

Nonlinear wave group shoaling

Amin Chabchoub

Centre for Wind, Waves and Water - School of Civil Engineering

`amin.chabchoub@sydney.edu.au`

2nd International Workshop on Waves, Storm Surges and Coastal Hazards

Melbourne, 14.11.2019

Collaborative work with

- Olivier Kimmoun, *Aix Marseille University*
- Hungchu Hsu, *Tainan Hydraulics Laboratory*
- Stefano Trillo, *University of Ferrara*

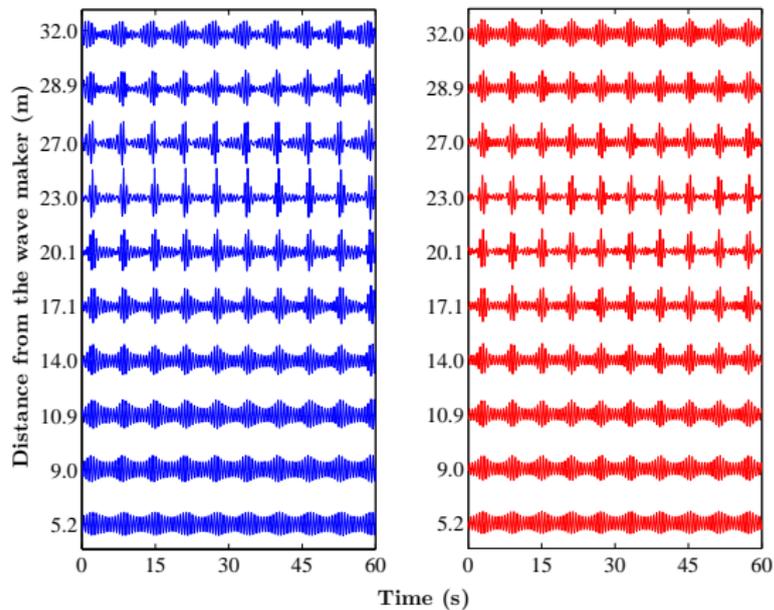






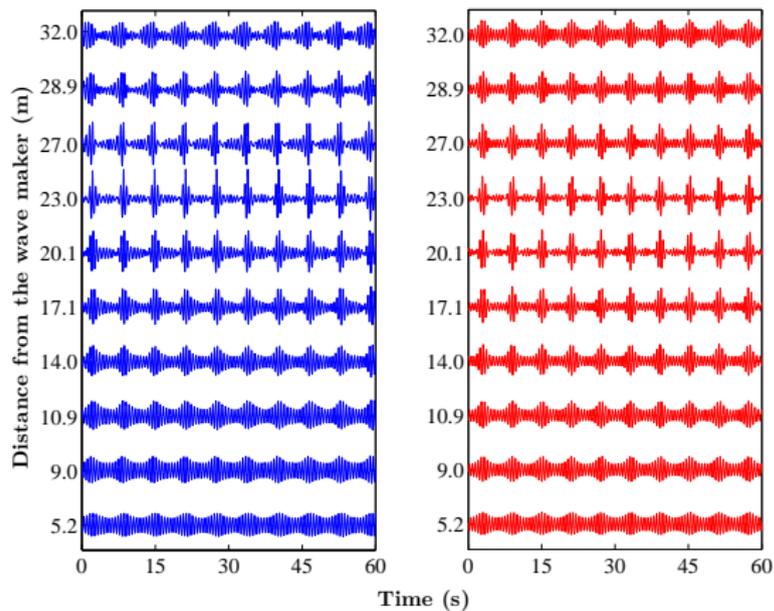
J. M. Dudley, G. Genty, A. Mussot, A. Chabchoub and F. Dias, Rogue waves and analogies in optics and oceanography, *Nat. Rev. Phys.* **1**, 675-689 (2019)

Modulation instability



Modulation instability

$$a = 1 \text{ cm}$$
$$ak = 0.10$$



Modulation instability

$$i \left(\frac{\partial A}{\partial x} + \frac{1}{C_g} \frac{\partial A}{\partial t} \right) = +\lambda \frac{\partial^2 A}{\partial t^2} + \nu |A|^2 A$$

$$\lambda = \frac{1}{2C_g \omega_0} \left[1 - \frac{gh}{C_g^2} (1 - kh\sigma) (1 - \sigma^2) \right]$$

$$\nu = \frac{\omega_0 k^2}{16C_g \sigma^2} \times$$

$$\left[9 - 10\sigma^2 + 9\sigma^4 - \frac{2C_g^2 \sigma^2}{gh - C_g^2} \left(4 \frac{C_p^2}{C_g^2} + 4 \frac{C_p}{C_g} (1 - \sigma^2) + 4 \frac{gh}{C_g^2} (1 - \sigma^2) \right) \right]$$

H. Hasimoto and H. Ono, *J. Phys. Soc. Jpn.* **33** (1972)

Laboratory observations of wave group evolution, including breaking effects

By MARSHALL P. TULIN AND TAKUJI WASEDA†

Ocean Engineering Laboratory, University of California Santa Barbara, CA93106

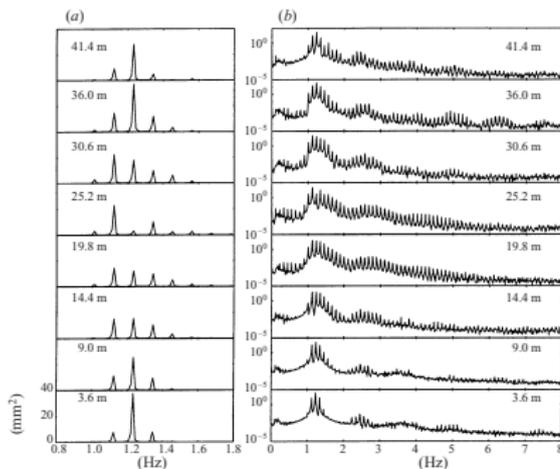
(Received 17 October 1997 and in revised form 11 August 1998)

