

# Nonlinear wave group shoaling

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2<sup>nd</sup> 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*



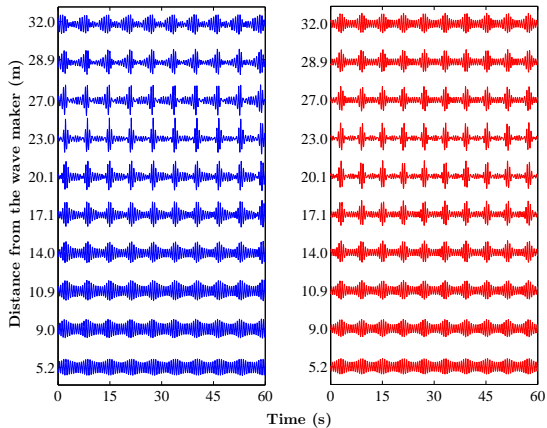






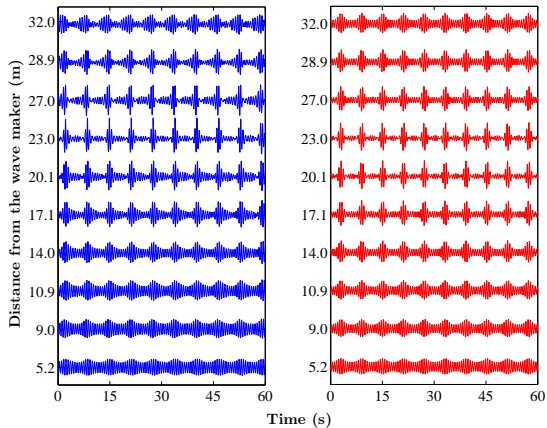
J. M. Dudley, G. Genty, A. Mussot, A. Chabchoub and F. Dias, Rogue waves and analogies in optics and oceanography, *Nat. Rev. Phys.* **1**, 675-689 (2019)

# 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)

*J. Fluid Mech.* (1999), vol. 378, pp. 197–232. Printed in the United Kingdom  
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## 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

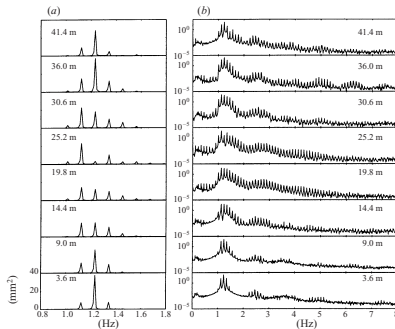
(Received 17 October 1997 and in revised form 11 August 1998)

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*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*

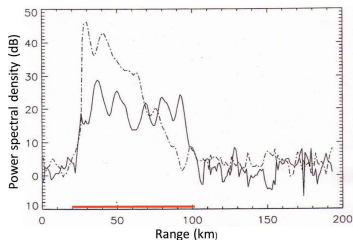
# Modulation instability

*Feature Article:*

DOI. No. 10.1109/MAES.2017.170062

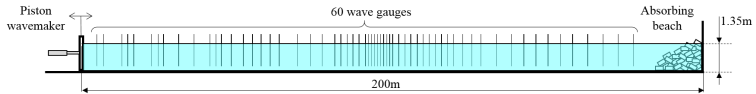
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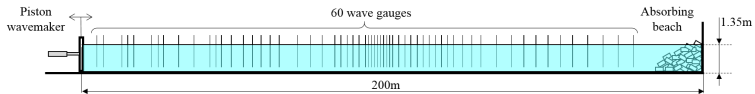




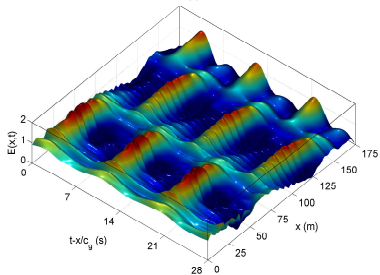
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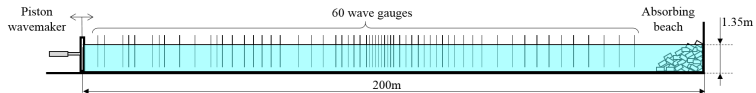
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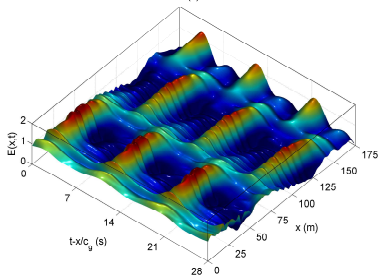
(a)



