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Wave Breaking Probability in Highly Directional Seas

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Wave Breaking in Crossing Seas

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"[In crossing seas] breaking becomes less crest-amplitude limiting for sufficiently large crossing angles and involves the formation of near-vertical jets"

M. L. McAllister et al., 2019

Contents

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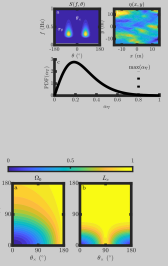
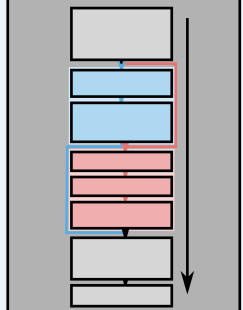
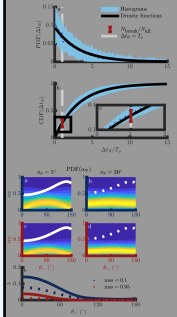
Definitions



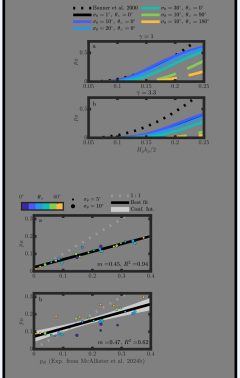
Framework



Analysis



Assessment



Motivation

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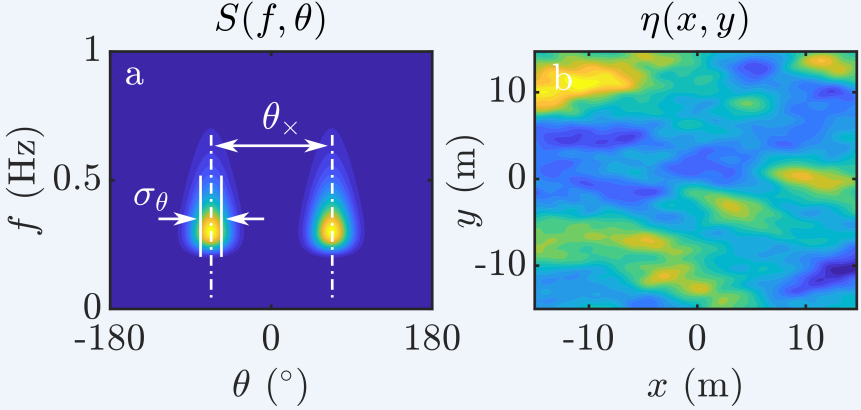
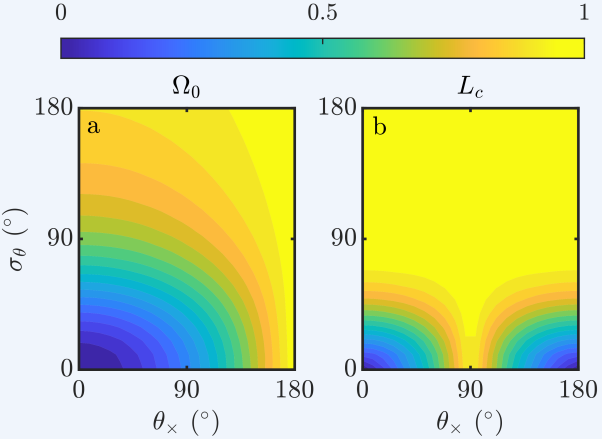
- Breaking probability an intermediate step on the way to breaking dissipation
- How does strong directionality affect prevalence of breaking events?
- Current models assume a consistent amount of directionality or/ and constant threshold values

Directionality I



Directionality II



$$\Omega_0 = 1 - \left| \frac{\iint S(f,\theta) e^{i\theta} \, \mathrm{d}f \, \mathrm{d}\theta}{E} \right|$$

$$L_c^2 = \frac{(m_{20} + m_{02}) - \sqrt{(m_{20} - m_{02})^2 + 4m_{11}^2}}{(m_{20} + m_{02}) + \sqrt{(m_{20} - m_{02})^2 + 4m_{11}^2}}$$

