Currituck Sound:

Highly Dense Soliton and Breather Turbulence in Ocean Surface Waves

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Ocean Surface Waves

- The ***Traditional View***: The random phase, Gaussian approximation describes ocean surface waves
- The ***Problem is***: This is untrue!

Alfred R. OSBORNE

NONLINEAR OCEAN WAVES

and the Inverse Scattering Transform

For more than 200 years, the Fourier Transform has been one of the most important mathematical tools for understanding the dynamics of linear wave trains. *Nonlinear Ocean Waves and the Inverse Scattering Transform* presents the development of the nonlinear Fourier analysis of measured space and time series, which can be found in a wide variety of physical settings including surface water waves, internal waves, and equatorial Rossby waves. This revolutionary development will allow hyperfast numerical modelling of nonlinear waves, greatly advancing our understanding of oceanic surface and internal waves. Nonlinear Fourier analysis is based upon a generalization of linear Fourier analysis referred to as the inverse scattering transform, the fundamental building block of which is a generalized Fourier series called the Riemann theta function. Elucidating the art and science of implementing these functions, in the context of physical and time series analysis and modeling, is the goal of this book.

- **Topics include: physical foundations, nonlinear Fourier analysis, nonlinear time series analysis, hyperfast nonlinear numerical modeling, rogue waves, internal solitons and ocean acoustics, nonlinear coastal zone dynamics**
- **Geared toward the introductory as well as advanced reader venturing further into mathematical and numerical analysis**
- **Suitable for classroom teaching as well as research**

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NONLINEAR OCEAN WAVES and the Inverse Scattering Transform

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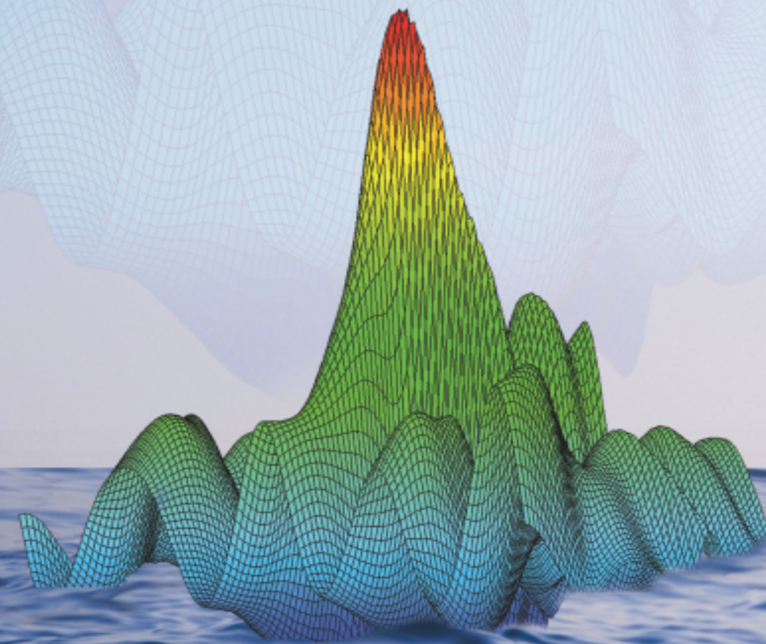

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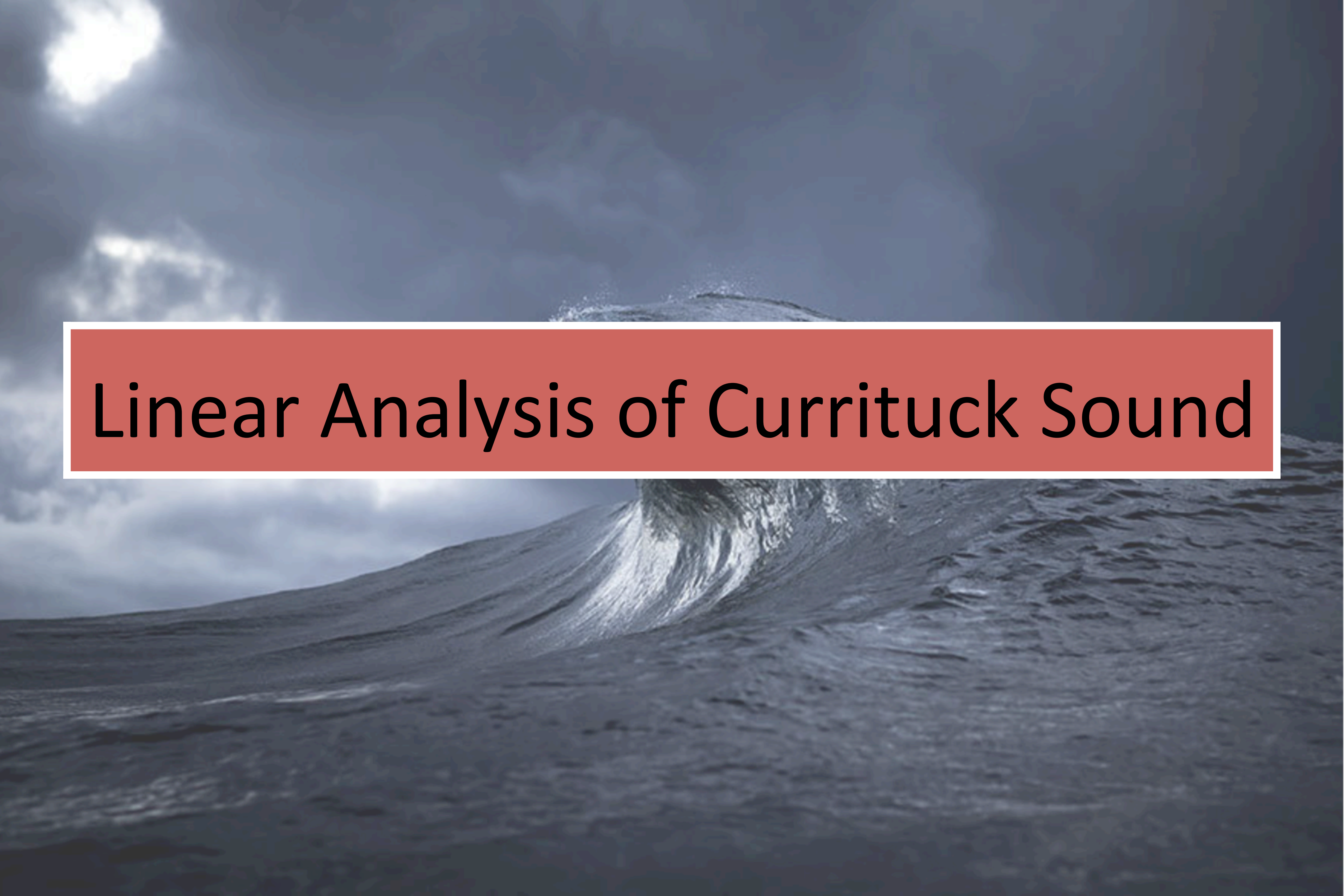
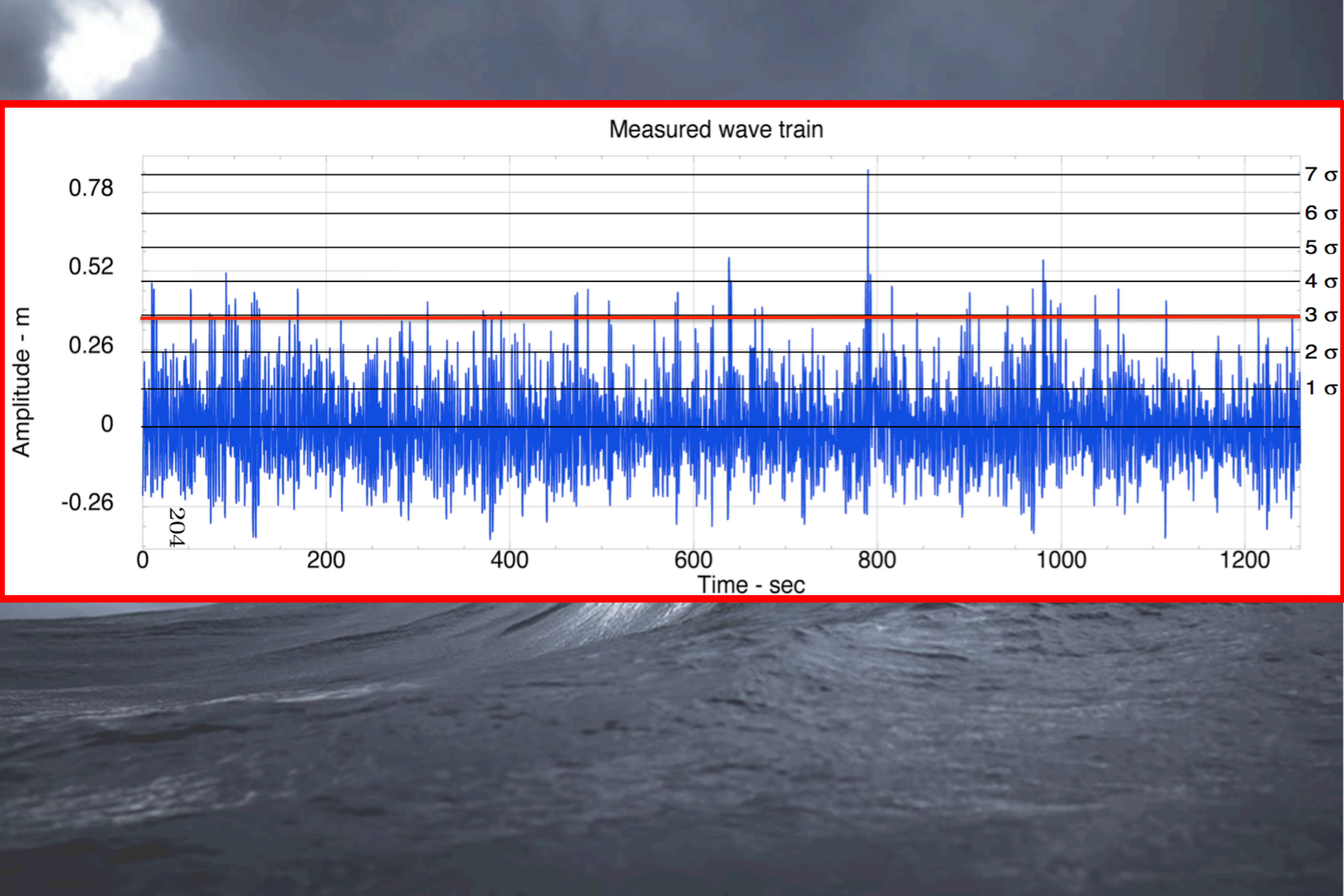
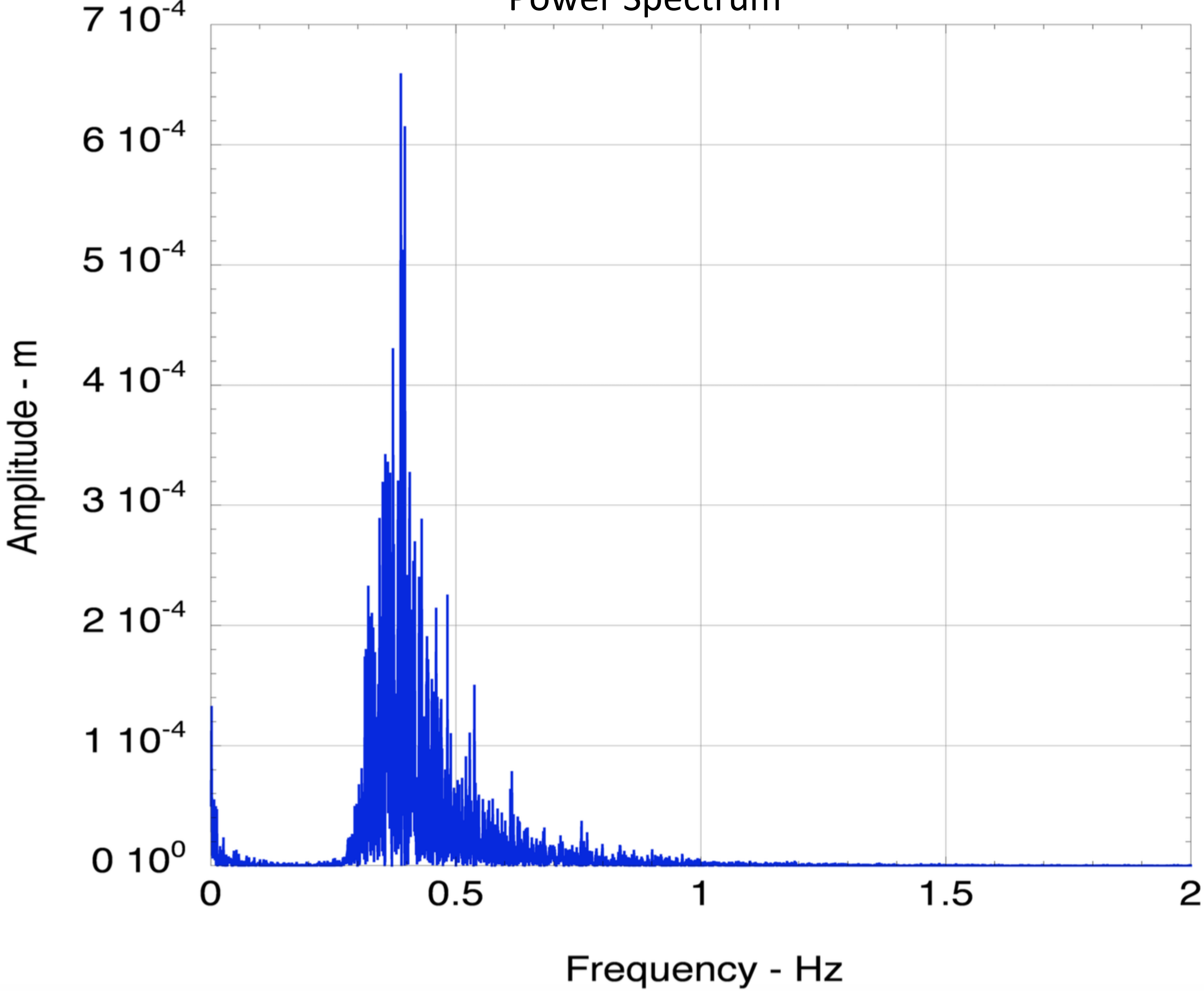
Linear Analysis of Currituck Sound

