THE NATURE OF THE DRAUPNER GIANT WAVE OF 1ST JAN 1995 AND THE ASSOCIATED SEA-STATE

AND

HOW TO ESTIMATE DIRECTIONAL SPREADING FROM AN EULERIAN SURFACE ELEVATION TIME HISTORY

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With thanks to Sverre Haver of Statoil

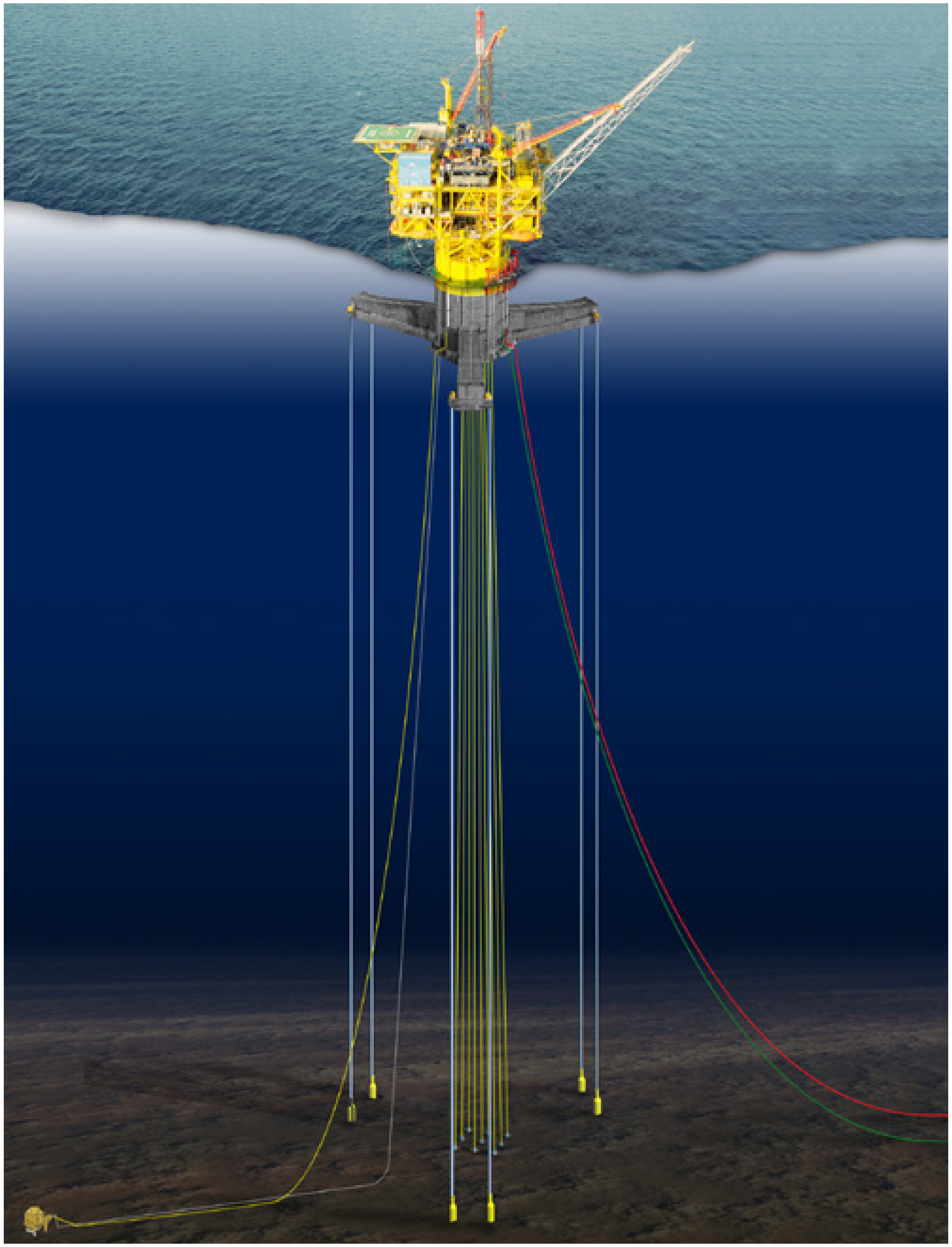
The engineering context for the modelling of large waves

Extremes in the natural environment
- recent hurricanes in the Gulf of Mexico

- Ivan
- Katrina
- Rita
- most named storms in 2005 - above previous max set in 1969
- massive damage to offshore oil/gas infrastructure

Chevron’s mini-TLP

named Typhoon



Unfortunate choice of name

September 29, 2005

Market responds to Rita-related damage to Gulf production facilities

"\.. **Chevron Corp's Typhoon Tension Leg Platform**
was severed from its moorings by Hurricane Rita and is floating upside down
… natural-gas futures skyrocketed…

Thus, …. in the U.S, ..it's …going to be a long, cold, *expensive* winter."

From http://blog.kir.com/archives/002473.asp

A big jack-up rig reduced to scrap metal

Coastal damage as well as offshore

A moderate storm in the northern North Sea in the winter

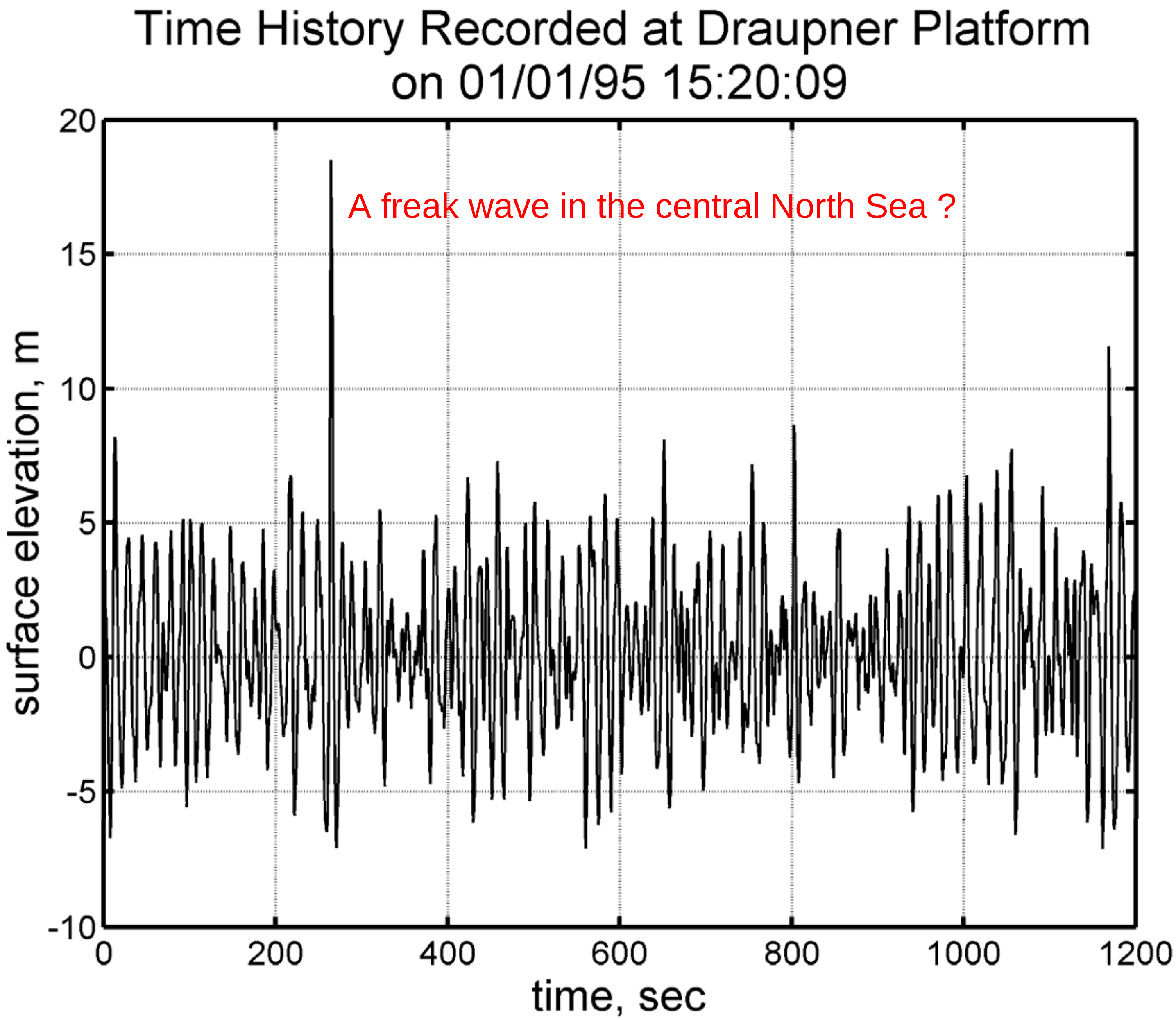

Time History Recorded at Draupner Platform
on 01/01/95 15:20:09
A freak wave in the central North Sea ?
surface elevation, m
time, sec
20
15
10
5
0
-5
-10
0
200
400
600
800
1000
1200

Fig. 0. The Draupner S and Draupner E platforms in the North Sea,
Photo: Øyvind Hagen, Statoil.