# Modulation instability

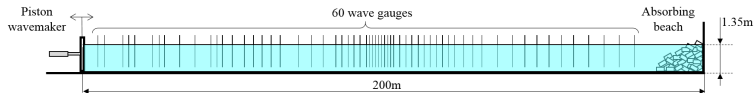


(a)

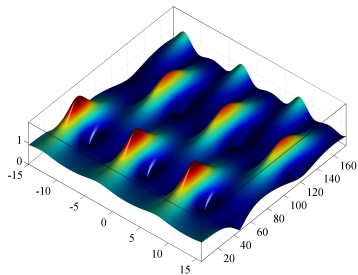
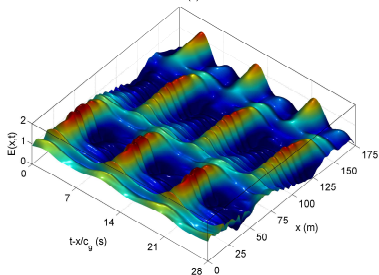


$$iq_x + q_{tt} + 2|q|^2q = iDq$$

# Modulation instability

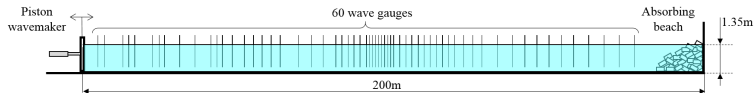


(a)

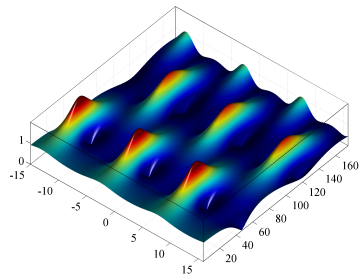
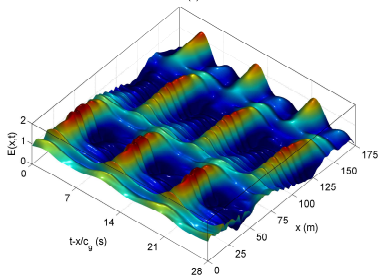


$$iq_x + q_{tt} + 2|q|^2q = iDq$$

# Modulation instability



(a)



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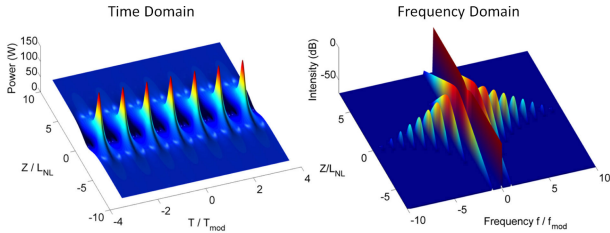
**Modulation Instability and Phase-Shifted Fermi-Pasta-Ulam Recurrence**

Received: 11 March 2018  
Accepted: 20 May 2018

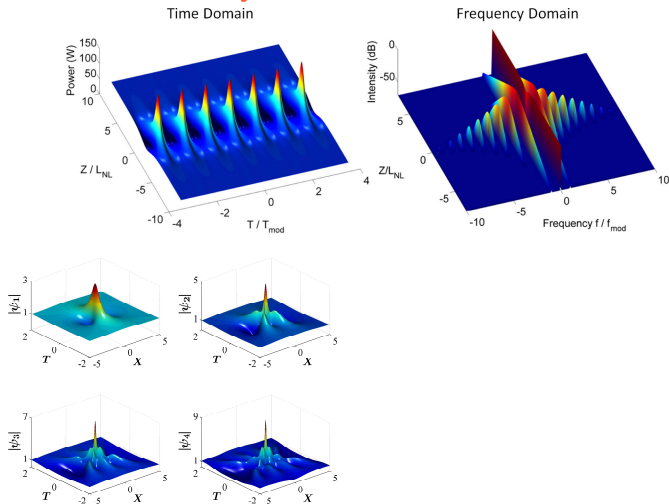
O. Kimmoun<sup>1</sup>, H. C. Hsu<sup>2</sup>, H. Branger<sup>2</sup>, M. S. U<sup>3</sup>, V. Y. Chen<sup>2</sup>, C. Khelif<sup>4</sup>, M. Onorato<sup>1</sup>,  
E. J. R. Kelleher<sup>5</sup>, B. Kibler<sup>6</sup>, N. Akhmediev<sup>7</sup> & A. Chabchoub<sup>1,4</sup>