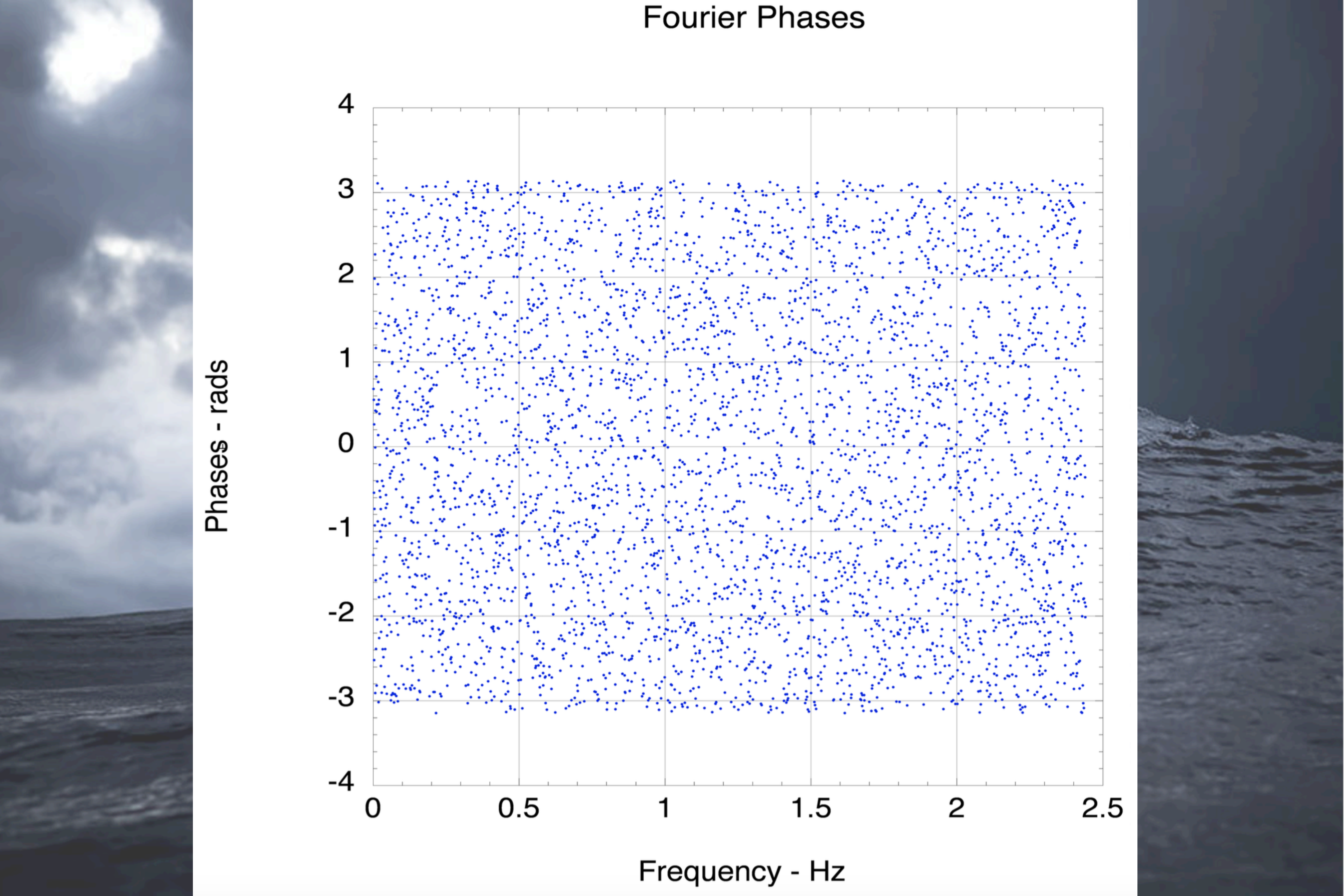


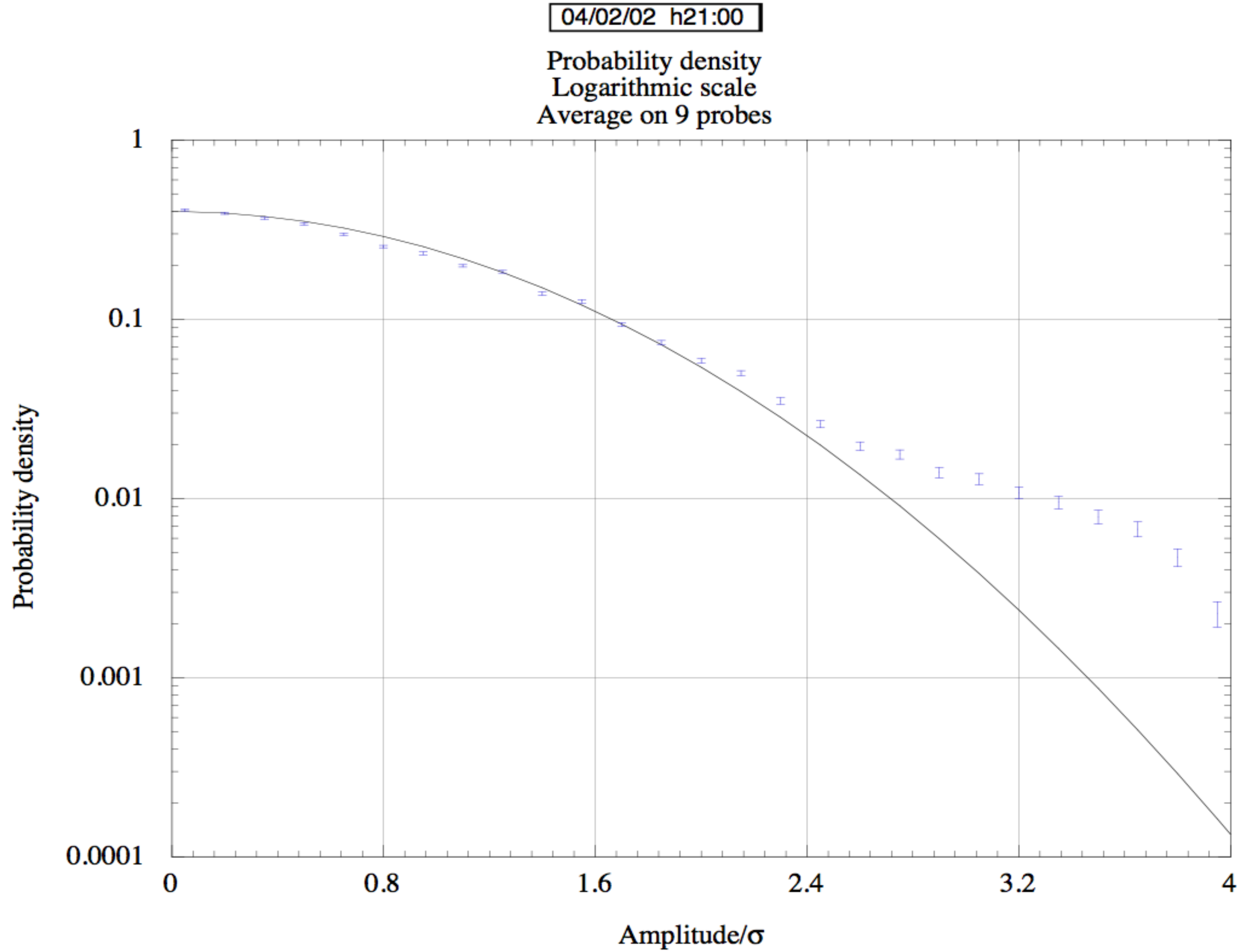


Measured wave train
Amplitude - m
0.78
0.52
0.26
0
-0.26
0
200
400
600
800
1000
1200
Time - sec
7 σ
6 σ
5 σ
4 σ
3 σ
2 σ
1 σ

Power Spectrum



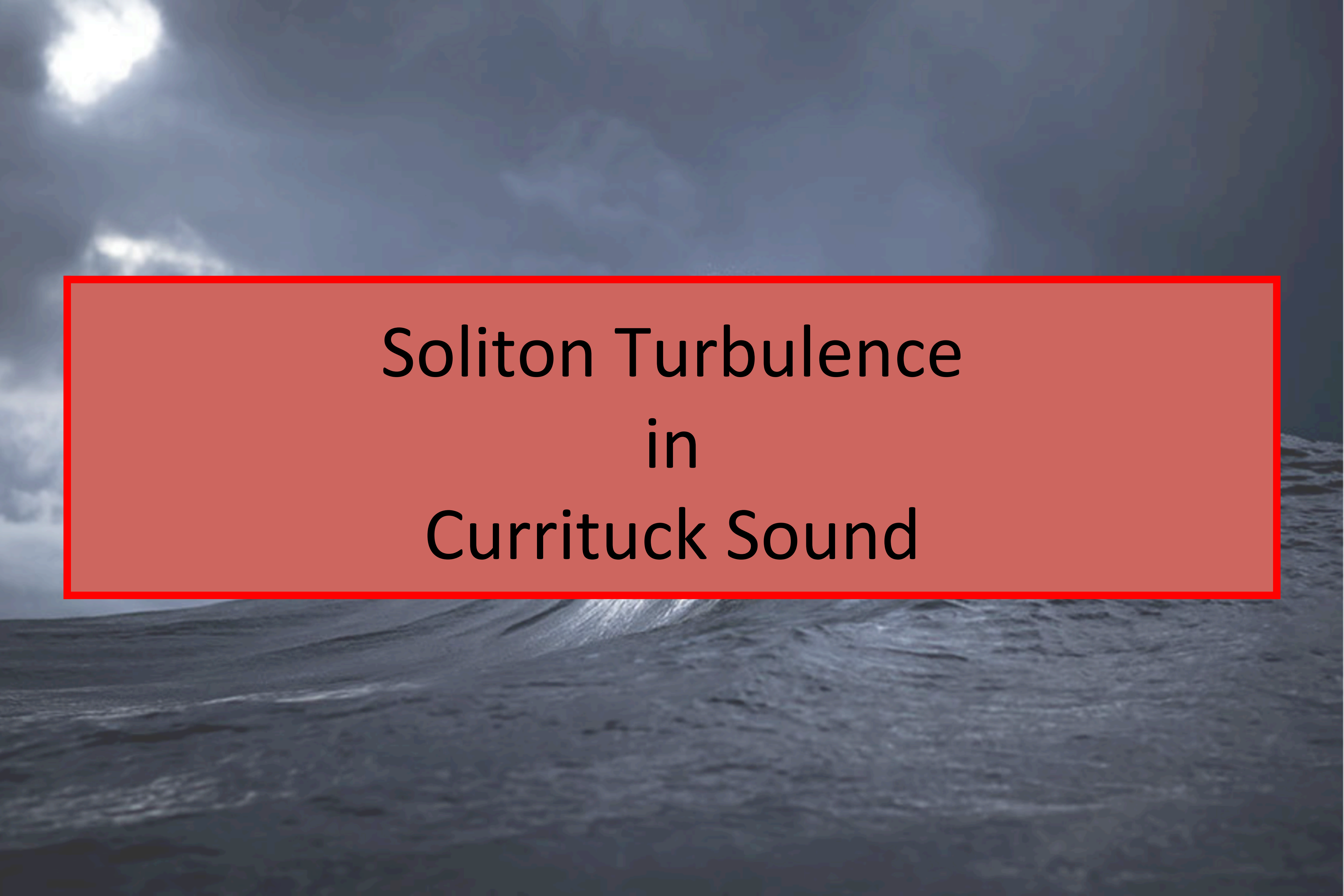

Fourier Phases
Phases - rads
Frequency - Hz
4
3
2
1
0
-1
-2
-3
-4
0
0.5
1
1.5
2
2.5



04/02/02 h21:00
Probability density
Logarithmic scale
Average on 9 probes
Probability density
1
0.1
0.01
0.001
0.0001
0
0.8
1.6
2.4
3.2
4
Amplitude/σ

Conclusions:
The Traditional View

- Ocean waves are a ***near linear Random Process*** whose amplitudes are ***Gaussian*** [Kinsman's book].
- If the spectrum is "narrow banded" then the envelope (modulation) is ***Rayleigh*** [Longuet-Higgins, 1955], implying that the wave heights are also Rayleigh.
- The probability "tail" at high amplitude is due to the ***Stokes correction***, which makes the waves higher and steeper.


