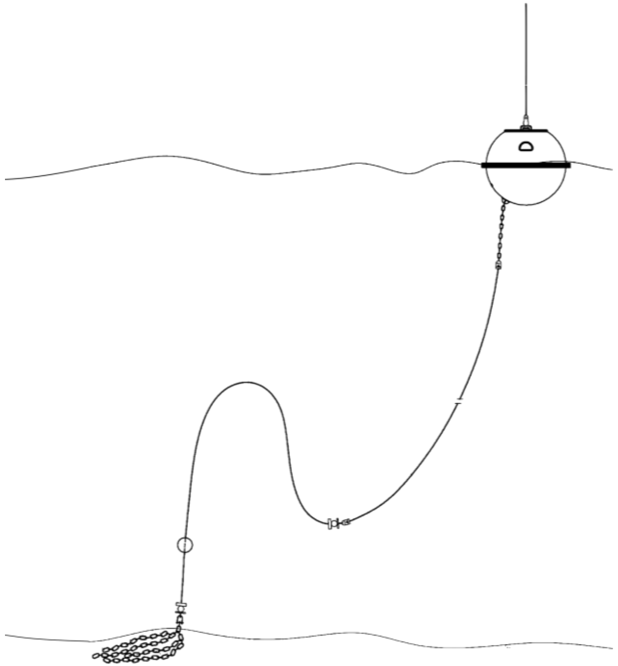
Lagrangian Measurement of Waves by Buoys

Mark L. McAllister and Ton S. van den Bremer

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

11th November 2019



Lagrangian Measurement of Waves by Buoys

- Motivation
- Second-Order Motion of a Wave-Following Measurement Buoy
- Statistical Properties of Directionally Spread Ocean Waves Measured by Buoys
- Approximate retrospective correction method for crest heights

SUPERGEN UKCMER

EPSRC
Engineering and Physical Sciences Research Council

wave energy SCOTLAND

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Motivation

Chair: Val Swail

A1 8:50 a.m. ***Quantifying Wave Measurement Differences in Historical and Present Wave Buoy Systems***
R.E. Jensen, V. Swail, R.H. Bouchard and B. Bradshaw
Presenter: Jensen Download Presentation

A2 9:10 a.m. ***Field Evaluation of the Wave Module for NDBC's New Self-Contained Ocean Observing Payload (SCOOP) on Modified NDBC Hulls***
Richard Bouchard, Rodney R. Riley, Lex A. LeBlanc, Michael Vasquez, Michael Robbie, Robert E. Jensen, Mary A. Bryant and Laura A. Fiorentino
Presenter: Bouchard Download Presentation

A3 9:30 a.m. ***Correcting for Changes in the NDBC Wave Records of the United States***
Elizabeth A. Livermont, Jon K. Miller and Thomas O. Herrington
Presenter: Livermont Download Presentation

9:50 a.m. Break

Session B: Wave Measurement - 2

Chair: Robert Jensen

B1 10:30 a.m. ***Data Buoy Cooperation Panel (DBCP) Task Team on Wave Measurement (TT-WM)***
Val Swail and Robert Jensen
Presenter: Swail Download Presentation

B2 10:50 a.m. ***Open Ocean Storm Waves in the Arctic***
Takuji Waseda, Adrean Webb, Kazutoshi Sato, Jun Inoue, Alison Kohout, Bill Penrose and Scott Penrose
Presenter: Waseda Download Presentation

B3 11:10 a.m. ***A project of concrete stabilized spar buoy for monitoring near-shore environement***
Sergei I. Badulin, Vladislav V. Vershinin, Andrey G. Zatsepin, Dmitry V. Ivonin, Dmitry G. Levchenko, Alexander G. Ostrovskii and Leopold I. Lobkovsky
Presenter: Badulin Download Presentation

B4 11:30 a.m. ***Measuring the 'First Five' with HF radar***
Lucy R Wyatt
Presenter: Wyatt Download Presentation

B5 11:50 a.m. ***The use and limitations of satellite remote sensing for the measurement of wind speed and wave height***
Ian Young
Presenter: Young Download Presentation