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

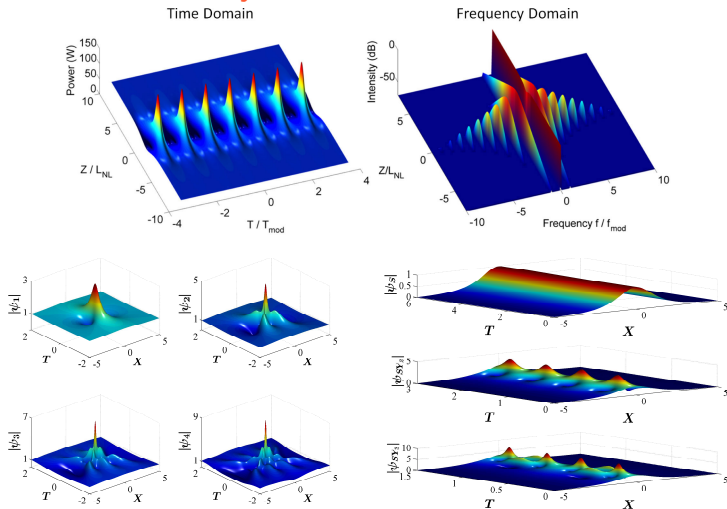
# Modulation instability



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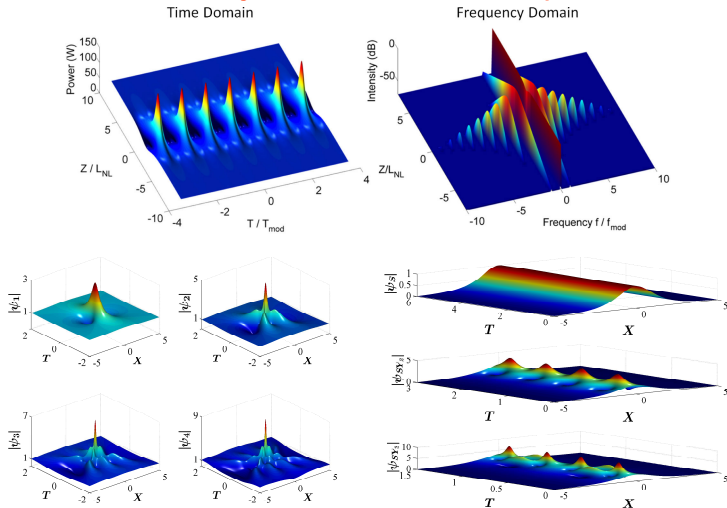


# Modulation instability





# Modulation instability - Nonlinear wave packet interaction



# Modulation instability - Nonlinear wave packet interaction

*Proceedings of the Twenty-seventh (2017) International Ocean and Polar Engineering Conference  
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ISBN 978-1-880653-97-5; ISSN 1098-6189*

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## Experiments on Spontaneous Modulation Instability in Hydrodynamics

Amin Chabchoub<sup>1,2,3</sup>, Goëry Genty<sup>4</sup>, John M. Dudley<sup>5</sup>, Bertrand Kibler<sup>6</sup> and Takuji Waseda<sup>2</sup>

<sup>1</sup>Department of Mechanical Engineering, Aalto University, Espoo, Finland

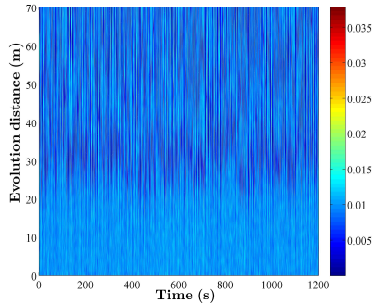
<sup>2</sup>Graduate School of Frontier Sciences, The University of Tokyo, Chiba, Japan

<sup>3</sup>School of Civil Engineering, The University of Sydney, Sydney, NSW, Australia

<sup>4</sup>Department of Physics, Tampere University of Technology, Tampere, Finland

<sup>5</sup>Institut FEMTO-ST, UMR 6174 CNRS-Université de Franche-Comté, Besançon, France

<sup>6</sup>Laboratoire ICB, UMR 6303 CNRS - Université Bourgogne Franche-Comté, Dijon, France



