



UNIVERSITY OF  
**OXFORD**

# ***GIANT WAVES ON THE OPEN SEA***

## ***- MARINERS' TALL TALES OR ALARMING FACT ?***

Paul H. Taylor

Department of Engineering Science, University of Oxford

Acknowledgements:

William Bateman, Richard Gibbs, Dan Walker, Harrif Santo, Alison Raby and Tom Adcock  
Alistair Borthwick, Rodney Eatock Taylor, Chris Swan, Peter Tromans  
Shell and BP, EPSRC

Portreath: November 2009

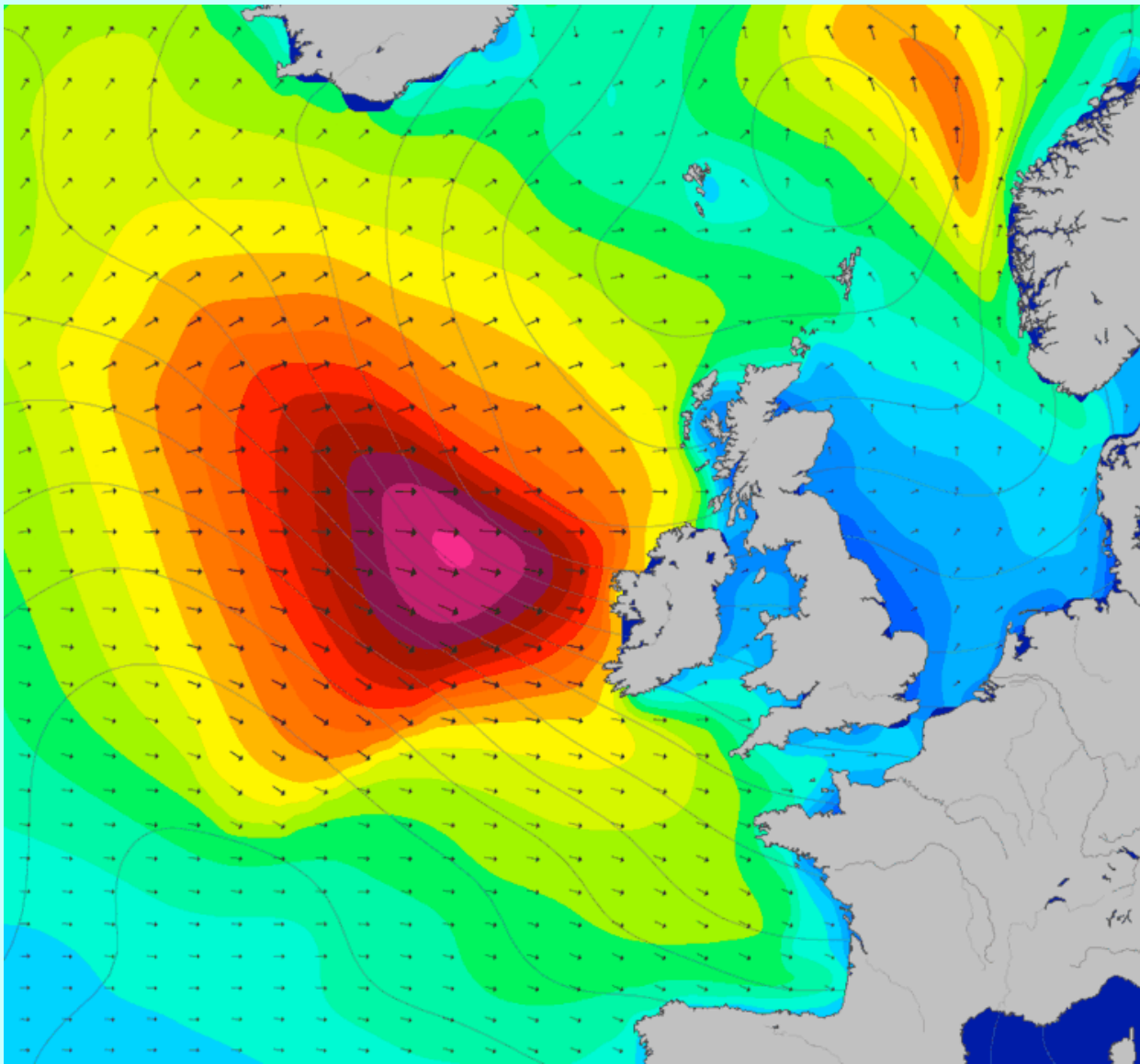


After: 4 January 2014



BBC News  
7 January 2014

Large waves are important at the coast



Wed 2<sup>nd</sup> March 2016 - peak  $H_s$  ~ 42ft  
<http://magicseaweed.com/UK-Ireland-Surf-Chart/1/>

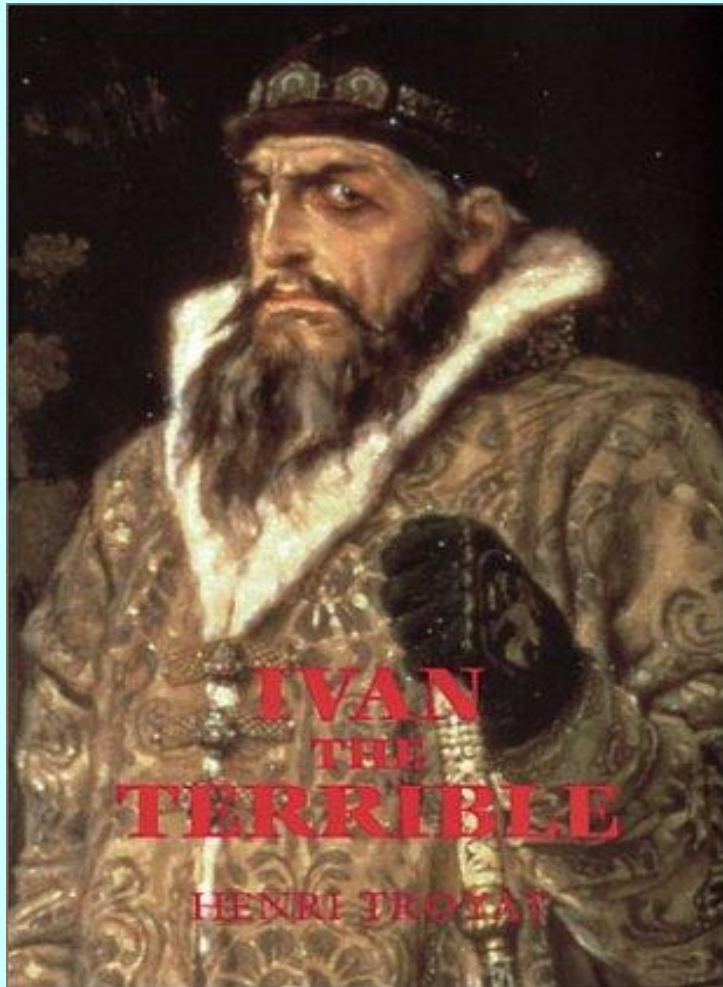


## UK winter storms destroy railway line at Dawlish, Feb 2014

The track was swept away with part of the sea wall in early February, cutting off the service linking Cornwall and much of Devon with the rest of the UK.

Line was re-opened in April, rebuilt at a cost of approx £35M.





Examples of big waves in  
offshore and coastal engineering  
– seriously expensive damage

Hurricanes:

Andrew

Ivan

Katrina

Rita

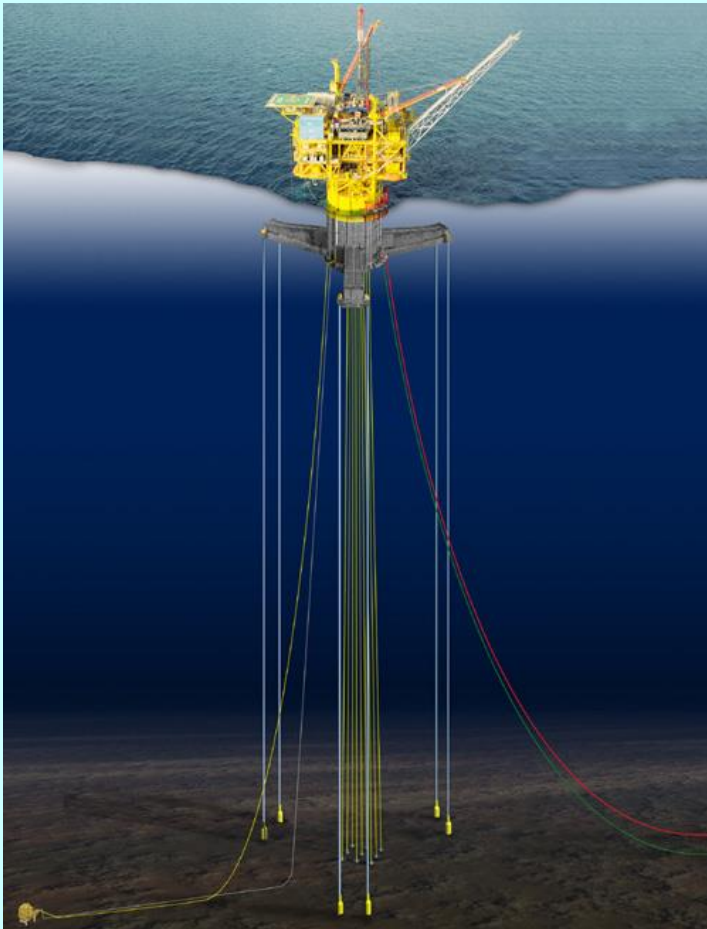
.....



