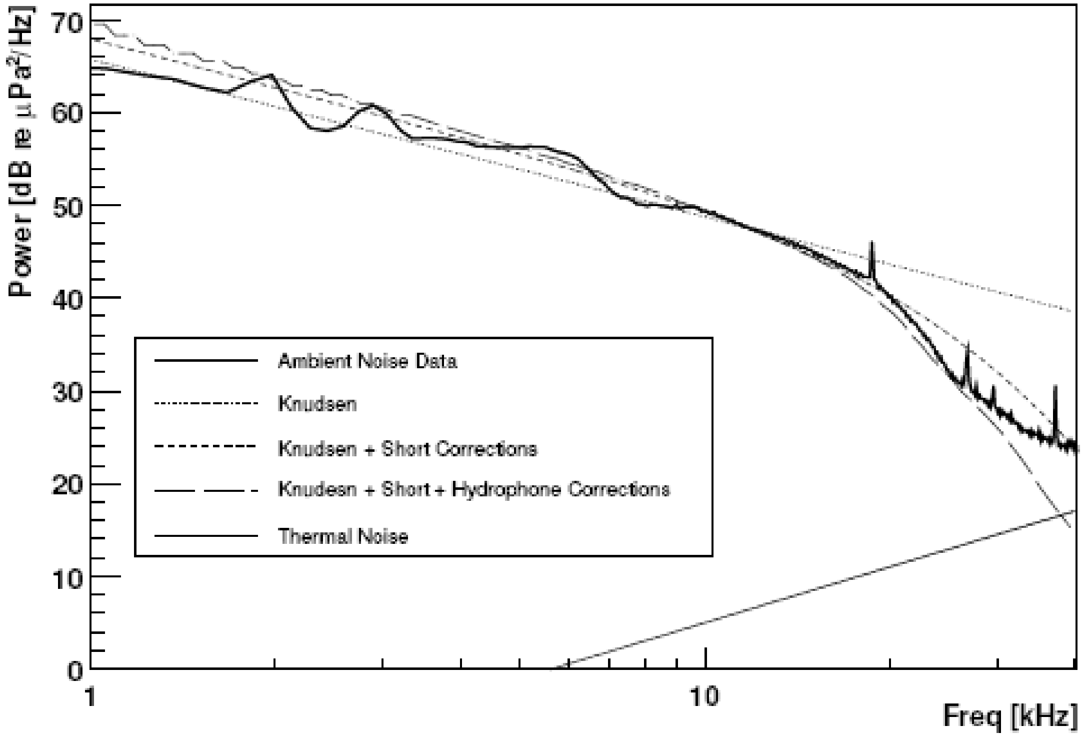
$^*P_{ss}$ fitted independently after calculation

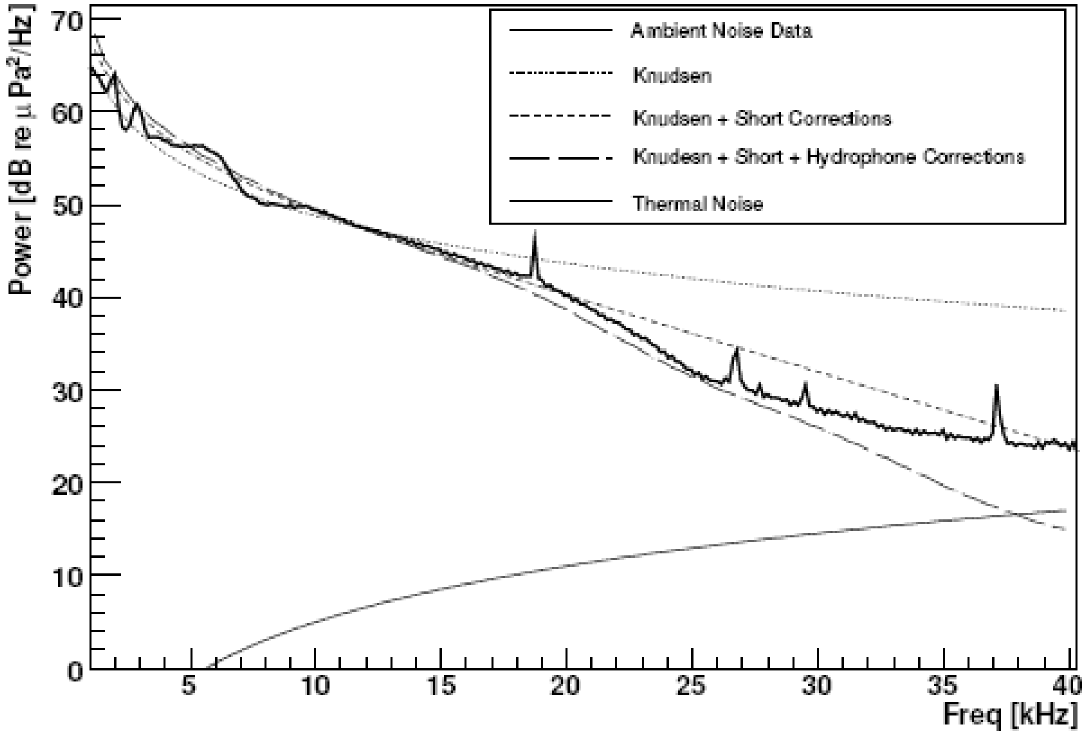


Averaged data of all
11 days 49 hydrophones

Knudsen
power law

Knudsen power law with
J. Short's depth correction





Results

$$J_0(a,h) =$$

$$2\pi J_\infty \int_0^{\pi/-} \cos^{n-1}\theta e^{-ah\sec\theta} \underline{g(\theta,f)} \sin\theta d\theta$$

