Predicting the Wave Breaking Onset

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Why the waves break?

2920 Phys. Fluids, Vol. 14, No. 8, August 2002 Guillemette Caulliez

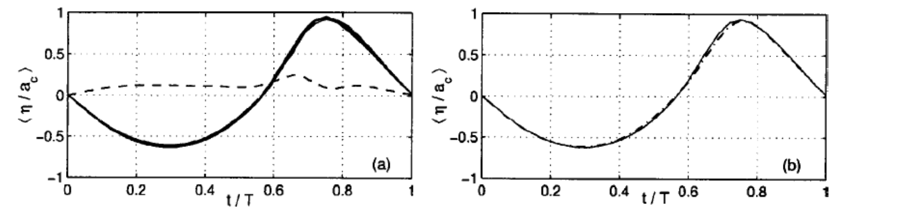

FIG. 5. Average nondimensional profiles of the near-breaking waves observed at 10 m/s wind speed for (a) pure wind waves at various fetches between 15 and 30 m, and (b) pure wind waves (solid line) and mechanically generated waves amplified by wind (dash–dotted line). The typical evolution of the standard deviation of the nondimensional water height distribution along these profiles is shown in (a) (dashed line). Here a_c is the wave crest height.

- Motivation: lack of understanding of incipient breaking (asymmetry)
- What theory can reproduce asymmetric waves?

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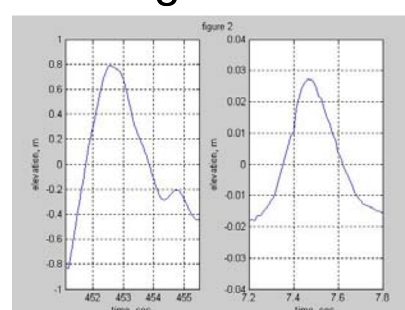
$$\begin{aligned} \text{skewness}_i &= 0.45, \\ \text{skewness}_p &= 0.31, \\ \text{kurtosis}_i &= 3.34, \\ \text{kurtosis}_p &= 2.96, \\ \text{asymmetry}_i &= -0.186, \quad \text{and} \\ \text{asymmetry}_p &= -0.017. \end{aligned} \tag{11}$$

Young and Babanin, JPO, 2006

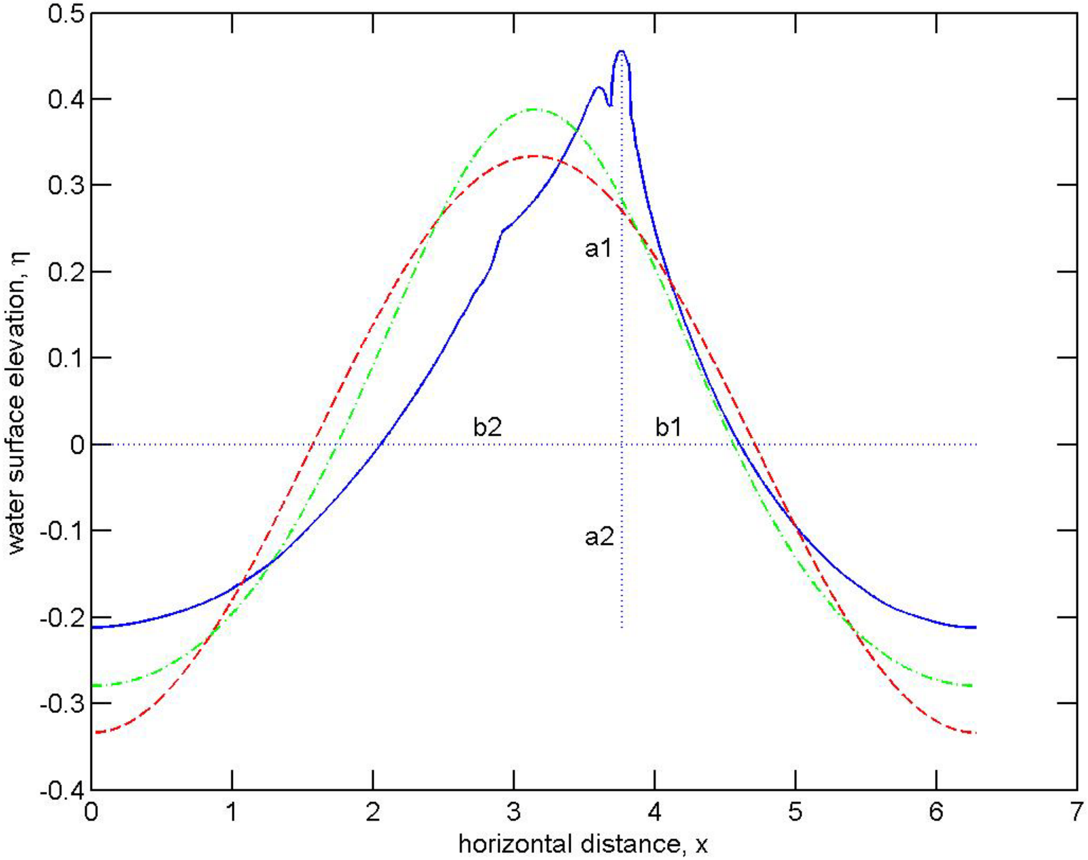


Real waves:

-Black Sea

- ASIST

What theory can reproduce asymmetric waves?