Assumptions

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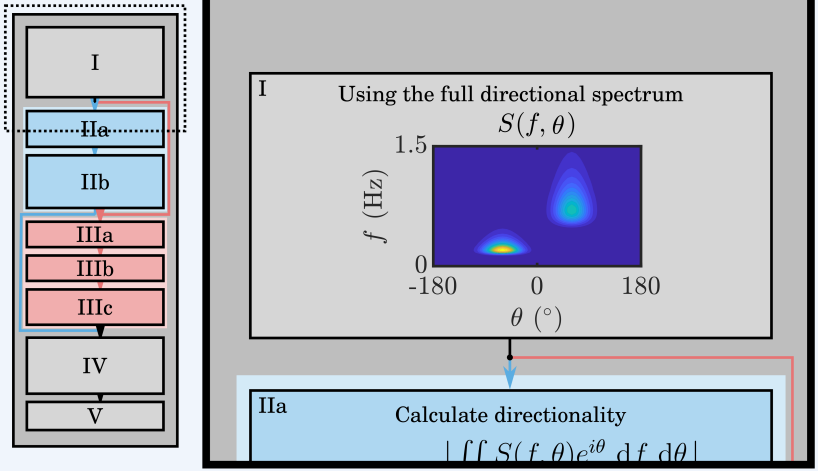
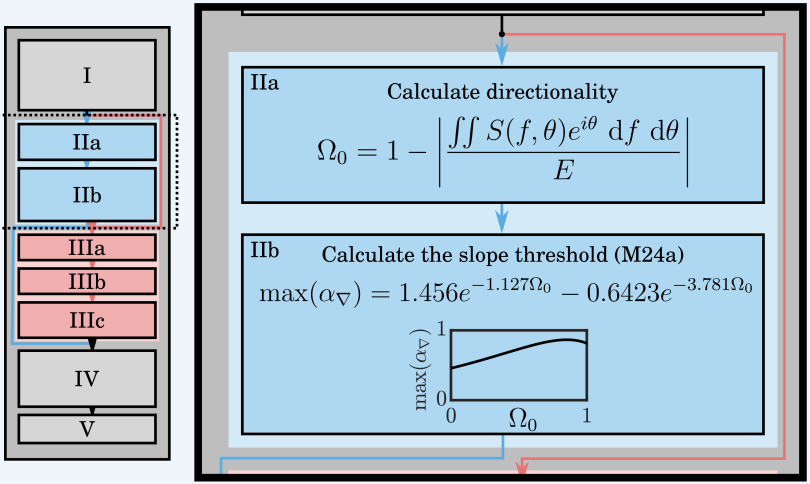
- Gaussian distributed free surface
- Slope-limited wave breaking
- Continuous and independent breaking events

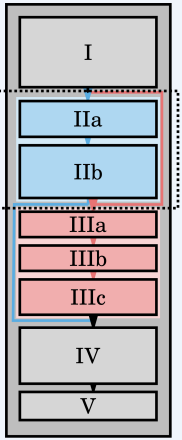
Framework

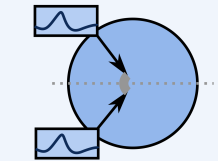

I
IIa
IIb
IIIa
IIIb
IIIc
IV
V
I
Using the full directional spectrum
$S(f,\theta)$
1.5
f (Hz)
0
-180
0
180
θ (°)
IIa
Calculate directionality
$|\int\int S(f,\theta)e^{i\theta}\,\mathrm{d}f\,\mathrm{d}\theta|$