Soliton Turbulence
in
Currituck Sound

Soliton Turbulence in Shallow Water Ocean Surface Waves

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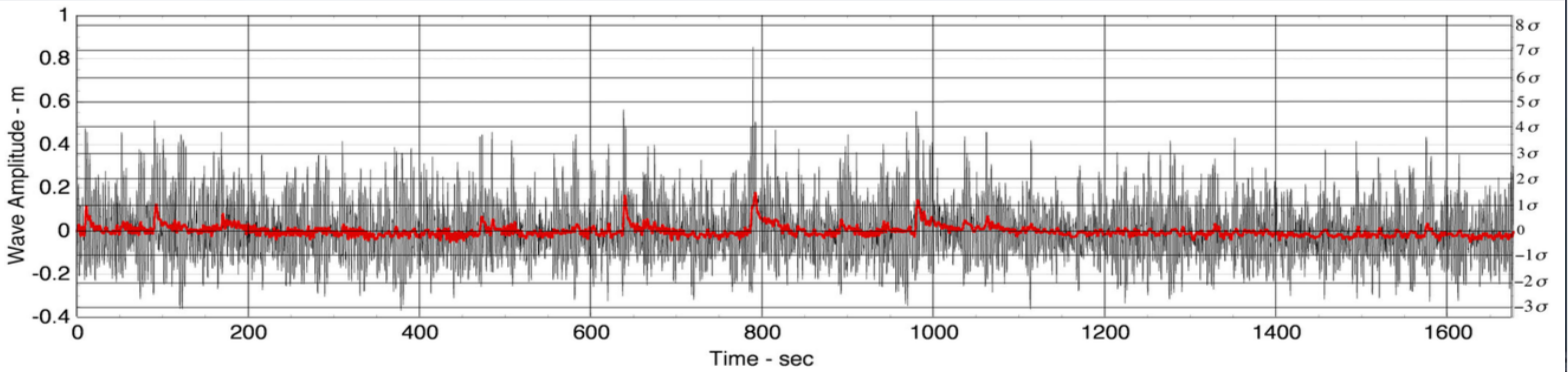
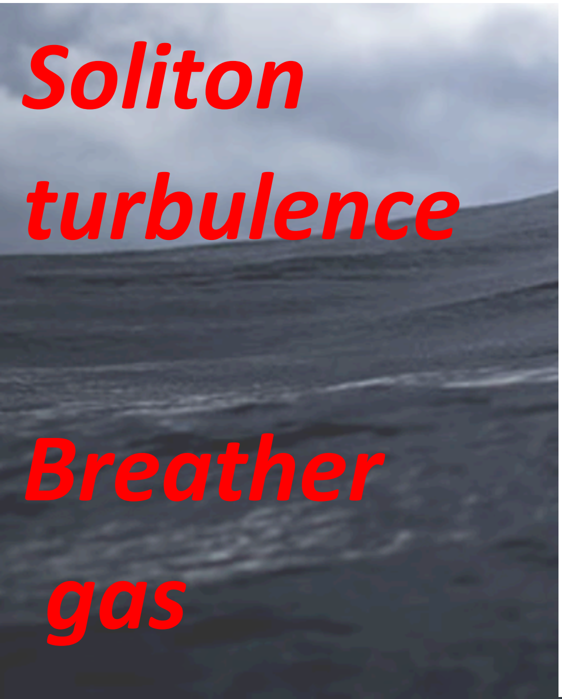
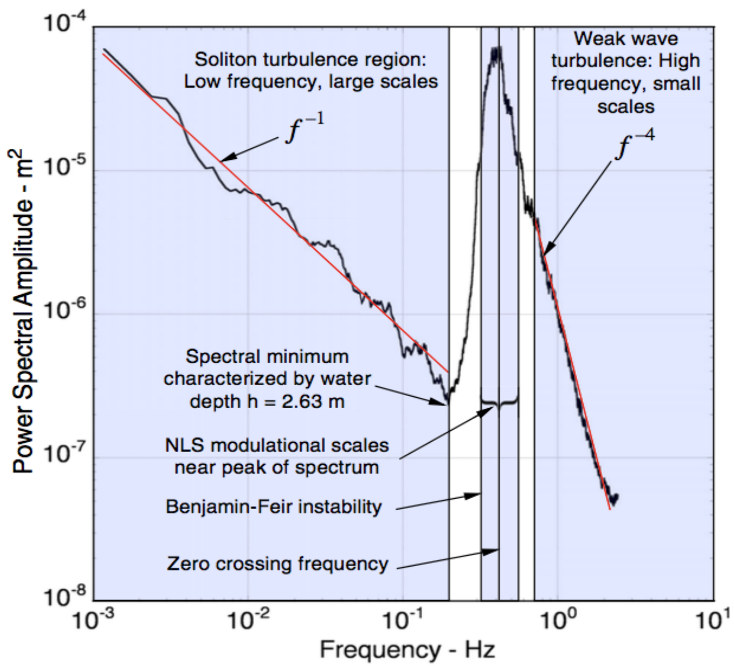
We analyze shallow water wind waves in Currituck Sound, North Carolina and experimentally confirm, for the first time, the presence of soliton turbulence in ocean waves. Soliton turbulence is an exotic form of nonlinear wave motion where low frequency energy may also be viewed as a dense soliton gas, described theoretically by the soliton limit of the Korteweg–deVries equation, a completely integrable soliton system: Hence the phrase "soliton turbulence" is synonymous with "integrable soliton turbulence." For periodic-quasiperiodic boundary conditions the ergodic solutions of Korteweg–deVries are exactly solvable by finite gap theory (FGT), the basis of our data analysis. We find that large amplitude measured wave trains near the energetic peak of a storm have low frequency power spectra that behave as $\sim\omega^{-1}$. We use the linear Fourier transform to estimate this power law from the power spectrum and to filter densely packed soliton wave trains from the data. We apply FGT to determine the soliton spectrum and find that the low frequency $\sim\omega^{-1}$ region is soliton dominated. The solitons have random FGT phases, a soliton random phase approximation, which supports our interpretation of the data as soliton turbulence. From the probability density of the solitons we are able to demonstrate that the solitons are dense in time and highly non-Gaussian.

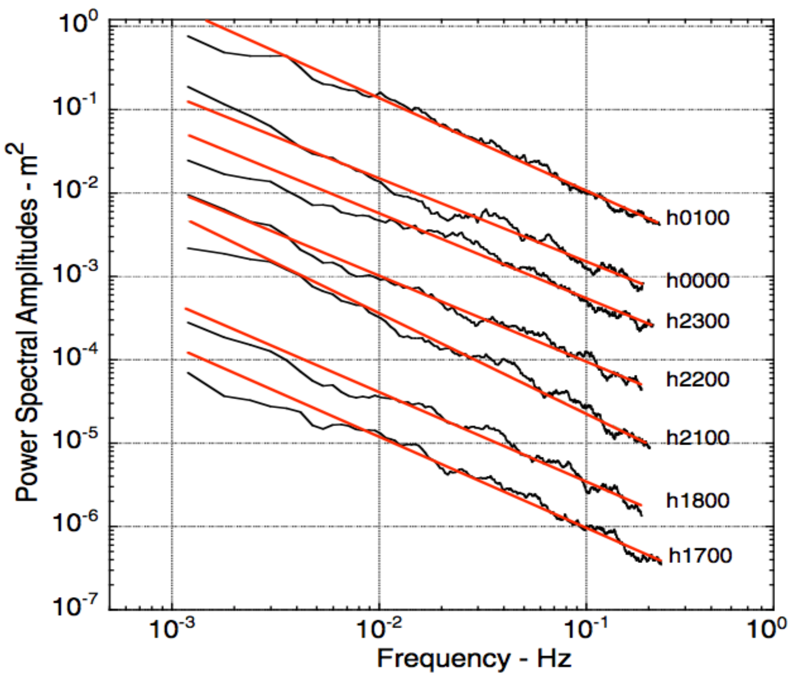
DOI: 10.1103/PhysRevLett.113.108501 PACS numbers: 92.10.Hm, 92.10.Lq, 92.10.Sx