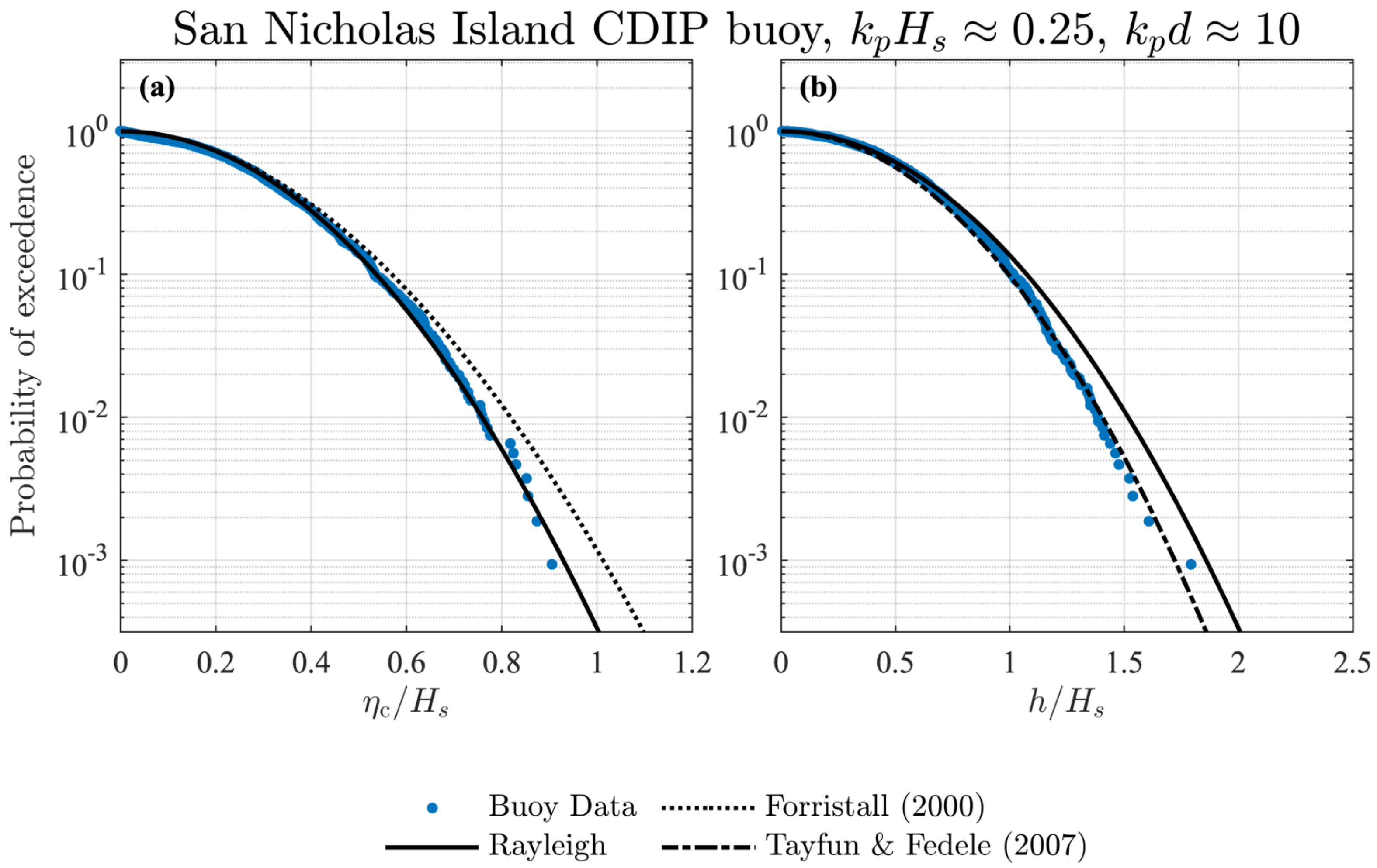
12:10 p.m. Lunch

Session C: Wave Design Criteria

Chair: Andrew Cox

C1 1:30 p.m. ***Individual Wave Height and Wave Crest Distributions - Full Scale Measurements - North Sea***
Børge Kvingedal
Presenter: Kvingedal Download Presentation

Motivation


San Nicholas Island CDIP buoy, $k_p H_s \approx 0.25$, $k_p d \approx 10$
(a)
(b)
Probability of exceedence
10^0
10^{-1}
10^{-2}
10^{-3}
0
0.2
0.4
0.6
0.8
1
1.2
η_c / H_s
0
0.5
1
1.5
2
2.5
h / H_s
Buoy Data
Rayleigh
Forristall (2000)
Tayfun & Fedele (2007)

Motivation

- Buoys avoid large crest
- Lack or mooring compliance drags buoys under crests
- Low sampling rate misses crests
- Lagrangian motion “linearises” crests
- Instrumentation and signal processing