## 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.”



Interstate-10 bridge across Escambia Bay, Florida, after Hurricane Ivan  
- looking east from Pensacola



**Wave damage in  
coastal engineering**

Odyssey opens as this weekend's British National Surfing Championships begin. **Nick Harris** reports

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America's Mike Parsons rides a wave measured at 64 feet at the legendary Jaws break in Maui, Hawaii, in a scene from the documentary 'Billabong Odyssey', which is released in British cinemas this weekend. (Below) Sam Lamiroy, Britain's No 1 surfer and the man behind a forthcoming UK-based Odyssey project, in action before this weekend's National Championships at Tynemouth Beach, near Newcastle *Revolver/O'Neill*

Jaws on the north coast of Hawaii

This is a giant wave

**BUT not a rogue wave – it was entirely expected !!**





**Australian waves**



# Waves in history and art



**The Bell Rock Lighthouse  
by JMW Turner**

- on an almost completely submerged reef on the east coast of Scotland

Constructed by Robert Stevenson in 1811  
1<sup>st</sup> of the famous Lighthouse Stevensons,  
who for 3 generations designed, built and maintained  
all the Scottish lights.

- the black sheep of the family, **one Robert Louis,**  
**let the family down by writing children's books**  
**such as **Treasure Island** instead!**





**Katsushika Hokusai** (葛飾北齋) (1760-1849)  
Creator of the block prints Thirty-six Views of Mount Fuji, including  
"In the Hollow of a Wave off the Coast at Kanagawa."

**The  
Economist**

AUGUST 18TH-24TH 2007

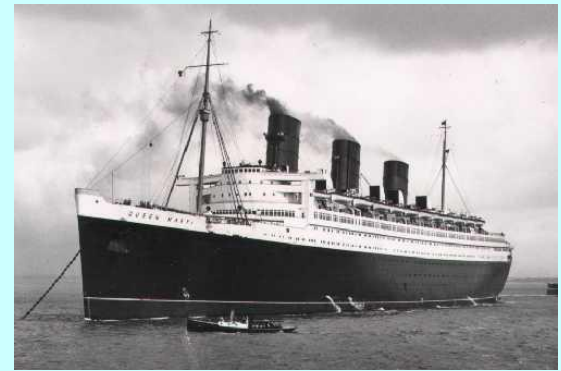
www.economist.com

The Republicans after Rove  
Toxic toys from China  
Latin America's new middle class  
Carving up the Arctic  
Asia's skills shortage

# Surviving the markets



# The **real** Poseidon Adventure (almost)



December, 1942,

The famous British liner *Queen Mary* was carrying 15,000 American troops to England.

700 miles west of Scotland during a gale,  
.... **hit broadside by a giant rogue wave.**

**The immense wall of water**

... damaged lifeboats and broke windows on the bridge – 90 feet above the waterline.

Caused an astounding **52° list**

~ 3° more would have made the vessel turn turtle.

Crew thought the ship would capsize.

The incident was classified **Top Secret** - and later made into a terrible film



## Another Queen and another wave

Capt. Ronald Warwick, of the liner *Queen Elizabeth II*, was on the bridge at 4 a.m. on Sept. 11, 1995. The ship was off Newfoundland, bound for New York and trying, without success, to dodge Hurricane Luis.

Monstrous seas had just smashed windows in the Grand Salon, 72 feet off the water.

Suddenly, **a huge wave loomed** off the bow, huge even for the QE2.  
**.... a breaking wall of water ... like the white cliffs of Dover.**  
Officers on the bridge were eyeball to eyeball with the crest.....

The 'learning outcomes' of these events are

.. don't go on a cruise across the North Atlantic in winter

.. if you must go, avoid Cunard liners!

Captain Warwick on the *QE2*, his passengers and crew were lucky. No one was seriously injured.



... a far different fate for the German container ship **München**, which vanished in the middle of the Atlantic in the winter of 1978.

a fierce storm had been raging.... The München had been designed to cope with such conditions, and carried on with her voyage.

The exceptional flotation of the vessel meant that she was widely regarded as being practically unsinkable....

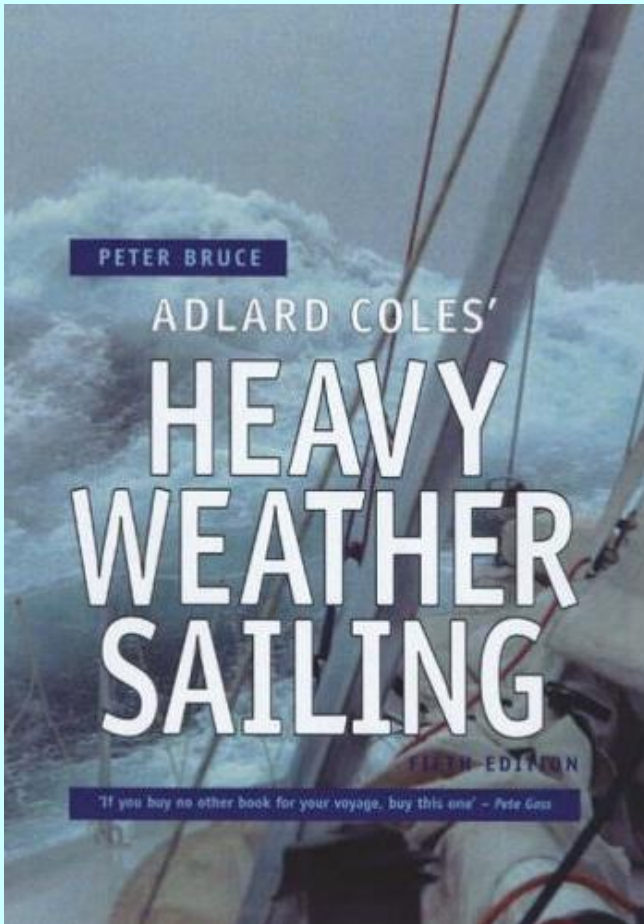




## The München - the explanation ?

- Investigators considered the possibility that she had encountered a freak wave....
- ...suddenly faced with a wall of water between 80 to 100 feet high,
- ...breaking across her bow and
- ...likely smashing into the bridge, breaking the windows and flooding her.
- ...lost her bridge and steering, presumably also lost her engines
- ...turned broadside onto the waves
- ...seems to have floated for a number of hours, eventually flooded or capsized

Any sailors among us ?



Fastnet Race 1979  
..dozens of yachts lost and 3 people killed

Sydney-Hobart 1998  
... loss of 6 sailors, 5 boats sank and  
66 of 115 starters retired

Velux 5 Oceans Race 2006  
8 entrants, 5 forced to take shelter to make  
repairs after a storm in the Bay of Biscay  
within a few days of starting

“To contemplate an offshore passage without having read it first would be plain imprudent”

Daily Telegraph



Waves can be big on the open sea  
- even bigger when they interact with structures

Oseberg-A 100m water depth, west of Bergen, Norway

Perhaps the most famous **freak** wave photograph  
– a wall of water well offshore in the Bay of Biscay