Laboratory observations of wave group evolution, including breaking effects

By MARSHALL P. TULIN AND TAKUJI WASEDA†

Ocean Engineering Laboratory, University of California Santa Barbara, CA93106

(Received 17 October 1997 and in revised form 11 August 1998)



Feature Article:

DOI. No. 10.1109/MAES.2017.170062

OTH Radar Phenomenology: Signal Interpretation and Target Characterization at HF

Stuart Anderson, University of Adelaide, Adelaide, Australia

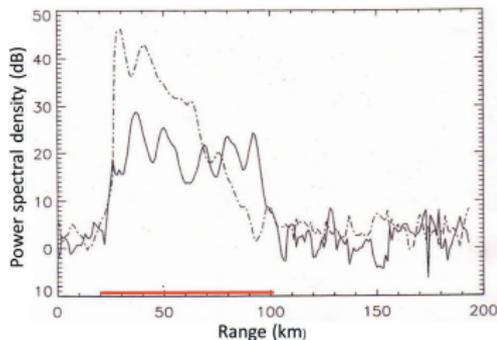
Modulation instability

Feature Article:

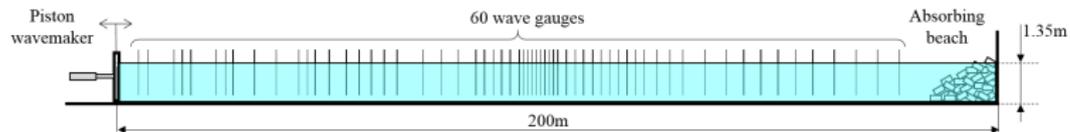
DOI: No. 10.1109/MAES.2017.170062

OTH Radar Phenomenology: Signal Interpretation and Target Characterization at HF

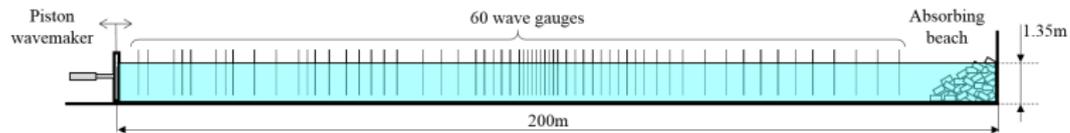
Stuart Anderson, University of Adelaide, Adelaide, Australia



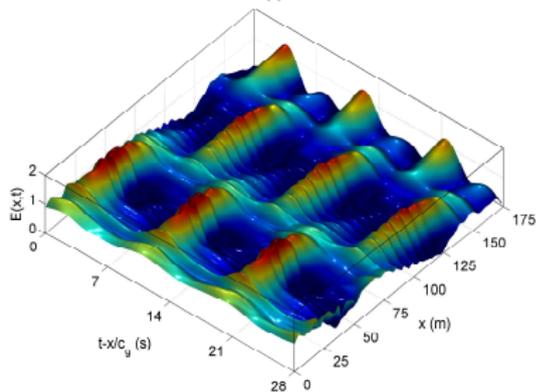
Modulation instability



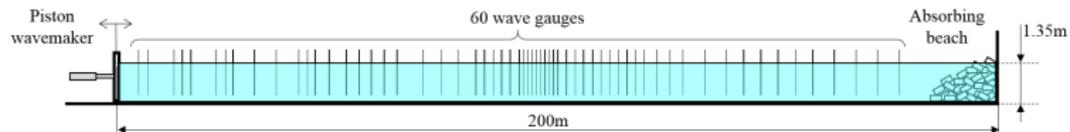
Modulation instability



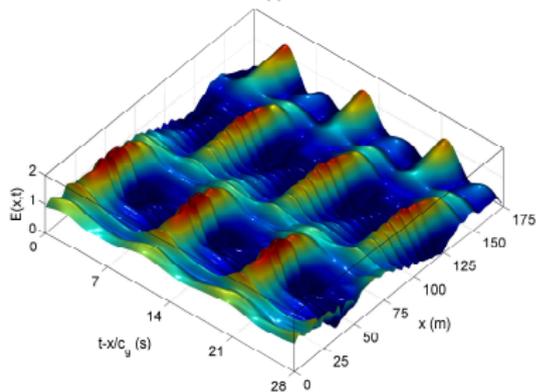
(a)



Modulation instability

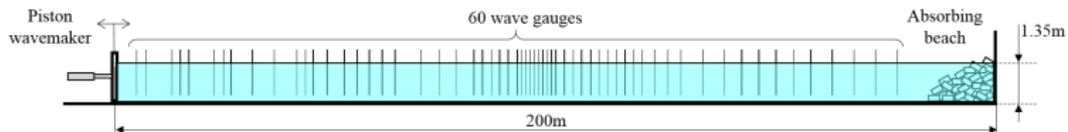


(a)