A Possible Freak Wave Event Measured at the Draupner Jacket January 1 1995

www.math.uio.no/karstent/seminarV05/Haver2004.pdf

Sverre Haver

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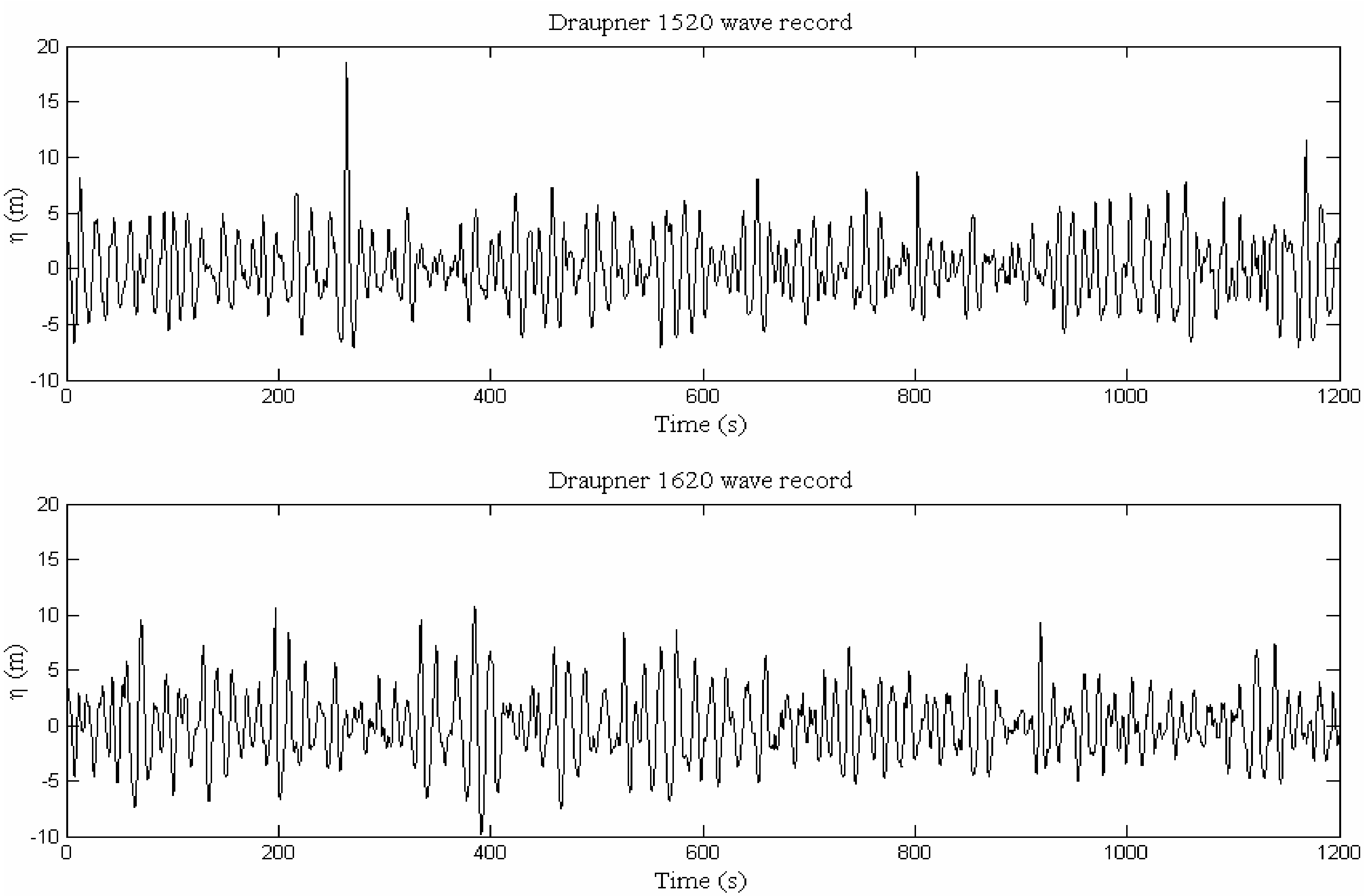
svha@statoil.com

Field data from Draupner 1st Jan 1995

The New Year wave and 1 hour later - similar H_s and spectrum



Talk will focus on

Height of Draupner crest

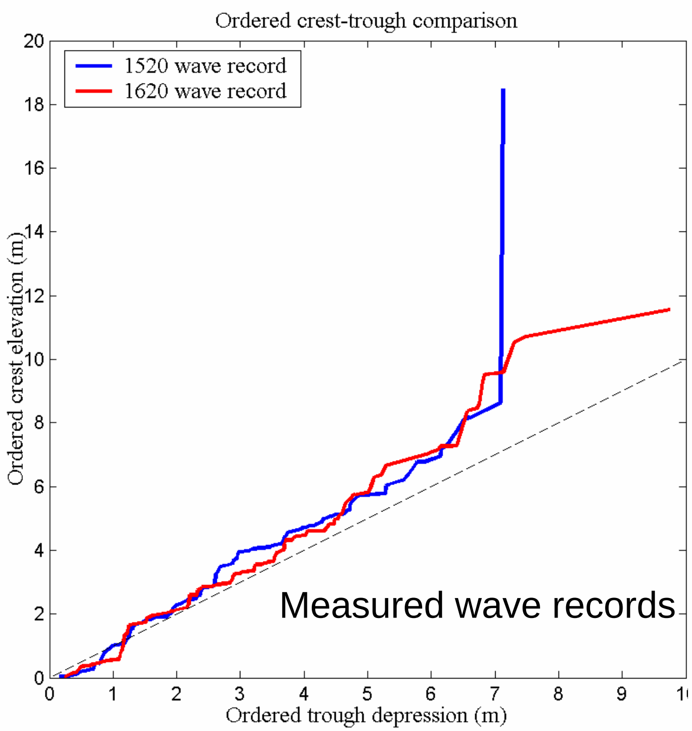
Trough-crest asymmetry - directional spreading

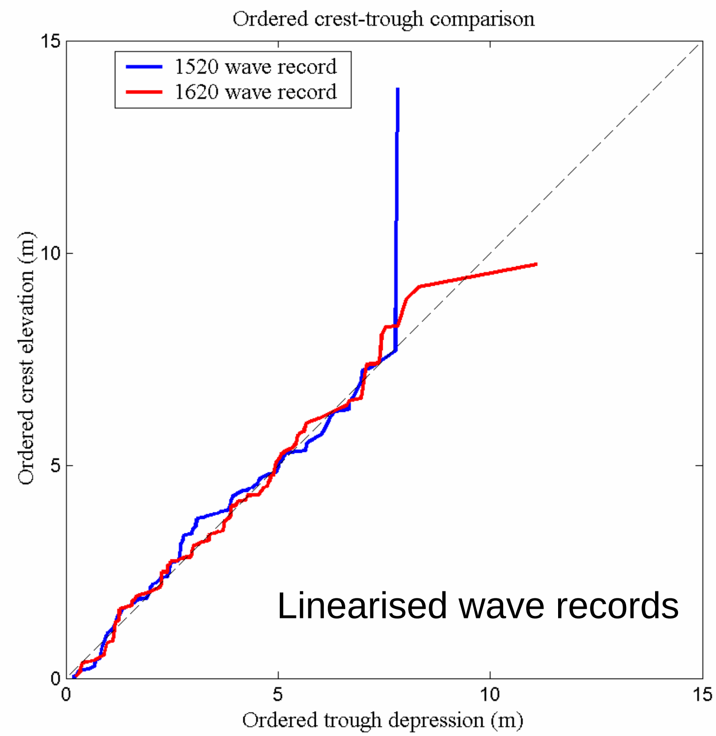
Set-down and set-up – bound long waves - directional spreading

Definition of a freak wave ?

Crest-trough comparison

- sort peak crest elevations and peak trough depressions into ascending order





Linearisation Local Stokes expansion backwards, then search for S_{22} value removing net skewness

$$\eta_L \approx \eta - \frac{S_{22}}{d}\left(\eta^2 - \eta_H{}^2\right)$$

Second and third order sum contributions

The first three terms of a Stokes water wave expansion:

$$\eta(t) = a\cos\phi + a^2 \frac{S_{22}}{d} \cos 2\phi + a^3 \frac{S_{33}}{d^2} \cos 3\phi$$

Linear contribution and its Hilbert transform:

$$\eta_L = a\cos\phi \quad \text{and} \quad \eta_{LH} = a\sin\phi$$

Second order sum contributions: $\eta_2 = \dfrac{S_{22}}{d} a^2 \cos 2\phi = \dfrac{S_{22}}{d} \left(\eta_L{}^2 - \eta_{LH}{}^2\right)$