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

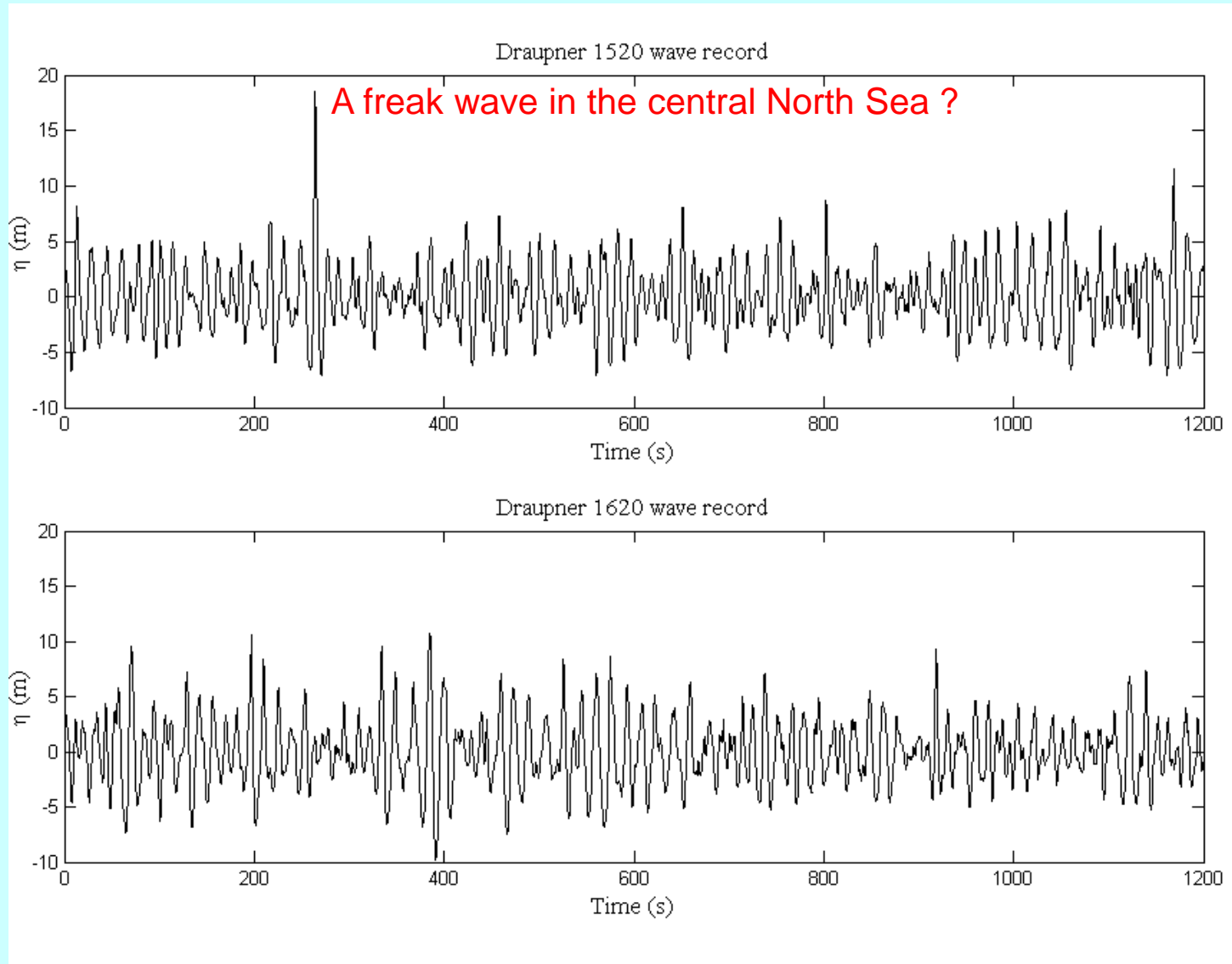
Sverre Haver

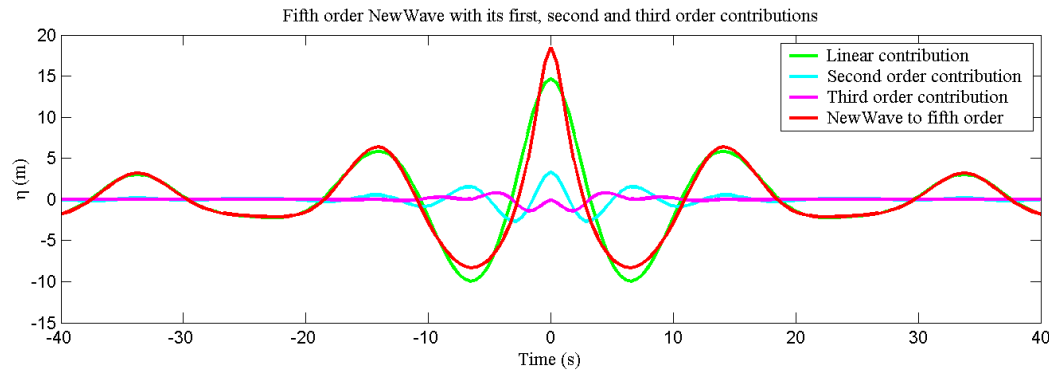
Marine Structures and Risers, Statoil ASA, N-4035 Stavanger, Norway  
[svha@statoil.com](mailto:svha@statoil.com)

[www.math.uio.no/karstent/seminarV05/  
Haver2004.pdf](http://www.math.uio.no/karstent/seminarV05/Haver2004.pdf)

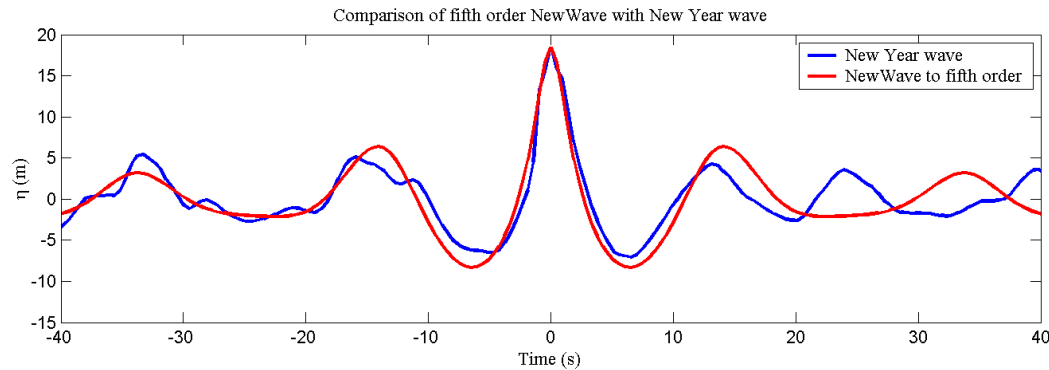
# Field data from the central North Sea

## - The New Year wave at Draupner in 1995





Linear model  
+ weakly nonlinear  
corrections



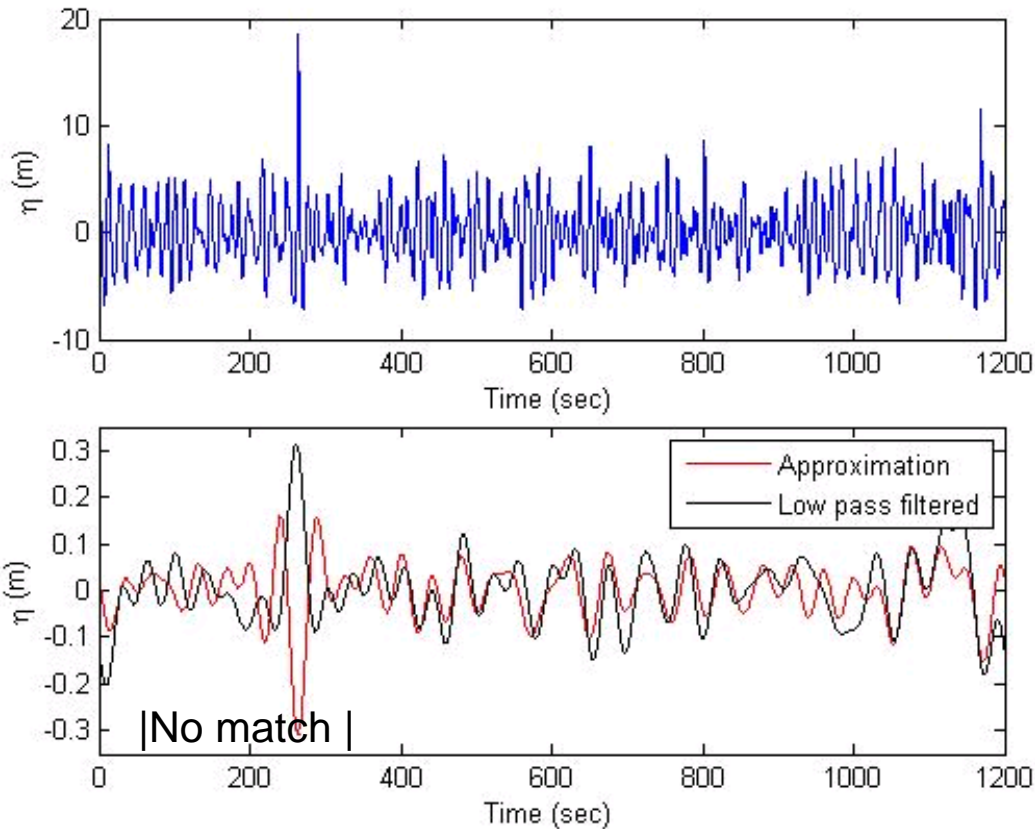
Comparison of model  
to measurement

Return period : ~ 1 in 200,000 waves in this sea-state

i.e. need ~100 storms of this severity to expect to see a single crest this high

ANYTHING ELSE OTHER THAN THE HEIGHT STRANGE ABOUT THIS WAVE ?

# Is the Draupner wave a freak ?



For all large waves (top 10%)  
→ long wave set-down

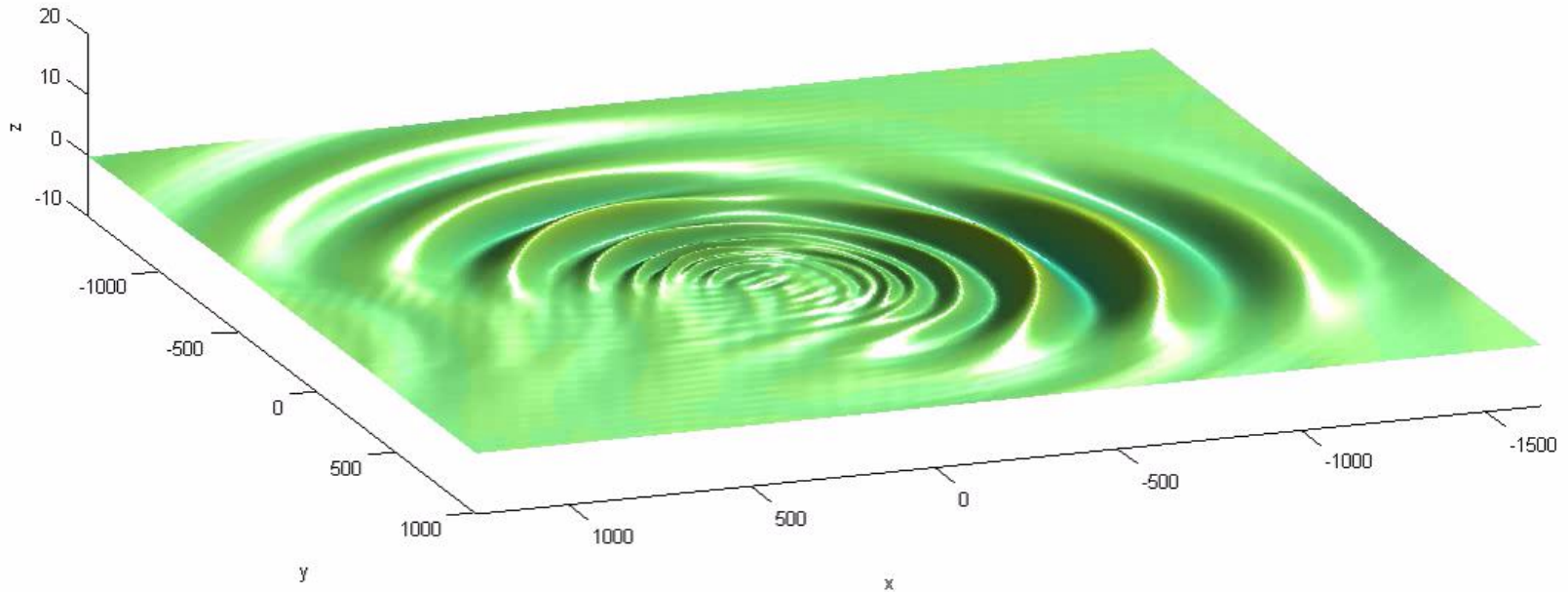
EXCEPT the New Year wave  
which ***exhibits a set-up!***

Small  $\sim 0.6m$  in  $18.5m$

**Reason – *crossing sea***

Comparison of measured long wave to 2<sup>nd</sup> order difference waves with  
**directional spreading of  $20^\circ$**





With thanks to Tom Adcock in Oxford and Qinqwei Ma at City University, London

So the Draupner wave arose in a violently crossing sea – ‘worst ever seen’ by ferry captains in central North Sea

2011 Adcock, Taylor, Yan, Ma, Janssen.

‘Did the Draupner wave occur in a crossing sea?’ Proc Roy Soc A, 467 (2134), pp. 3004-3021.