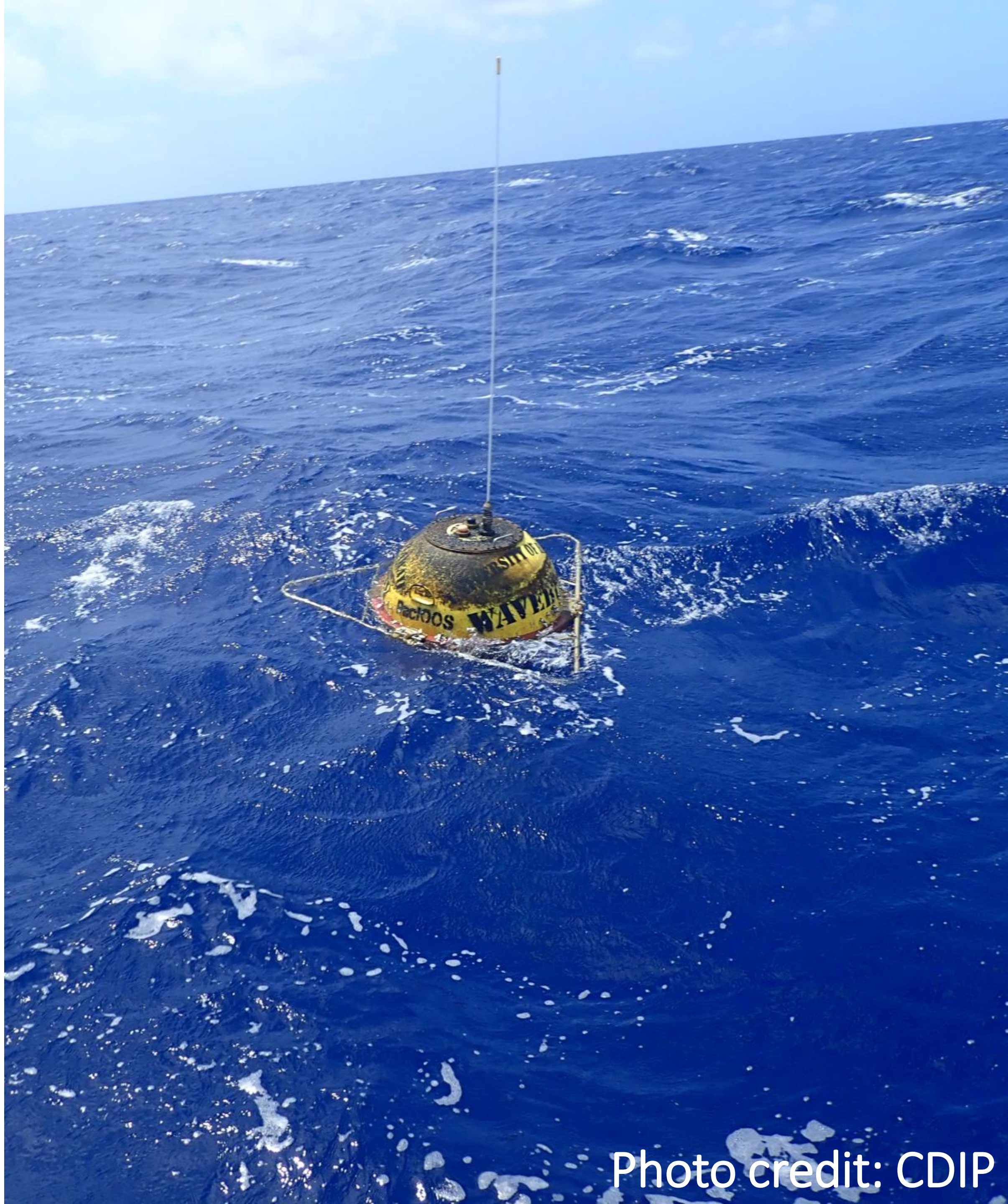
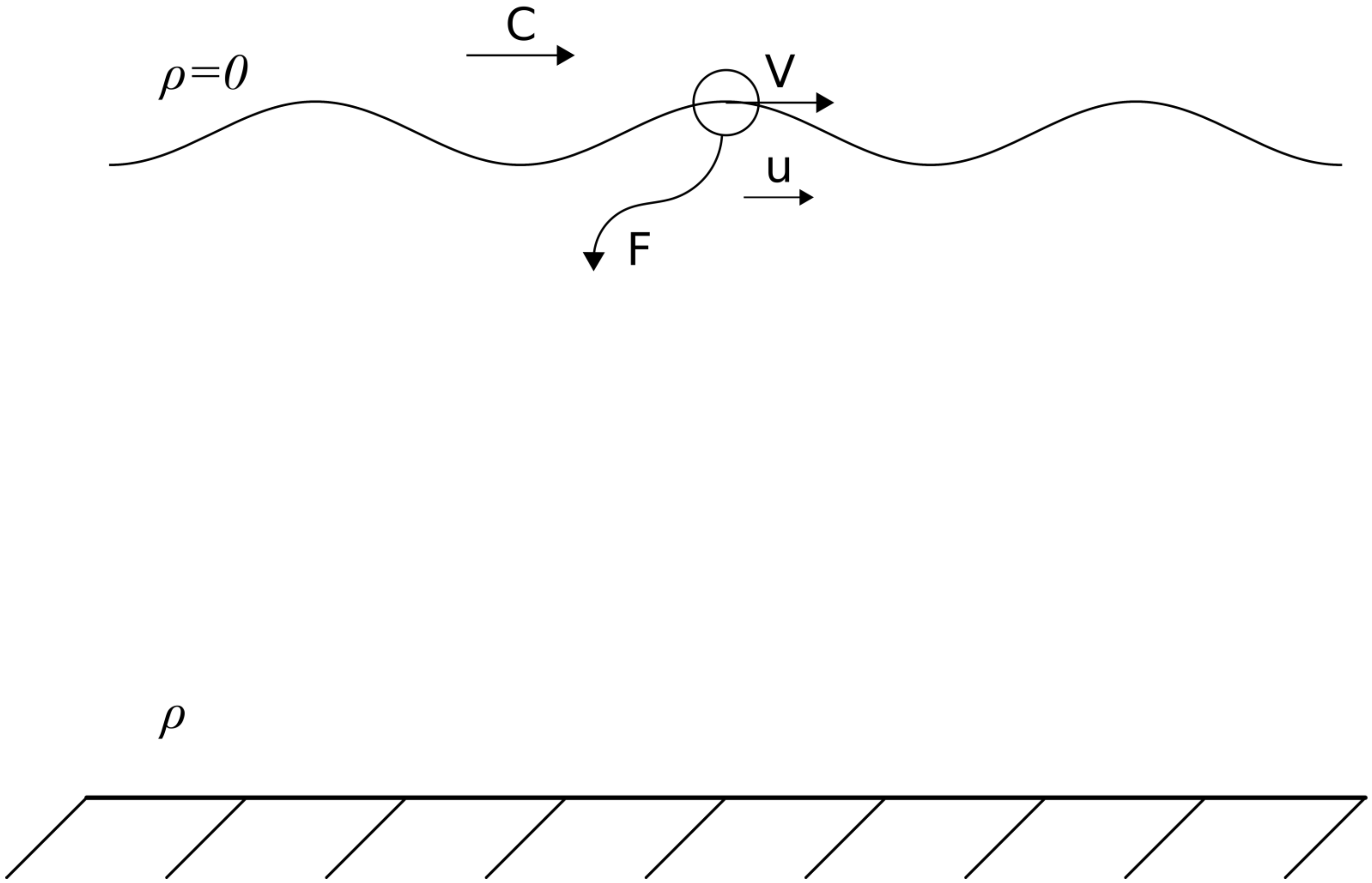