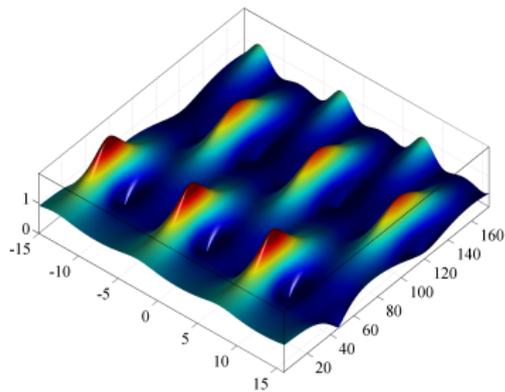
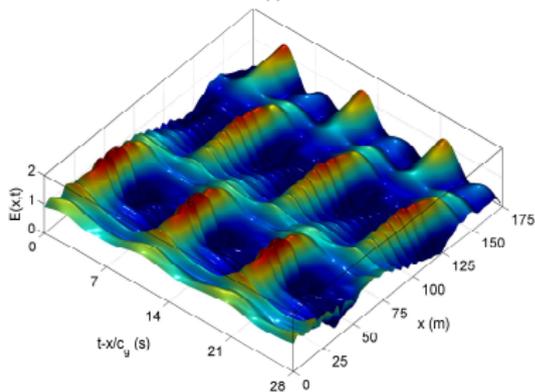


$$iq_x + q_{tt} + 2|q|^2q = iDq$$

Modulation instability

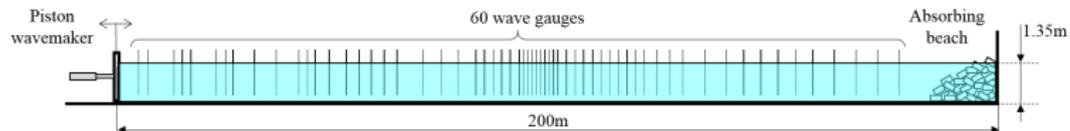


(a)

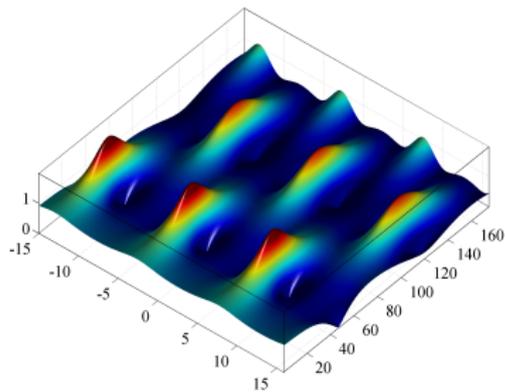
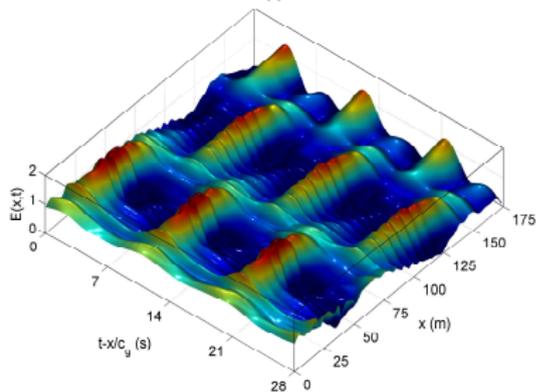


$$iq_x + q_{tt} + 2|q|^2q = iDq$$

Modulation instability



(a)



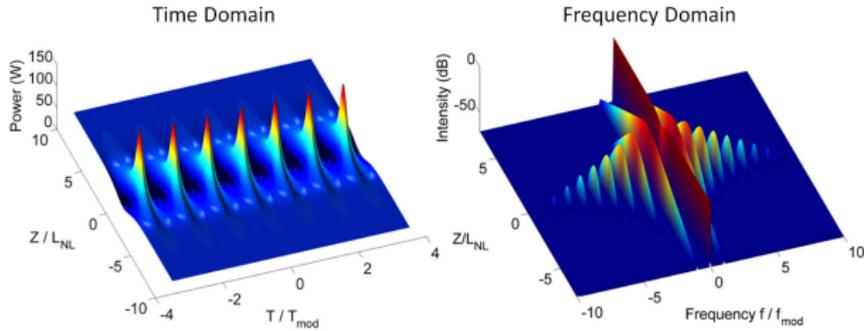
SCIENTIFIC REPORTS

OPEN Modulation Instability and Phase-Shifted Fermi-Pasta-Ulam Recurrence

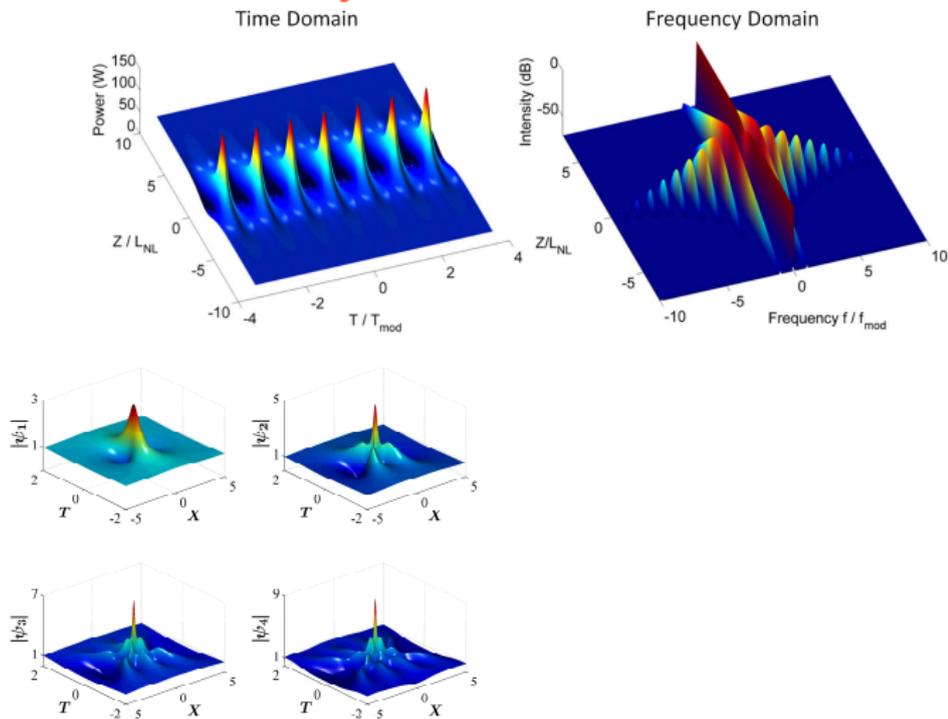
Received: 13 March 2018
Accepted: 20 May 2018
O. Kimmoun¹, H. C. Hsu², H. Branger², M. S. Uj¹, Y. Y. Chen¹, C. Kharif¹, M. Onorato¹, E. J. R. Keebler³, B. Kibler³, N. Akhmediev⁴ & A. Chabchoub^{1,4}