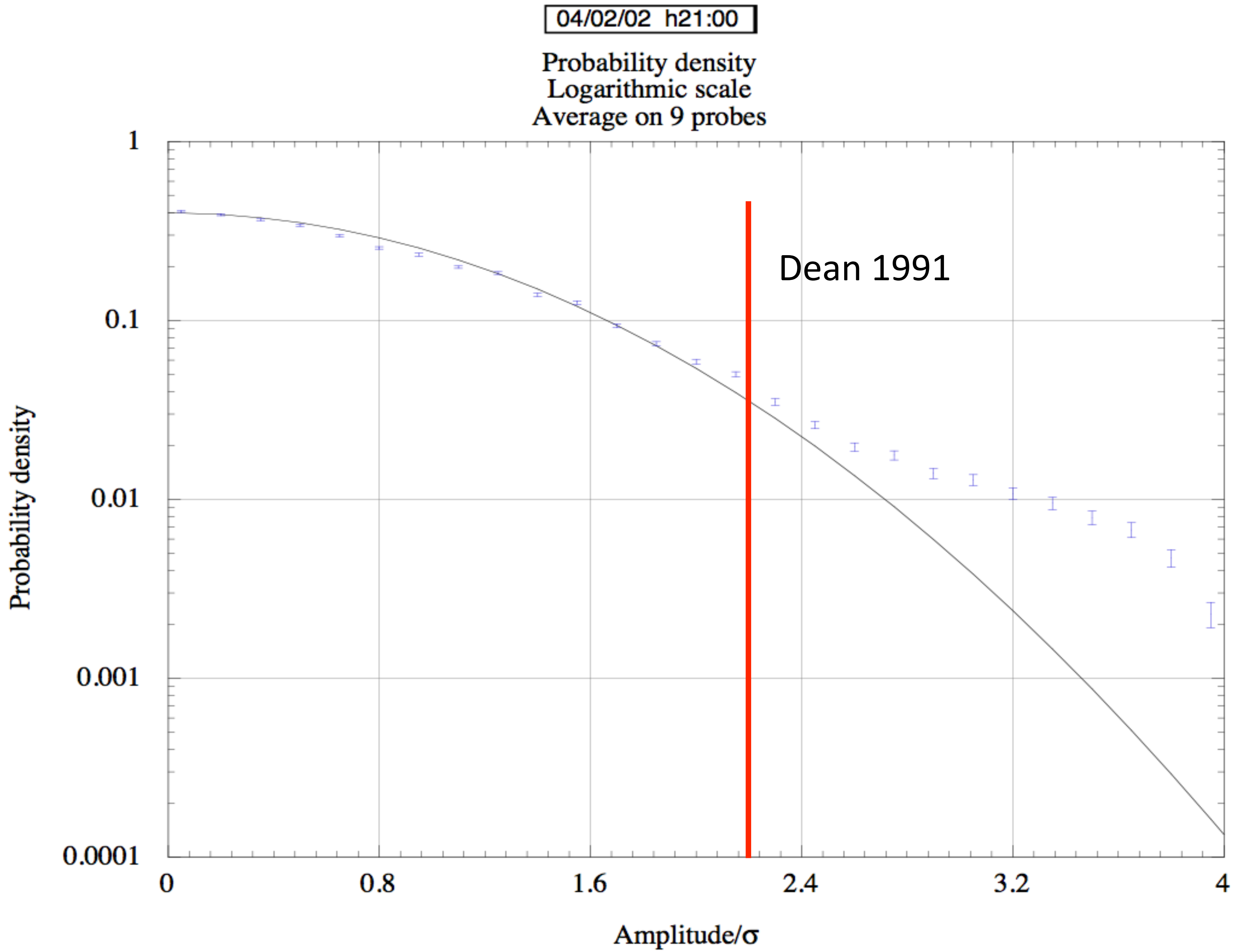
Understanding Nonlinear Data











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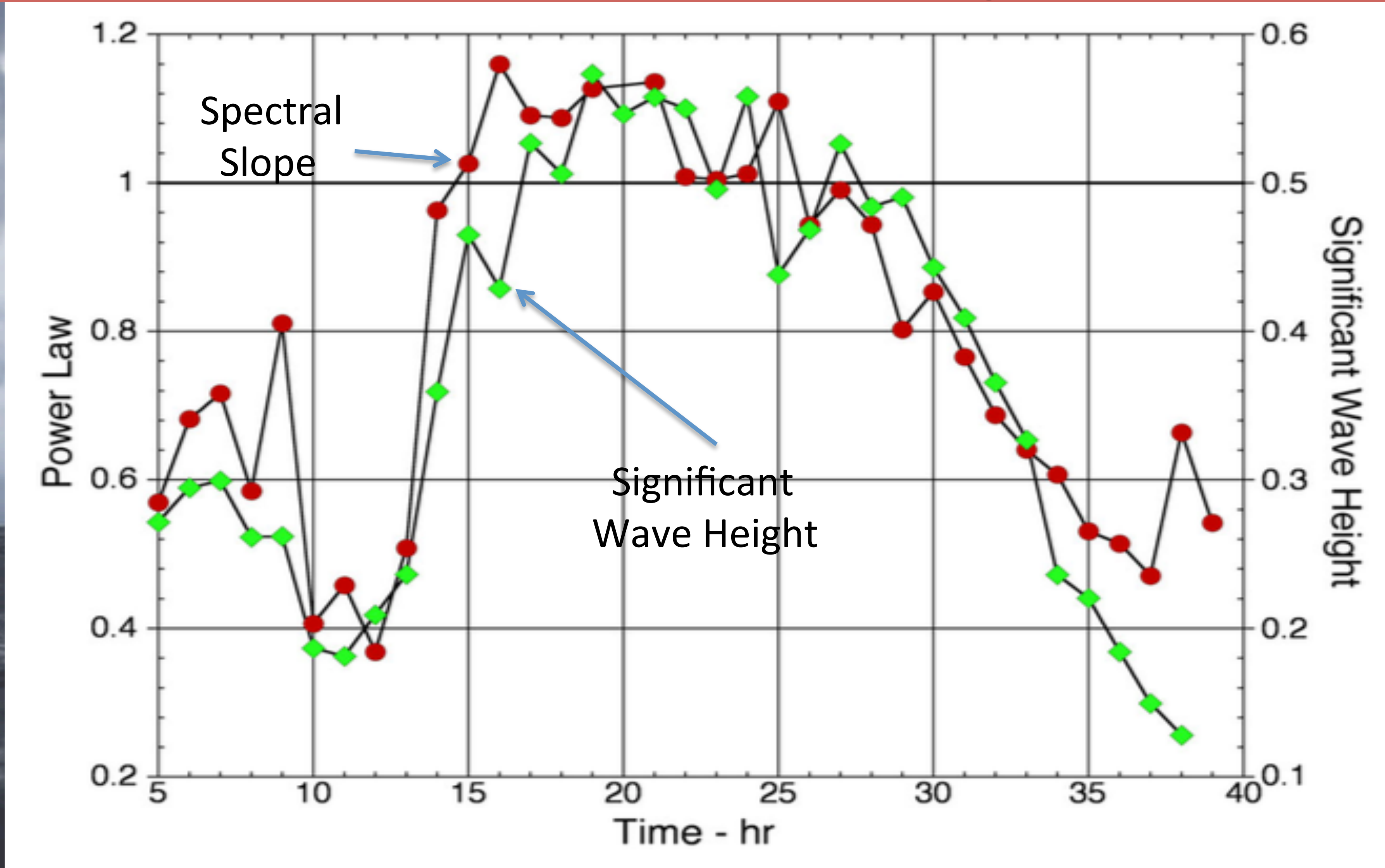
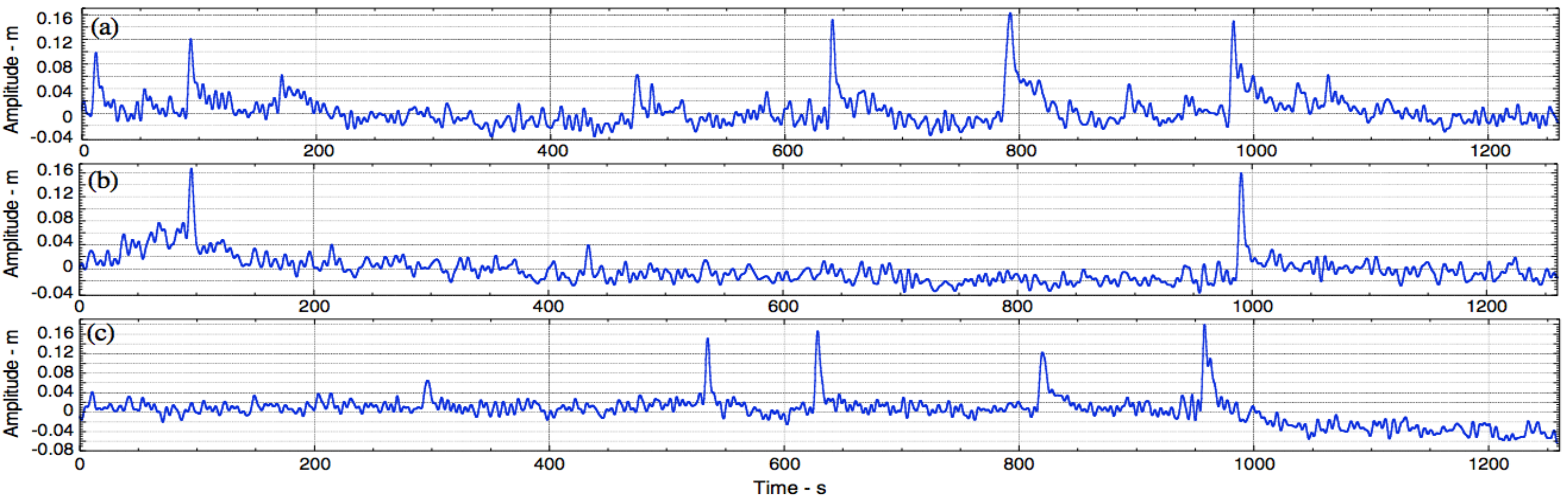
Probability density
Logarithmic scale
Average on 9 probes
Dean 1991
Probability density
1
0.1
0.01
0.001
0.0001
0
0.8
1.6
2.4
3.2
4
Amplitude/σ

