Ocean Currents Trigger Rogue Waves

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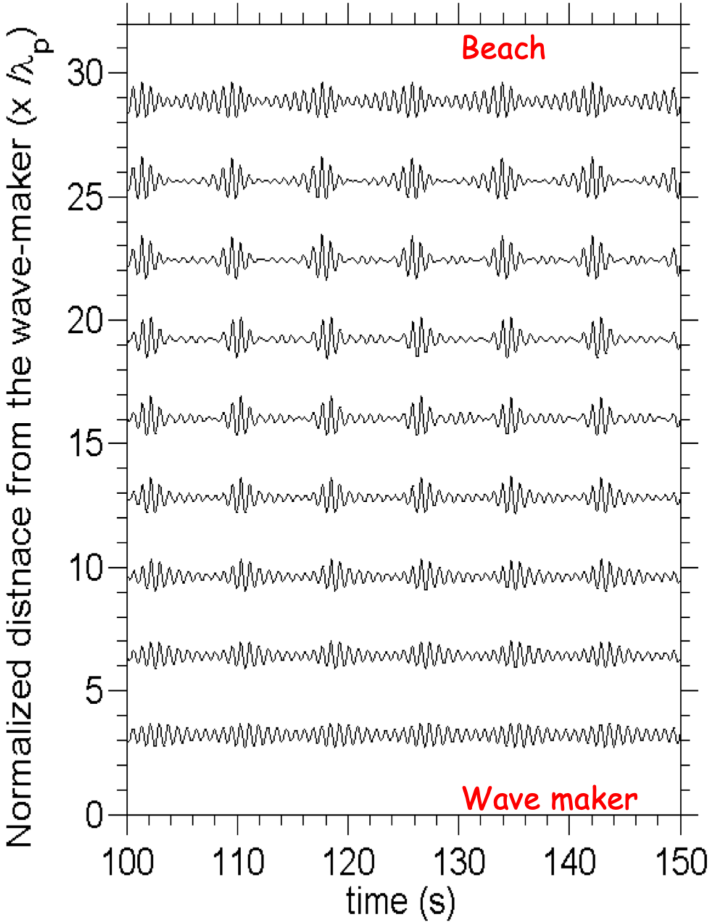
THE UNIVERSITY OF MELBOURNE

Air-Sea-Ice Lab Project

Modulational instability and extreme waves



CARRIER WAVES: T = 1.23 (s);

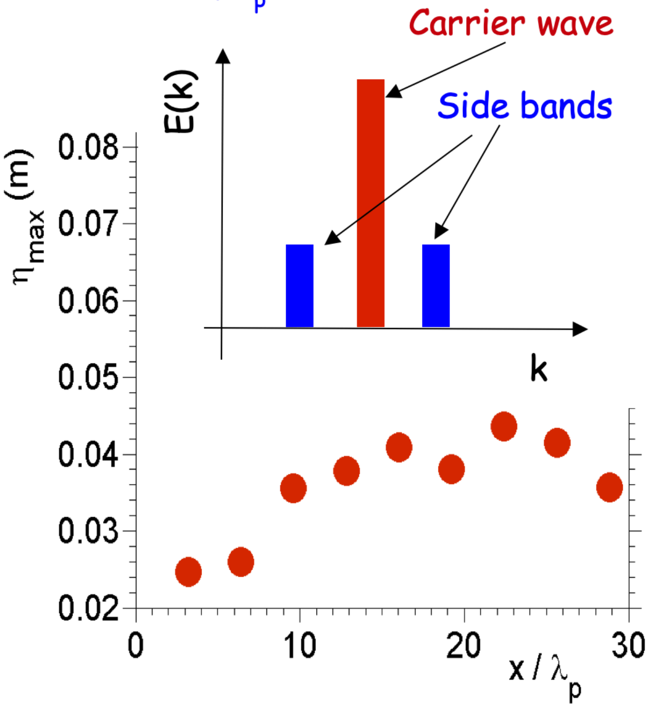
ka = 0.1 (wave steepness)

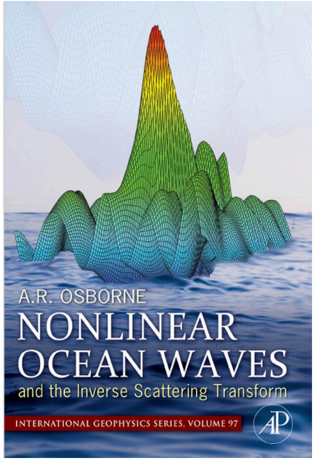
+

TWO PERTURBATIONS:

$\Delta k = 0.20$; $a_p = 0.25a$

$$BFI = \frac{\varepsilon\sqrt{2}}{\Delta k / k}$$

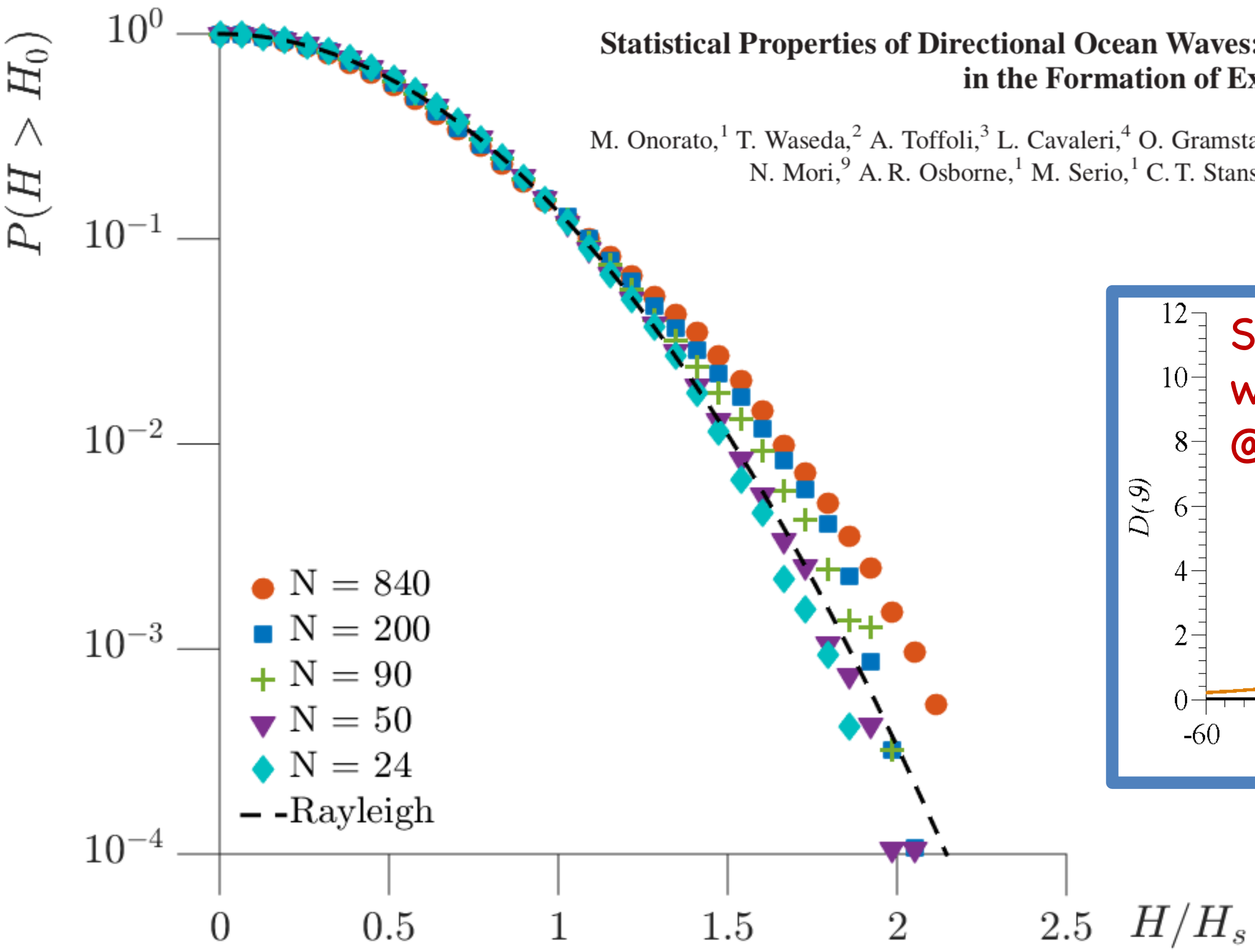


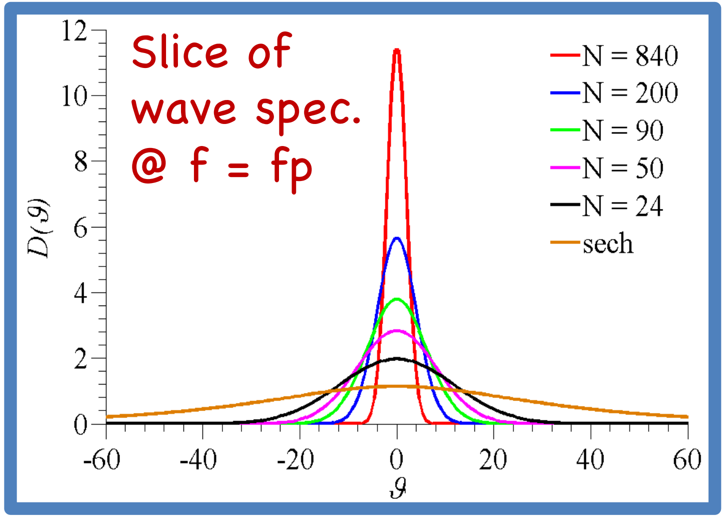


PRL **102,** 114502 (2009) PHYSICAL REVIEW LETTERS week ending 20 MARCH 2009

Statistical Properties of Directional Ocean Waves: The Role of the Modulational Instability in the Formation of Extreme Events

M. Onorato,[1] T. Waseda,[2] A. Toffoli,[3] L. Cavaleri,[4] O. Gramstad,[5] P. A. E. M. Janssen,[6] T. Kinoshita,[7] J. Monbaliu,[8] N. Mori,[9] A. R. Osborne,[1] M. Serio,[1] C. T. Stansberg,[10] H. Tamura,[11] and K. Trulsen[5]

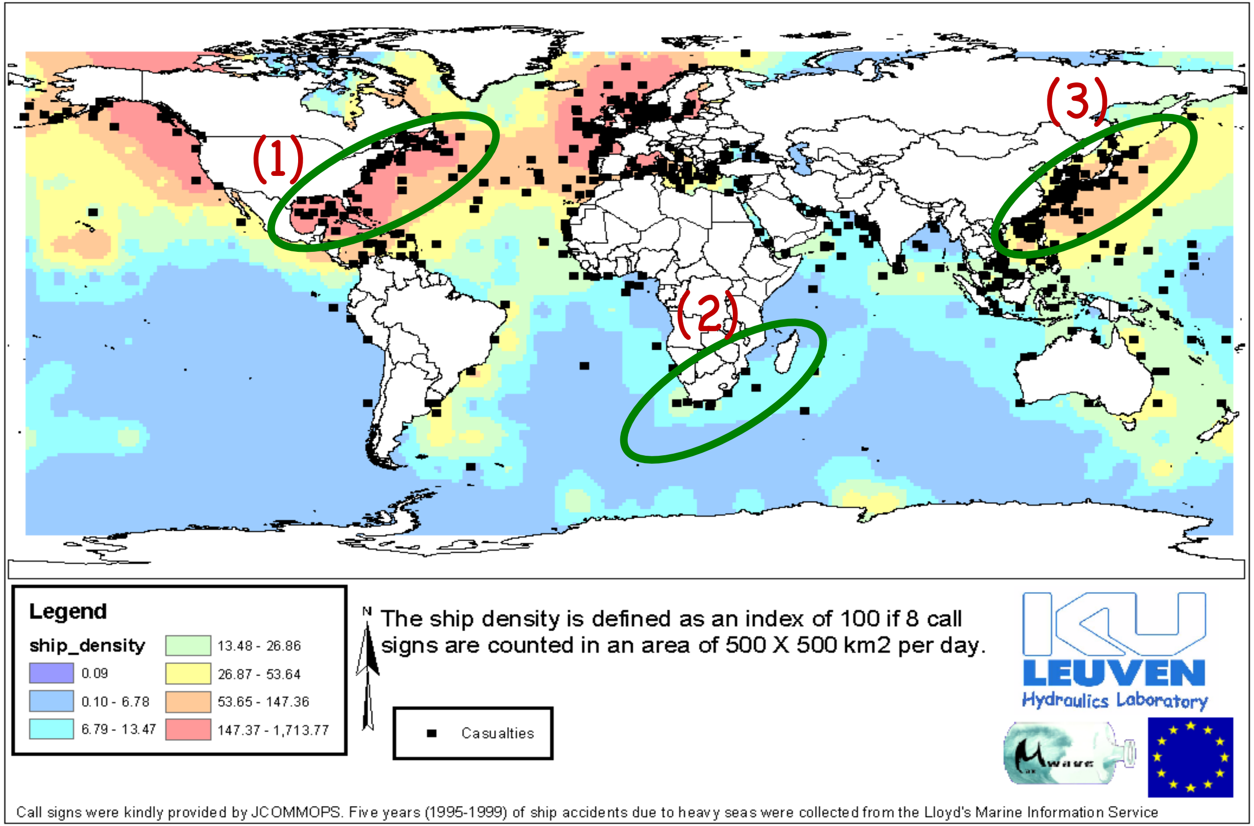




Ship accidents data base

Five years (1995-1999) of ship accidents reported as being due to bad weather conditions (Lloyd's Marine Information Service were analysed) - Toffoli et al. (2005)