Photo credit: CDIP

Second-Order Motion of a Wave-Following Measurement Buoy



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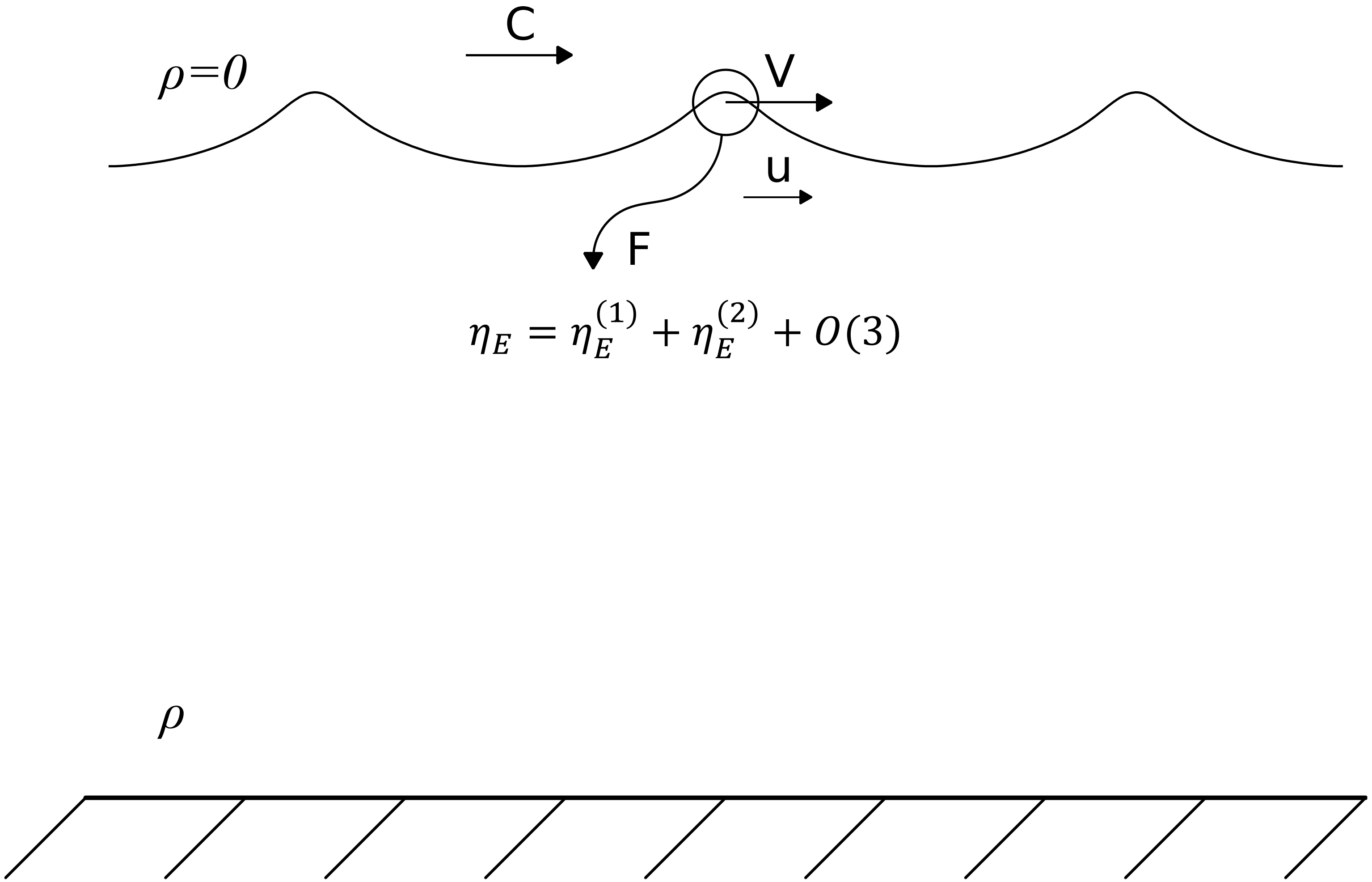
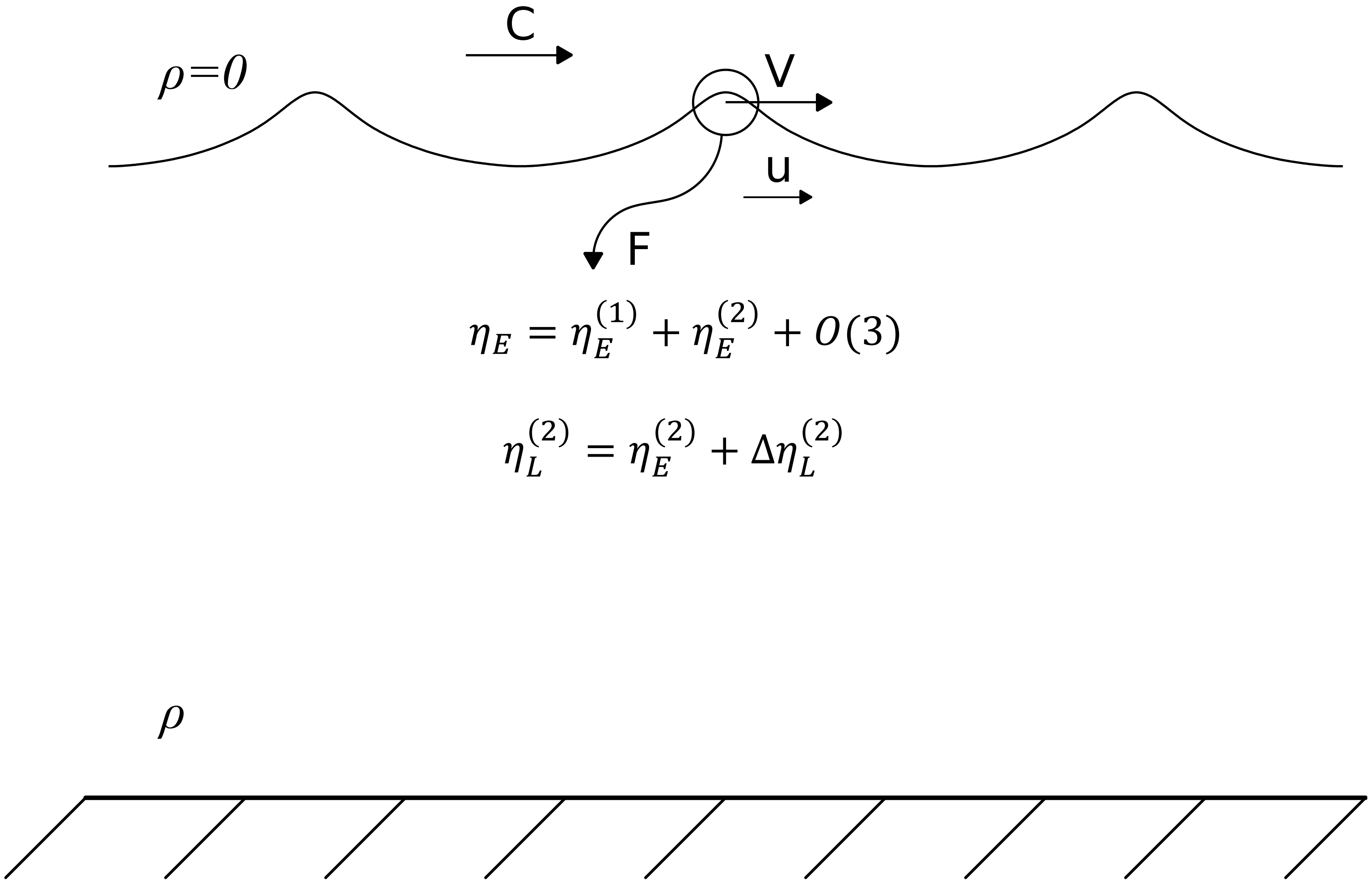


$$\eta_E = \eta_E^{(1)} + \eta_E^{(2)} + O(3)$$

Second-Order Motion of a Wave-Following Measurement Buoy



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$$\eta_L^{(2)} = \eta_E^{(2)} + \Delta\eta_L^{(2)}$$