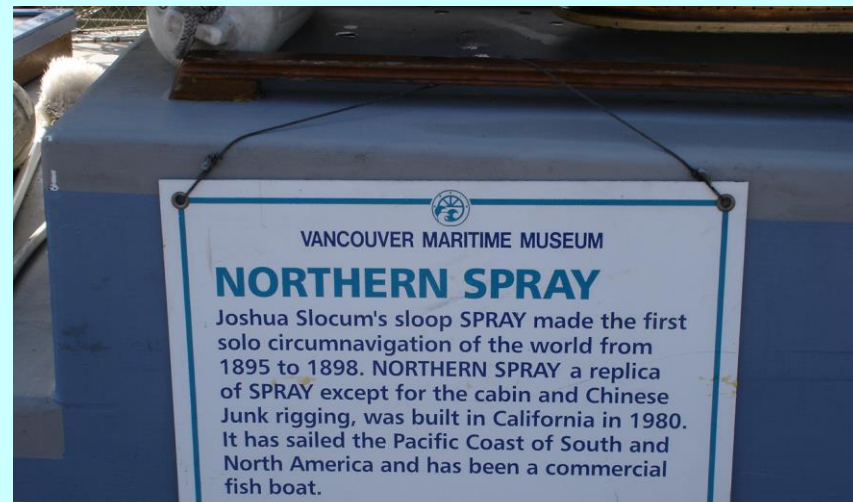
To echo Jean from yesterday: **There is much more to a sea-state than  $H_s$  and  $T_z$**



JOSHUA SLOCUM

‘SAILING ALONE AROUND THE WORLD’

1895-1898



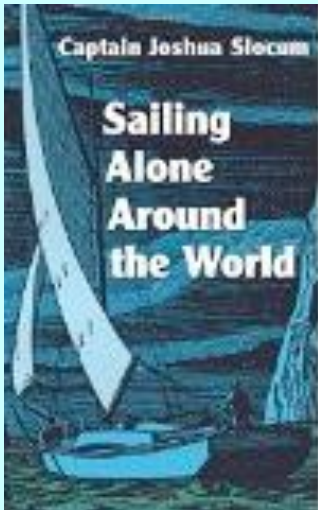
...one day, well off the Patagonian coast, .....

a tremendous wave, the culmination, it seemed, of many waves, rolled down upon her in a storm, roaring as it came.

.. I saw the mighty crest towering mast-high above me.

The mountain of water submerged my vessel.

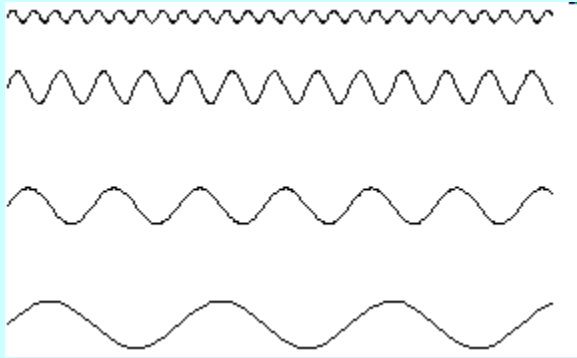
She shook in every timber and reeled under the weight of the sea, but rose quickly out of it, and rode grandly over the rollers that followed.



*Joshua Slocum - Sailing Alone Around the World, Chapter 7.*

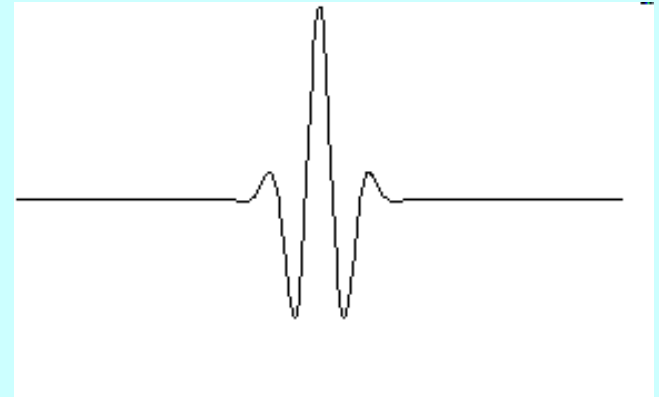
A large surface elevation occurs when many little crests of these *individual long and short waves happen to coincide at a single point*

... a tremendous wave, the culmination .... of many waves - Joshua Slocum



Sum of components

can give



Focussed event

# Water waves:

## Exact solutions of the Euler equations

Field equation

$$\nabla^2 j = 0$$

$$\underline{u} = \nabla j$$

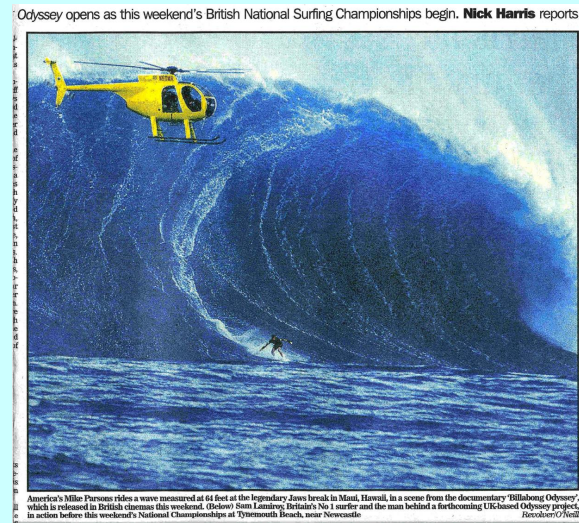
Boundary conditions

on the moving surface

$$p = 0$$

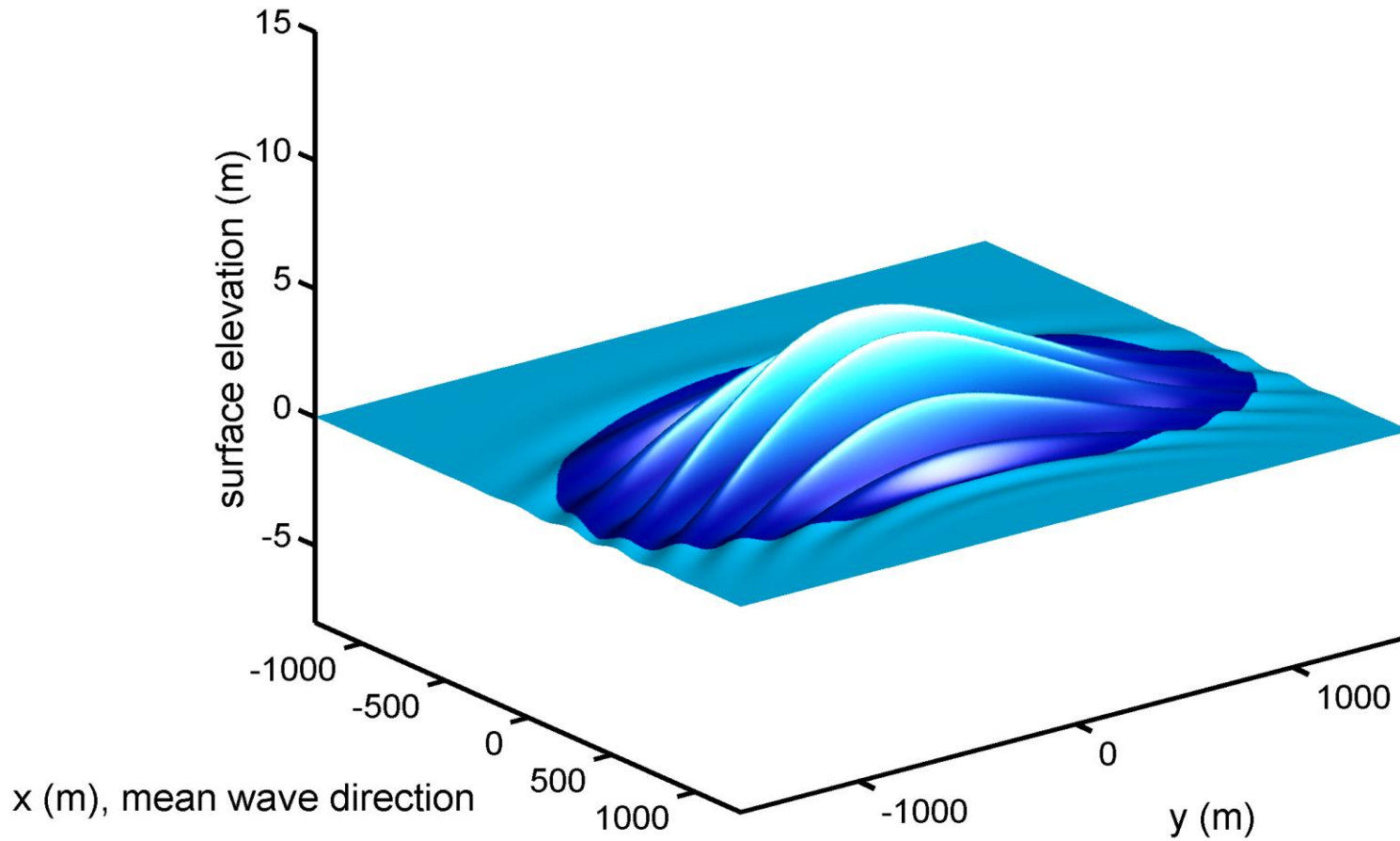
$$\frac{\partial h}{\partial t} = w - \underline{u}_H \cdot \nabla_H h$$