(1) Gulf Stream
(2) Agulhas
(3) Kuroshio



Extreme waves in opposing current

Refraction and directional focusing – a linear approach

J. Fluid Mech. (1998), *vol.* 355, *pp.* 113–138. Printed in the United Kingdom 113

On the chance of freak waves at sea

By BENJAMIN S. WHITE[1] AND BENGT FORNBERG[2]

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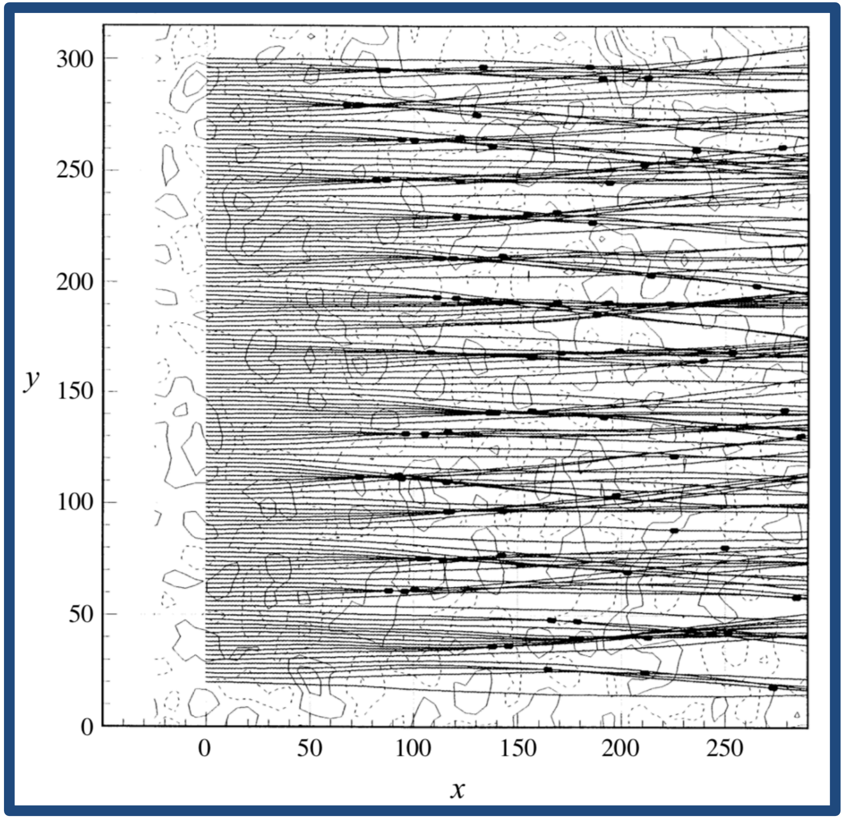
JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 113, C09023, doi:10.1029/2008JC004748, 2008

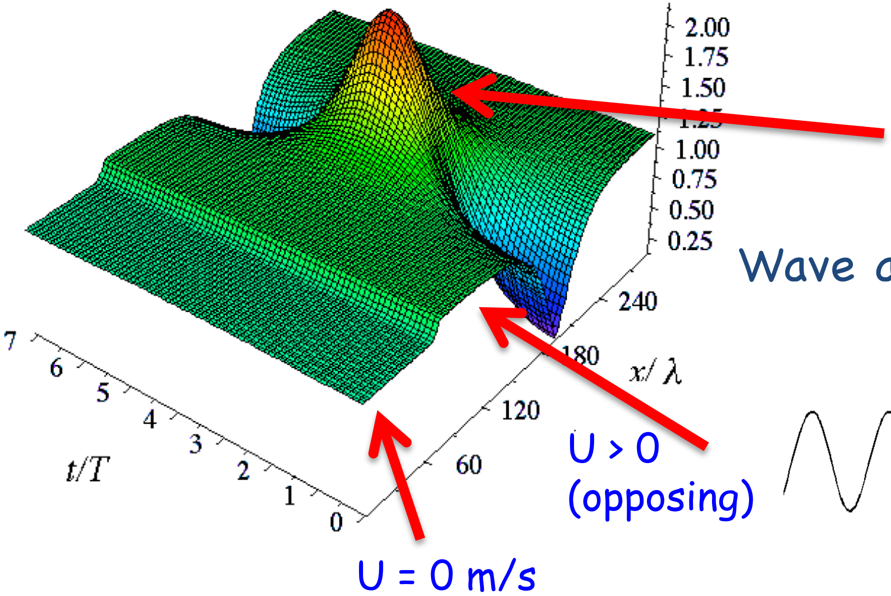
Refraction of a Gaussian seaway

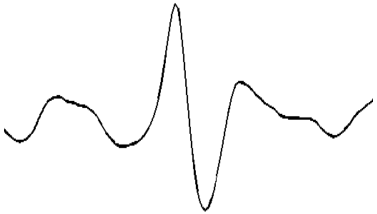
E. J. Heller,[1,2] L. Kaplan,[3] and A. Dahlen[4]



Nonlinear wave dynamics over an opposing current gradient with a current-modified NLS