$$iq_x + q_{tt} + 2|q|^2q = iDq$$

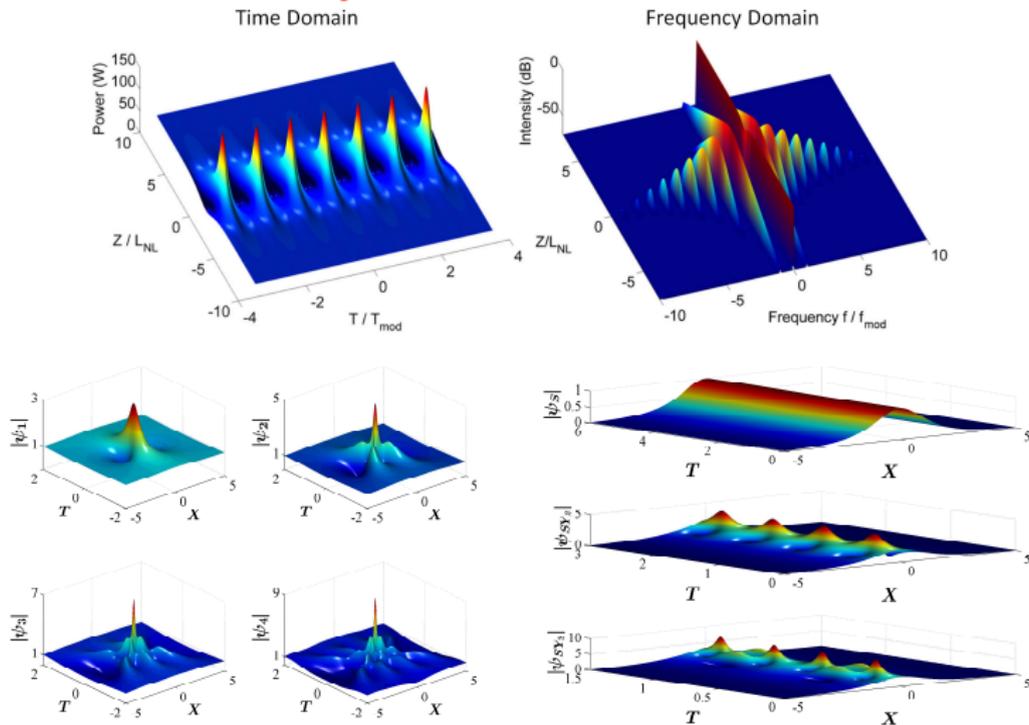
Modulation instability



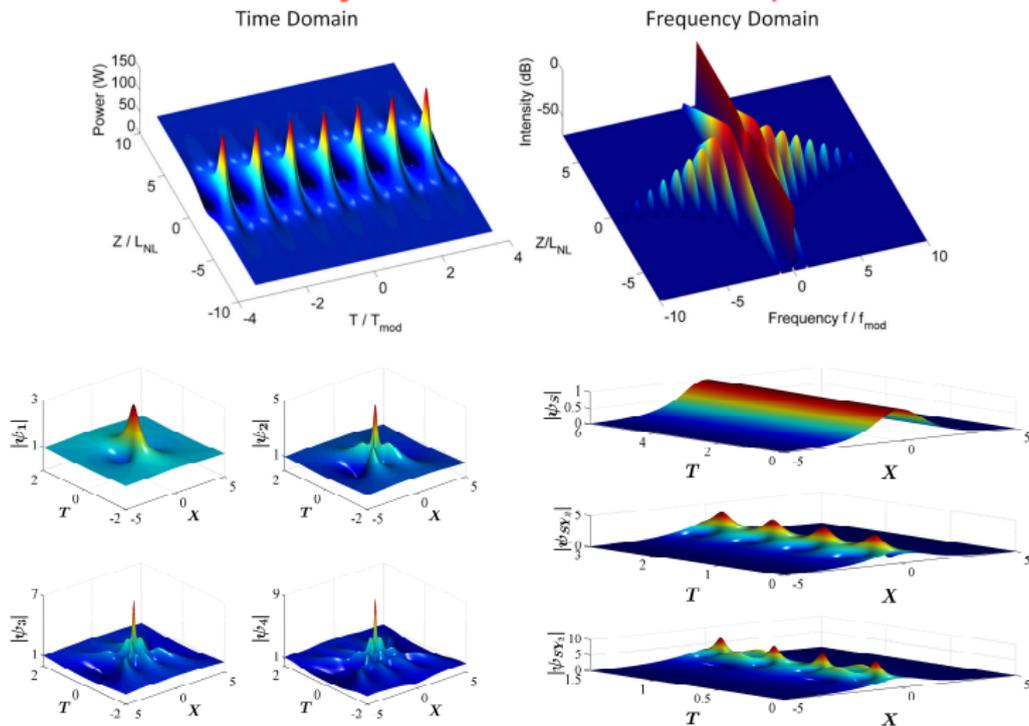
Modulation instability



Modulation instability



Modulation instability - Nonlinear wave packet interaction



Modulation instability - Nonlinear wave packet interaction

*Proceedings of the Twenty-seventh (2017) International Ocean and Polar Engineering Conference
San Francisco, CA, USA, June 25-30, 2017
Copyright © 2017 by the International Society of Offshore and Polar Engineers (ISOPE)
ISBN 978-1-880653-97-5; ISSN 1098-6189*

www.isopec.org

Experiments on Spontaneous Modulation Instability in Hydrodynamics

Amin Chabchoub^{1,2,3}, Goëry Genty⁴, John M. Dudley⁵, Bertrand Kibler⁶ and Takuji Waseda²