The Euler equations have solutions for plunging breakers and rogue waves

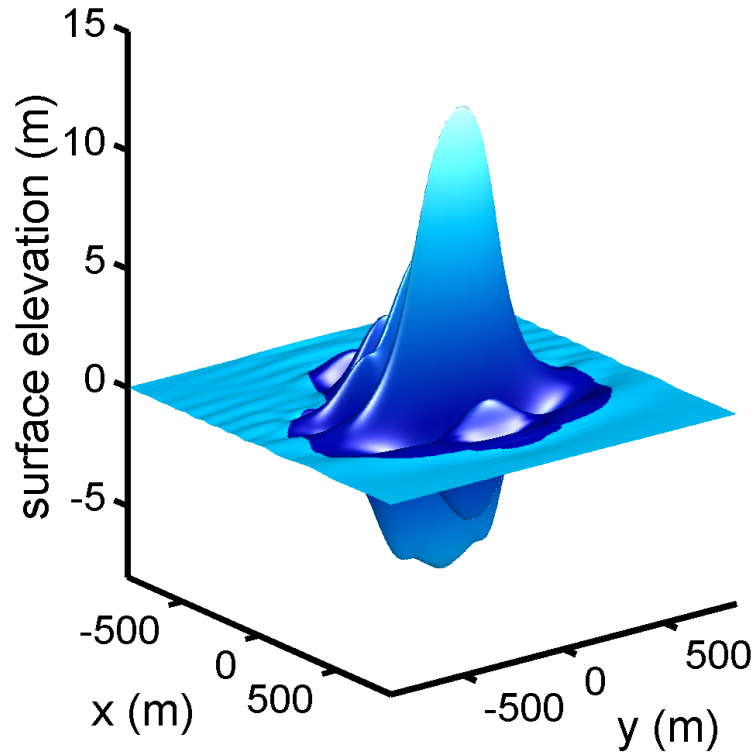


# Initial Surface Shape

20 periods before linear focus

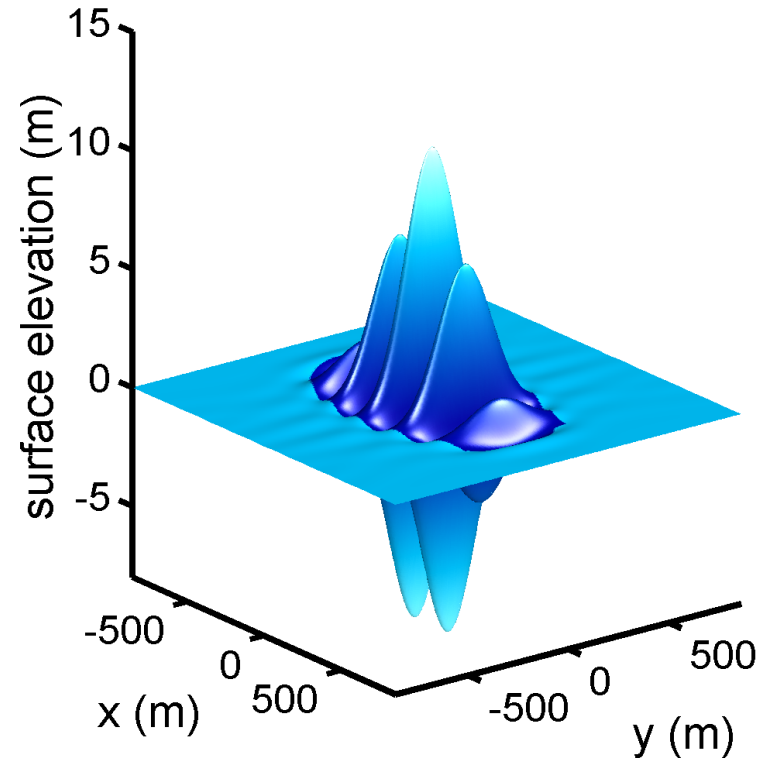


## Non-linear Focused Event



What can actually happen  
to a steep wave group

## Linear Focused Event



What the simplest models  
predict

# Simulations

- Show formation of extreme event from 20 periods before focus, and dispersion after focus
- Rapid structural changes to group close to focus point :  
**forms a broad wall of water with no precursors  
followed by a deep hole in the ocean and subsequent crests**
- Many features as reported by observers

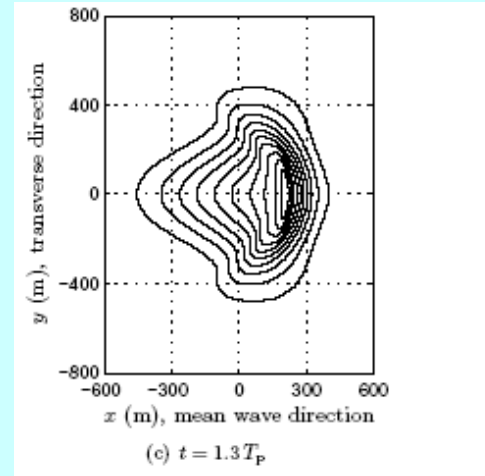
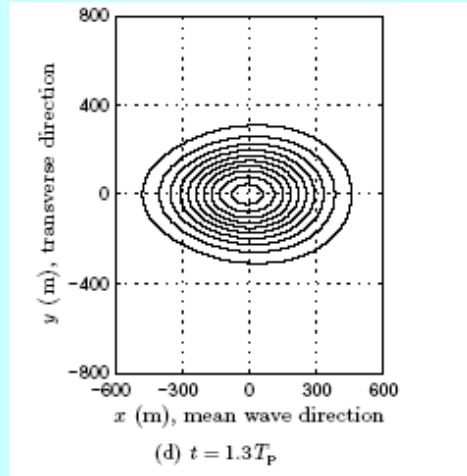




# Energy contour maps

Linear

Exact non-linear

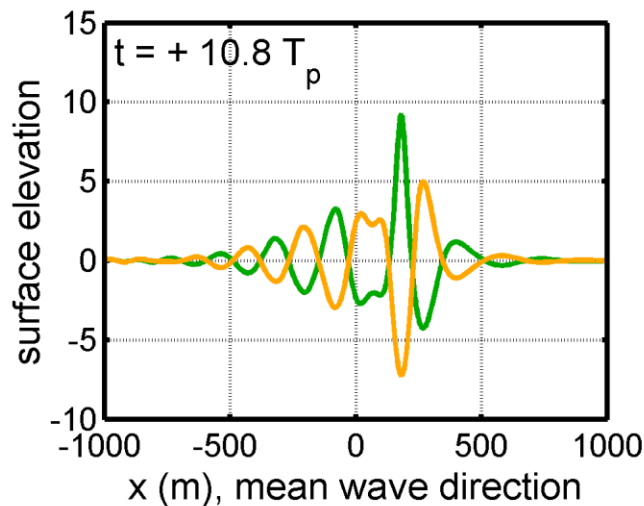
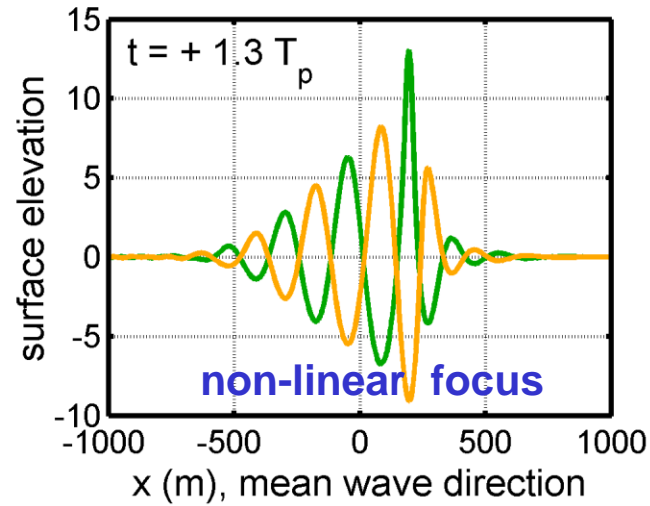
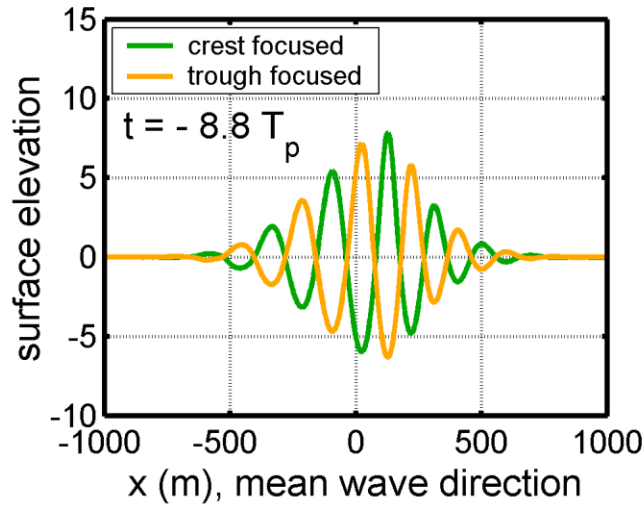


2-D dominant physics is  $x$ -contraction,  $y$ -expansion

- wall height and length correctly described by NLS eqn
- shift of position of wall to front of group is missing

We can replicate most of the features in mariners' tall tales if the conditions are just right – Tom Adcock's talk earlier

## Cross-sections of Non-linear Surface Elevation



No advance warning of the wall of water

Wall is persistent

Deep trench as likely as tall crest

Followed by train of waves

– Slocum's rollers

**But what about random variability in a linear field ?**

**What is the average shape of the largest waves in a random sea?**

A question that improves on further acquaintance....