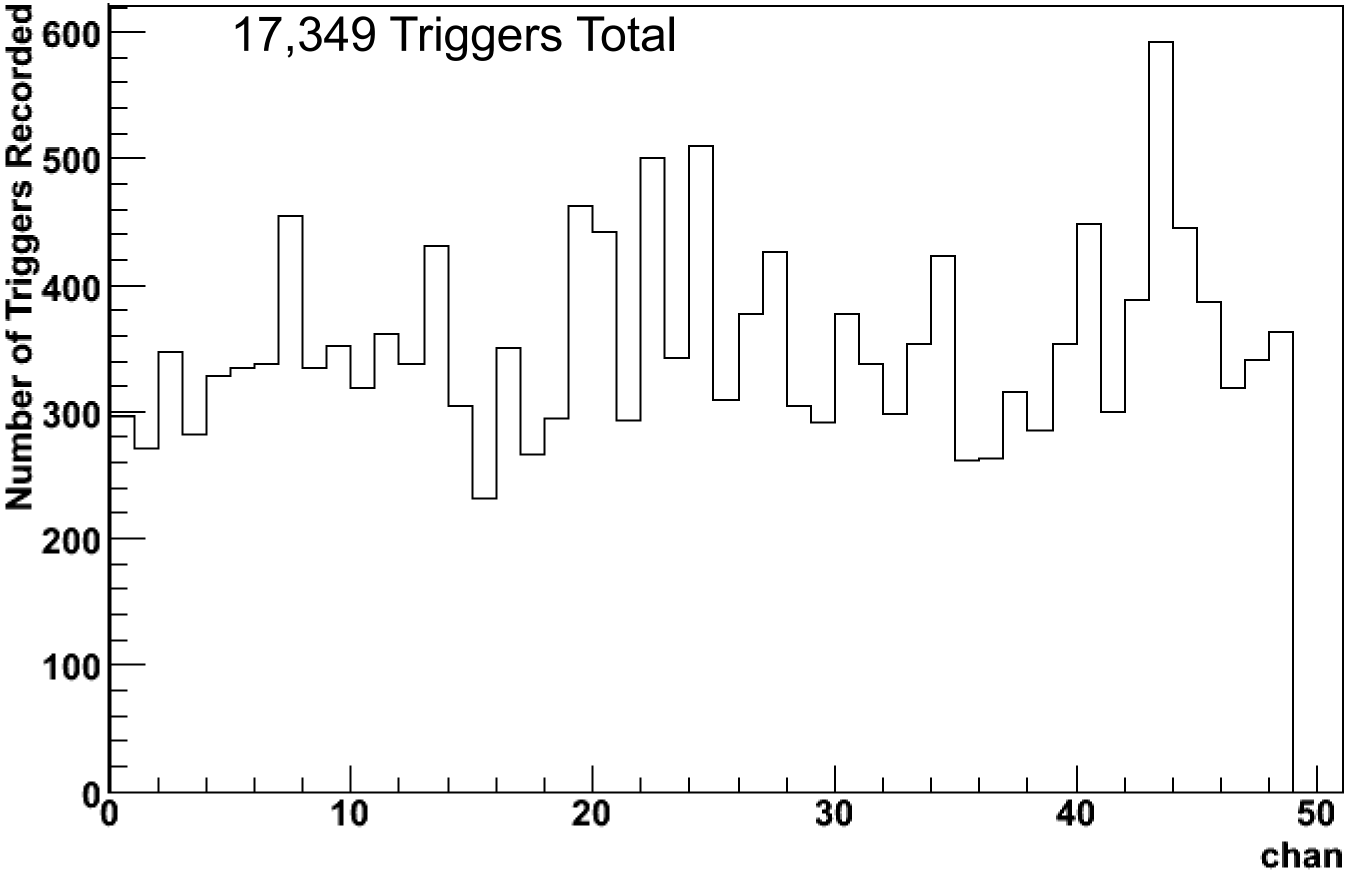
Introduce new term
g is the response function of the hydrophone

- not perfectly omnidirectional
- freq response not perferctly flat

Kurahashi and Gratta
arXiv:0712.1833v1 [physics.ao-ph]
Submitted to JASA, Dec 2007