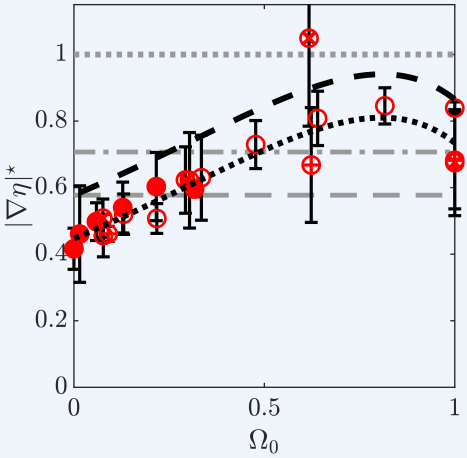
Framework: Maximum Slope



Framework: Maximum Slope

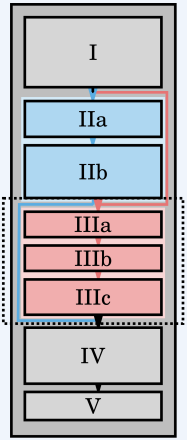


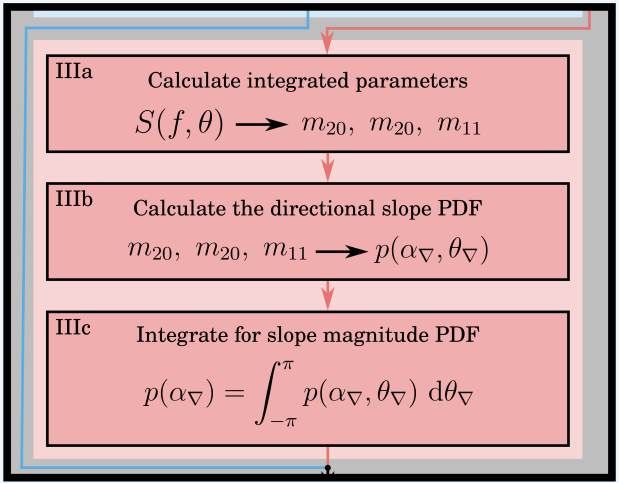




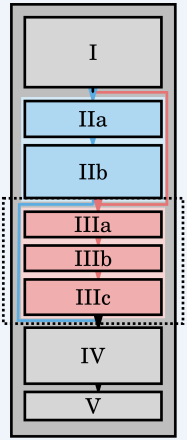
McAllister, M., et al.: Three-dimensional wave breaking. Submitted