**The average shape around an extreme  
in a linear random Gaussian process is proportional to  
the auto-correlation function of the random process**

The auto-correlation function is the Fourier transform of the power spectrum,

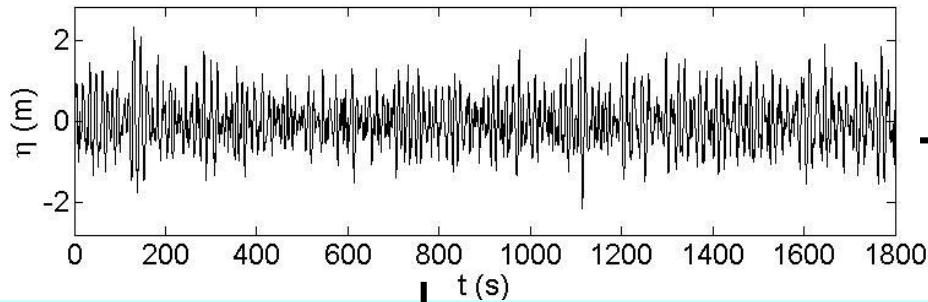
so

**The average shape of ANY EXTREME is related to  
a bulk property of ALL the waves - large and small,  
and has become known as NEWWAVE**

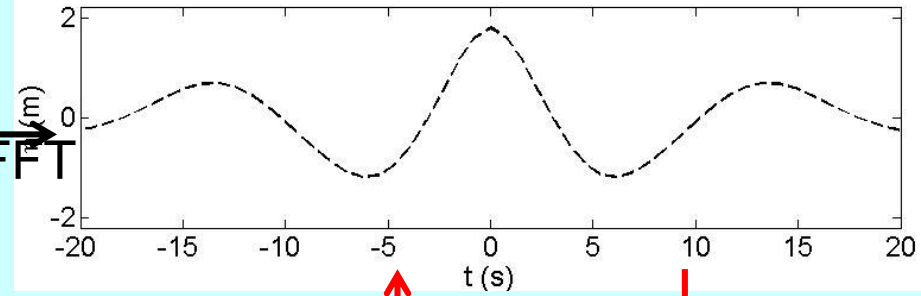
(Lindgren 1970, Boccotti 1983, Tromans .. 1991)

# NewWave replication of linearised average large wave profiles

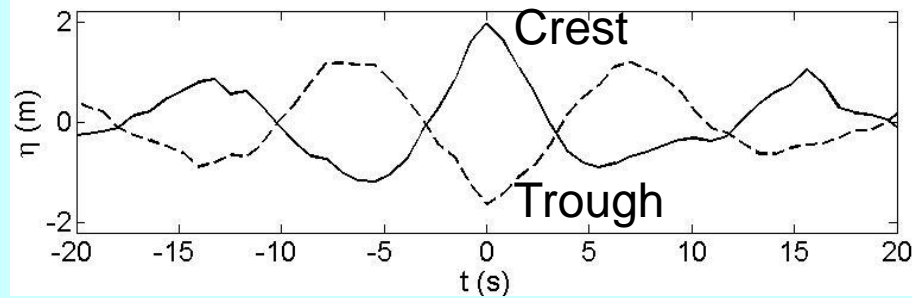
Measured data



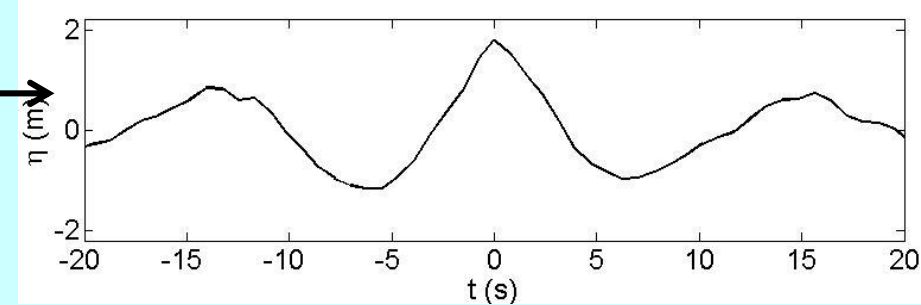
NewWave profile (FT of power spectrum)



Average large wave profiles



Linearised average profile (C-T)/2

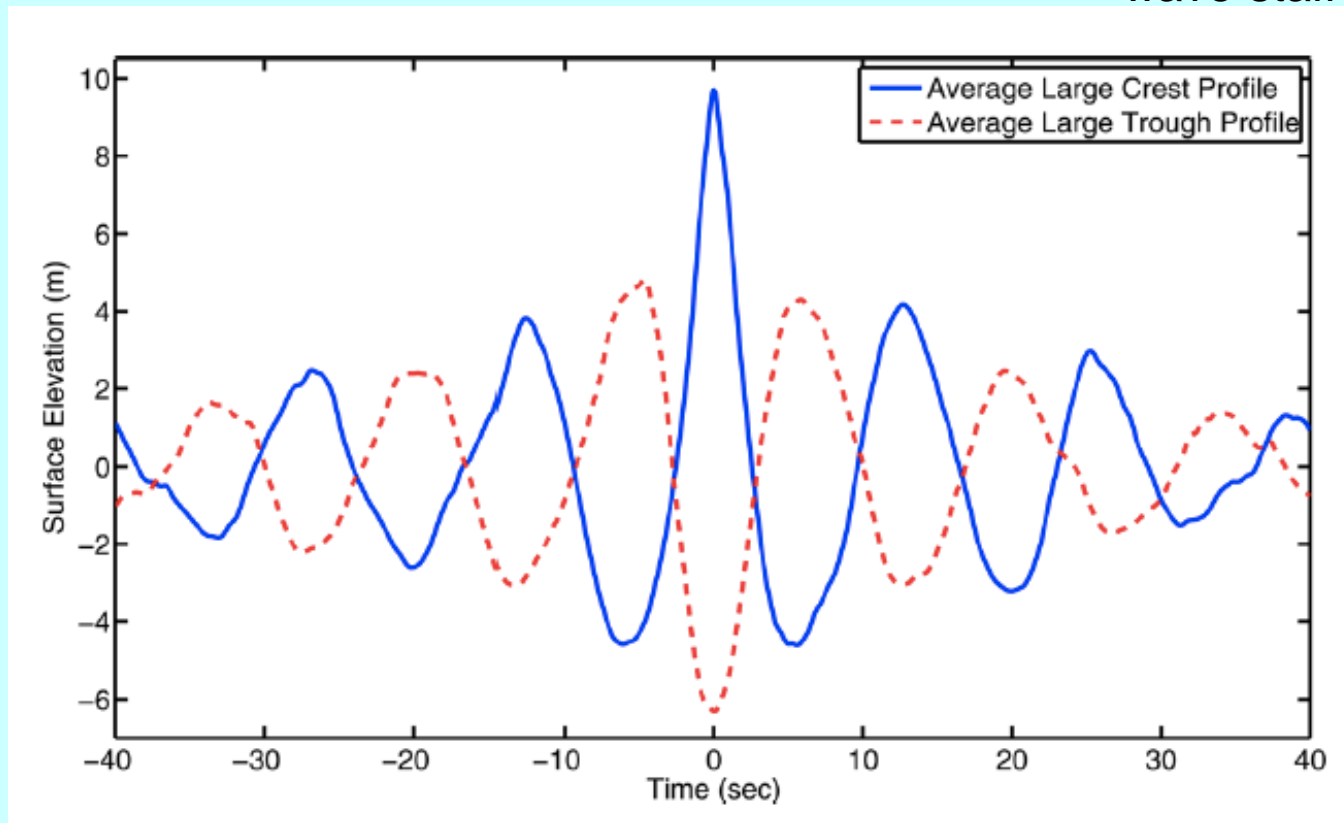


$$y_0^1(t) = \alpha r_t = \frac{\alpha}{\sigma^2} \sum_{i=1}^N S_{\eta\eta}(\omega_i) \cos(\omega_i t) \Delta\omega,$$

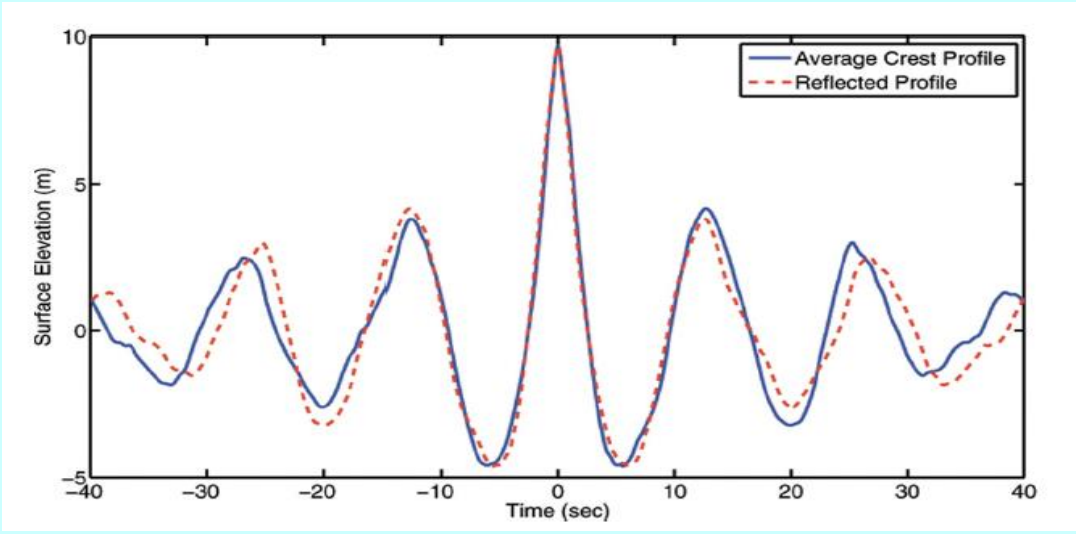
$$\sigma^2 = \sum S_{\eta\eta}(\omega_i) \Delta\omega.$$