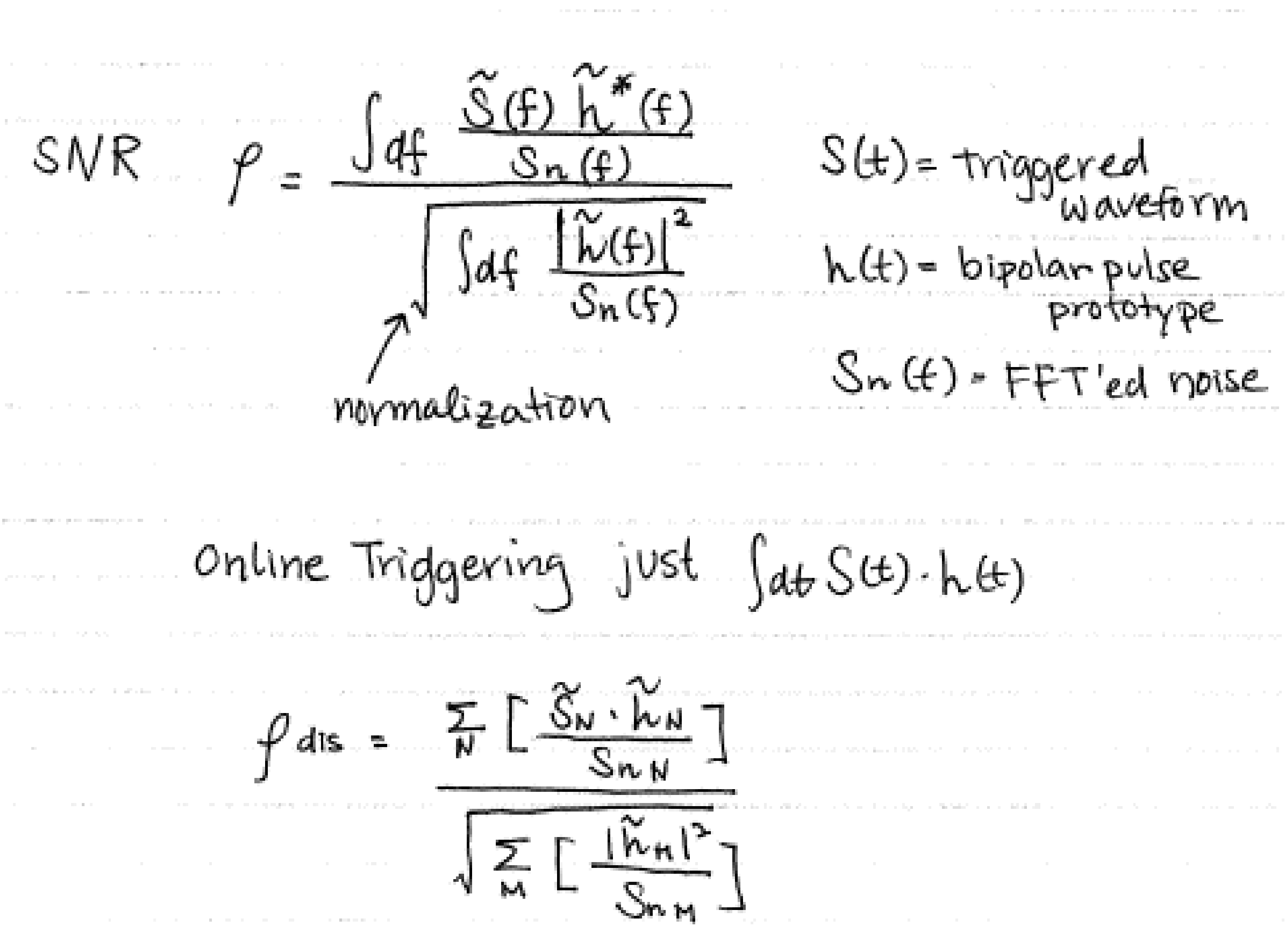
A Closer Look at a Subset of Data

0.5% of data
Randomly chosen in time
(collection of 10 second
windows of all 49 channels)



extract neutrino-like events out

Weiner Filter Signal-to-Noise



SNR $$\rho = \frac{\int df \, \frac{\tilde{S}(f)\,\tilde{h}^*(f)}{S_n(f)}}{\sqrt{\int df \, \frac{|\tilde{h}(f)|^2}{S_n(f)}}}$$