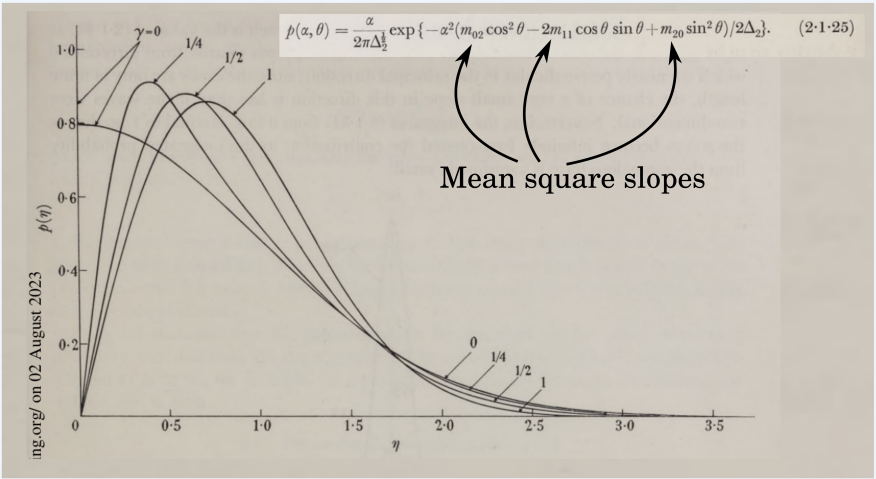
Framework: Slope Distribution





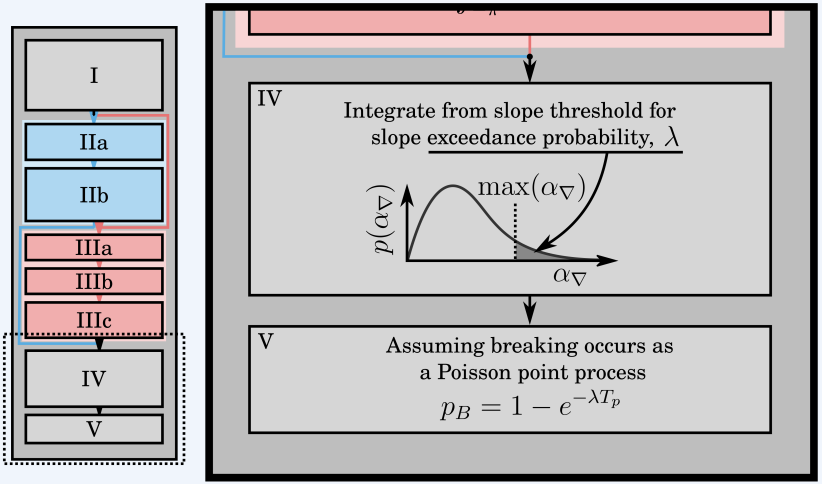
Framework: Slope Distribution





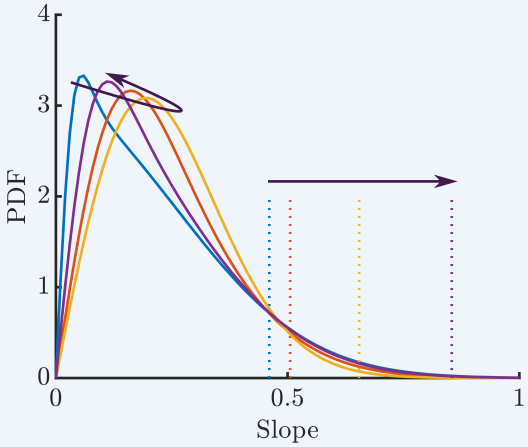
Longuet-Higgins, M. S., 1957: Statistical analysis of a random, moving surface. Philos. T. R. Soc. S.-A,

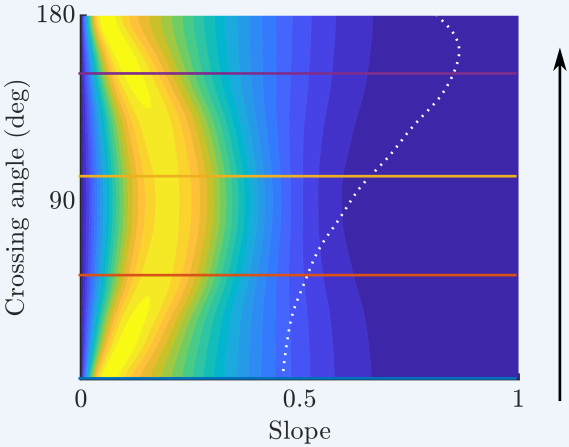
Framework: Breaking Prob.