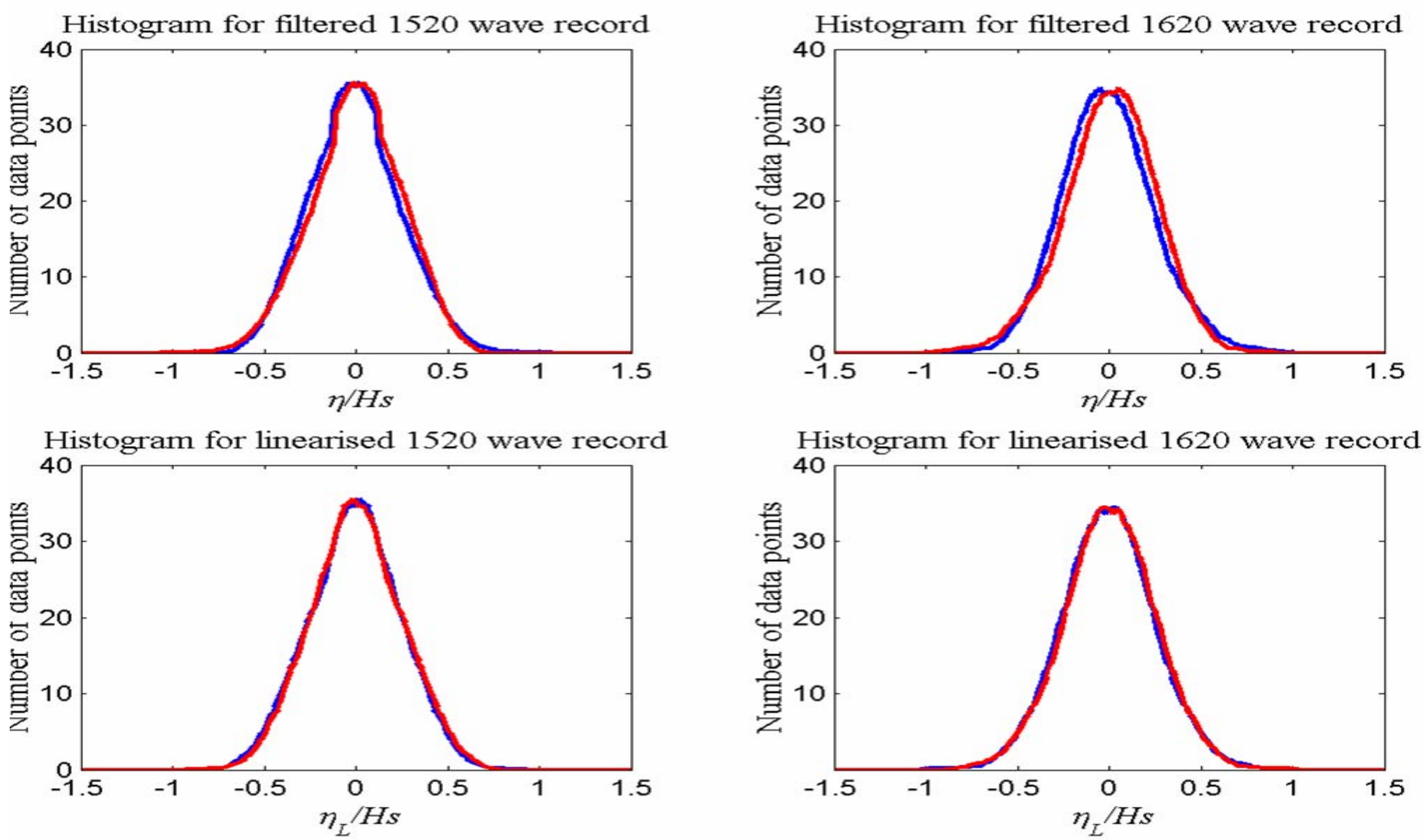
Linearised wave record: $\eta_L \approx \eta - \dfrac{S_{22}}{d} \left(\eta^2 - \eta_H{}^2\right)$

We seek the coefficient S_{22} that sets the skewness of η_L to zero

Second and third order sum contributions

- Histogram

- Reflected histogram



15:20 record : $S_{22} = 0.96$ (*with New Year wave removed*)

16:20 record : $S_{22} = 1.02$ ($D_2 = S_{22}/d$)

Second (and third) order sum contributions

Stokes water wave expansion for finite water depth (Fenton, 1990):

$$\eta(t) = a\cos\phi + a^2 kB_{22}\cos 2\phi + a^3k^2 B_{33}\cos 3\phi$$

$$B_{22} = \coth(kd)\,\frac{(1+2S)}{2(1-S)}$$

$$B_{33} = \frac{3\left(1+3S+3S^2+2S^3\right)}{8(1-S)^3}$$

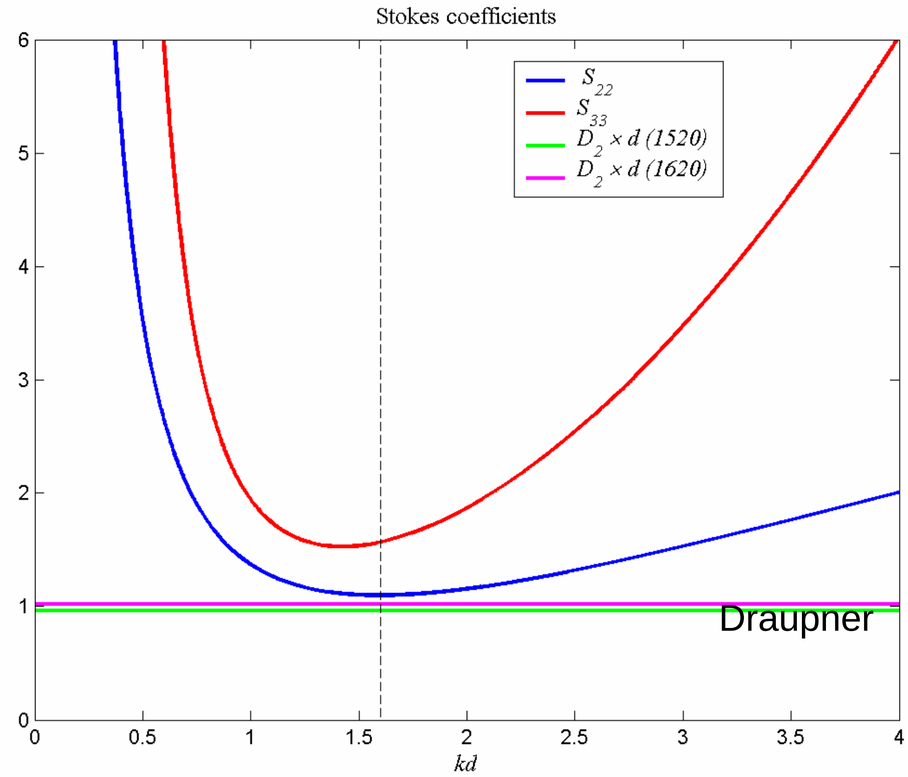
$$S = \operatorname{sech}(2kd)$$

This can be reformulated as:

$$\eta(t) = a\cos\phi + a^2\frac{S_{22}}{d}\cos 2\phi + a^3\frac{S_{33}}{d^2}\cos 3\phi$$

$$S_{22} = kB_{22}\times d$$

$$S_{33} = k^2 B_{33}\times d^2$$



Using kd =1.6: S_{22}= 1.0987

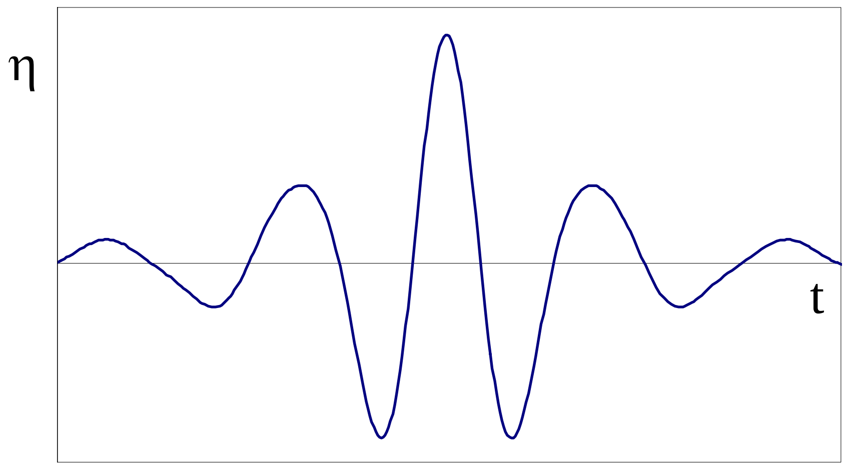
Average wave shape of extreme in linear random Gaussian process :

NewWave ~ auto-correlation function Lindgren 1970 Boccotti 1983

average shape Fourier transform of spectrum

- result connects **shape of extremes to mean properties**

- isolated wave group allows realistic modelling of an extreme event



$$NewWave = A_N \times \frac{\int S(\omega)\cos(\omega t)d\omega}{\int S(\omega)d\omega}$$

$$A_N = \left(2m_0\left(\ln N\right)\right)^{1/2}$$

A_N - magnitude of crest is Rayleigh distributed

Fifth order NewWave

- Stokes' 5th order wave theory is used

- Stokes' coefficients are defined using *kd* =1.6

- The temporal contributions for all non-linear terms up to 5th order are defined in terms of the linear wave record and its Hilbert transform