Average shape of the 20 largest wave crests and the 20 deepest troughs measured in **Hurricane Camille** (category 5, August 1969)

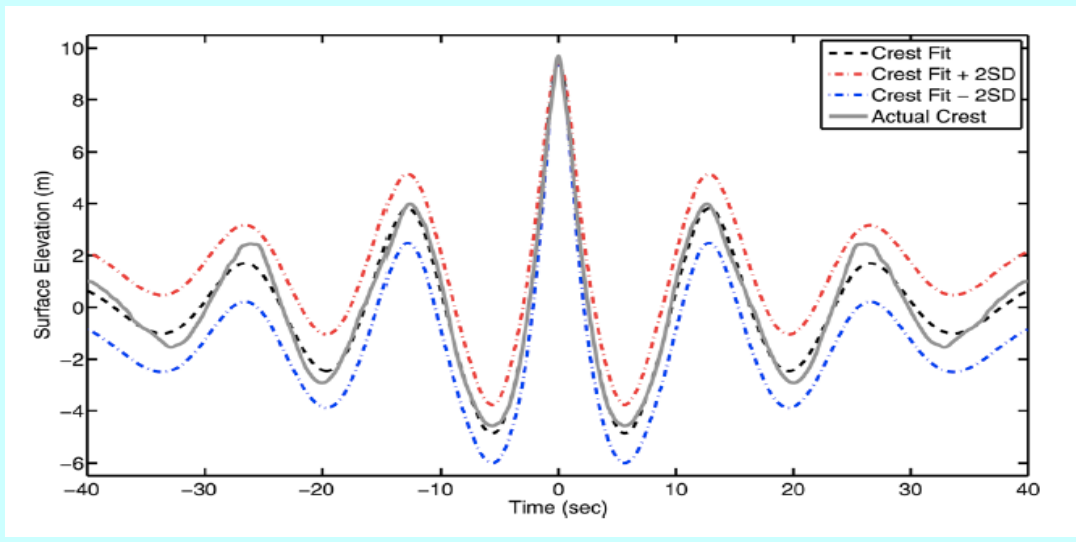
- most severe 30min record:  $H_S = 13.3\text{m}$ . Measured with Baylor wave staff



The averaged large Camille waves are very close to symmetric in time



Average shape fits theoretical Lindgren/Boccotti form



How good is the Camille data?

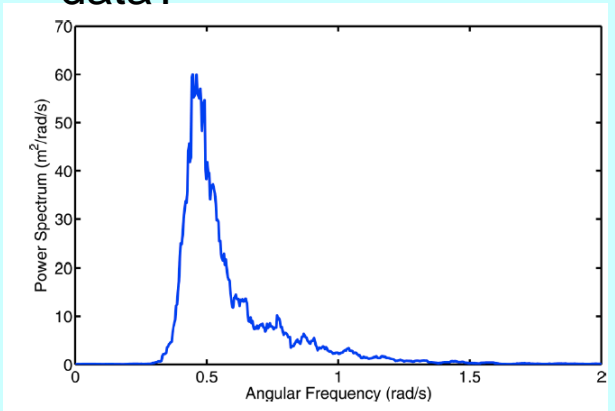
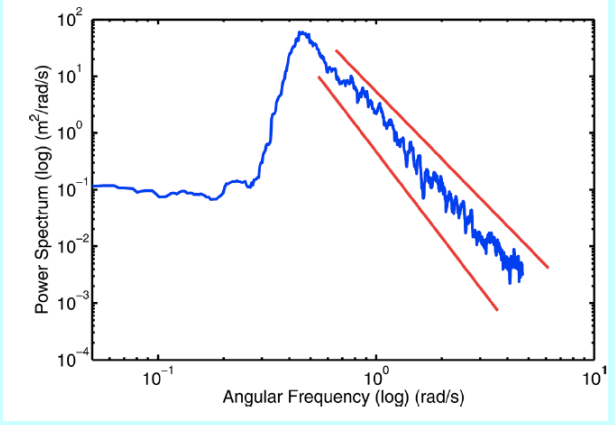
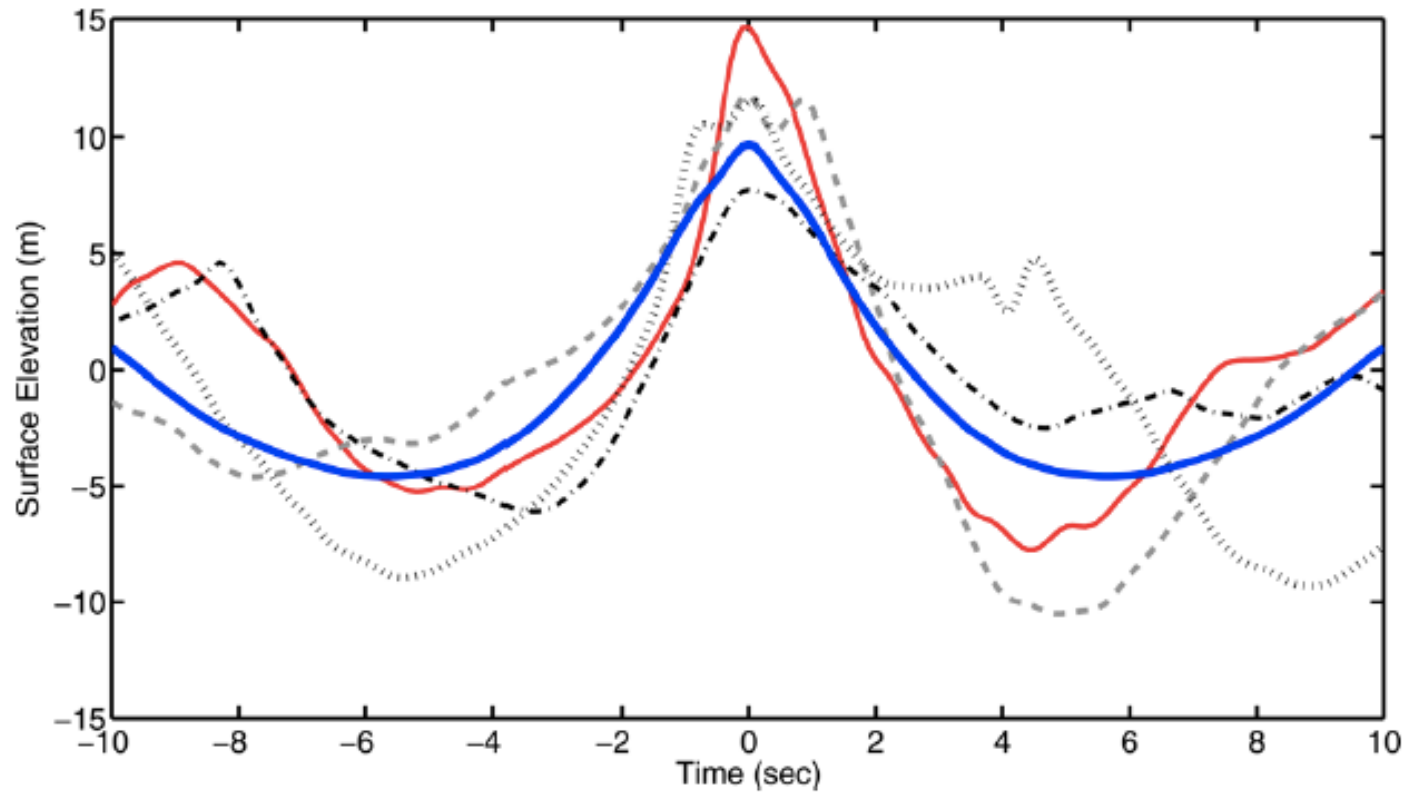


Fig. 13 Wave spectrum from Camille



Answer: very good, even the high freq tail  $\omega^{-4.5}$

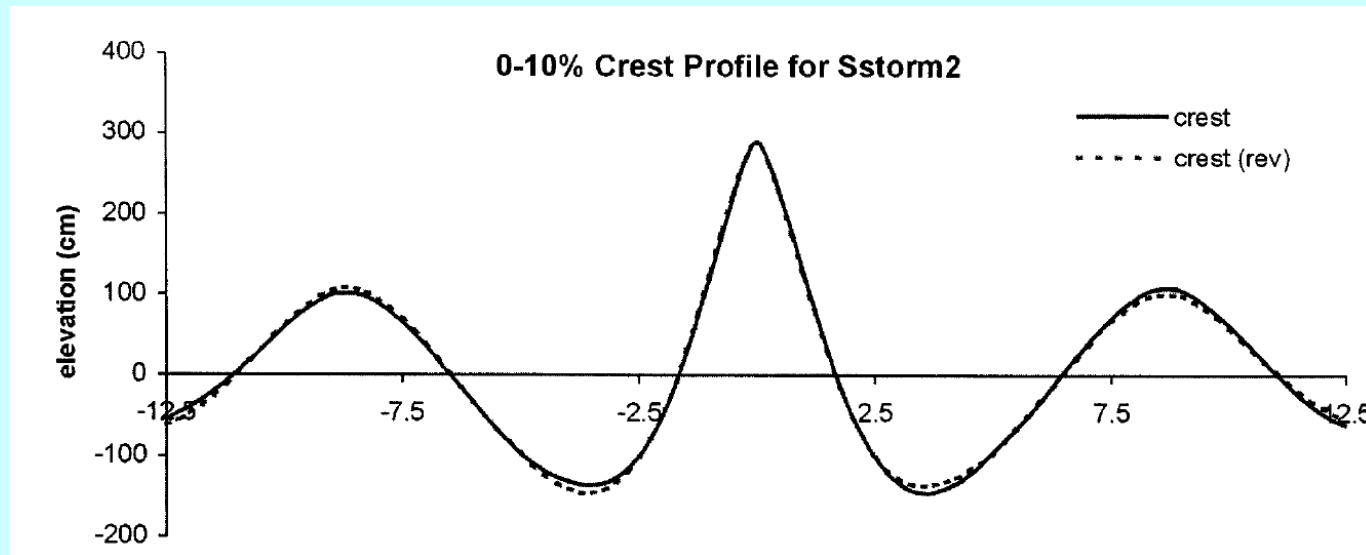


Examples of individual waves in Camille: - there is a lot of variability

Largest crest **red**, 2<sup>nd</sup> 3<sup>rd</sup> and 20<sup>th</sup> **black**, average of top 20 **blue**