Few tens of wavelengths from current gradient





Wave are now unstable & freak wave grow

Waves cross a current gradient ΔU and shrink & become steeper

Stable wave train in a region of no current

PRL **107,** 184502 (2011) PHYSICAL REVIEW LETTERS week ending 28 OCTOBER 2011

Triggering Rogue Waves in Opposing Currents

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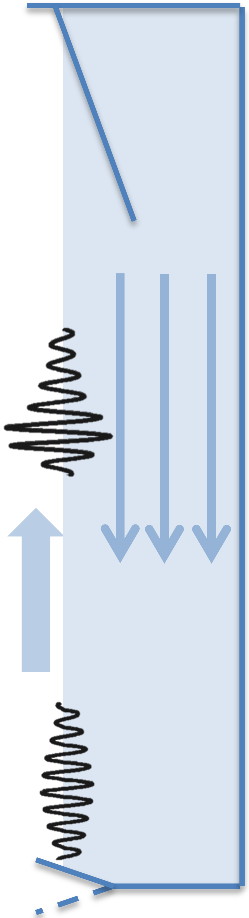
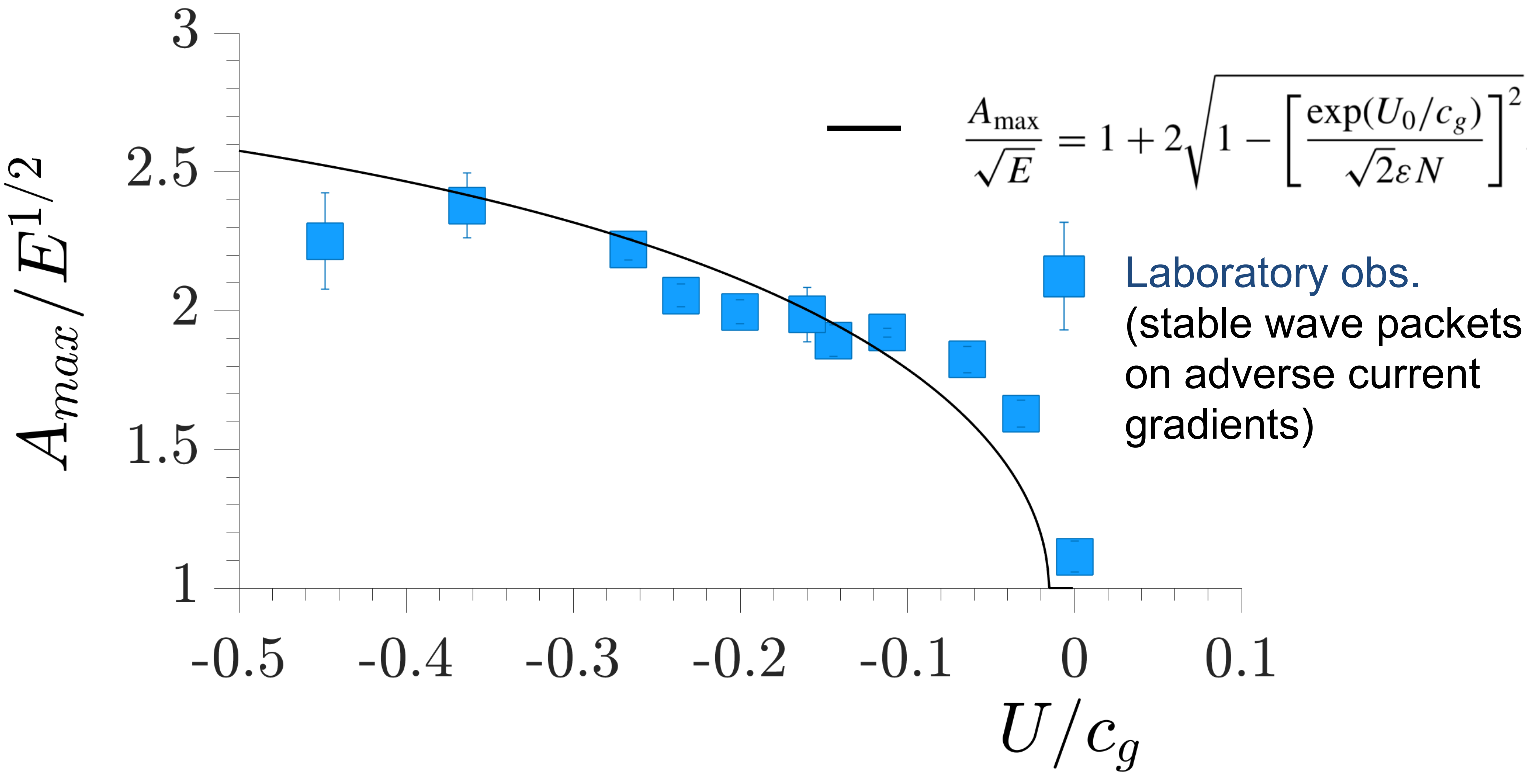
INFN, Sezione di Torino, Via Pietro Giuria 1, 10125 Torino, Italy

PHYSICAL REVIEW E **87**, 051201(R) (2013)

Excitation of rogue waves in a variable medium: An experimental study on the interaction of water waves and currents

A. Toffoli,[1,2] T. Waseda,[3] H. Houtani,[3,4] T. Kinoshita,[5] K. Collins,[2] D. Proment,[6] and M. Onorato[7,8]





Objectives

Can an opposing current gradient trigger nonlinear dynamics in *random* wave fields that would otherwise be stable?

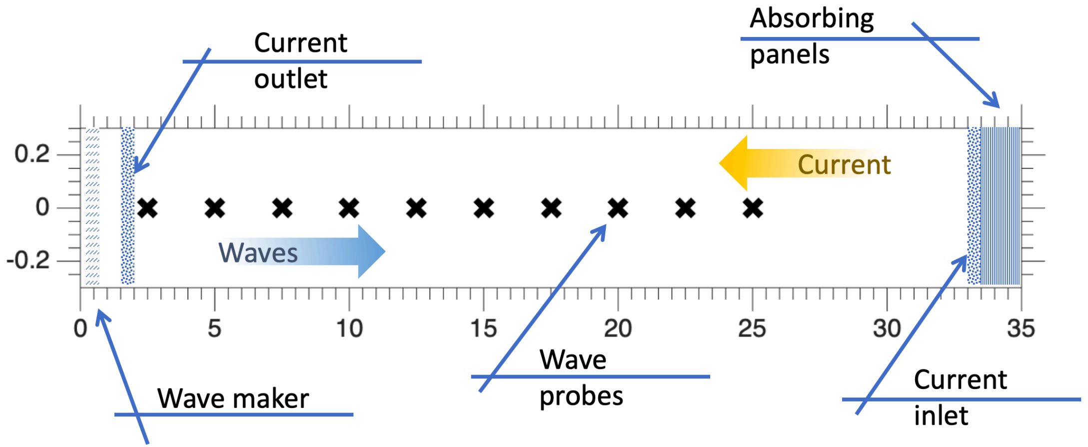
Can the current gradient increase the probability of occurrence for extreme/rogue waves?

Laboratory experiments

J. Fluid Mech. (2015), vol. 769, pp. 277–297. © Cambridge University Press 2015 277
doi:10.1017/jfm.2015.132

Rogue waves in opposing currents: an experimental study on deterministic and stochastic wave trains