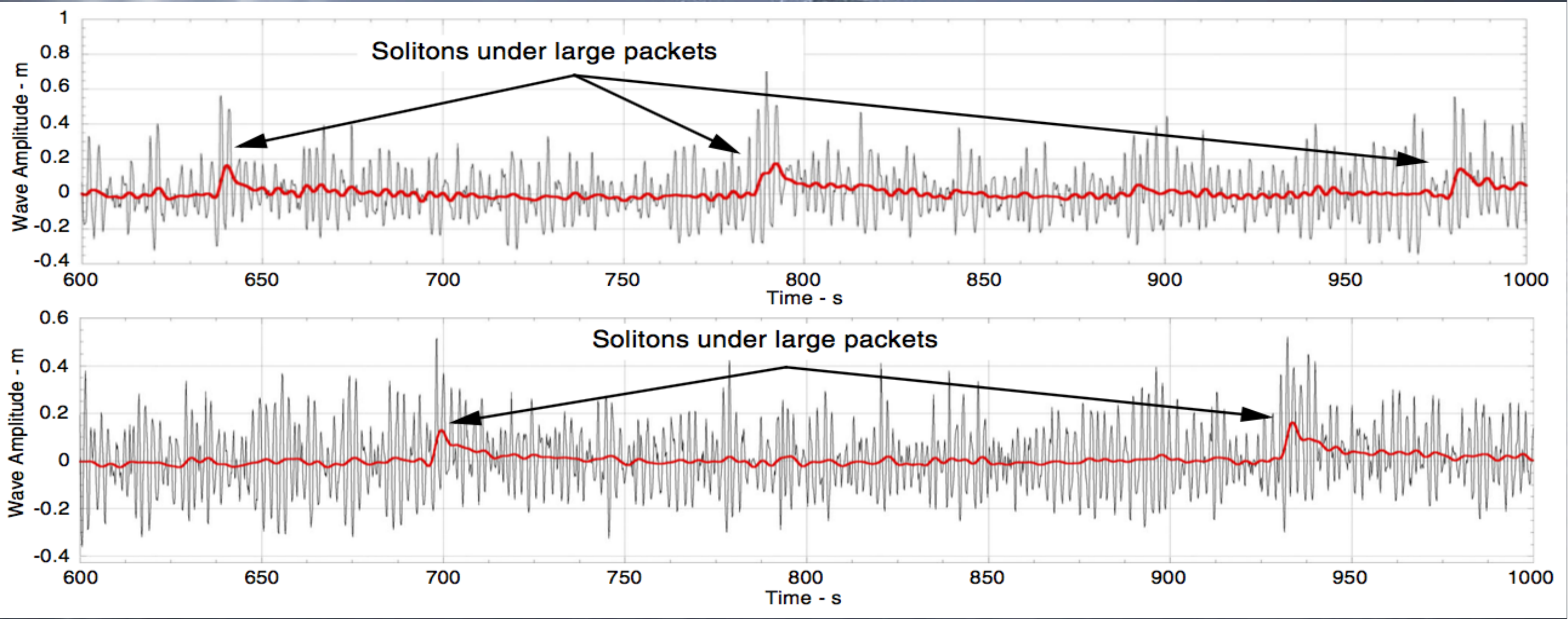
Significant Wave Height vs. Power Law in Power Spectrum



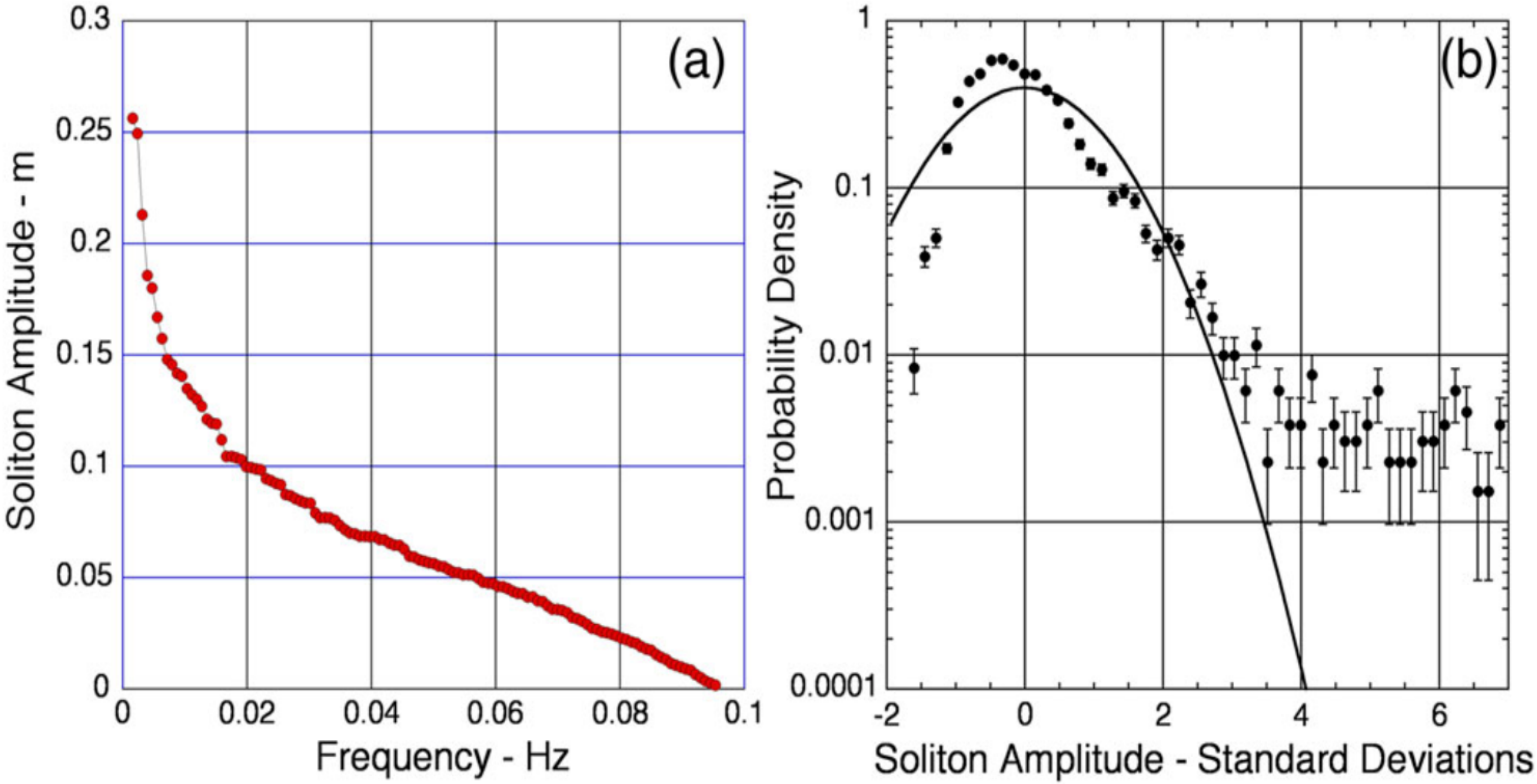
Soliton Signals Filtered from Measured Currituck Sound Data