$$S_k = \frac{a_1}{a_2} - 1$$

$$A_s = \frac{b_1}{b_2} - 1$$

$S_k = 0$, $A_s = 0$

$S_k = 0.39$ $A_s = 0$

$S_k = 1.15$ $A_s = -0.51$

Same H and ¸

Chalikov-Sheinin Model

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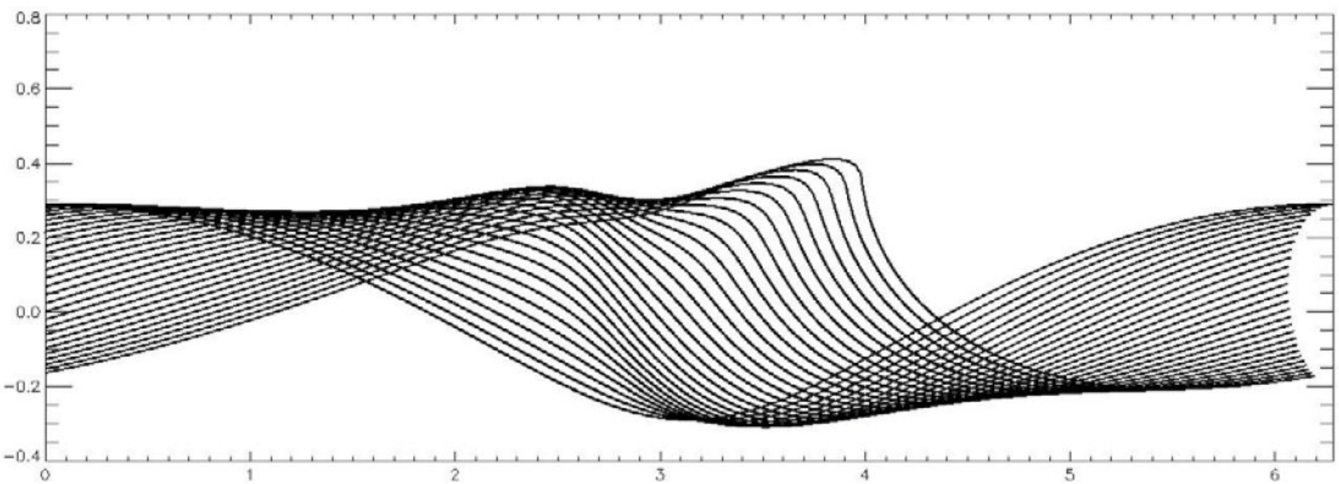
Modeling extreme waves based on equations of potential flow with a free surface

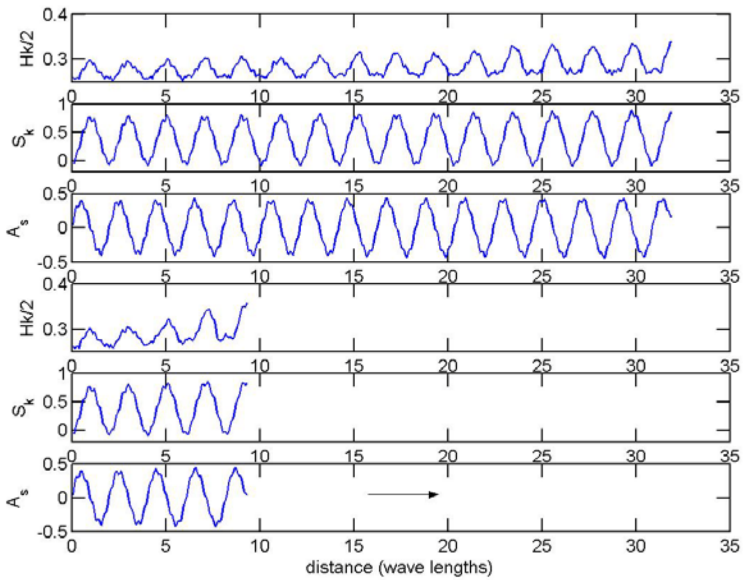
Dmitry Chalikov [a,*], Dmitry Sheinin [b]

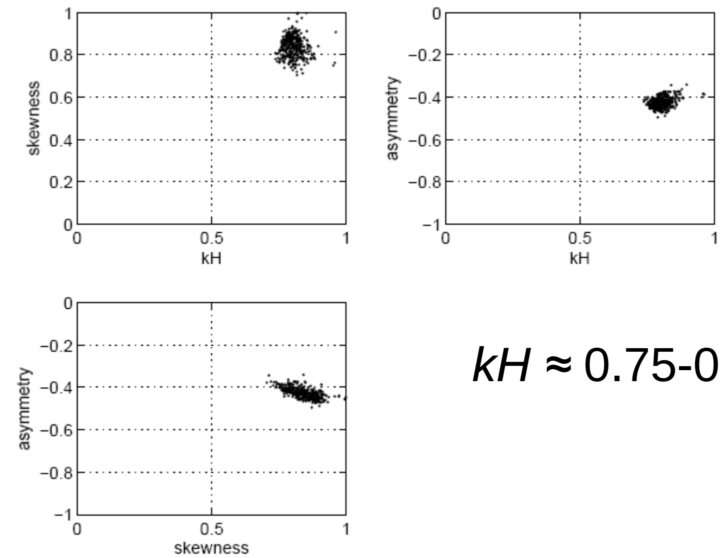
- fully non-linear
- very high precision
- stable for hundreds of periods
- coupled with atmosphere



CSM: steep wave developing asymmetry

Numerical Simulations of Wave Evolution





kH ≈ 0.75-0.85

Individual waves, from start to breaking

IMS = 0.26, U/c = 2.5, U/c = 5.0

Initial skewness and asymmetry are zero

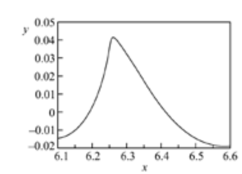
S_k and A_s oscillate

Wind doubles, distance to breaking reduces 4 times

Dyachenko & Zakharov (2005)