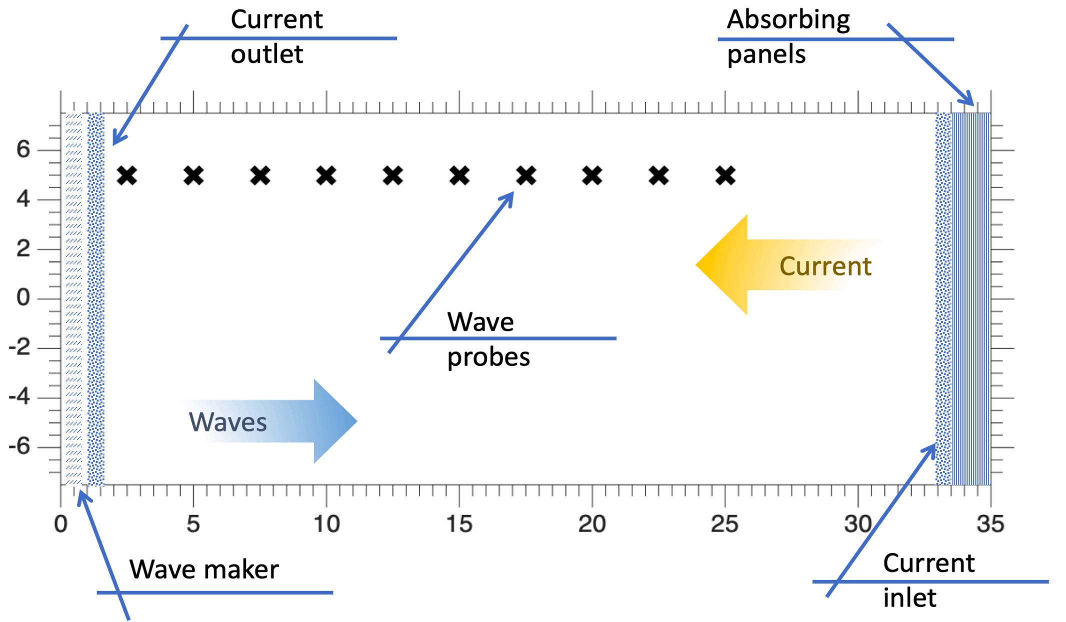
A. Toffoli[1,†], T. Waseda[2], H. Houtani[2,3], L. Cavaleri[4], D. Greaves[5] and M. Onorato[6,7]



Flume:

Tp = 0.8s (Lp = 1m, Cg = 0.63m/s)

Steepness kp Hs / 2 ~ 0.07



Basin:

Tp = 0.7s (Lp = 0.77m, Cg = 0.55m/s)

Steepness kp Hs / 2 ~ 0.07

JONSWAP Spec. with g = 3

BFI ~ 0.5

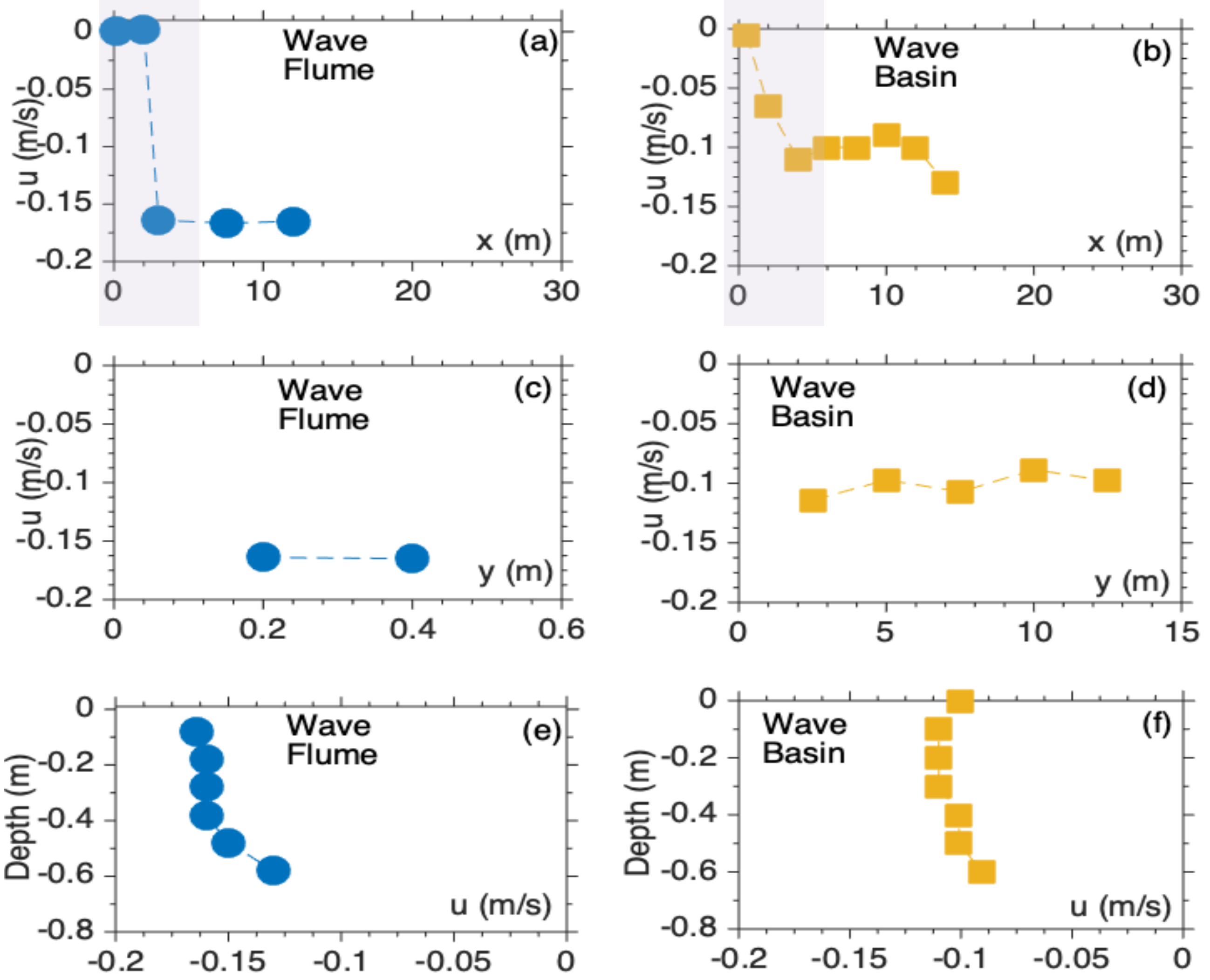
U/cg from -0 to -0.4

Current speed

Along the tank

Cross tank

Vertical profile



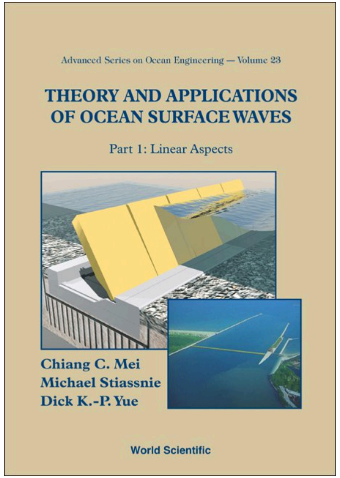
Numerical model

Current modified Euler equation solved with HOS method:

- nonlinearity up to 3rd order &
- horizontal effects of wave-current interaction (increase of steepness)

$$\frac{\partial \eta}{\partial t} = \left(1+|\nabla\eta|^2\right) W_w - \nabla\phi_w^s.\nabla\eta - \mathbf{u_c}.\nabla\eta + w_c \qquad @ \quad z=\eta(\mathbf{x},t)$$