Measured Wave Trains with Filtered Soliton Signals

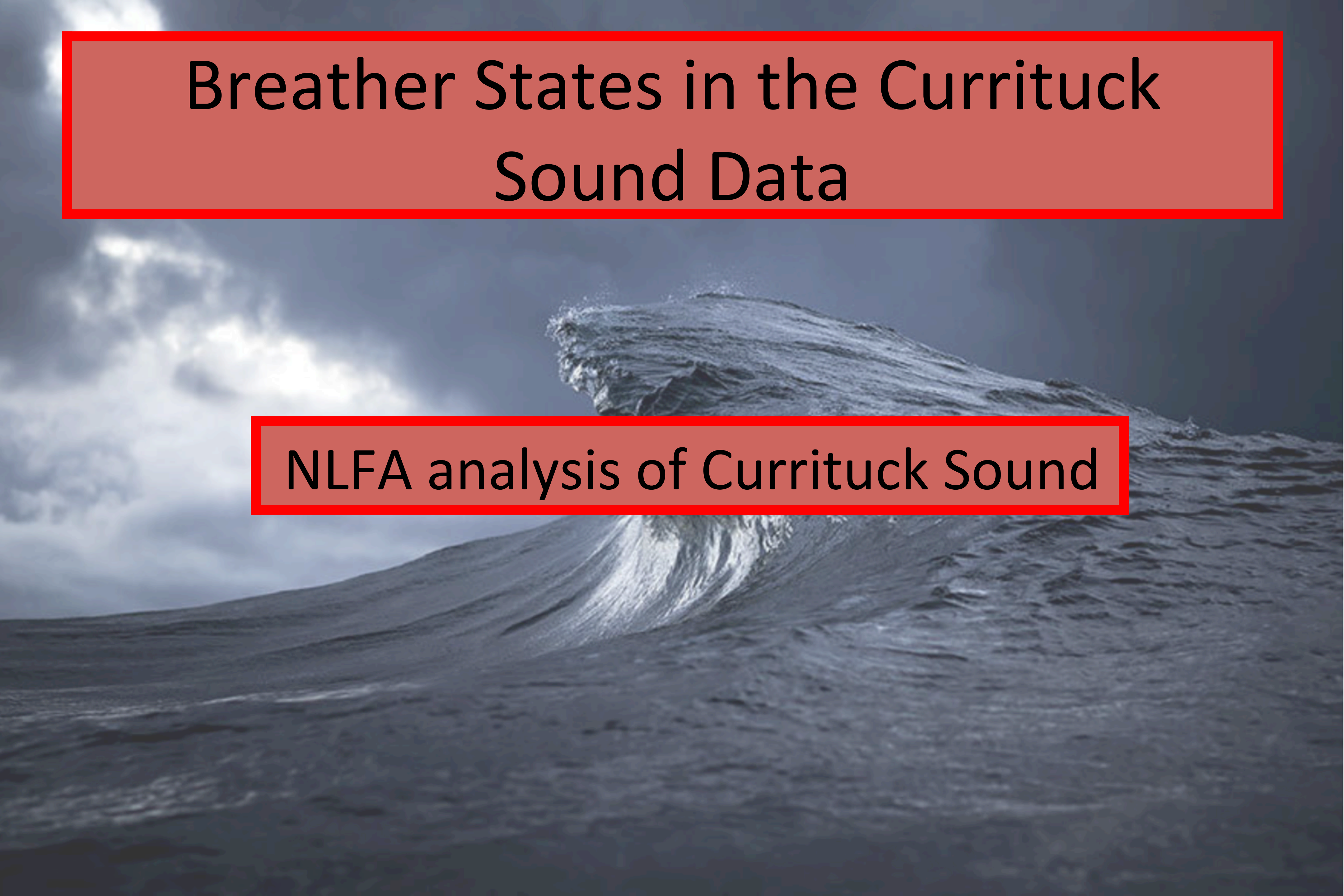


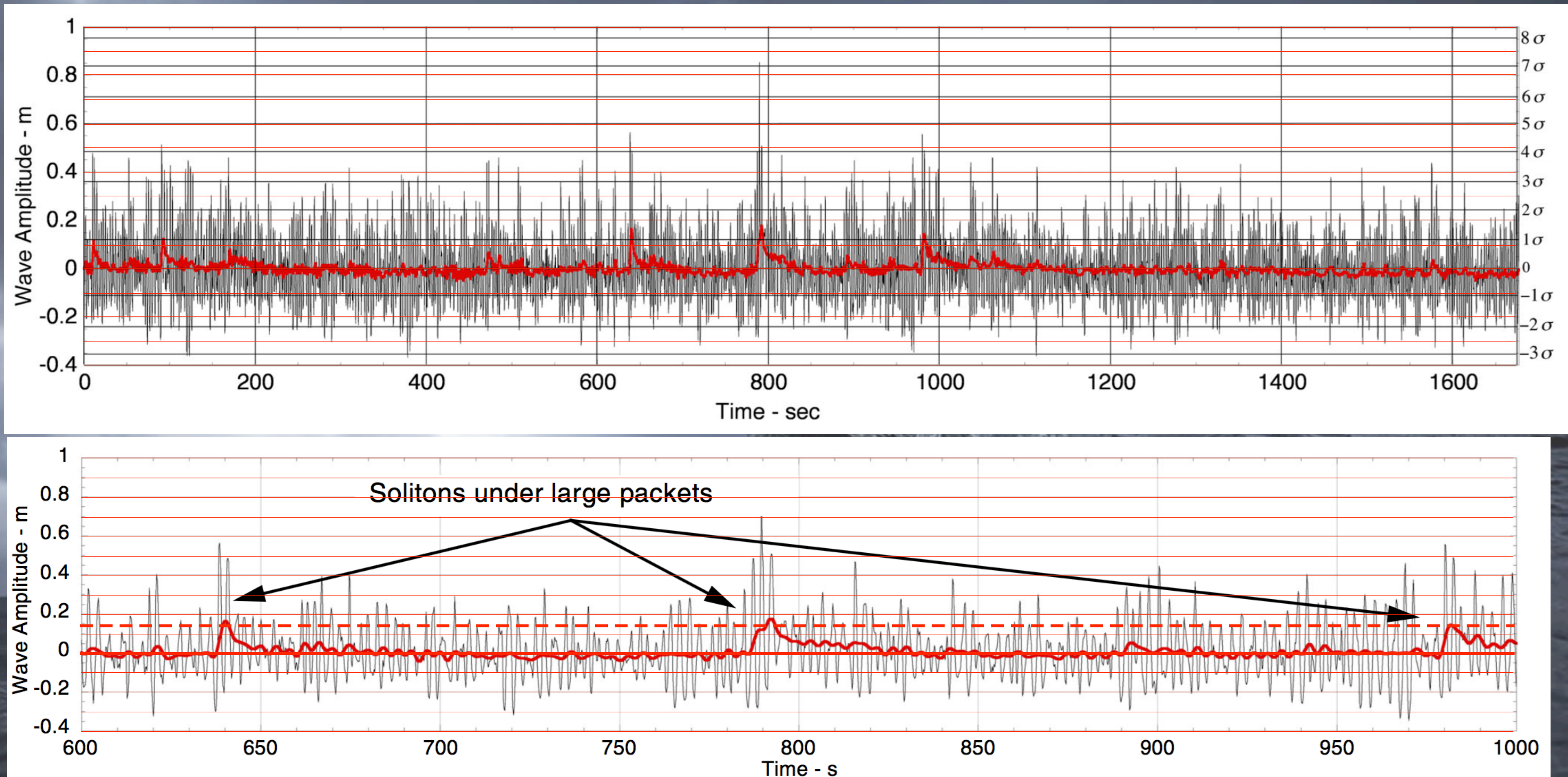
Soliton Spectrum and Probability Density