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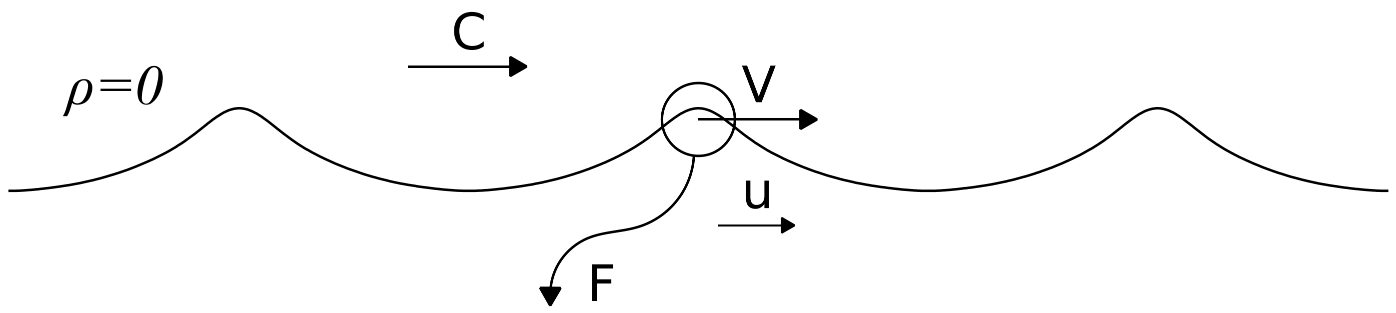

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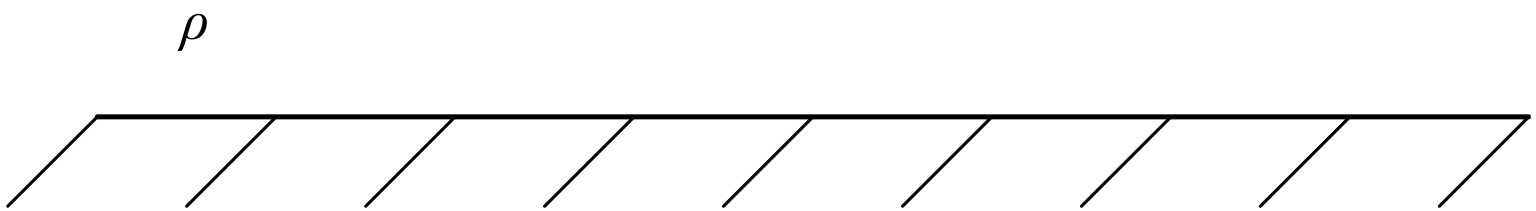
$$\Delta\eta_L^{(1)} = \Delta x_H^{(1)} \cdot \nabla_H \eta^{(1)}$$



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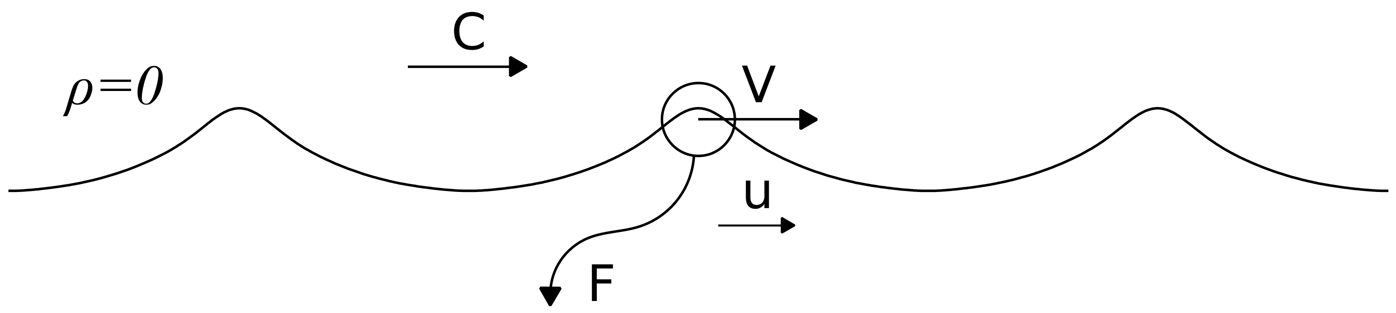

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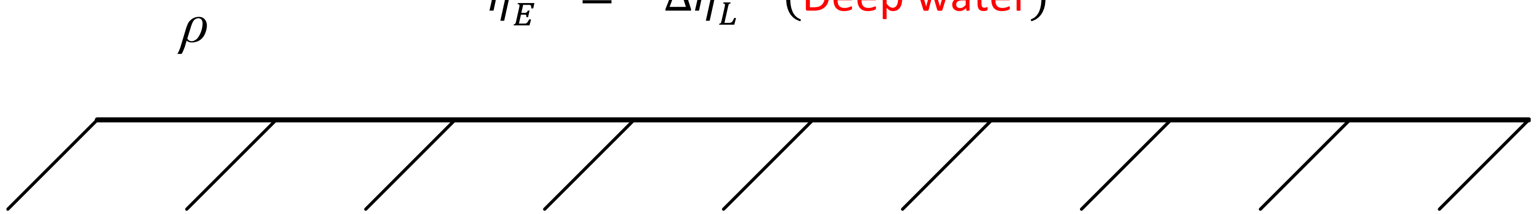
$$\eta_E^{(2)} = -\Delta\eta_L^{(2)} \text{ (Deep water)}$$



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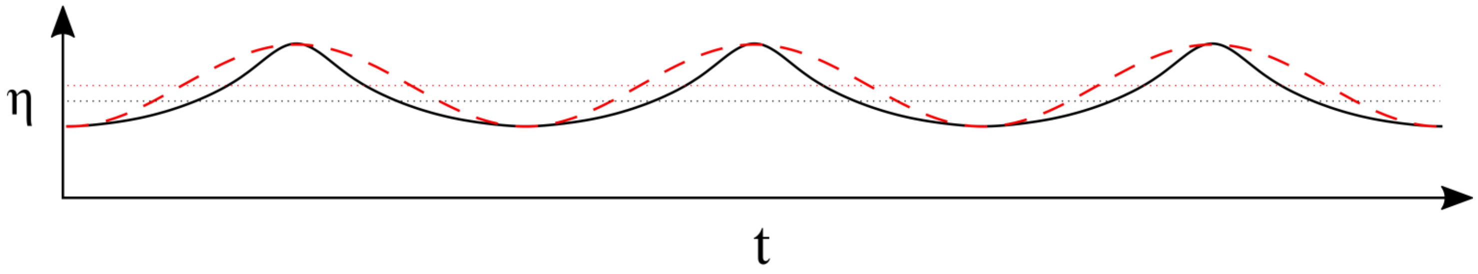