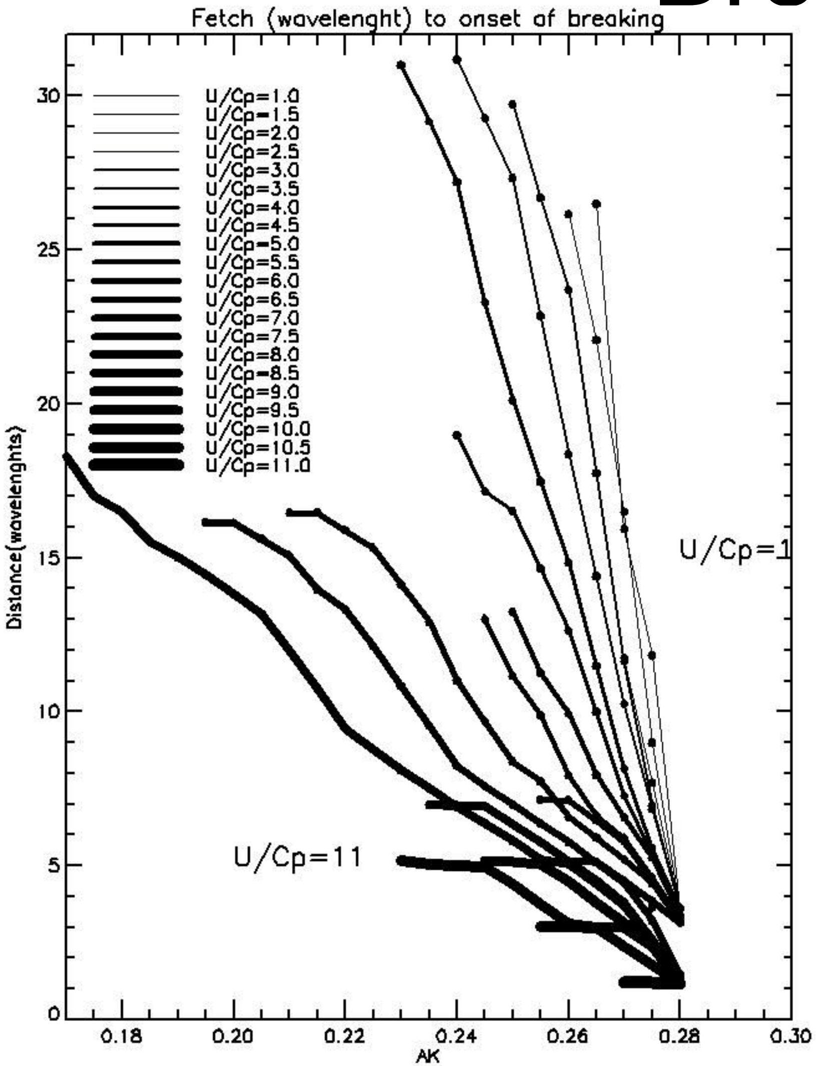
Fully non-linear model

kH/2 = 0.44



Shape is different from the Stokes shape

Numerical Simulations. Distance to Breaking



IMS

If *IMS* > 0.3, waves will break immediately

If *IMS* < 0.1, waves with no wind forcing will never break

Between the limits, dimensionless distance to breaking decreases if *IMS* increases

Wind:

- Accelerates wave steepness growth

- Can reduce the critical steepness if strong (*U/c* >10)

- Affects the breaking severity

Laboratory Experiment at ASIST, RSMAS, University of Miami

• near-monochromatic two-dimensional deep-water mechanically-generated waves

• recorded at 4.55m, 10.53m, 11.59m and 12.56m from the wave maker

• *IMS* varied to make the waves break just after one of the wave probes

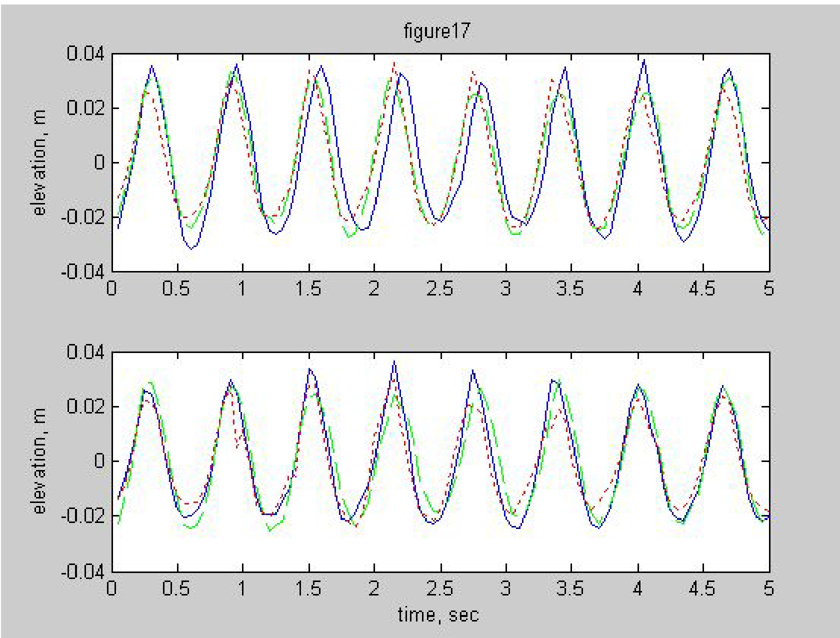
• the fact that breaking could be predicted and controlled by manipulating steepness only is a powerful corroboration of the numerical model

• qualitative rather than exact quantitative agreement is expected: no modes, no three-dimensional crest instability in the model