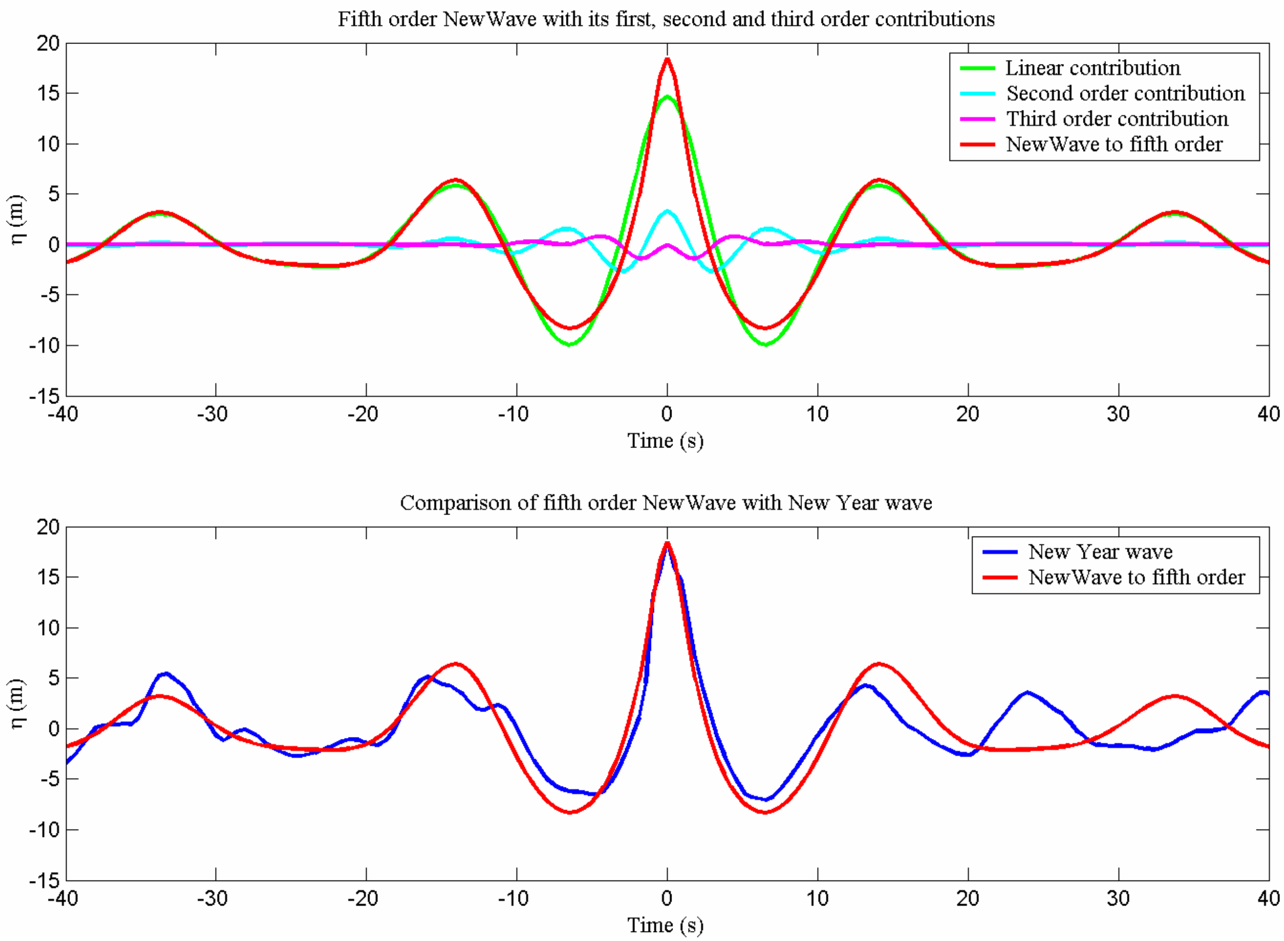
- **Amplitude of linear NewWave = 14.*7m***

- **Crest of fifth order NewWave = 18.5*m* = *Crest of New Year wave***

Stokes wave expansion up to fifth order:

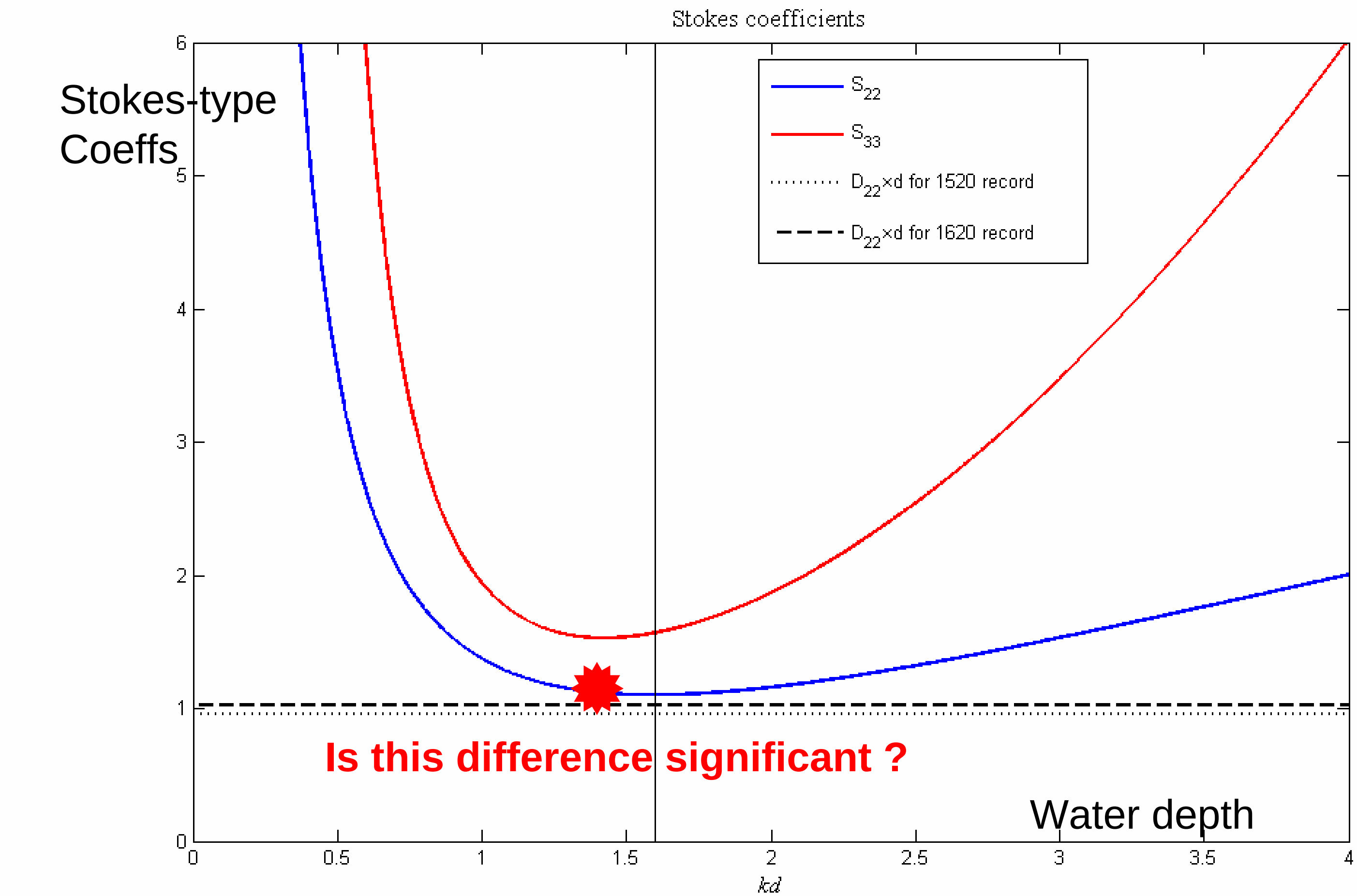
$$\eta(t) = a\cos\phi + a^2\frac{S_{22}}{d}\cos 2\phi + a^3\frac{S_{31}}{d^2}\cos\phi + a^3\frac{S_{33}}{d^2}\cos 3\phi + a^4\frac{S_{42}}{d^3}\cos 2\phi + a^4\frac{S_{44}}{d^3}\cos 4\phi$$
$$+ a^5\frac{S_{51}}{d^4}\cos\phi + a^5\frac{S_{53}}{d^4}\cos 3\phi + a^5\frac{S_{55}}{d^4}\cos 5\phi$$

Walker, Taylor and Eatock Taylor AOR 26, 73 (2004)



For linear crest amplitude 14.7*m*,
Draupner wave is a 1 in ~ 200,000 wave

but… 10% reduced Stokes 2nd order coeff and local wave SHAPE ?



Draupner vertical asymmetry –15:20 and 16:20 records (100 waves each)

Eulerian surface elevation time history from a single sensor

Any directional information ?

linear signal – **NO**

nonlinear Stokes-like bound harmonics – **MAYBE**

Largest harmonics are 2nd order

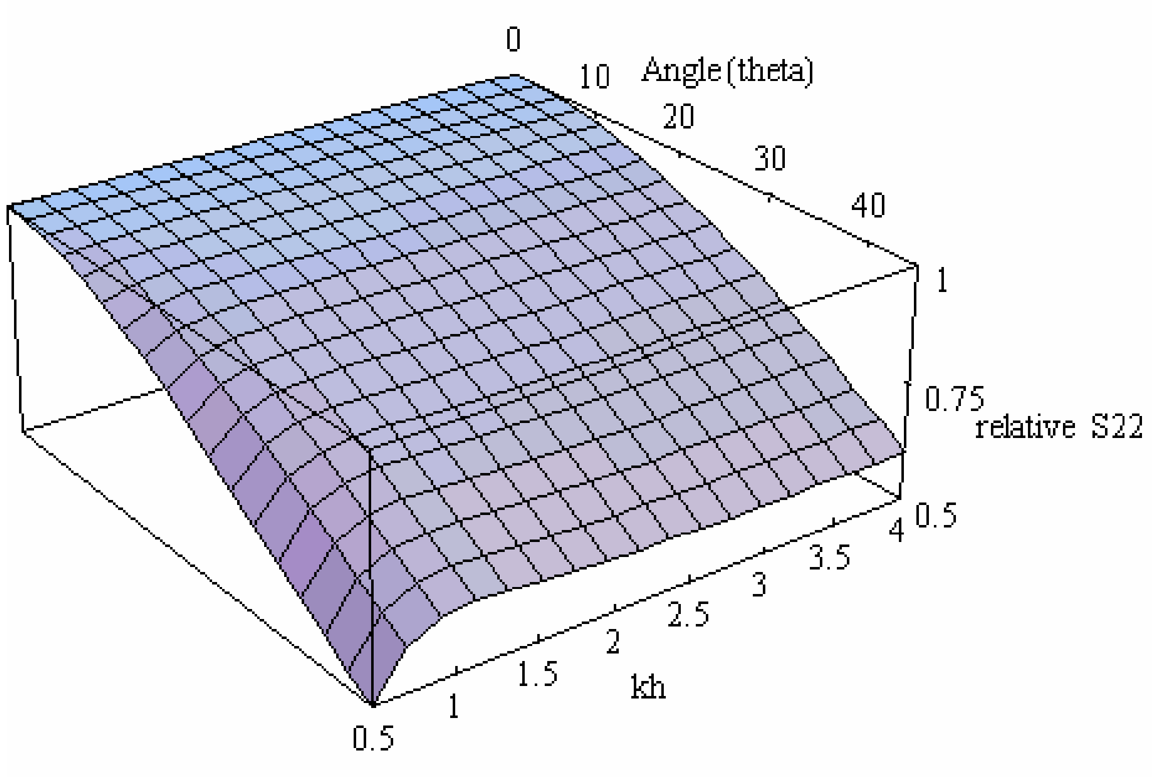
sum (crest-trough vertical asymmetry) and **difference** (wave group structure)