normalization

$S(t)$ = triggered waveform

$h(t)$ = bipolar pulse prototype

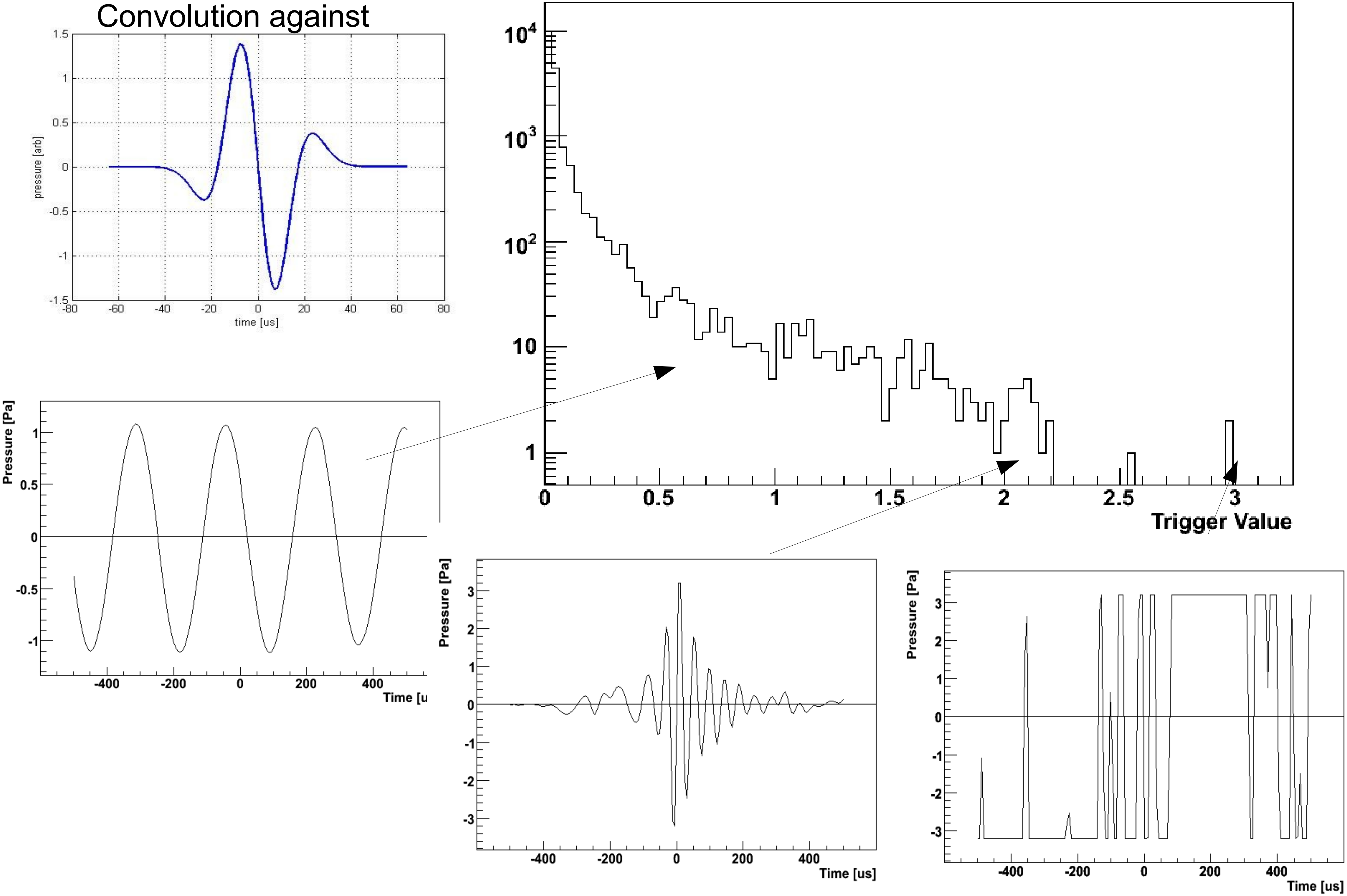
$S_n(t)$ = FFT'ed noise

Online Triggering just $\int dt \, S(t) \cdot h(t)$