Experiment. Time Series

4.55 m, *IMF* = 1.6Hz

U/c = 0, *IMS* = 0.31, 0.25, 0.23

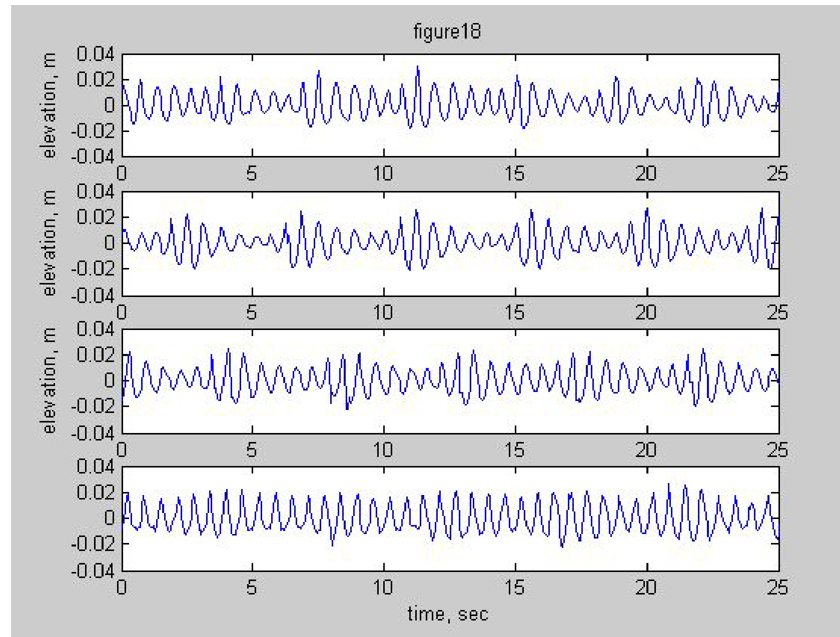


IMS = 0.23, U/c = 0, 1.4, 11

10.53 m, *IMF* = 1.6Hz

U/c = 0, *IMS* = 0.31, 6 waves

U/c = 0, *IMS* = 0.25, 7 waves



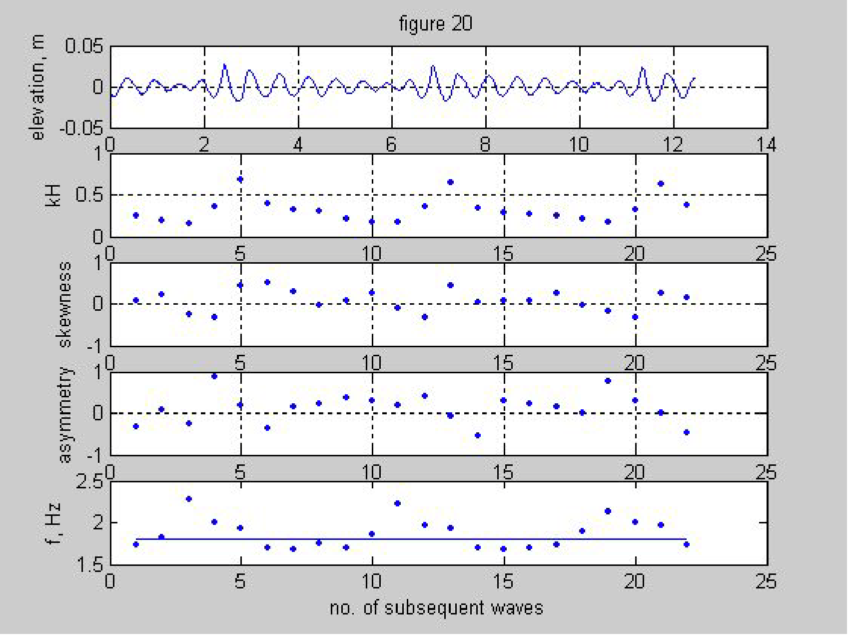
U/c = 0, *IMS* = 0.23, 7.5 waves
U/c = 11, *IMS* = 0.23, 7.5 waves,
modulation smeared

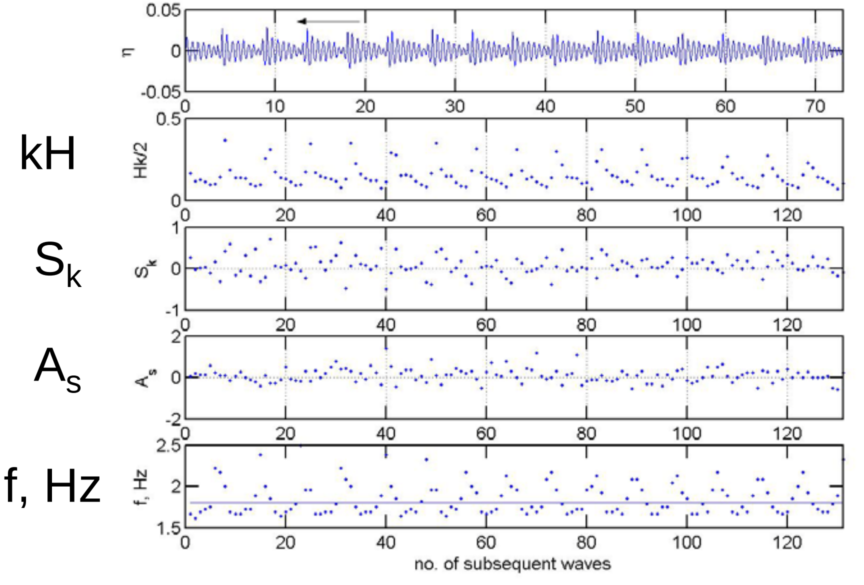
Modulational Index defines number of waves in the modulation:

$$M_I = \frac{\epsilon}{\Delta f / f_0}$$

Experiment. Time Series Analysis

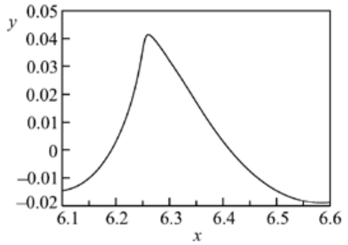
- *IMF* = 1.8Hz, *IMS* = 0.30, U/c = 0, breaking immediately after the 10.73 m probe
- note a conceptual change in the frame of reference compared to the numerical model results
- major features seen in the numerical model are confirmed