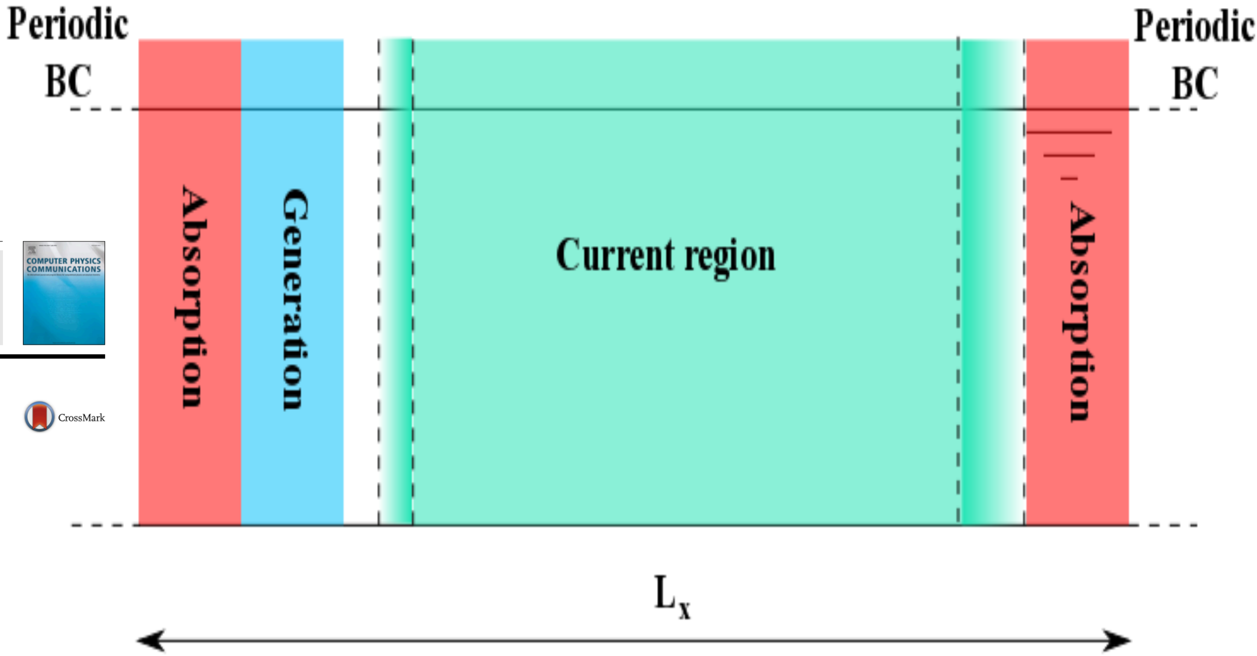
$$\frac{\partial \phi_w^s}{\partial t} = -p_{atm} - g\eta - \frac{1}{2}|\nabla\phi_w^s|^2 + \frac{1}{2}\left(1+|\nabla\eta|^2\right) W_w^2 - \mathbf{u_c}.\nabla\phi_w^s - \frac{1}{2}\left(\mathbf{u_c}.\mathbf{u_c} + w_c^2\right) \qquad @ \quad z=\eta(\mathbf{x},t)$$



Numerical wave tank

Current modified Euler equation solved with HOS method:

- nonlinearity up to 3rd order &
- horizontal effects of wave-current interaction (increase of steepness)



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journal homepage: www.elsevier.com/locate/cpc

HOS-ocean: Open-source solver for nonlinear waves in open ocean based on High-Order Spectral method☆

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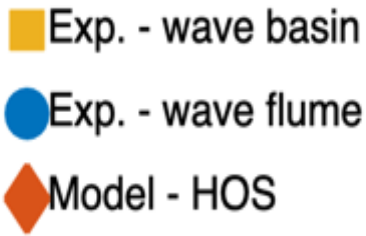
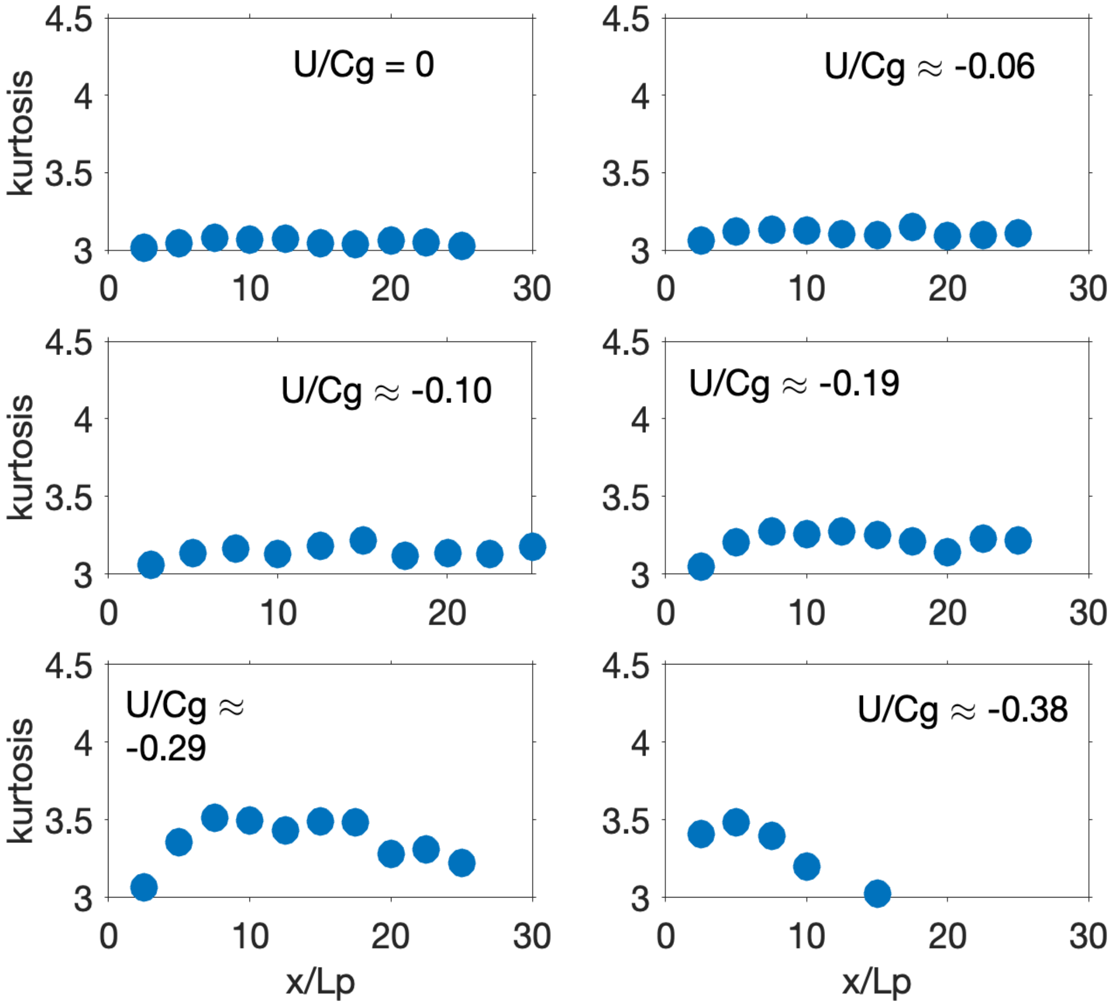
Numerical & Experimental Tests