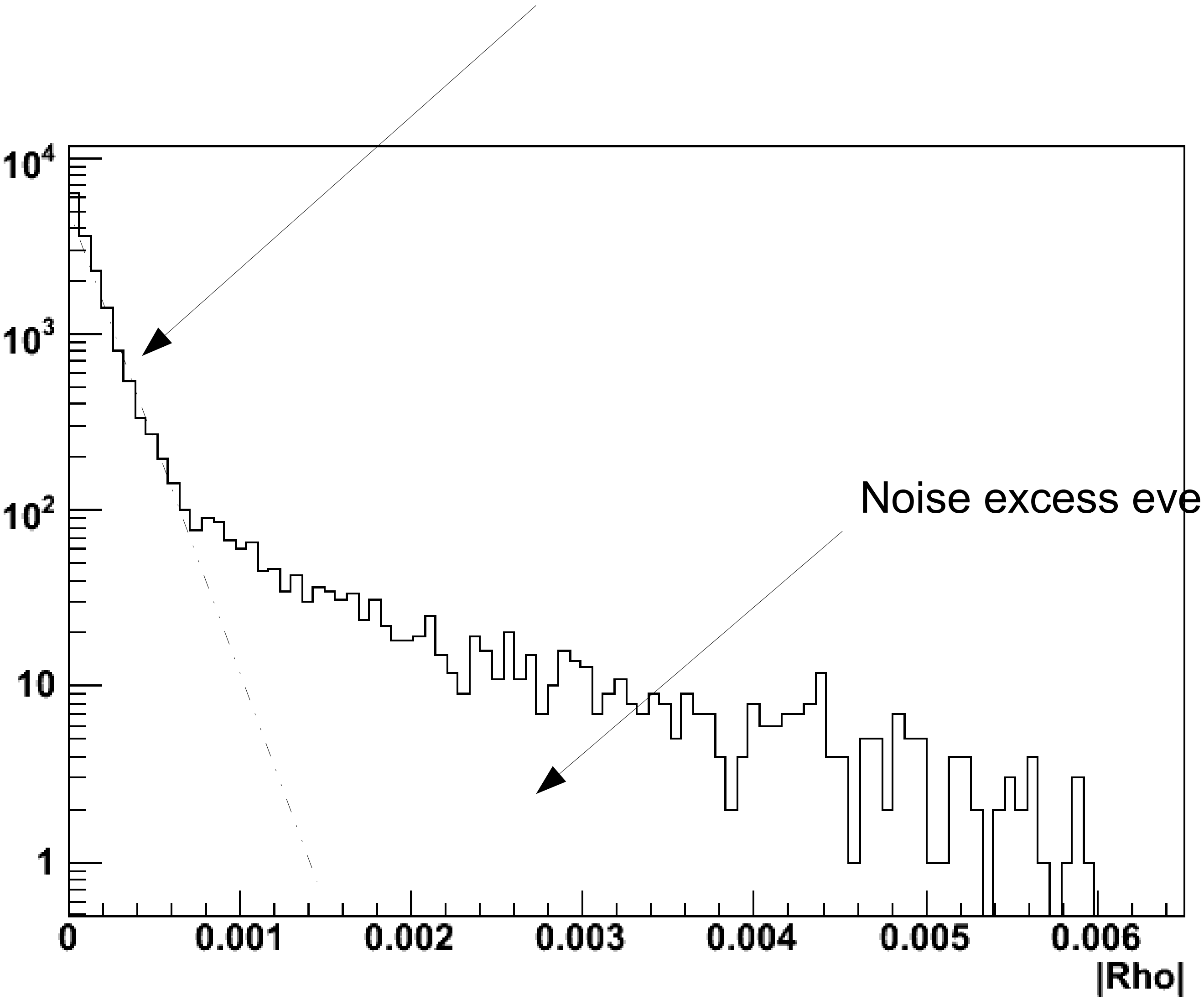
$$\rho_{DIS} = \frac{\sum_N \left[\frac{\tilde{S}_N \cdot \tilde{h}_N}{S_{nN}} \right]}{\sqrt{\sum_M \left[\frac{|\tilde{h}_M|^2}{S_{nM}} \right]}}$$