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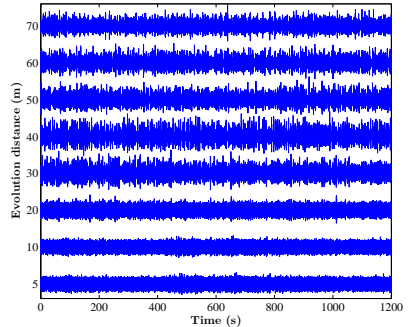
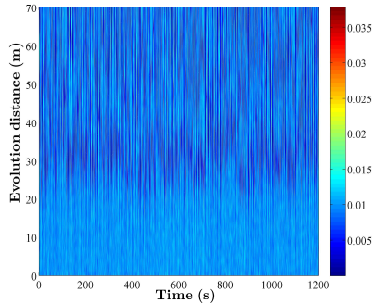
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# Modulation instability - Nonlinear wave packet interaction

## BREAKING OF OCEAN WAVES AND DOWNSHIFTING

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*Ocean Engineering Laboratory*  
*University of California, Santa Barbara*

# Modulation instability - Nonlinear wave packet interaction

## BREAKING OF OCEAN WAVES AND DOWNSHIFTING

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*Ocean Engineering Laboratory  
University of California, Santa Barbara*

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MARSHALL P. TULIN

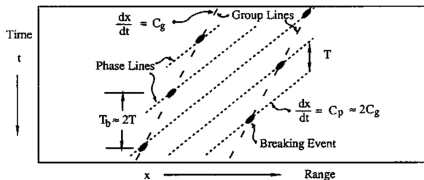
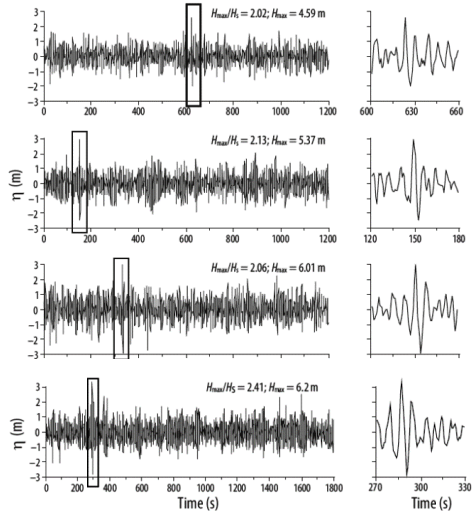
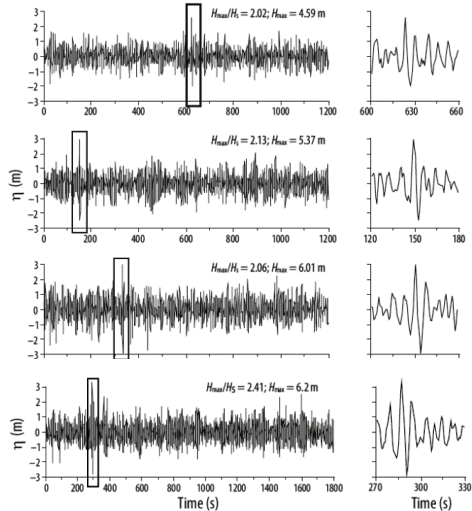


Figure 1: Wave groups delineated by breaking events.  
Schematic of low grazing radar observations.

# Nonlinear wave group shoaling



# Nonlinear wave group shoaling



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

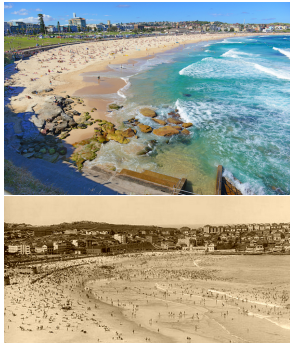
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# Nonlinear wave group shoaling