First, we consider the **sum term**

IN PARTICULAR, S_{22} IS SENSITIVE
TO THE LOCAL DIRECTIONAL SPREADING

Relative change of 2nd order sum interaction kernel S_{22} away from in-line Stokes 2nd order coefficient for a pair of single freq components at an angle

from Dalzell AOR 1999, Dean & Sharma 1981



Relative change of S_{22} is

virtually independent of water depth and quadratic with angle

S_{22} coefficients for **Draupner** lower than Stokes theory

Corresponding to ***estimated*** **rms spreading angle ~ 20° and 15°**

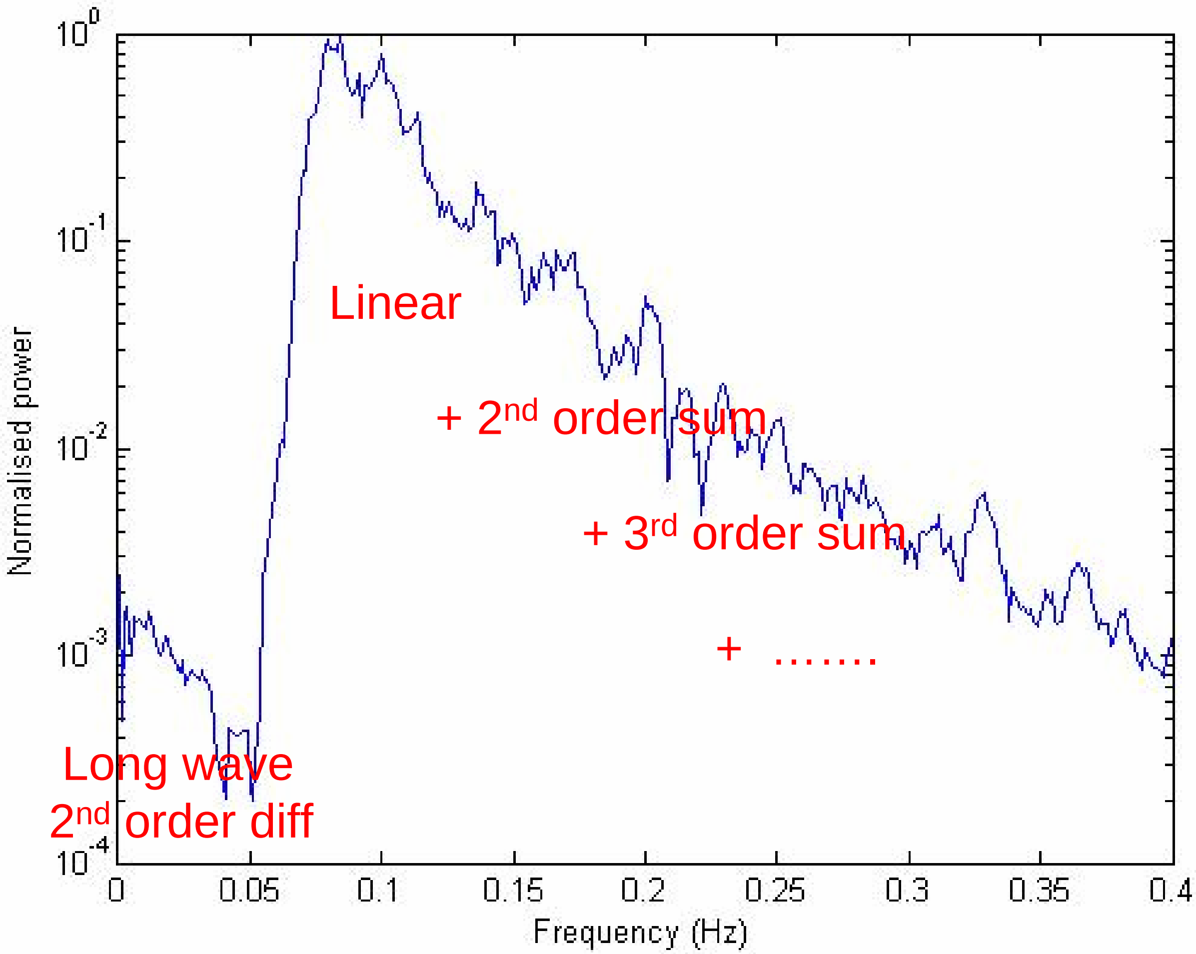
Directional buoy measurements of **spreading angle ~ 20°** from Auk