¹Department of Mechanical Engineering, Aalto University, Espoo, Finland

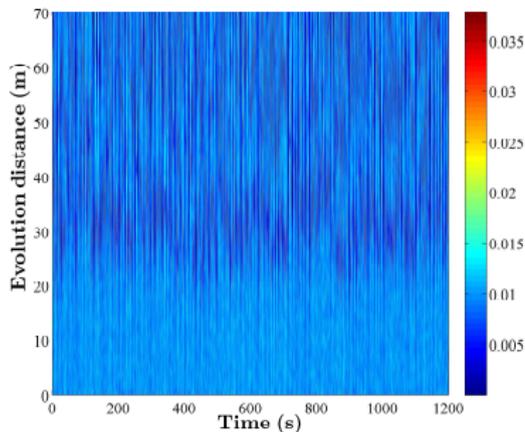
²Graduate School of Frontier Sciences, The University of Tokyo, Chiba, Japan

³School of Civil Engineering, The University of Sydney, Sydney, NSW, Australia

⁴Department of Physics, Tampere University of Technology, Tampere, Finland

⁵Institut FEMTO-ST, UMR 6174 CNRS-Universit  de Franche-Comit e, Besan on, France

⁶Laboratoire ICB, UMR 6303 CNRS - Universit  Bourgogne Franche-Comit e, Dijon, France



Modulation instability - Nonlinear wave packet interaction

Proceedings of the Twenty-seventh (2017) International Ocean and Polar Engineering Conference
San Francisco, CA, USA, June 25-30, 2017
Copyright © 2017 by the International Society of Offshore and Polar Engineers (ISOPE)
ISBN 978-1-880653-97-5; ISSN 1098-6189

www.isopec.org

Experiments on Spontaneous Modulation Instability in Hydrodynamics

Amin Chabchoub^{1,2,3}, Goëry Genty⁴, John M. Dudley⁵, Bertrand Kibler⁶ and Takuji Waseda²

¹Department of Mechanical Engineering, Aalto University, Espoo, Finland

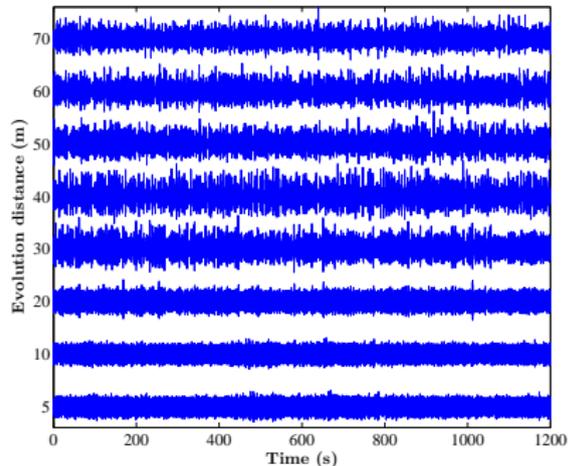
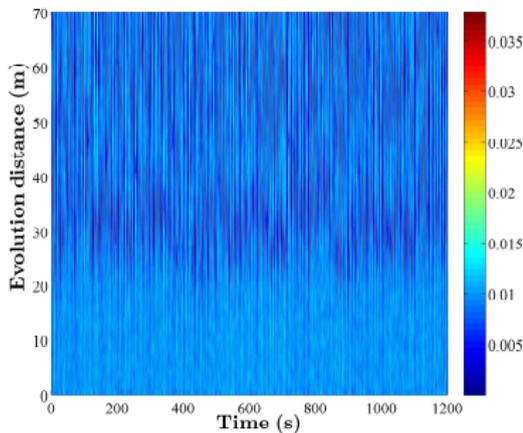
²Graduate School of Frontier Sciences, The University of Tokyo, Chiba, Japan

³School of Civil Engineering, The University of Sydney, Sydney, NSW, Australia

⁴Department of Physics, Tampere University of Technology, Tampere, Finland

⁵Institut FEMTO-ST, UMR 6174 CNRS-Universit  de Franche-Comit e, Besan on, France

⁶Laboratoire ICB, UMR 6303 CNRS - Universit  Bourgogne Franche-Comit e, Dijon, France



Modulation instability - Nonlinear wave packet interaction

BREAKING OF OCEAN WAVES AND DOWNSHIFTING

MARSHALL P. TULIN
Ocean Engineering Laboratory
University of California, Santa Barbara

Modulation instability - Nonlinear wave packet interaction

BREAKING OF OCEAN WAVES AND DOWNSHIFTING

MARSHALL P. TULIN
Ocean Engineering Laboratory
University of California, Santa Barbara