Slope Distribution

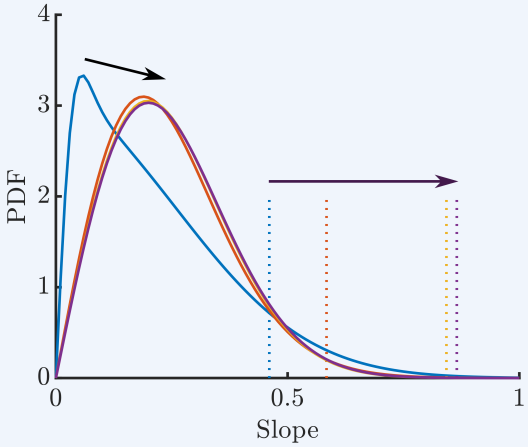
Crossing Performance

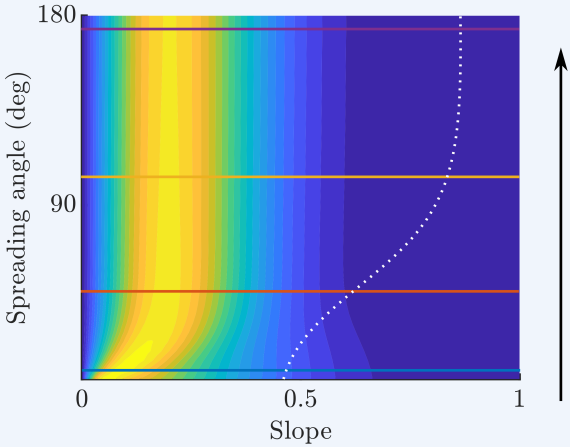




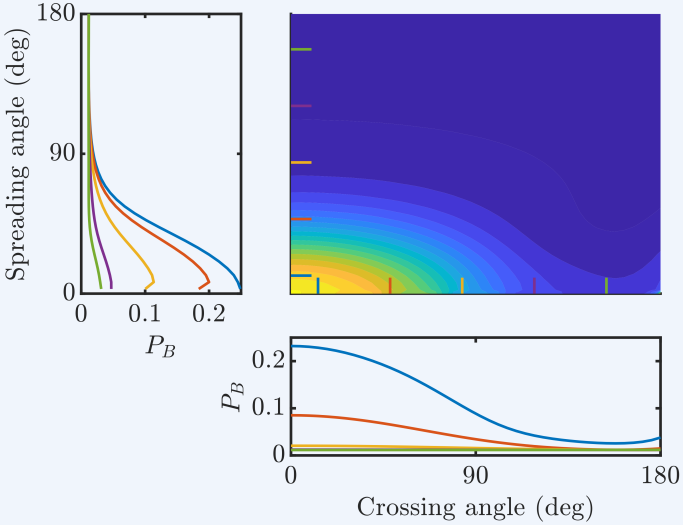
Slope Distribution

Spreading Performance

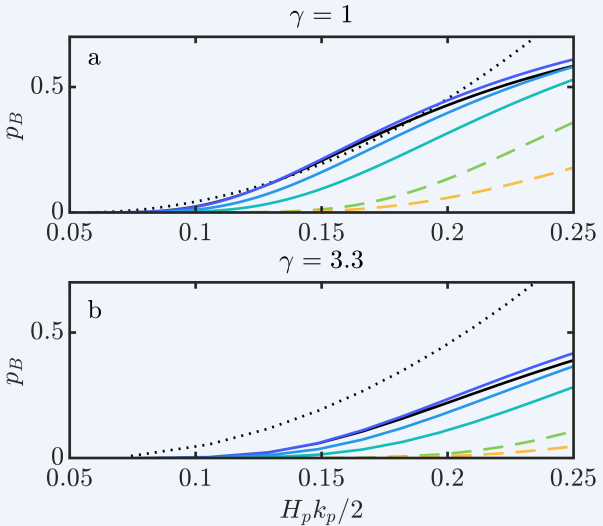


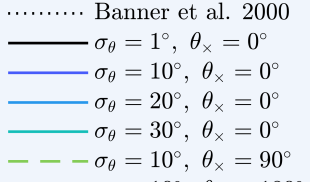


Breaking Probability

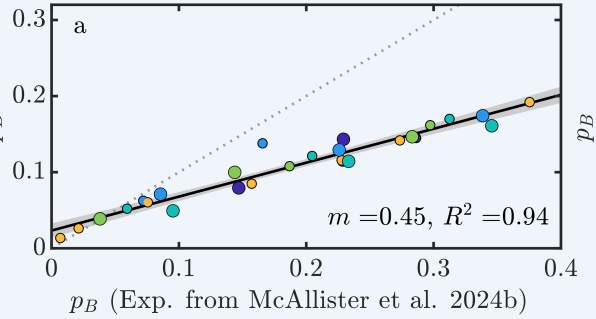


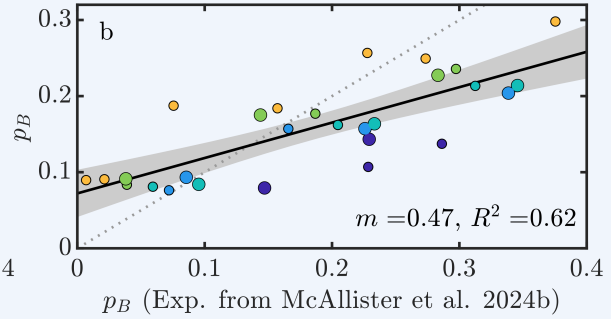
Assessment

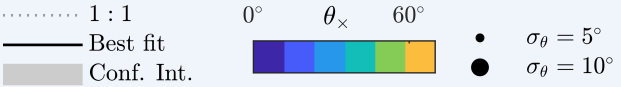

γ = 1
a
0.5
p_B
0
0.05
0.1
0.15
0.2
0.25
γ = 3.3
b
0.5
p_B
0
0.05
0.1
0.15
0.2
0.25
$H_p k_p/2$