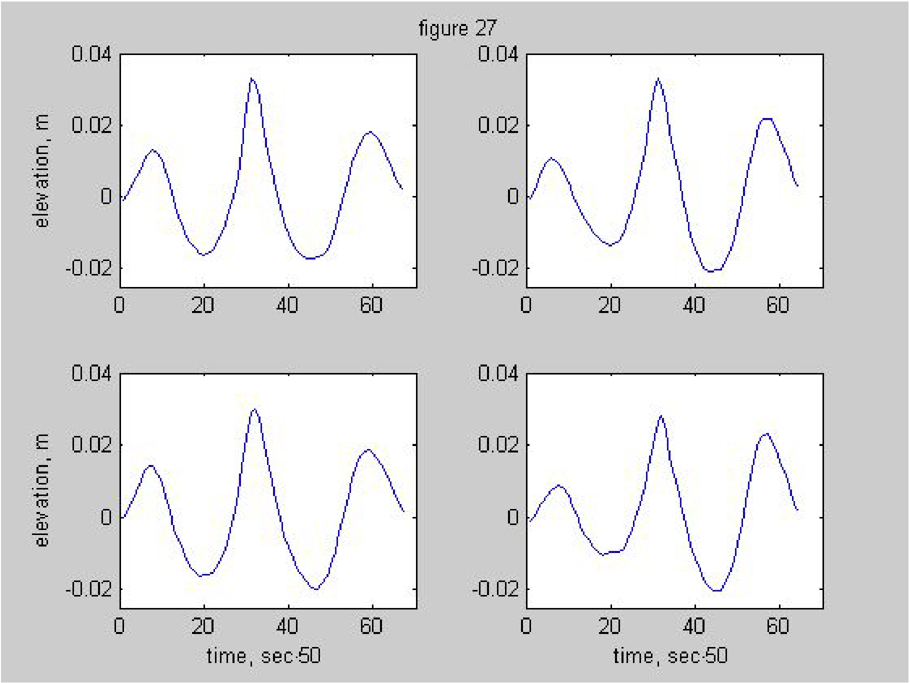


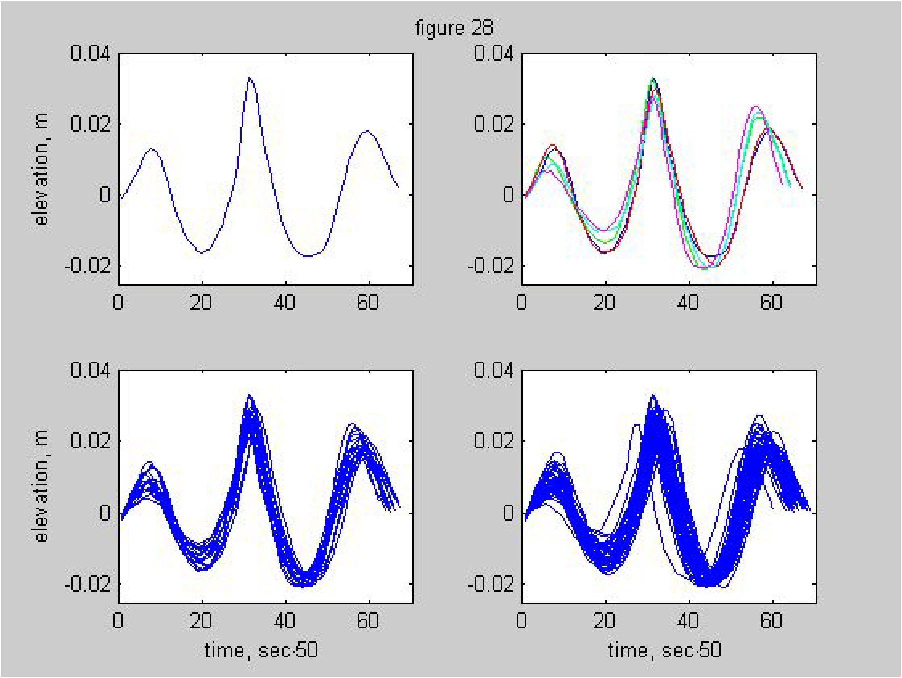


- incipient breaking waves are the steepest waves in the wave train
- steepness, skewness and asymmetry oscillate. Asymmetry is shifted
- at the point of breaking S_k is maximal, A_s is small, frequency is increased