178

MARSHALL P. TULIN

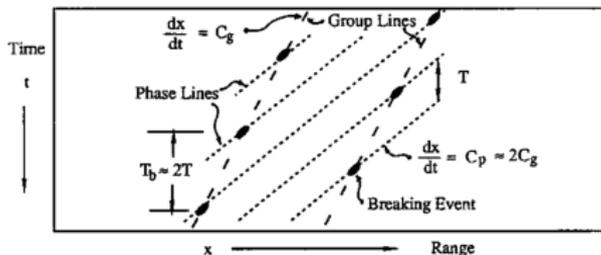
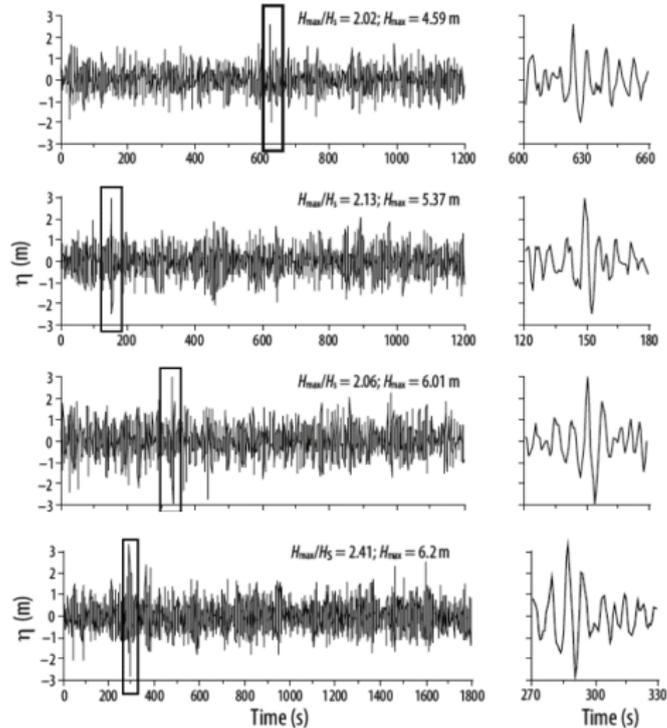
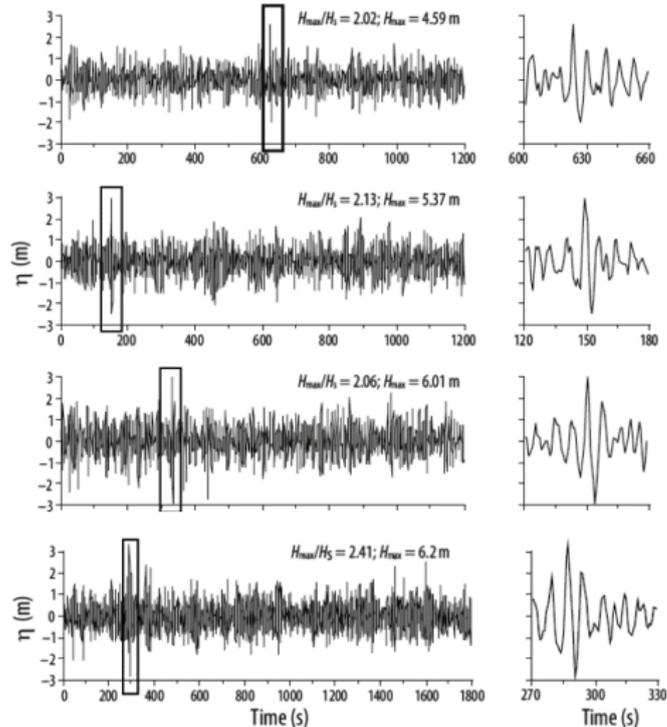


Figure 1: Wave groups delineated by breaking events.
Schematic of low grazing radar observations.

Nonlinear wave group shoaling



Nonlinear wave group shoaling

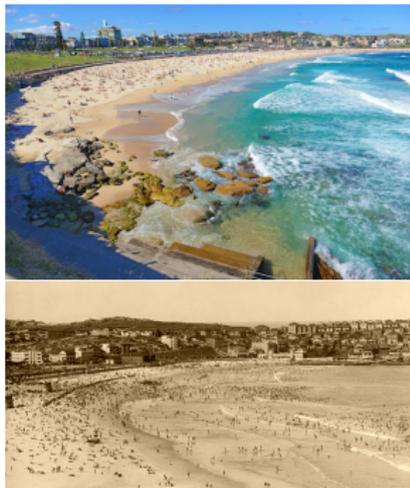


W. Sulisz et al., Cienc. mar. 42 (2016)

Nonlinear wave group shoaling



Nonlinear wave group shoaling



Nonlinear wave group shoaling



Nonlinear wave group shoaling

$$i \left(\frac{\partial A}{\partial x} + \frac{1}{C_g} \frac{\partial A}{\partial t} \right) = -i \mu \frac{d(kh)}{dx} A + \lambda \frac{\partial^2 A}{\partial t^2} + \nu |A|^2 A + i \frac{\sigma}{C_g} A$$

$$\mu = \frac{(1 - \sigma^2)(1 - kh\sigma)}{\sigma + kh(1 - \sigma^2)},$$

$$\lambda = \frac{1}{2C_g\omega_0} \left[1 - \frac{gh}{C_g^2} (1 - kh\sigma)(1 - \sigma^2) \right]$$