- Numerical and experimental tests ran with the same initial/input conditions
- 4 X 20 minutes times series with different random amplitudes and phases

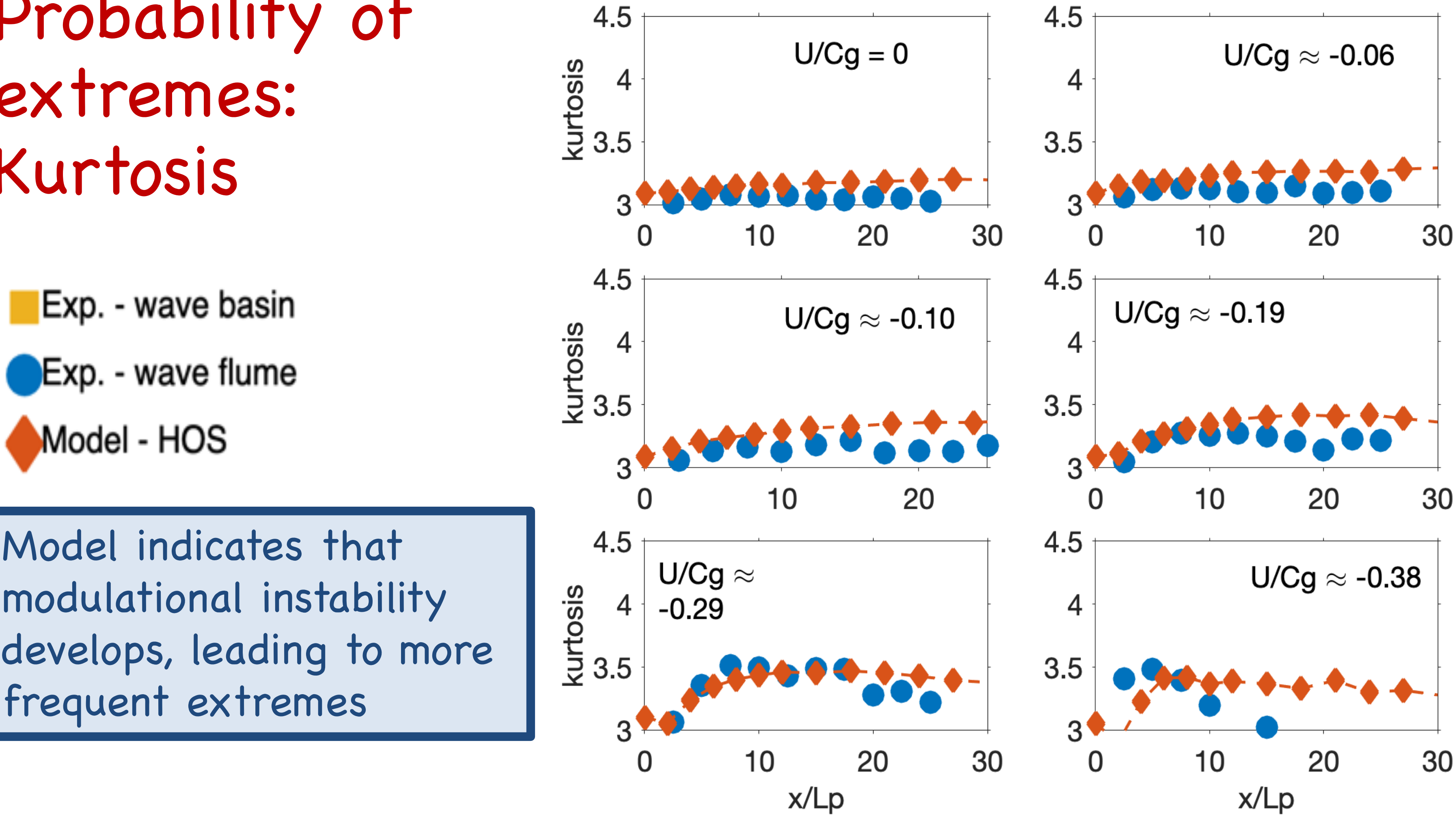
Probability of extremes: Kurtosis



A stable irregular wave fields switch into an unstable system

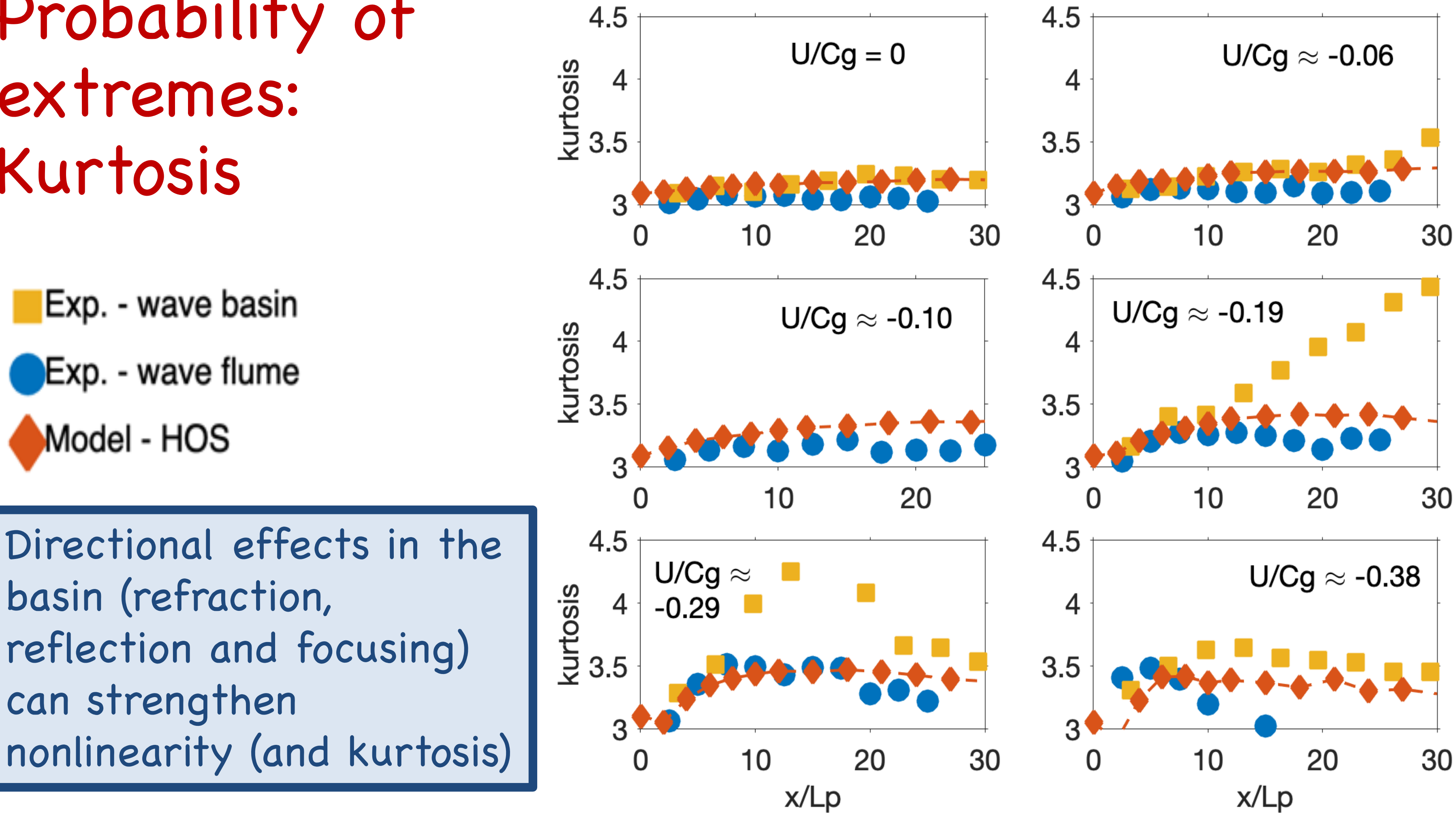


Probability of extremes: Kurtosis



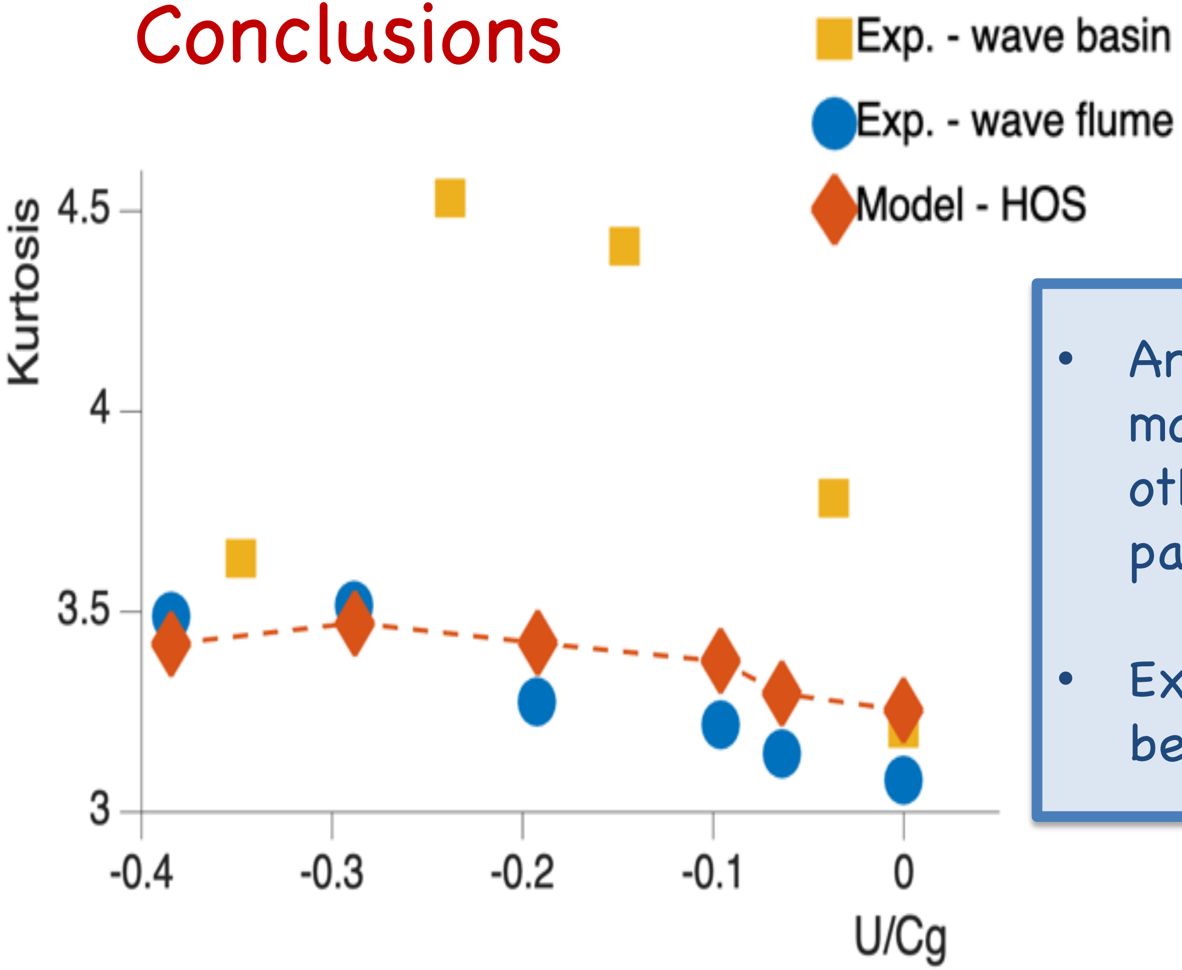