Take a look at the trigger value

Convolution against



Signal-to-Noise

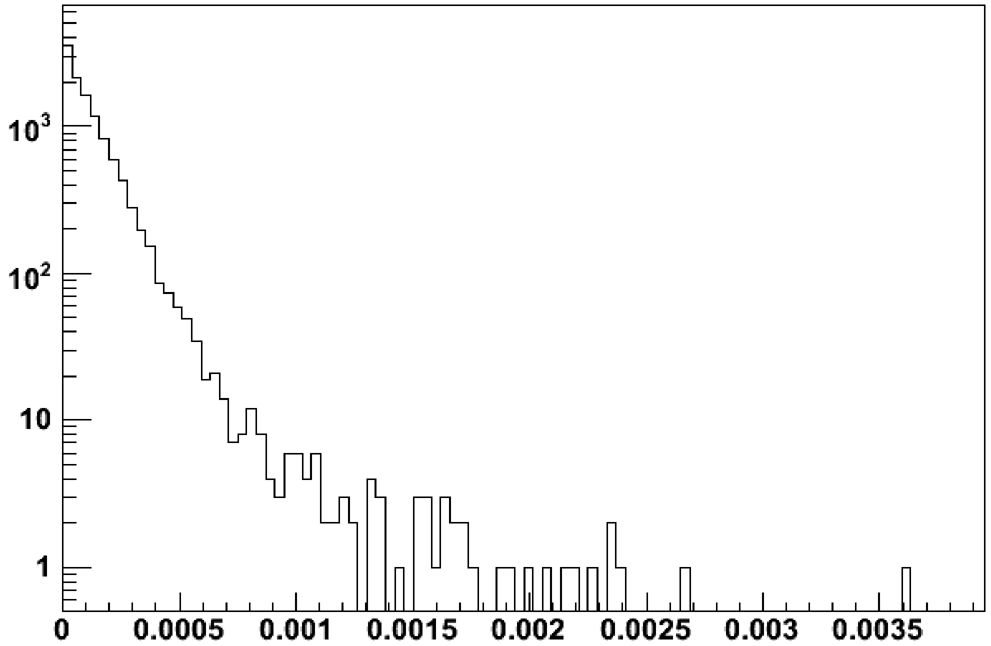


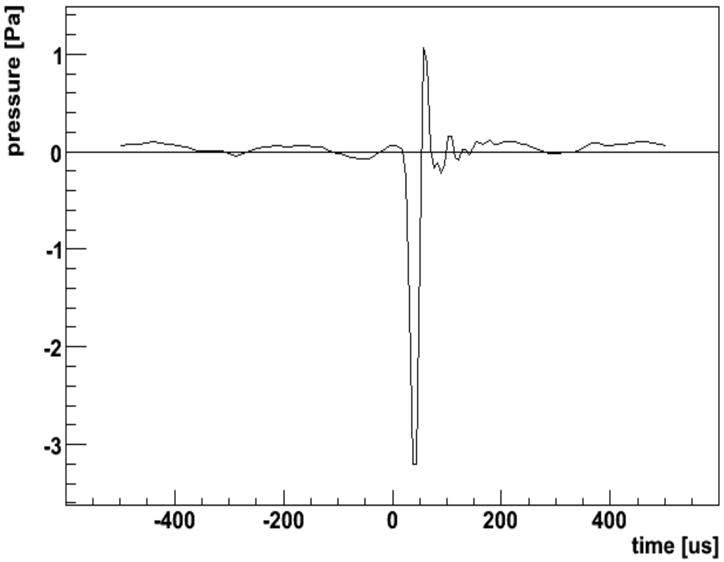
Noise floor

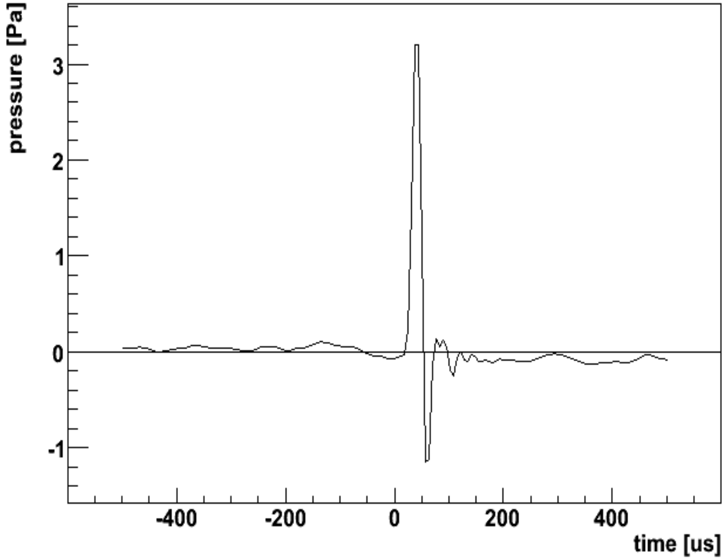
Noise excess events

After some further “cuts” such as

- Enough high frequency components (to remove loud low freq event)
- Not mono-frequency