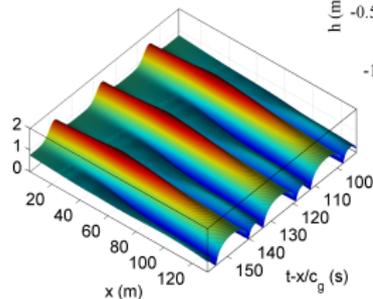
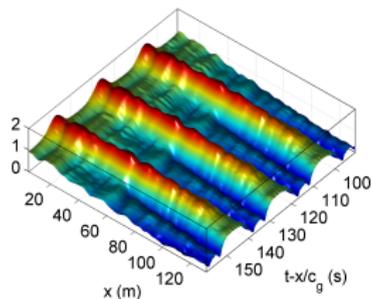
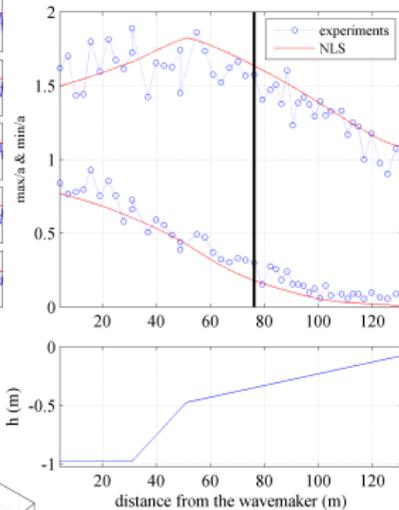
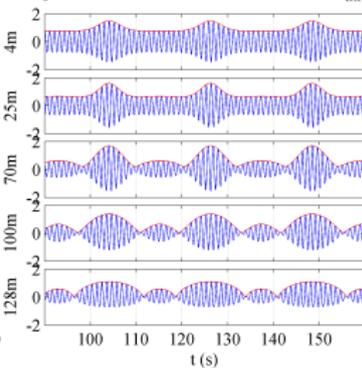
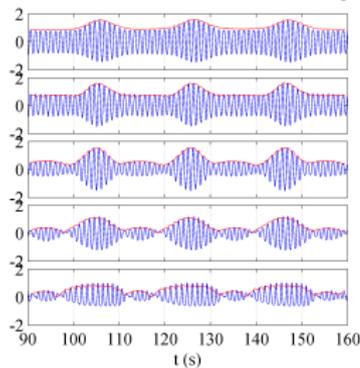
$$\nu = \frac{\omega_0 k^2}{16C_g \sigma^2} \times$$

$$\left[9 - 10\sigma^2 + 9\sigma^4 - \frac{2C_g^2 \sigma^2}{gh - C_g^2} \left(4 \frac{C_p^2}{C_g^2} + 4 \frac{C_p}{C_g} (1 - \sigma^2) + 4 \frac{gh}{C_g^2} (1 - \sigma^2) \right) \right]$$

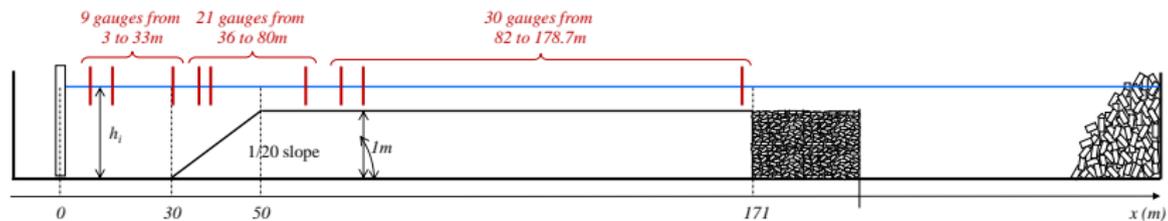
V. D. Djordjevic and L. G. Redekopp, *J. Phys. Oceanogr.* **8** (1978)

Nonlinear wave group shoaling

$kh_0=3.3$, $a_0k=0.08$, $T=1.085\text{s}$, $a=0.35$, $x_f=76\text{m}$, $x_{\text{threshold}}=76\text{m}$

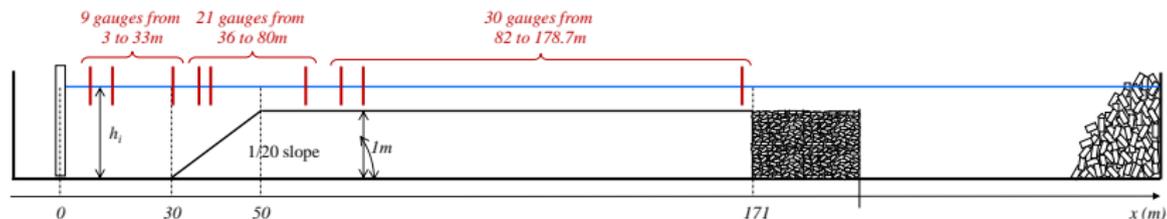


Nonlinear wave group shoaling



Nonlinear wave group shoaling

Unstable wave dynamics over variable bottom topography





Article

Statistics of Extreme Waves in Coastal Waters: Large Scale Experiments and Advanced Numerical Simulations

Jie Zhang ^{1,2}, Michel Benoit ^{1,2,*} , Olivier Kimmoun ^{1,2}, Amin Chabchoub ^{3,4} and Hung-Chu Hsu ⁵

¹ École Centrale Marseille, 13013 Marseille, France; zhang@irphe.univ-mrs.fr (J.Z.); olivier.kimmoun@centrale-marseille.fr (O.K.)

² Aix Marseille Univ, CNRS, Centrale Marseille, IRPHE UMR 7342, 13013 Marseille, France

³ Centre for Wind, Waves and Water, School of Civil Engineering, The University of Sydney, Sydney, NSW 2006, Australia; amin.chabchoub@sydney.edu.au

⁴ Marine Studies Institute, The University of Sydney, Sydney, NSW 2006, Australia

⁵ Department of Marine Environment and Engineering, National Sun Yat-Sen University, Kaohsiung 80424, Taiwan; hchsu@mail.nsysu.edu.tw

* Correspondence: benoit@irphe.univ-mrs.fr

Received: 7 February 2019; Accepted: 20 May 2019; Published: 29 May 2019





Article

Statistics of Extreme Waves in Coastal Waters: Large Scale Experiments and Advanced Numerical Simulations

Jie Zhang ^{1,2}, Michel Benoit ^{1,2,*} , Olivier Kimmoun ^{1,2}, Amin Chabchoub ^{3,4} and Hung-Chu Hsu ⁵

¹ École Centrale Marseille, 13013 Marseille, France; zhang@irphe.univ-mrs.fr (J.Z.); olivier.kimmoun@centrale-marseille.fr (O.K.)