Eulerian η = ————

Lagrangian η = - - - - - - - - -

$$\eta_L^{(2)} = \eta_E^{(2)} + \Delta\eta_L^{(2)}$$

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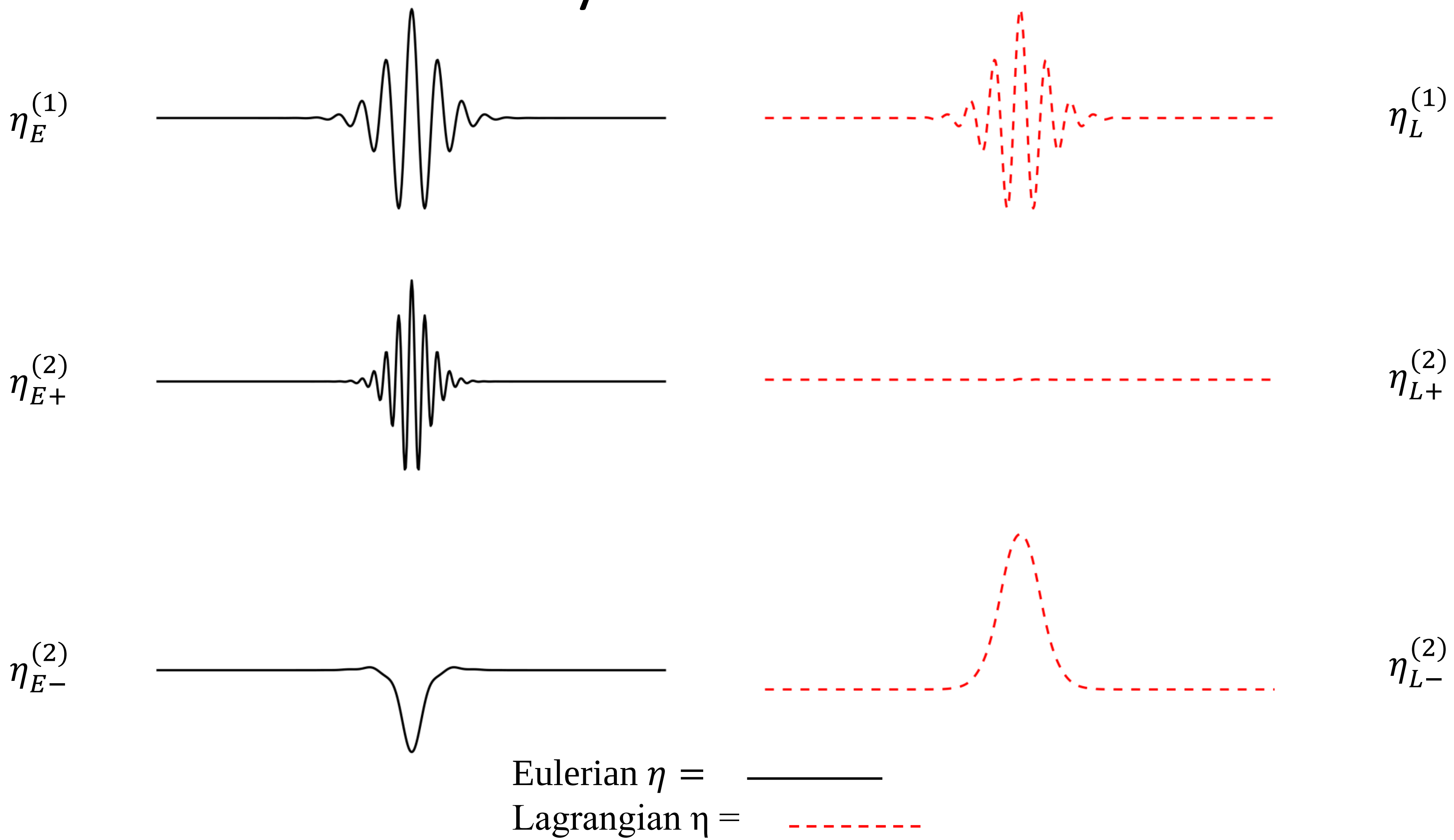
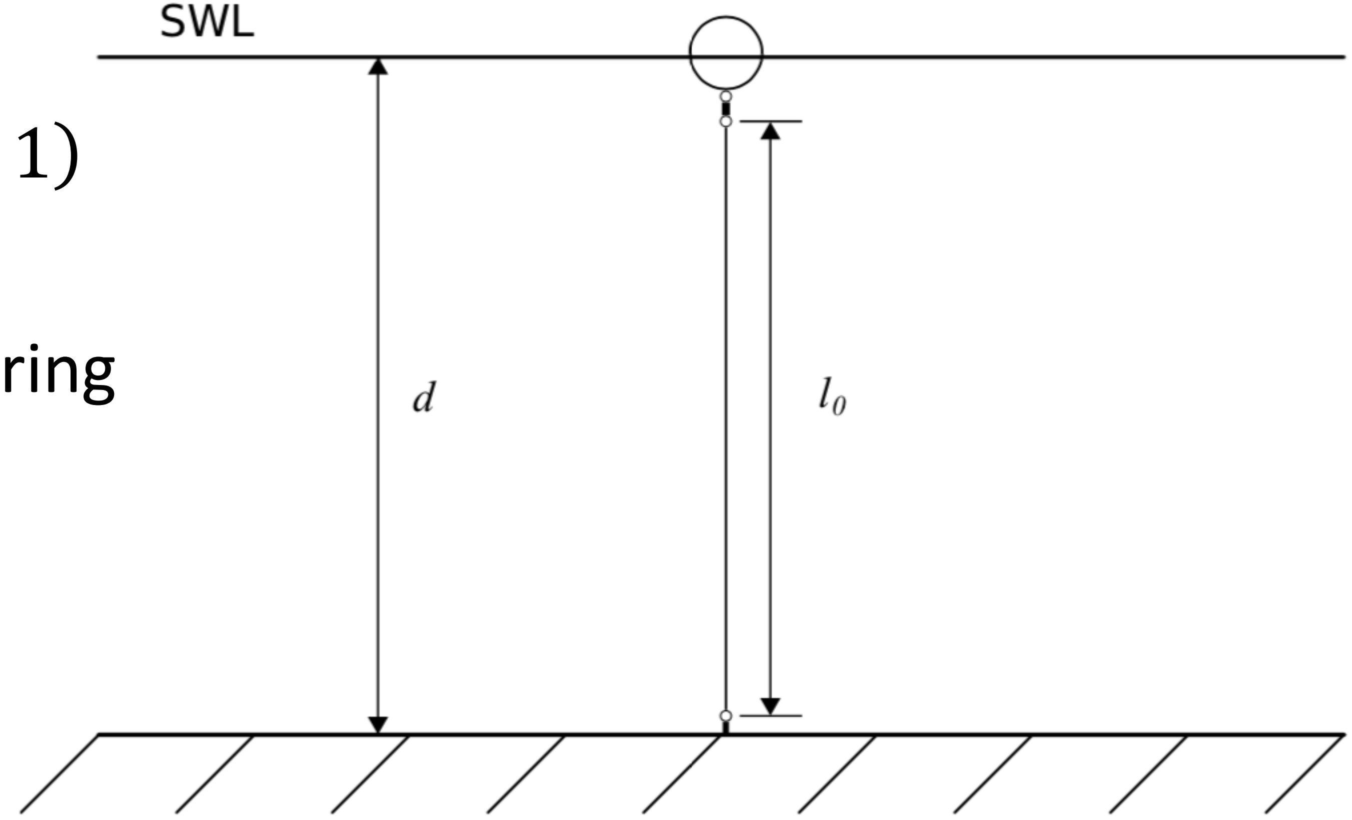
Second-Order Motion of a Wave-Following Measurement Buoy