Banner et al. 2000
$\sigma_\theta = 1°,\ \theta_\times = 0°$
$\sigma_\theta = 10°,\ \theta_\times = 0°$
$\sigma_\theta = 20°,\ \theta_\times = 0°$
$\sigma_\theta = 30°,\ \theta_\times = 0°$
$\sigma_\theta = 10°,\ \theta_\times = 90°$
$\sigma_\theta = 10°,\ \theta_\times = 180°$

Assessment


Full Directional Spectrum
a
m =0.45, R^2 =0.94
p_B
p_B (Exp. from McAllister et al. 2024b)


Constant Directional Dist. Assumed
b
m =0.47, R^2 =0.62
p_B
p_B (Exp. from McAllister et al. 2024b)


1 : 1
Best fit
Conf. Int.
0°
$\theta_\times$
60°
$\sigma_\theta = 5°$
$\sigma_\theta = 10°$

Assumptions Revisited

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- Gaussian distributed free surface
  - Applicability to intermediate/shallow waters?
  - Effect of bound harmonics on slope distribution?
- Slope-limited wave breaking
  - Could this framework be applied with a kinematic criterion?
- Continuous and independent breaking events
  - How does wavetrain modulation affect this?

Conclusions and Future Work

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- Framework based on experiments to determine slope threshold and PDF of slopes to find exceedance proportion
- Framework shows decrease in breaking probability for all types of directionality
- Framework able to consolidate measured and predicted breaking probability of various directional distributions, 0.5 scaling
- Higher-order slope PDF
- Stronger crossing angle validation experiments

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Questions and Comments

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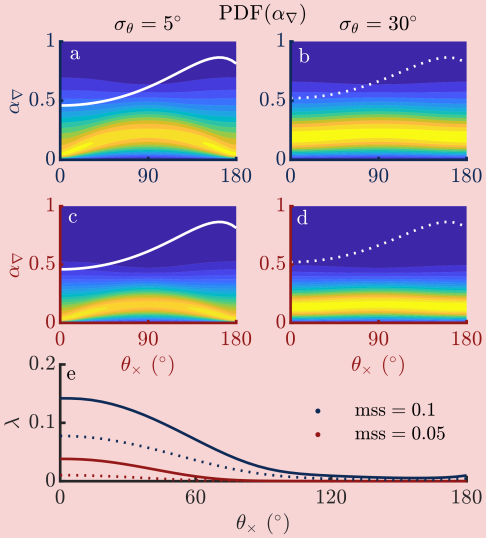
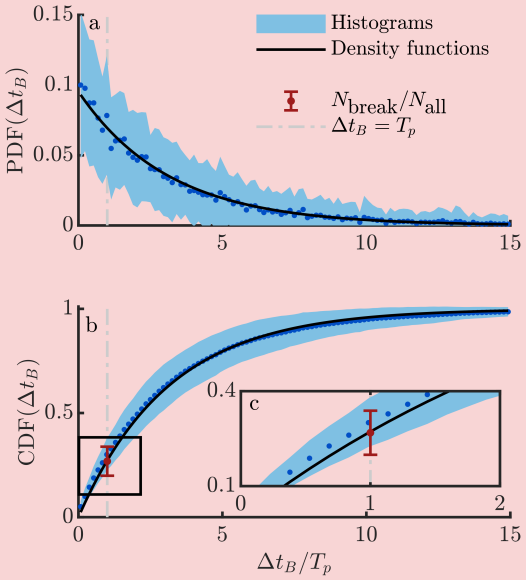
Analysis


PDF(α_∇)
$\sigma_\theta = 5°$
$\sigma_\theta = 30°$
a
b
c
d
e
α_∇
$\theta_\times$ (°)
λ
mss = 0.1
mss = 0.05

Analysis



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