Breather States in the Currituck Sound Data

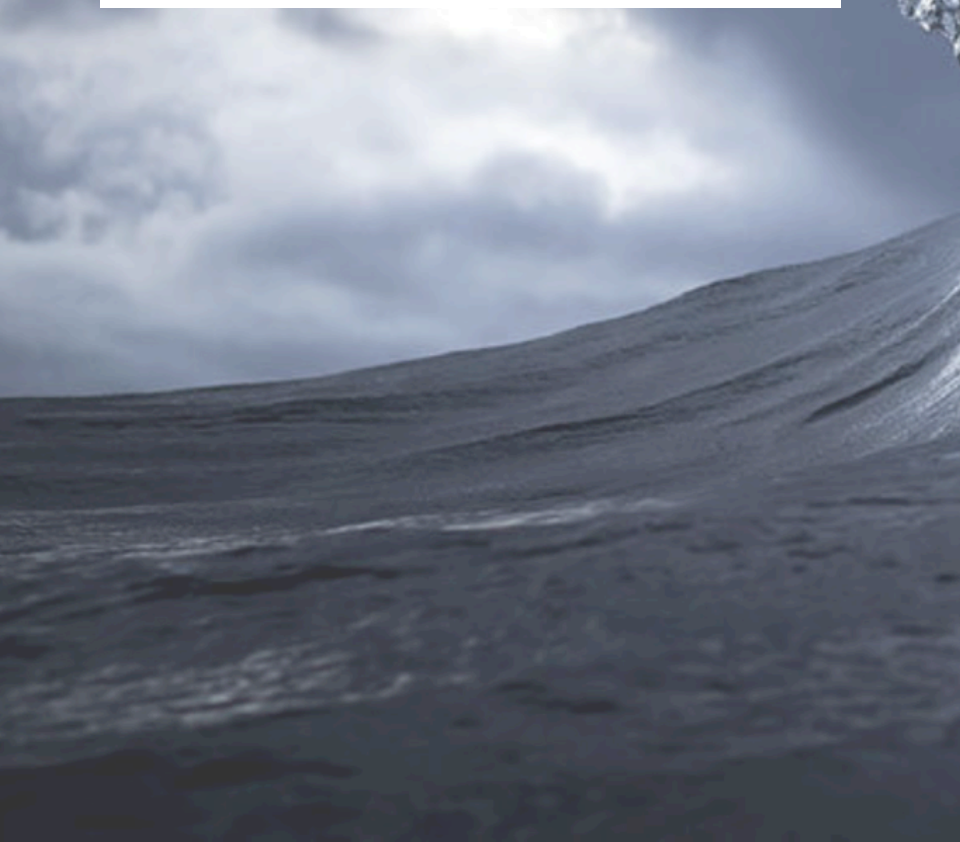
NLFA analysis of Currituck Sound

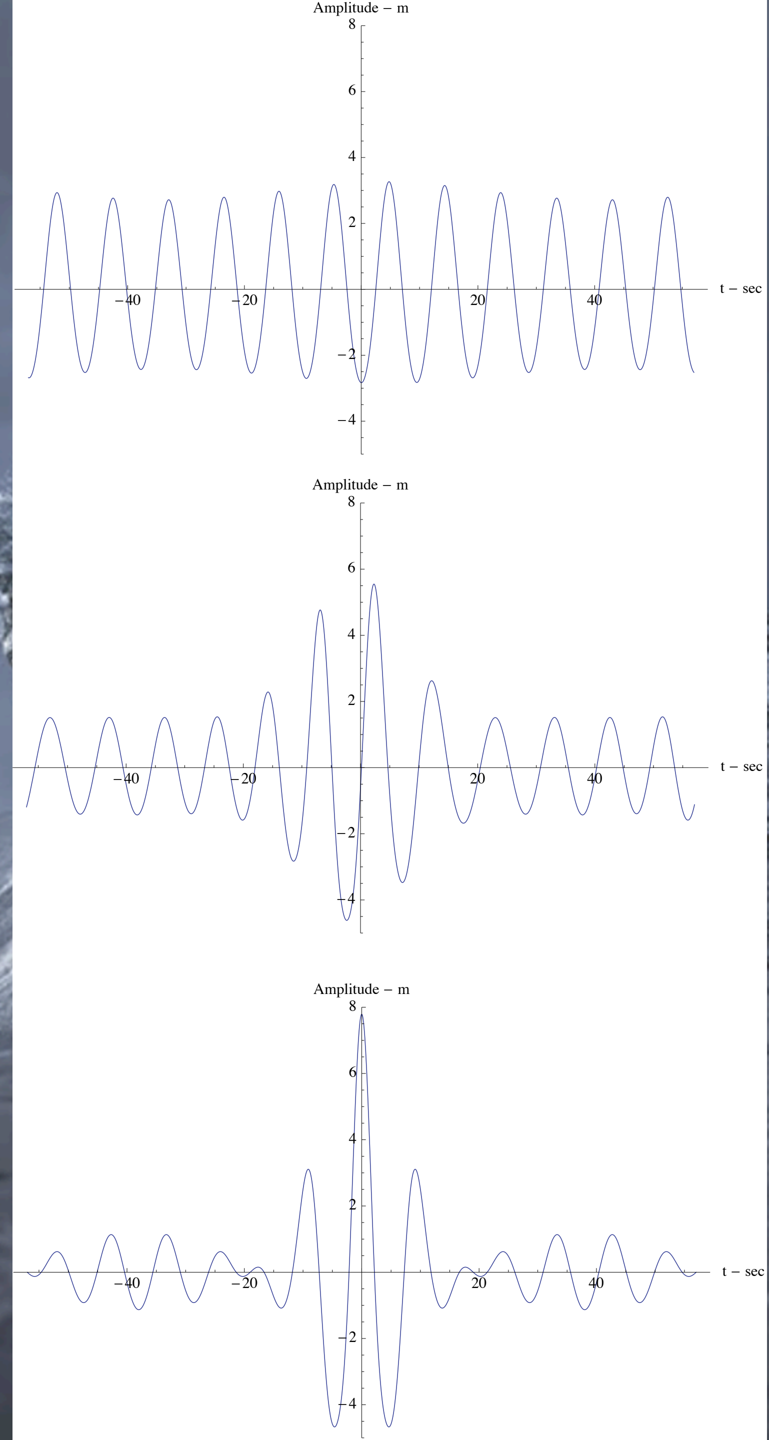




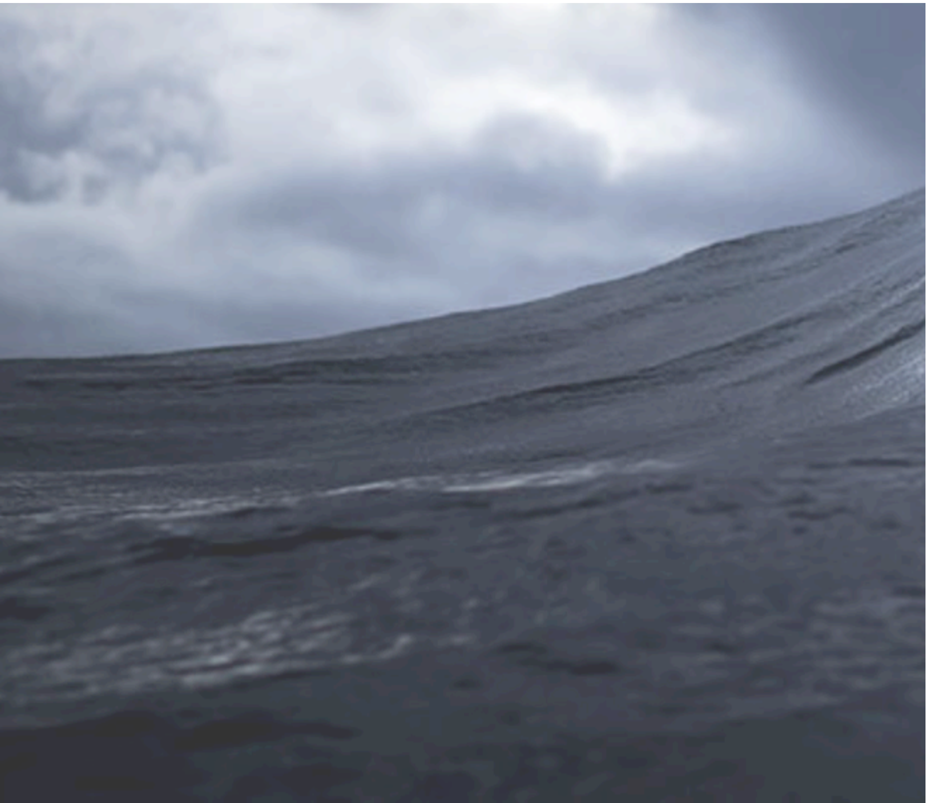
Wave Amplitude - m
Time - sec
8σ
7σ
6σ
5σ
4σ
3σ
2σ
1σ
0
−1σ
−2σ
−3σ
Solitons under large packets
Wave Amplitude - m
Time - s

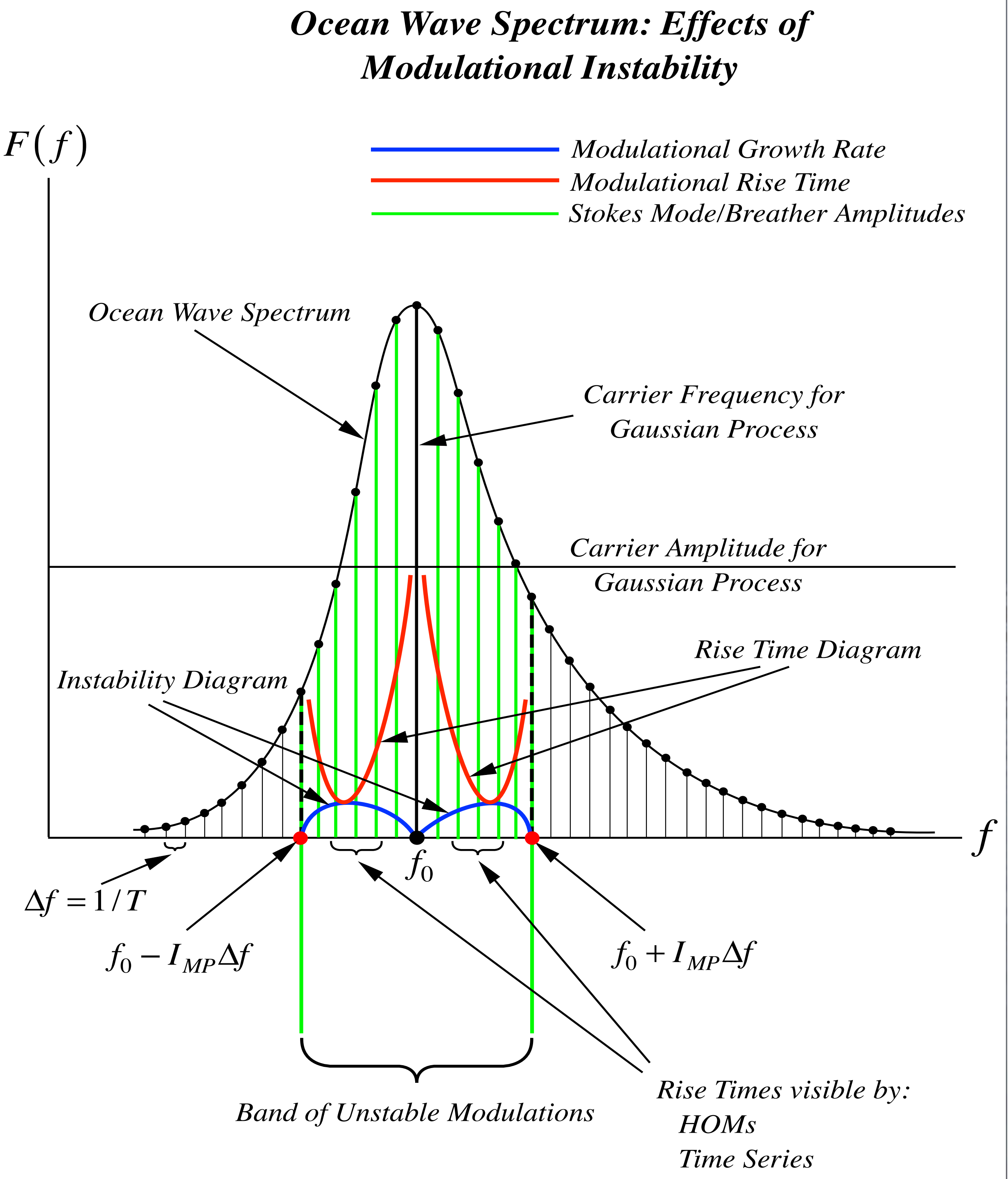
Rogue Wave Evolution in 1+1





Modulational Instability in Ocean Wave Spectra





Curritruck Sound