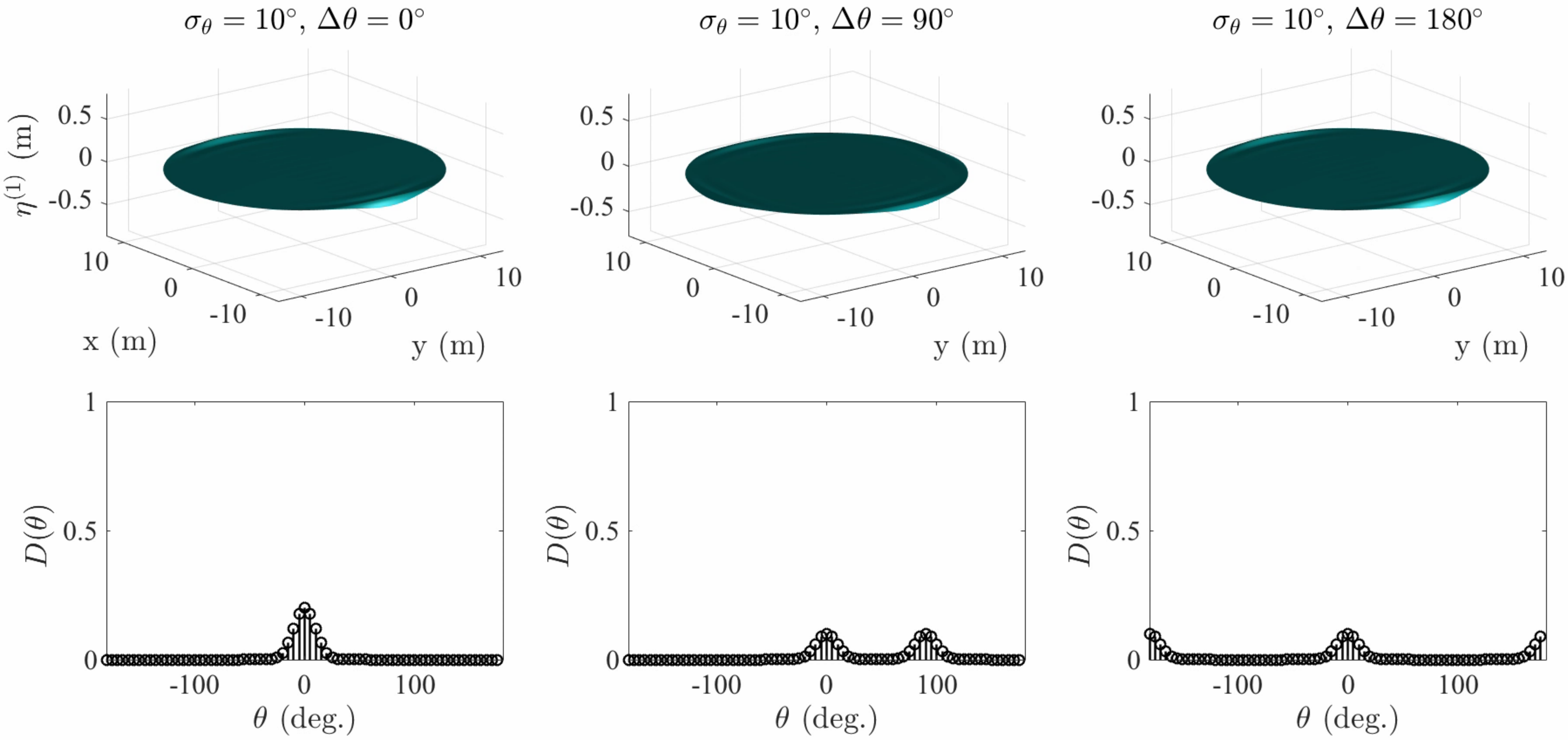


Second-Order Motion of a Wave-Following Measurement Buoy

- Diameter 0.07m ($D/\lambda_0 \ll 1$)
- Density $\approx 0.5\rho_w$
- Highly-flexible taught mooring
- Depth 2 m ($k_0 d = 3 - 4$)
- Wave amplitude ≈ 0.2 m ($k_0 a_0 / k_p H_s \approx 0.3$)