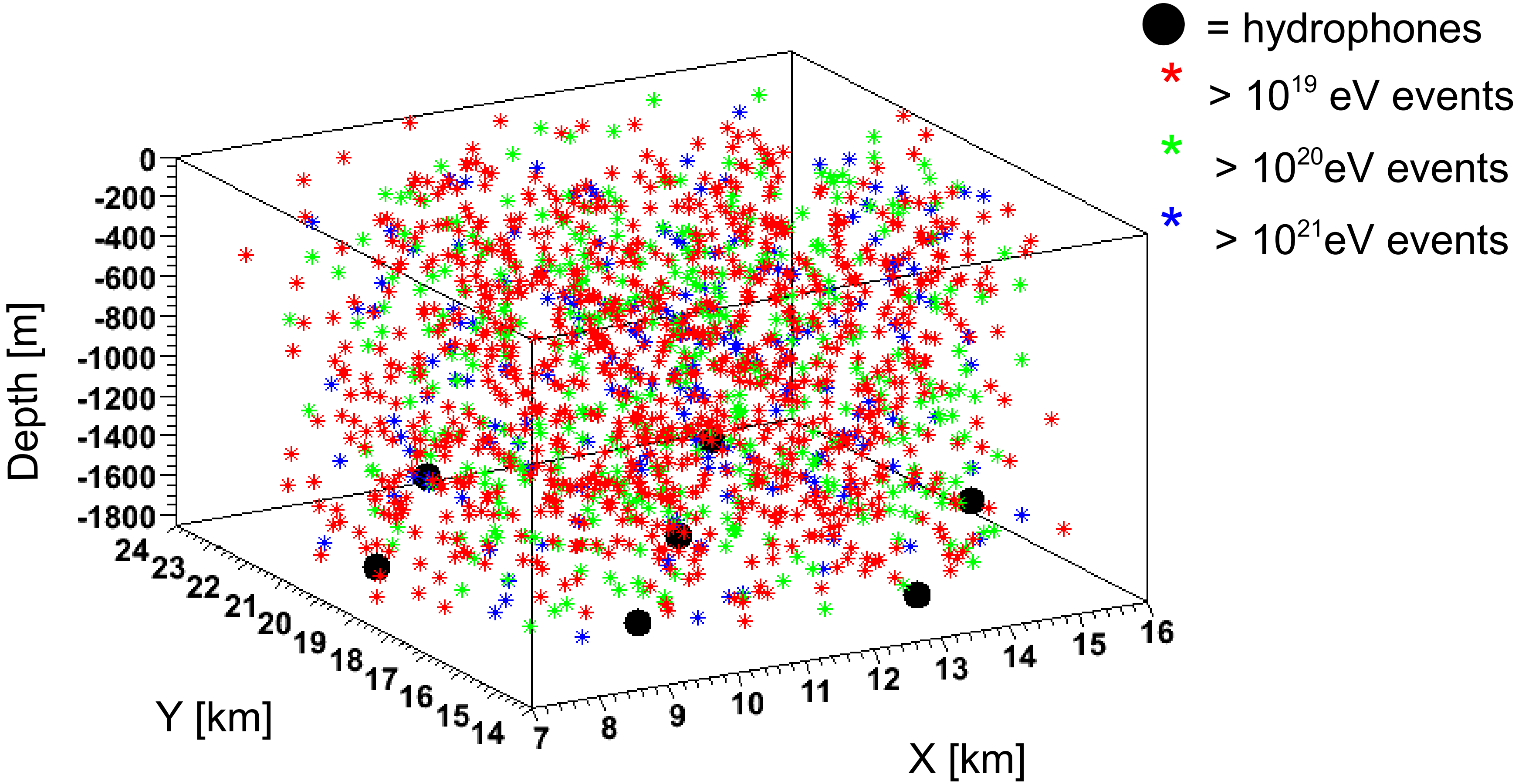






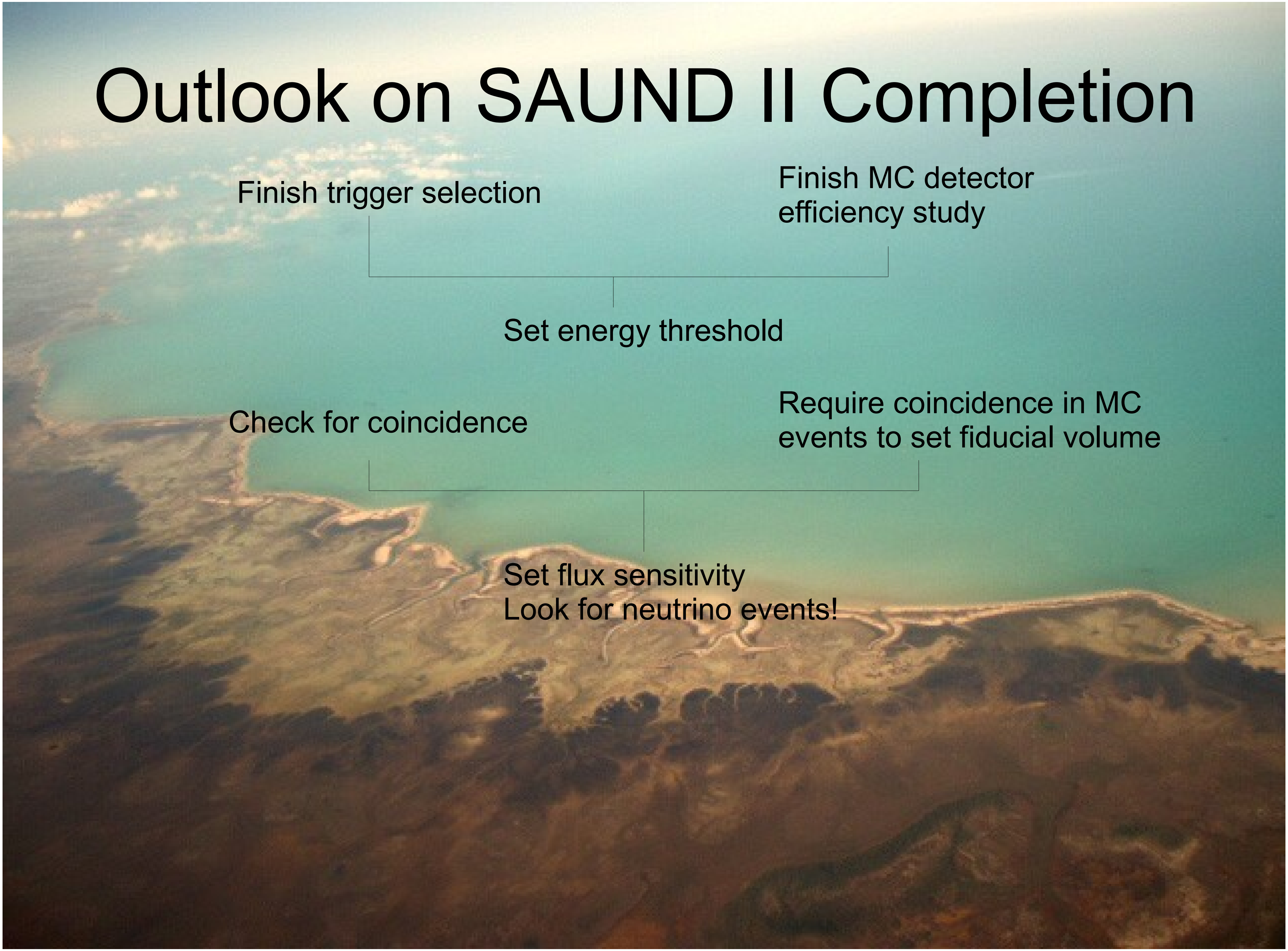
Phase response of the system not clear

Monte Carlo Events for Efficiency Study



Assuming a diffuse incoming flux, right angular/spacial distribution using ANIS

Outlook on SAUND II Completion



Finish trigger selection

Finish MC detector efficiency study

Set energy threshold

Check for coincidence

Require coincidence in MC events to set fiducial volume

Set flux sensitivity
Look for neutrino events!