Spreading estimate reasonable but…

Unfortunately, we can't do any better – statistical variability

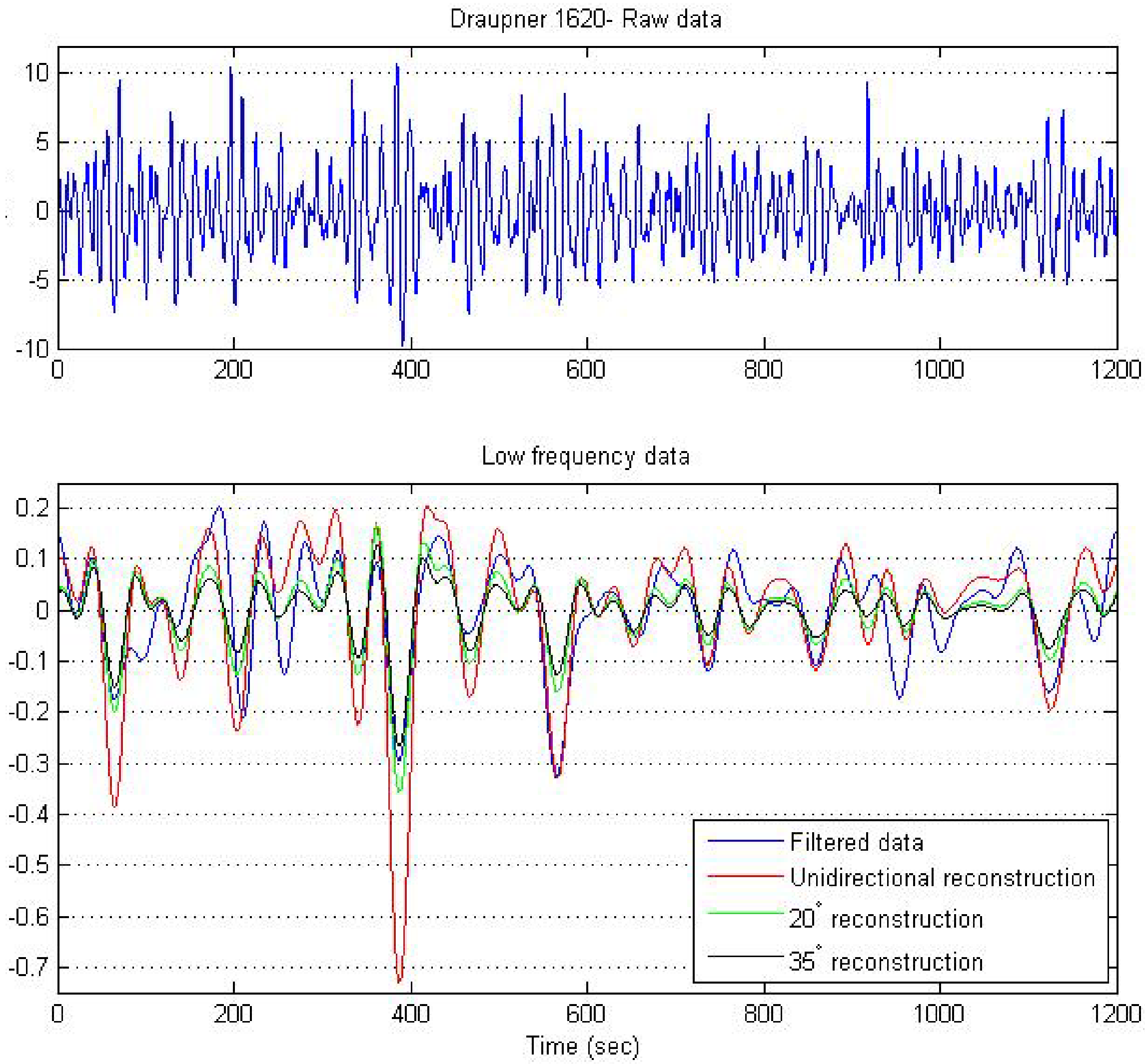
– 100 waves isn't enough

Power spectrum of 16.20 record

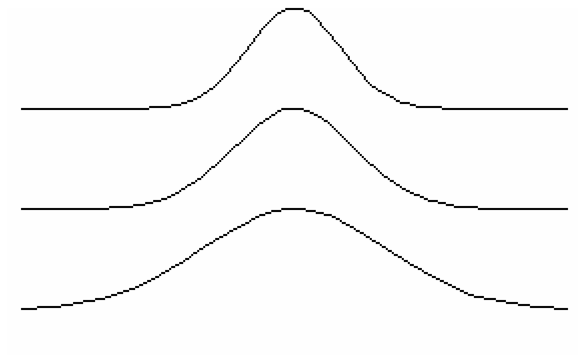


Long waves – small but cleanly separated in freq

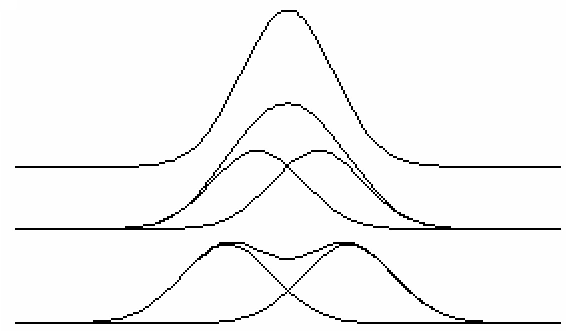
2^{nd} order difference fits to 16.20 filtered record based on Gaussian spreading of 0°, 20°, 35°



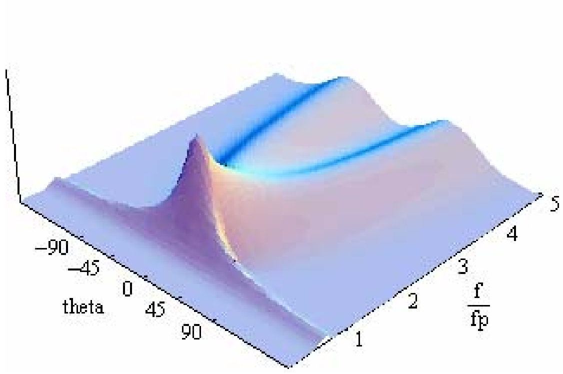
Possible *mean* spreading functions for Draupner sea-states



Simple Gaussian – scale width

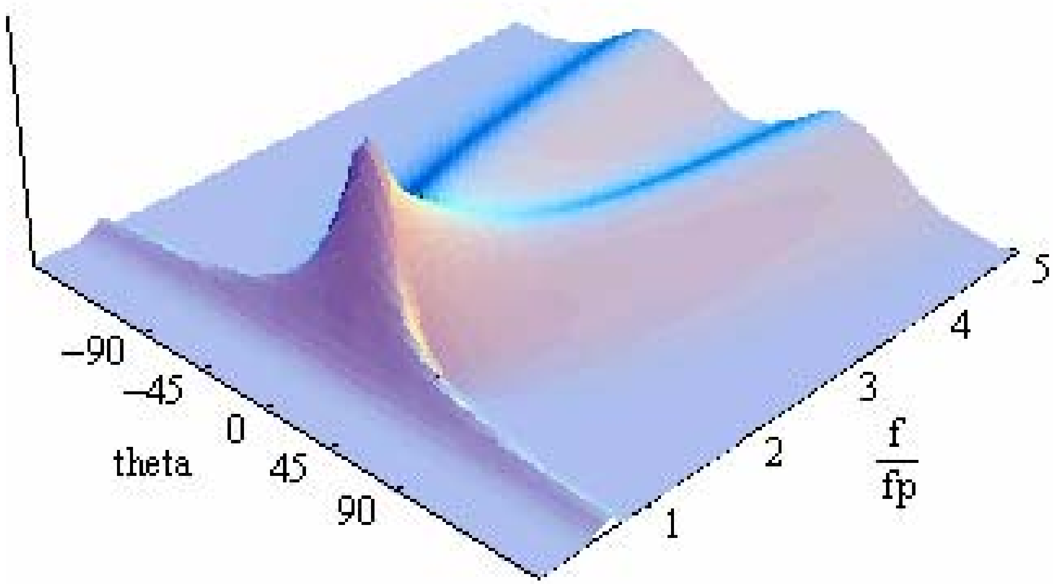


Twin 15° Gaussian – split

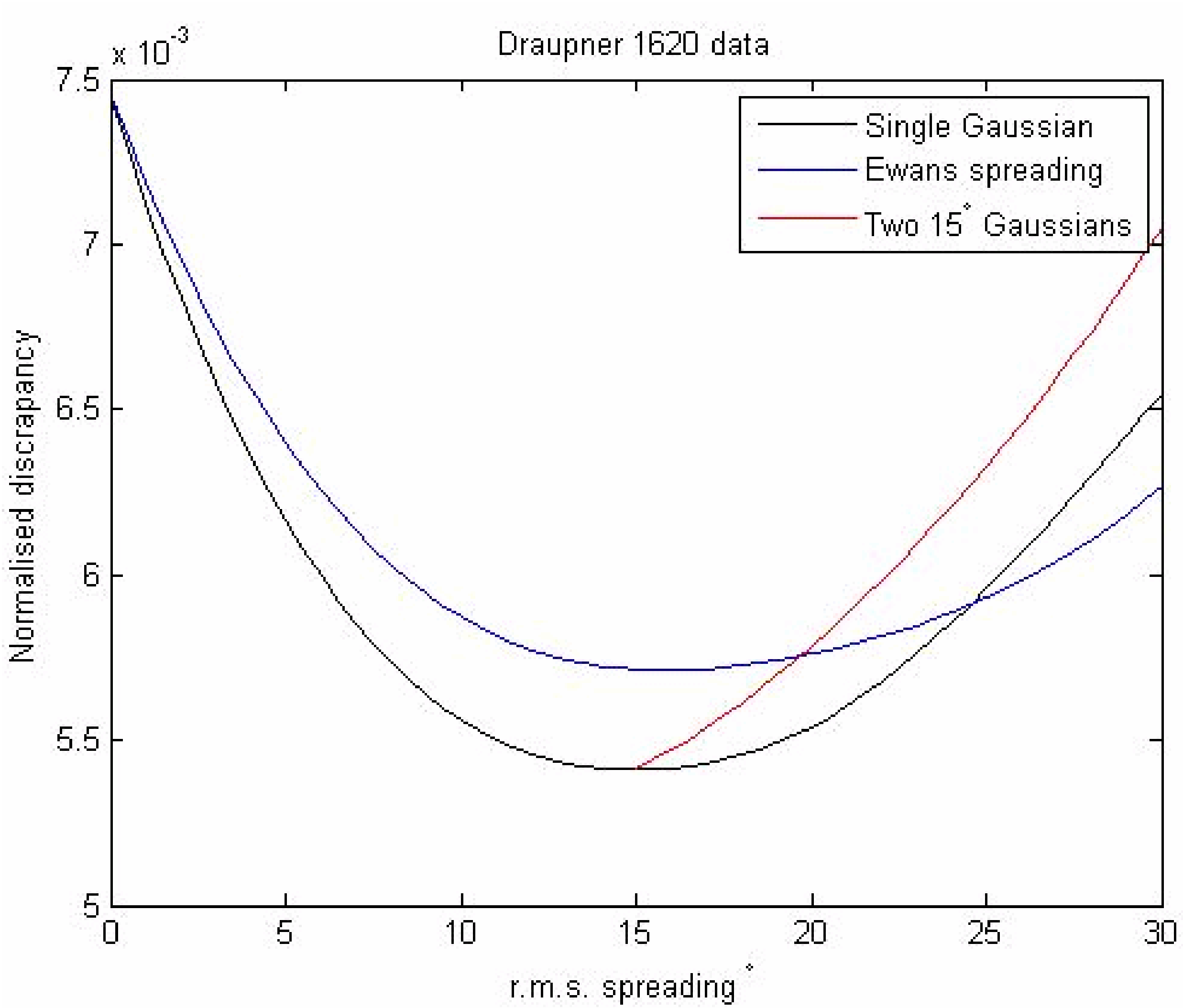


Ewans freq-dependent spreading
- broaden by scaling width of whole function

Ewans K
Observations of the directional spectrum of fetch-limited waves.
Jn. Phys.Oceanogr., 1998 **28**, 495-512.