² Aix Marseille Univ, CNRS, Centrale Marseille, IRPHE UMR 7342, 13013 Marseille, France

³ Centre for Wind, Waves and Water, School of Civil Engineering, The University of Sydney, Sydney, NSW 2006, Australia; amin.chabchoub@sydney.edu.au

⁴ Marine Studies Institute, The University of Sydney, Sydney, NSW 2006, Australia

⁵ Department of Marine Environment and Engineering, National Sun Yat-Sen University, Kaohsiung 80424, Taiwan; hchsu@mail.nsysu.edu.tw

* Correspondence: benoit@irphe.univ-mrs.fr

Received: 7 February 2019; Accepted: 20 May 2019; Published: 29 May 2019



H. B. Bingham et al. *Coast. Eng.*, **56**, 467-478 (2009)



Article

Statistics of Extreme Waves in Coastal Waters: Large Scale Experiments and Advanced Numerical Simulations

Jie Zhang ^{1,2}, Michel Benoit ^{1,2,*} , Olivier Kimmoun ^{1,2}, Amin Chabchoub ^{3,4} and Hung-Chu Hsu ⁵

¹ École Centrale Marseille, 13013 Marseille, France; zhang@irphe.univ-mrs.fr (J.Z.); olivier.kimmoun@centrale-marseille.fr (O.K.)

² Aix Marseille Univ, CNRS, Centrale Marseille, IRPHE UMR 7342, 13013 Marseille, France

³ Centre for Wind, Waves and Water, School of Civil Engineering, The University of Sydney, Sydney, NSW 2006, Australia; amin.chabchoub@sydney.edu.au

⁴ Marine Studies Institute, The University of Sydney, Sydney, NSW 2006, Australia

⁵ Department of Marine Environment and Engineering, National Sun Yat-Sen University, Kaohsiung 80424, Taiwan; hchsu@mail.nsysu.edu.tw

* Correspondence: benoit@irphe.univ-mrs.fr

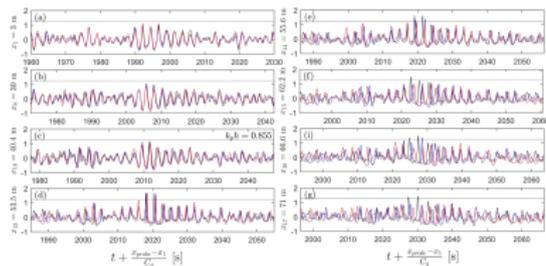
Received: 7 February 2019; Accepted: 20 May 2019; Published: 29 May 2019



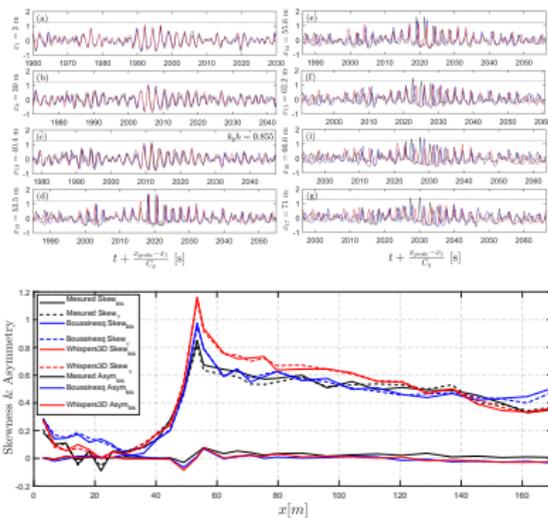
H. B. Bingham et al. *Coast. Eng.*, **56**, 467-478 (2009)

M. L. Yates et al., *Int. J. Numer. Methods Fluids*, **77**, 616-640 (2015)

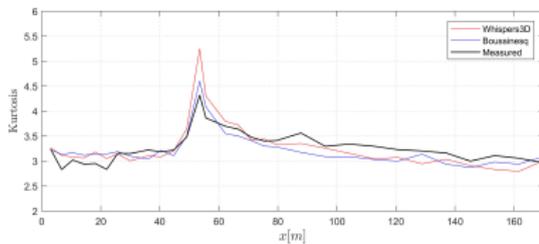
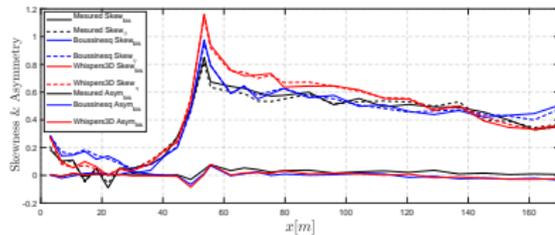
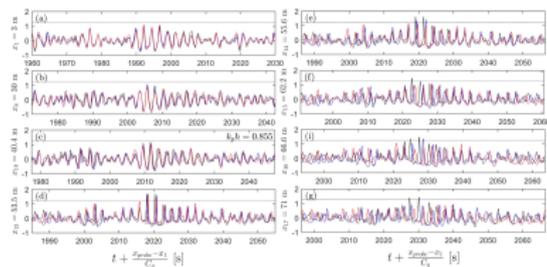
Nonlinear wave group shoaling



Nonlinear wave group shoaling



Nonlinear wave group shoaling



Thank you! Questions?