Northern shores of Andros Island from AUTEC plane

SAUND II Project

Naoko Kurahashi (Stanford University)
Giorgio Gratta (Stanford University)

Funded by NSF

Consultation

Scripps Institution of Oceanography
→ Mike Buckingham

Naval Postgraduate School
→ Daphne Kapolka

University of California, Berkeley
→ Justin Vandenbroucke

Massachusetts Institute of Technology
→ Sam Waldman

Stanford University
→ Nikolai Lehtinen

Support

Naval Undersea Warfare Center, United States Navy

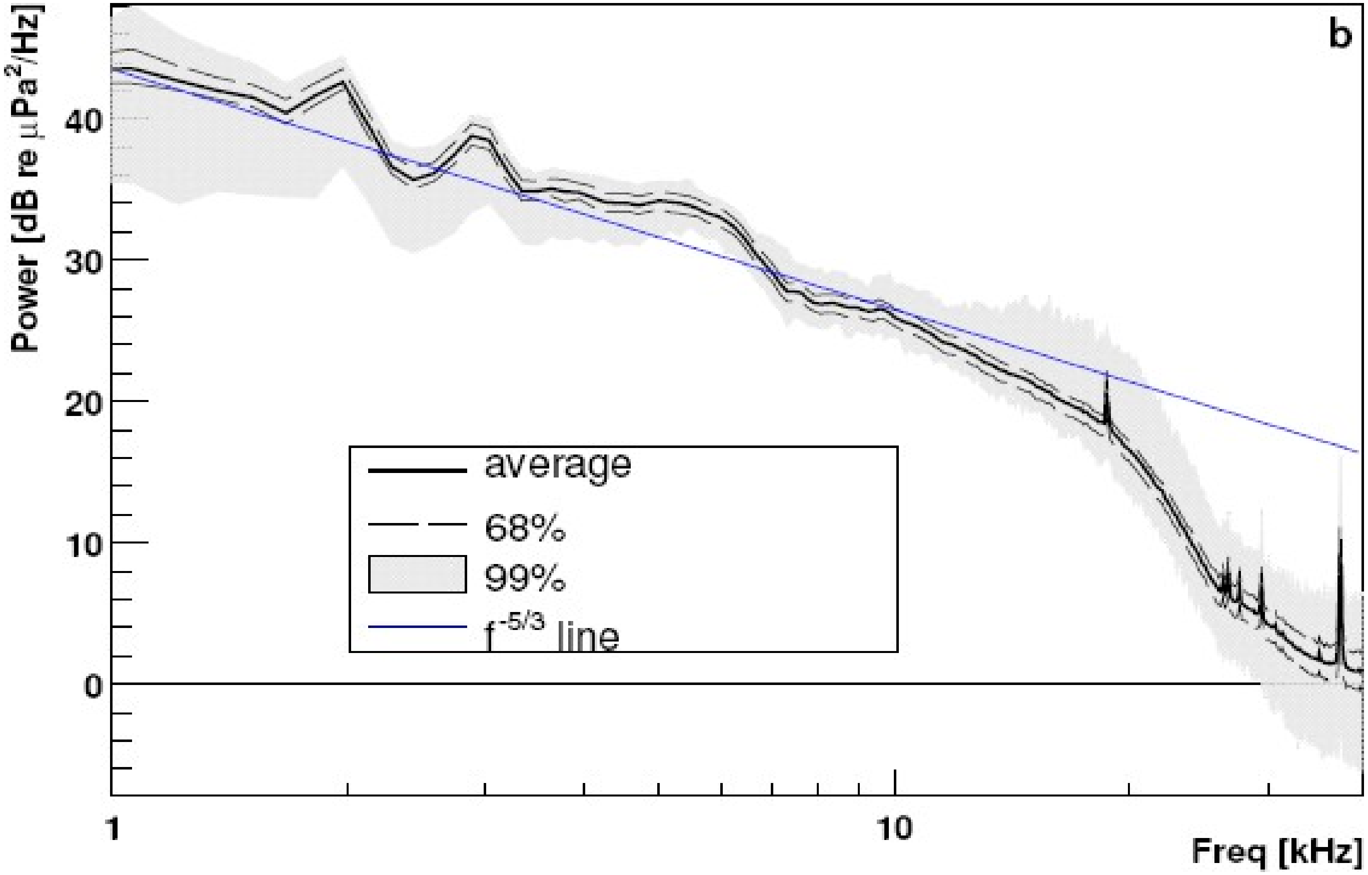
→ Dave Deveau
→ Trevor Kelly-Bissonnette

.... and many other US Navy related people that supported us on base

Consistency of the Spectral Shape

Check: Is the averaging over 24 hours (17280 spectra) washing out a daily feature?
Can the deviation form the power law be explained by an intermittent source?

Same “sea state subtracted” spectra from Oct 2nd 2006 (24h period)
spectra averaged every 5 min (287 total)



Once again, faster falloff of slope after 15 kHz is a CONSISTENT feature