WACSYS measurement programme off Dutch coast in ~ 17m depth  
SAAB radar – average shape of top 10% of all waves

- still very close to horizontal symmetry



2004. Taylor, Williams.

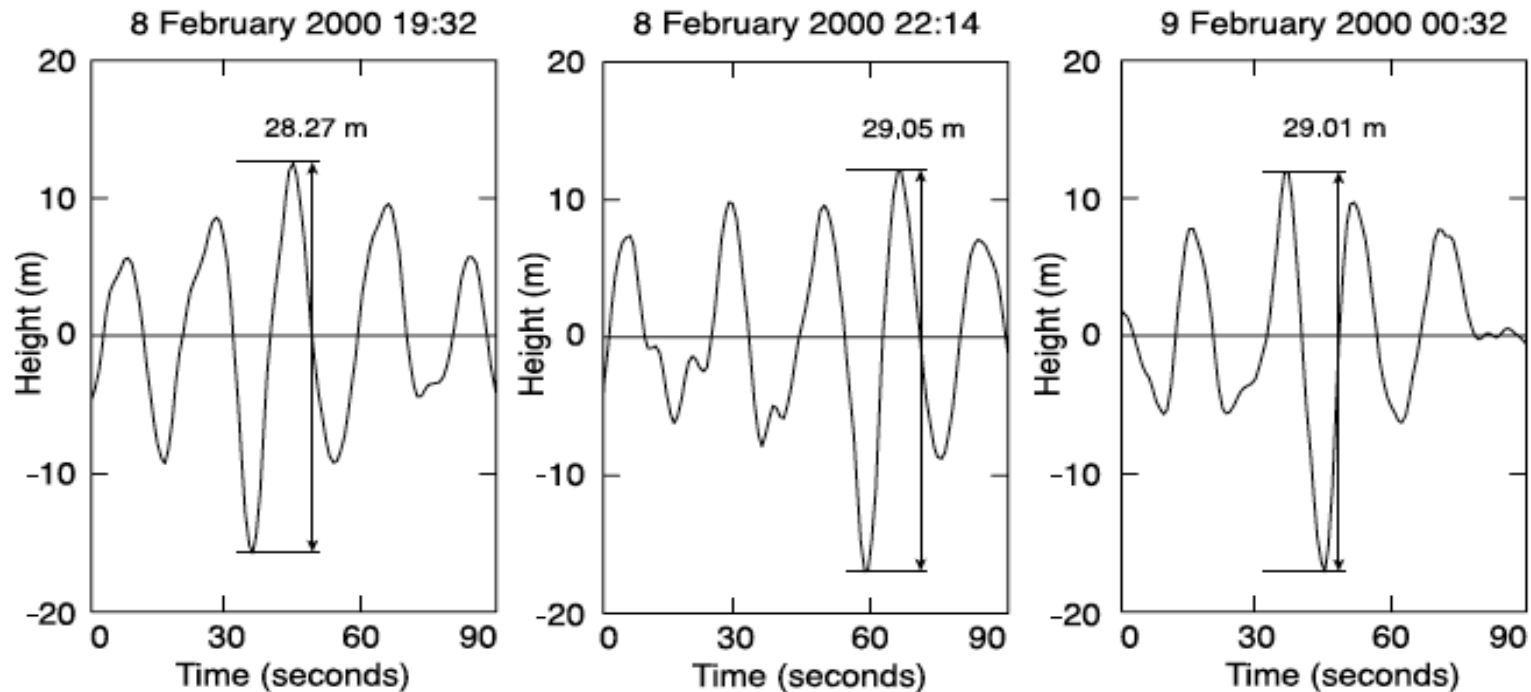
Wave statistics for intermediate depth water - NewWaves and symmetry.  
*Jn. of Offshore Mech. & Arctic Engineering*, 126 (1), pp. 54-59.



## Were extreme waves in the Rockall Trough the largest ever recorded?

Naomi P. Holliday,<sup>1</sup> Margaret J. Yelland,<sup>1</sup> Robin Pascal,<sup>1</sup> Val R. Swail,<sup>2</sup>  
Peter K. Taylor,<sup>1</sup> Colin R. Griffiths,<sup>3</sup> and Elizabeth Kent<sup>1</sup>

GEOPHYSICAL RESEARCH LETTERS, VOL. 33, L05613, doi:10.1029/2005GL025238, 2006



The wave records for the 3 largest measured individual waves

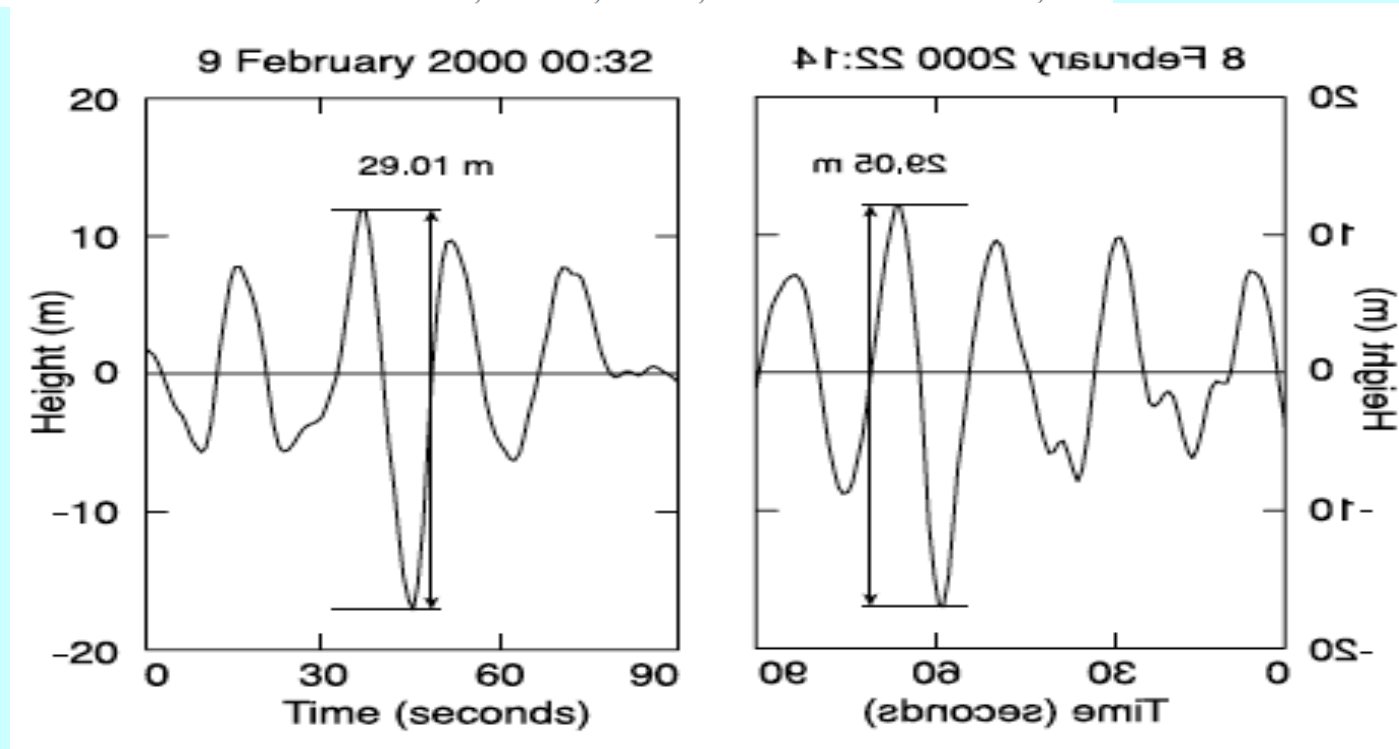
**$H_{\max} = 29.1\text{m}$  with  $H_{S-\max} = 18.5\text{m}$**

Given this  $H_{S-\max}$  maybe these individual waves are not that extreme ??

- could expect  $H_{MP} \approx 2x H_{S-\max}$  for Rayleigh statistics and severe Atlantic storms

# Were extreme waves in the Rockall Trough the largest ever recorded?

GEOPHYSICAL RESEARCH LETTERS, VOL. 33, L05613, doi:10.1029/2005GL025238, 2006



The 2 largest wave records are virtually (horizontal) mirror images

SO very little if any HORIZONTAL asymmetry

But still really remarkable observations

So

Draupner and Rockall waves are VERY large

- does this qualify them to be freak or rogue waves ?

-their shape is (close to) symmetric in time

and close to the scaled autocorrelation function (NewWave)

Large crests and deep holes can occur

-BUT averaged shape of large waves does not show any net time asymmetry  
(Tern, Camille, Dutch coast, CCO waves off Cornwall with  $k_z d$  3.4 – 0.6)

Large crests and deep holes can occur

-with loss of wave group time symmetry:

numerical simulations for waves on deep water show cubic wave-wave effects

-match descriptions of large wave crest (or hole) without precursors followed by  
Slocum's rollers, the Bay of Biscay freak wave photo.....

There is a need for more accurate individual wave simulations with better  
representation of wave directional/frequency spectrum on finite depth

-is a linearly dispersed NewWave the right starting point?

-how important is the background around the large group?



A sign on the top of a cliff in Nova Scotia

Would that it was all this simple!