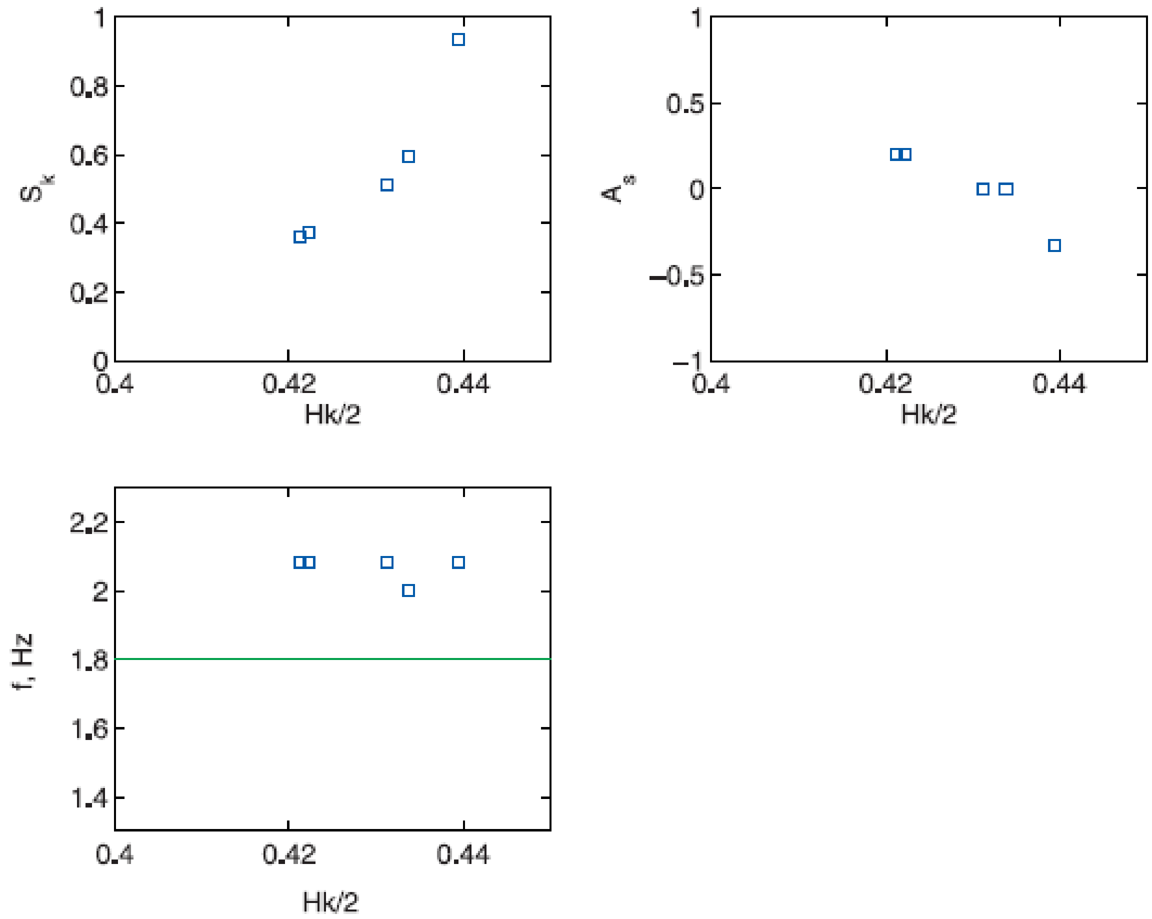
Experiment. The Incipient Breaking!