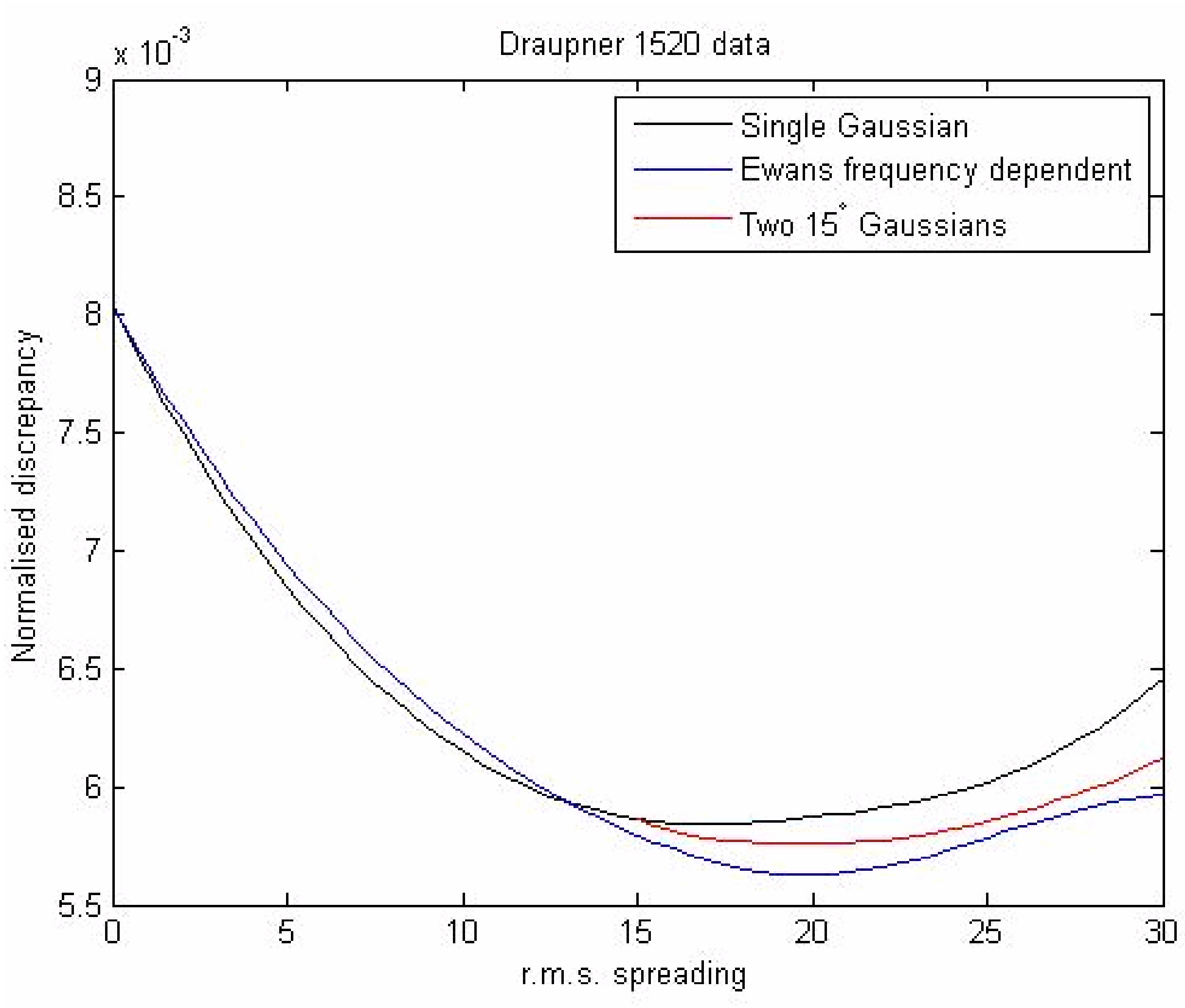


rms error – long waves vs. 2^{nd} order difference simulation



16.20 Best estimate single Gaussian 15°

rms error – long waves vs. 2nd order difference simulation



15.20 Best estimate
Ewans 20°

Spreading from 2^{nd} order sum and difference analysis is consistent

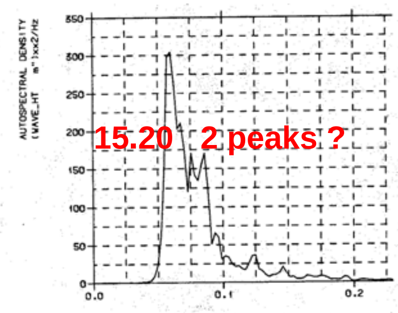


Fig. 15 Wave spectrum for the time history in Fig. 13.

15.20 20° spreading split at higher freq only

16.20 15° single Gaussian form

Why ?

Speculation :

1^{st} Jan meteorological event was

winter storm + polar low

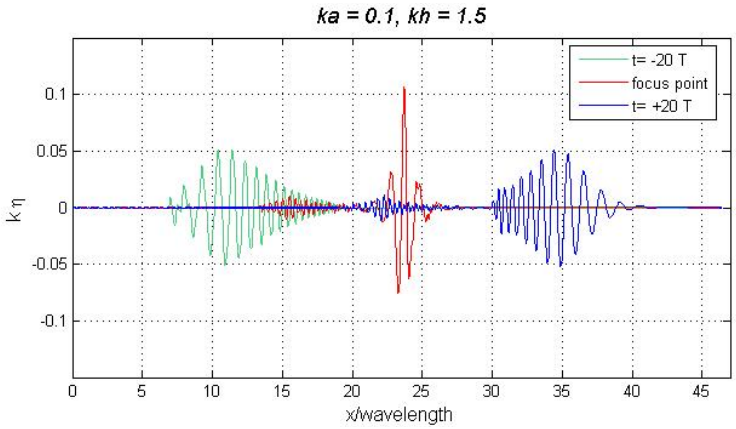
✸ crossing sea-state, which then merged

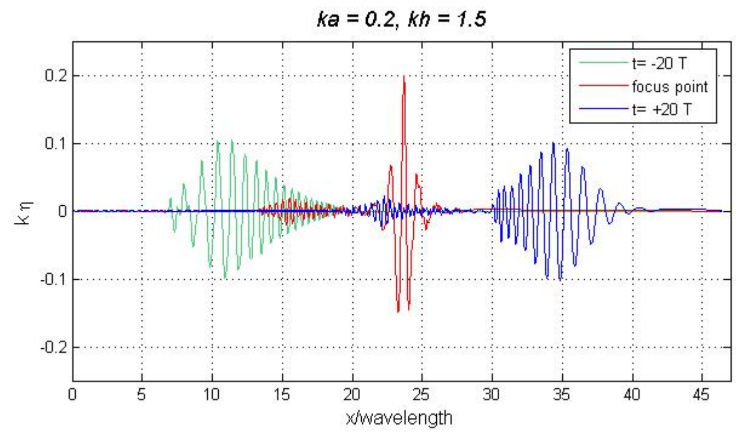
What spreading are we estimating?

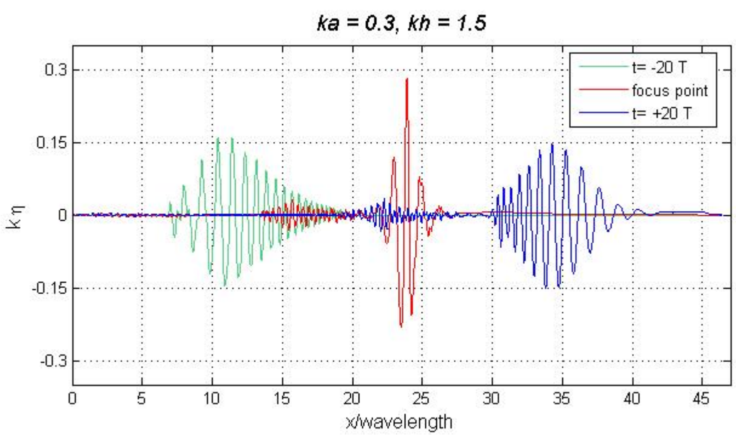
Not
the orthodox measure of directional deviation away from
a mean direction over 20min

Instead
the directional deviation of components within each wave
relative to the instantaneous mean for that wave