# Nonlinear wave group shoaling



# Nonlinear wave group shoaling



# Nonlinear wave group shoaling

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

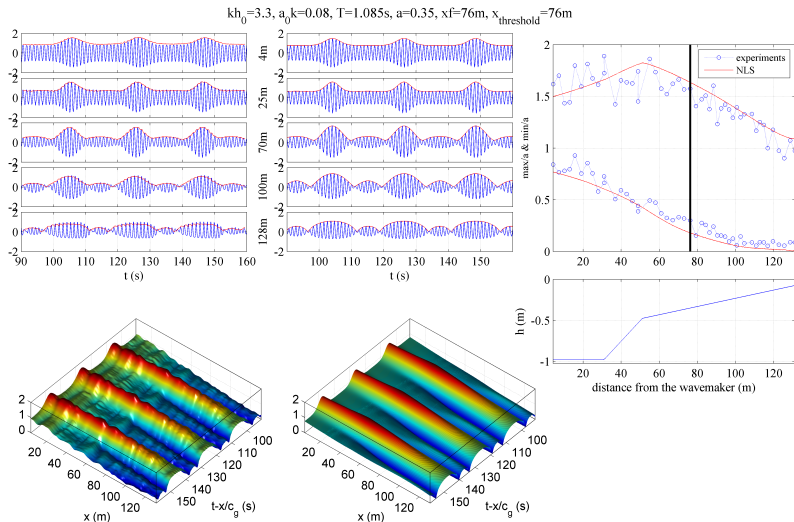
$$\mu = \frac{(1 - \sigma^2)(1 - kh \sigma)}{\sigma + kh(1 - \sigma^2)},$$

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

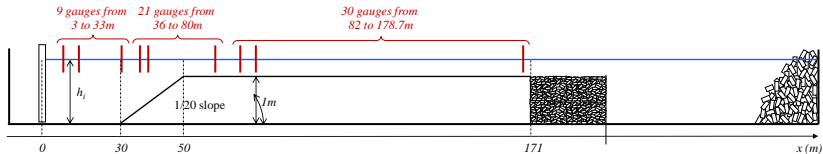
$$\nu = \frac{\omega_0 k^2}{16C_g \sigma^2} \times \left[ 9 - 10\sigma^2 + 9\sigma^4 - \frac{2C_g^2 \sigma^2}{gh - C_g^2} \left( 4 \frac{C_p^2}{C_g^2} + 4 \frac{C_p}{C_g} (1 - \sigma^2) + 4 \frac{gh}{C_g^2} (1 - \sigma^2) \right) \right]$$

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

# Nonlinear wave group shoaling

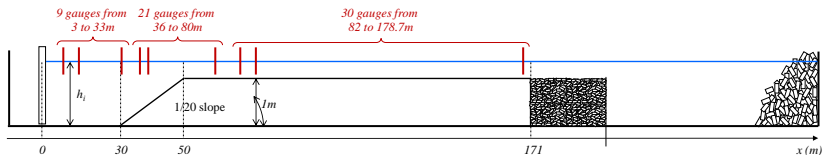


# Nonlinear wave group shoaling



# 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 <sup>1,2,\*</sup>, Michel Benoit <sup>1,2,\*</sup>, Olivier Kimmoun <sup>1,2</sup>, Amin Chabchoub <sup>3,4</sup> and Hung-Chu Hsu <sup>5</sup>

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<sup>2</sup> Aix Marseille Univ, CNRS, Centrale Marseille, IRPHE UMR 7342, 13013 Marseille, France

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

<sup>4</sup> Marine Studies Institute, The University of Sydney, Sydney, NSW 2006, Australia

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

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





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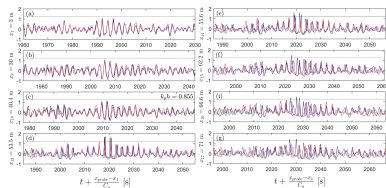
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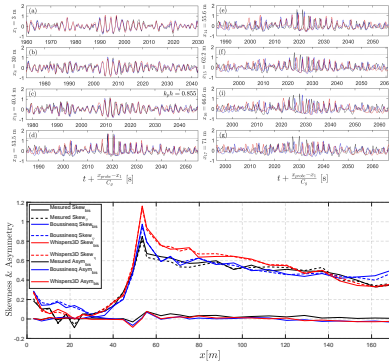
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M. L. Yates et al., *Int. J. Numer. Methods Fluids*, **77**, 616-640 (2015)

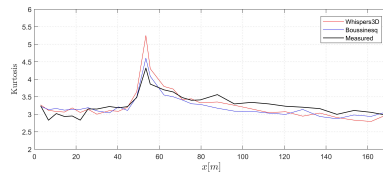
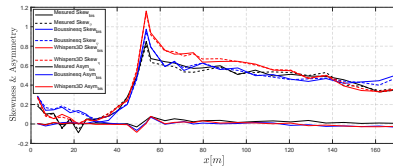
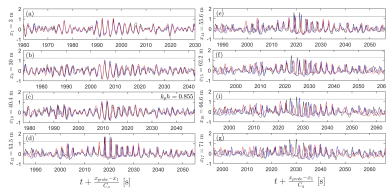
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# Thank you! Questions?