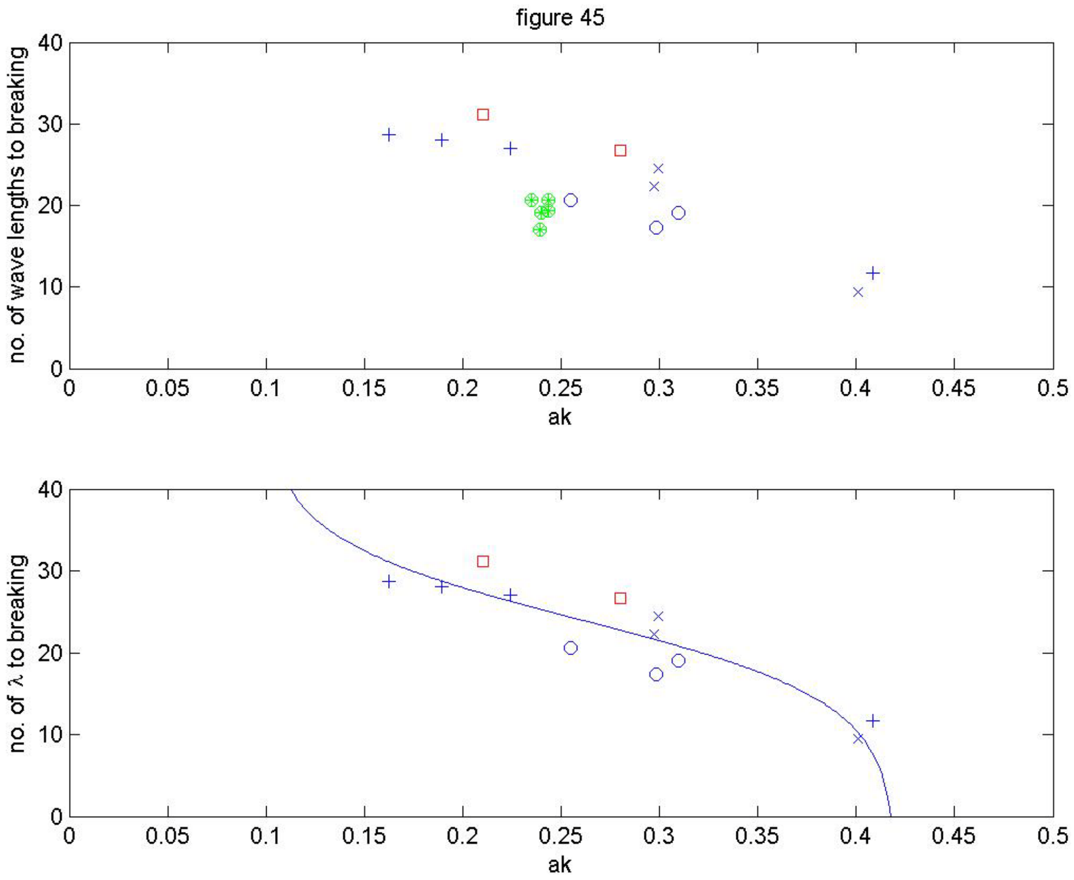


Incipient Breaking Statistics. Top 5



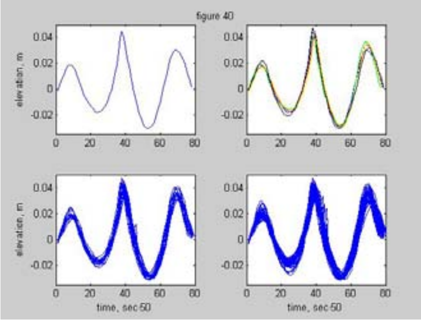
asymptotic limit of kH/2~0.44

Number of wave lengths to the breaking versus *IMS*.

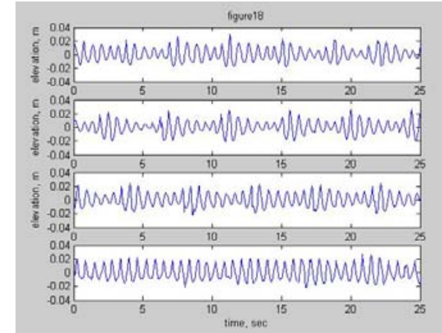


- No wind forcing, except filled green circles
- Red squares derived from Melville (1982)
- *IMS* > 0.44, break immediately
- *IMS* < 0.08, never break in the absence of wind forcing

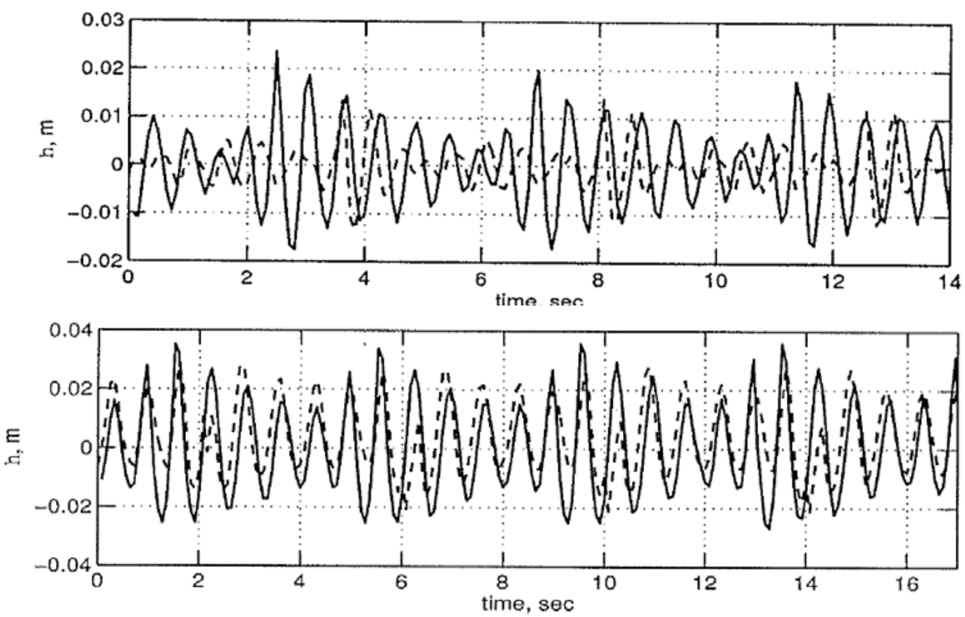
$$N = -11\,\mathrm{atanh}\left[5.5\left(IMS - 0.26\right) + 23\right]$$



Wind-Forced Breaking



- overall pattern, i.e. breaking onset etc. is the same
- modulation and dissipation are not the same



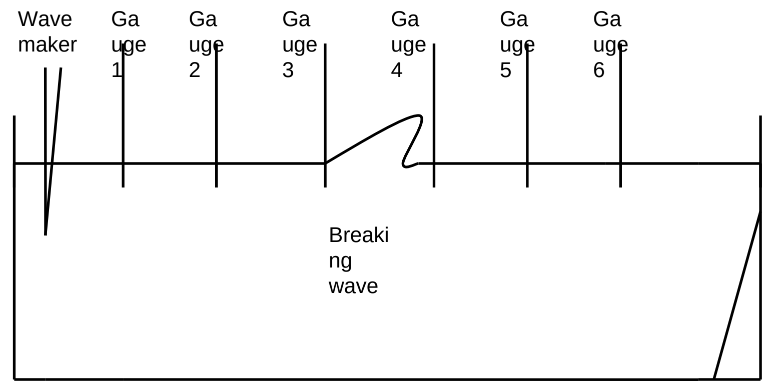
without the wind

$$R = \frac{H_h}{H_l}$$ modulation depth

with the wind (U/c=3.9)