This 2nd definition should be smaller than the orthodox measure





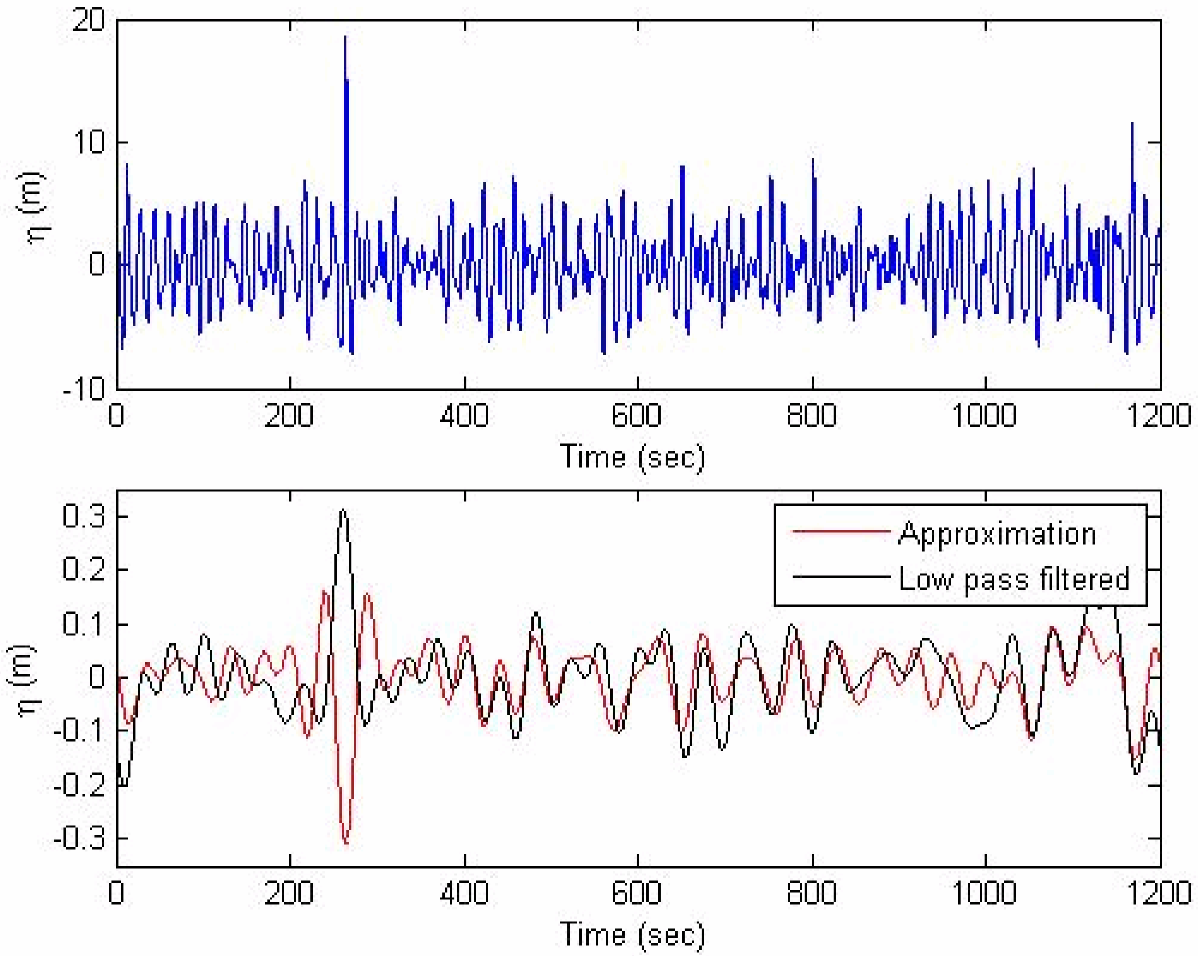


High-order Boussinesq 1-D simulations of Draupner wave

- focussing is close to linear,
no net 3rd order wave-wave interactions

- actually, very weakly de-focussing
Draupner is close to cut-off kd = 1.36 for NLS

Is the Draupner wave a freak ?

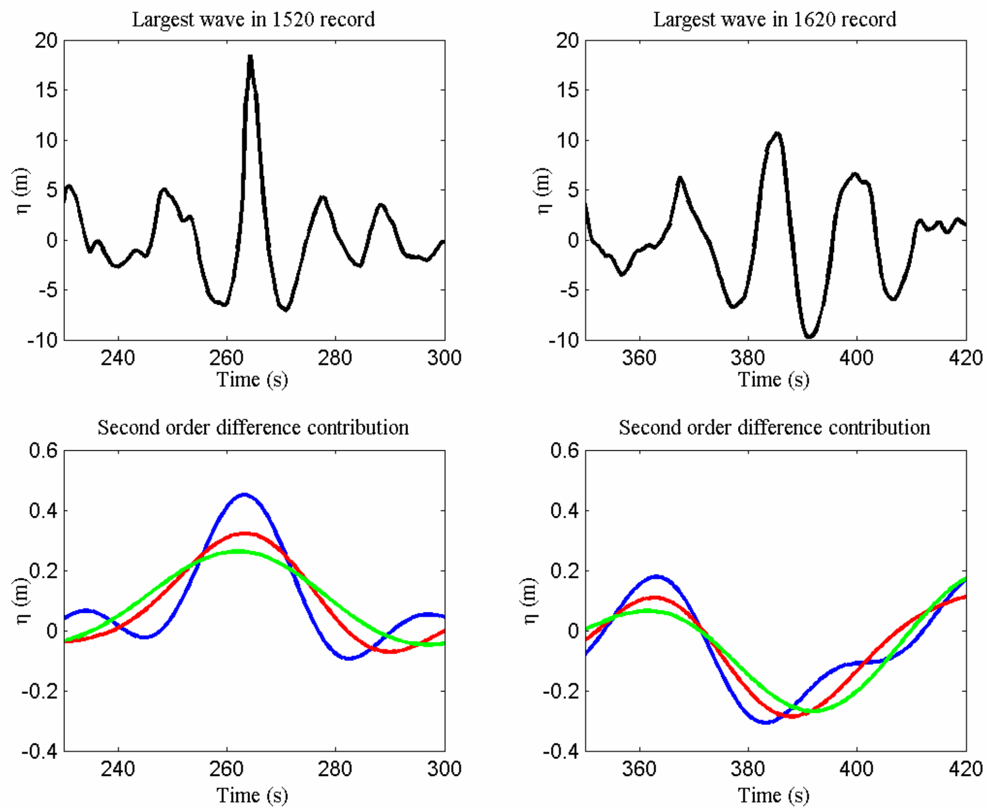


Comparison of measured long wave to
2nd order difference waves with Ewans spreading of 20°

Second order difference contribution to the New Year wave

For all large waves (largest 10%)
→ second order difference set-down

EXCEPT the New Year wave
which ***exhibits a set-up!***



2nd order difference contribution estimated by low-pass filtering at 0.04Hz 0.03Hz 0.02Hz

Small ⌖0.3*m* in 18.5*m* but curious!

In conclusion:

1st Jan 1995 sea-states

Severe

Consistent spreading from different 2nd order sum and difference analyses

Spread at 20° then 15°

Crossing seas which merge?

Giant wave

Shape – not too different from NewWave

Return period ~ 1 in 200,000

No evidence for strong 3rd order wave-wave interactions

Freak?

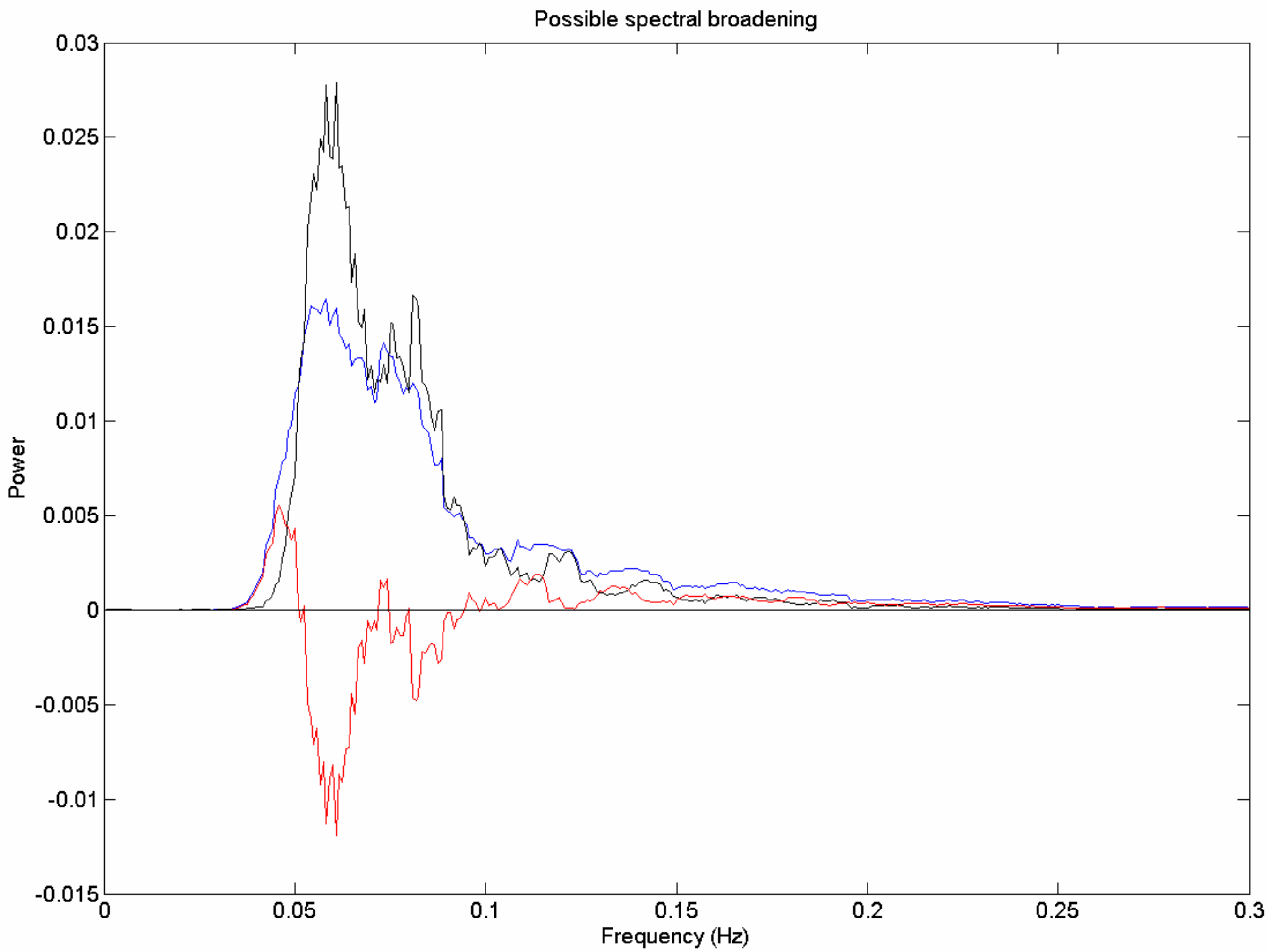
Local set-up not set-down – perhaps a definition for a freak wave ??

Speculations with 100 waves!

Questions and comments?

Thank you for your attention.

This is not a rogue (or freak) wave
– it was entirely expected !!



Possible spectral broadening
Power
Frequency (Hz)
0.03
0.025
0.02
0.015
0.01
0.005
0
-0.005
-0.01
-0.015
0
0.05
0.1
0.15
0.2
0.25
0.3