Model indicates that modulational instability develops, leading to more frequent extremes

Probability of extremes: Kurtosis



Directional effects in the basin (refraction, reflection and focusing) can strengthen nonlinearity (and kurtosis)

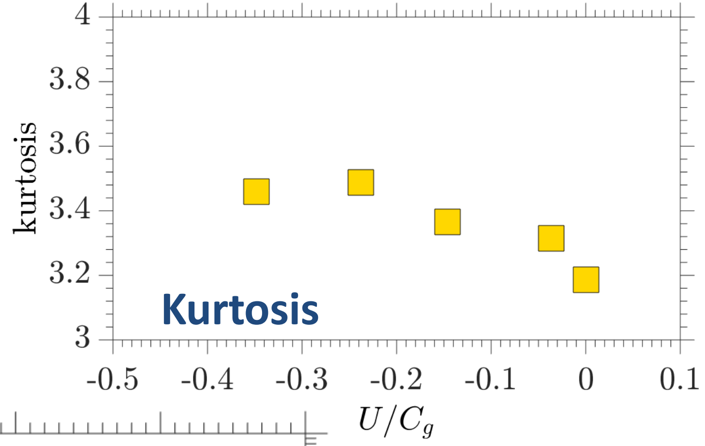
Conclusions



- An opposing current triggers modulational instability of otherwise stable wave packets

- Extreme (rogue) waves becomes more likely

Directional wave fields



Wave Height Distribution