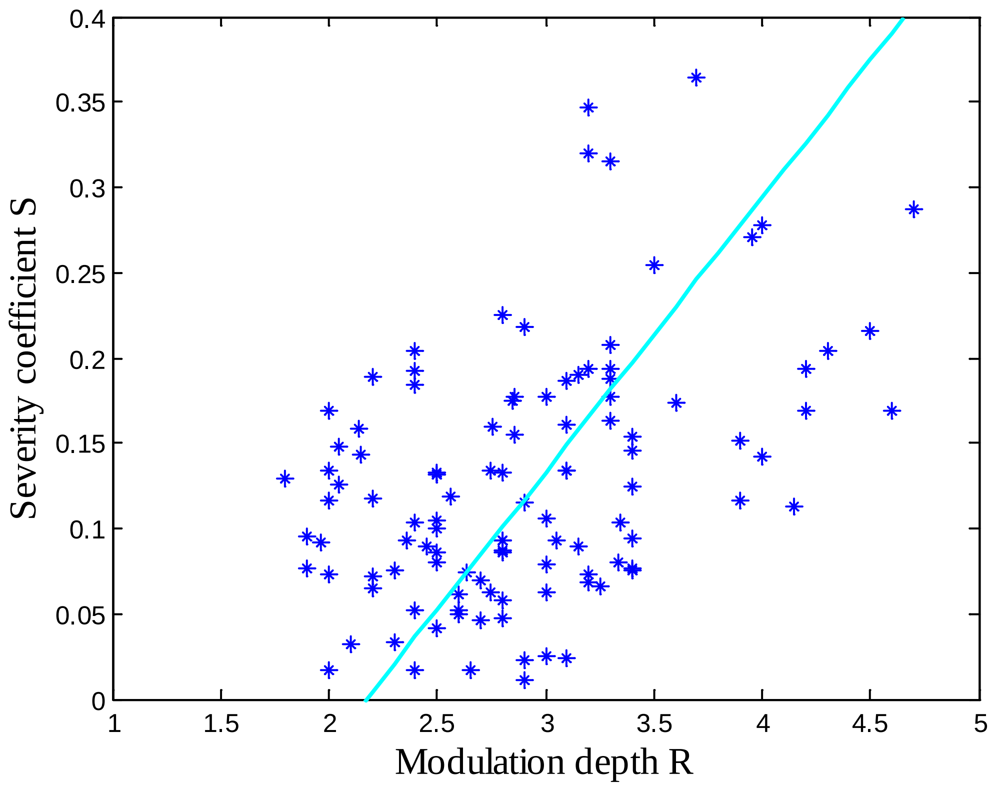
before (solid line) and after (dashed) the breaking

Laboratory Experiment at National Chen Kung University, Taiwan



24m long, 1.3m high and 1m wide

Laboratory Experiment at National Chen Kung University, Taiwan



$$S = \frac{E_{bb} - E_{ab}}{E_{bb}}$$

Breaking severity per wave group

Ranges from 2% to 35%

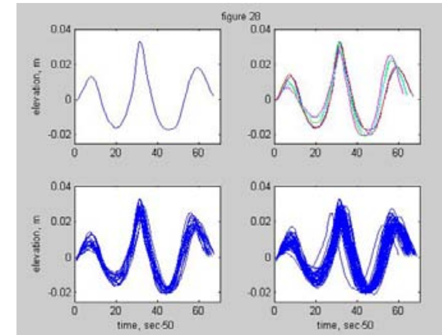
$$S = (0.16 \pm 0.03)R - (0.35 \pm 0.06)$$

Implications for Field Conditions

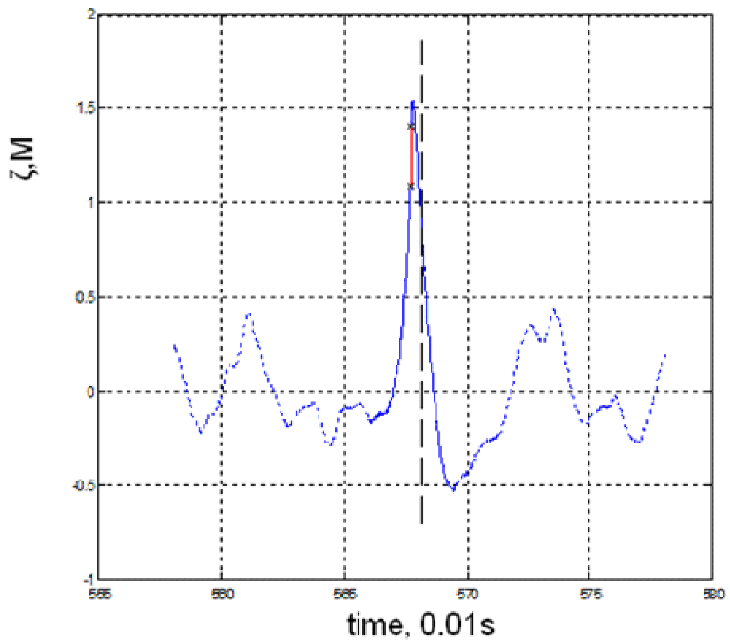
- waves are three-dimensional
- notion of an initial monochromatic steepness does not exist
- however, should waves reach critical steepness then they will break
- other processes can negotiate the critical steepness (wind, groups, superpositions)

  but $ak=0.44$ criterion appear to hold (eg. Brown and Jenssen, JGR, 2001)
- steepness of individual waves can be related to the spectral densities

Dominant Breaking in Field Conditions



- There is still hope!



- measuring breaking onset in a field is a challenge
- if measured, limiting steepness, skewness and other features appear similar to those due to 2D modulational instability

Vladimir Dulov, MHI, Sebastopol

Breaking onset, Black Sea, *kH~0.9*

Conclusions

- Breaking onset caused by modulational instability was investigated by numerical and laboratory means
- Breaking probability can be predicted in terms of initial steepness
- Once waves reach a limiting steepness, they break. The final steepness limit reached by these waves is very close to the Stokes limit
- Wind forcing plays multiple roles, one of them is alteration of the modulation depth
- The modulation depth is connected with the breaking severity