Second-Order Motion of a Wave-Following Measurement Buoy



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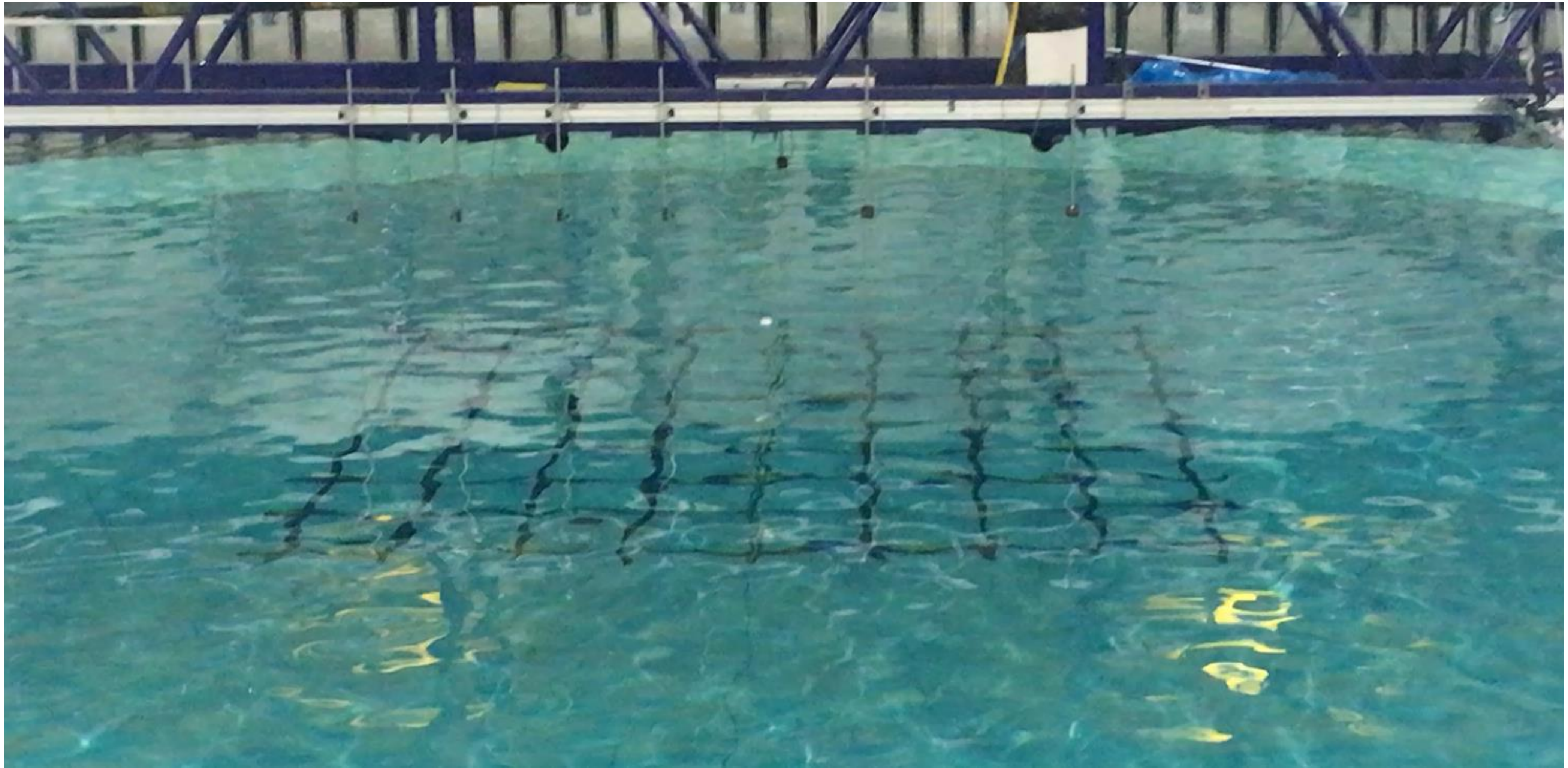

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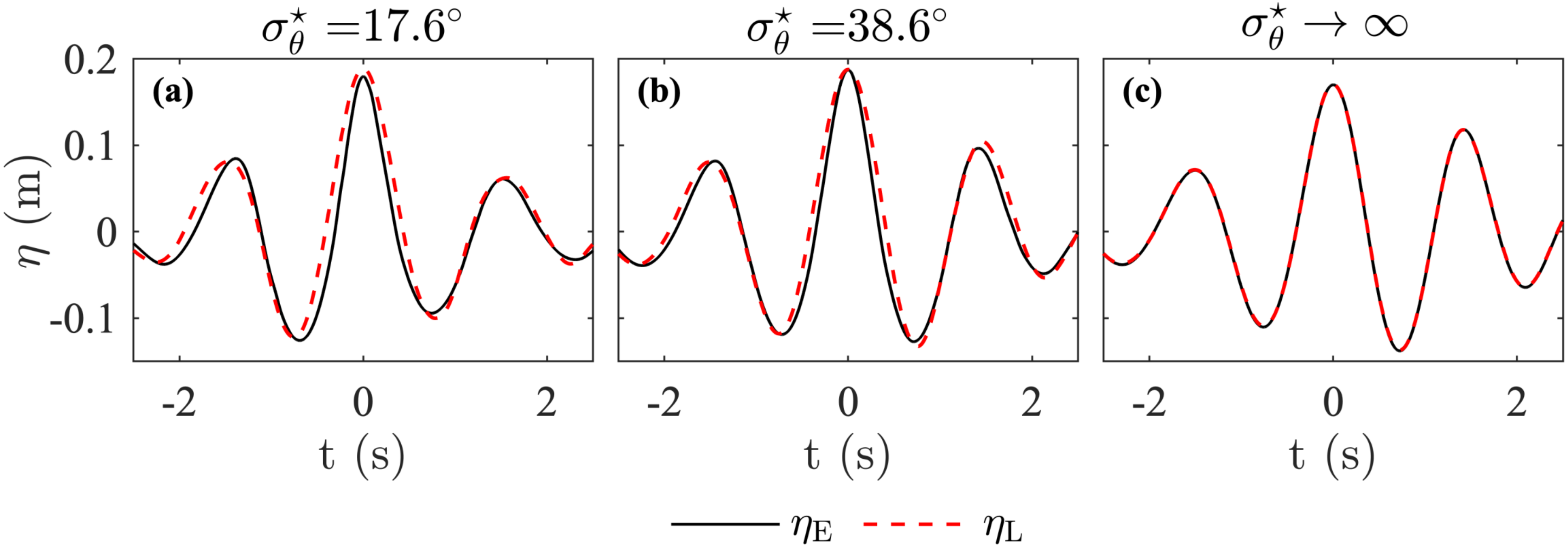

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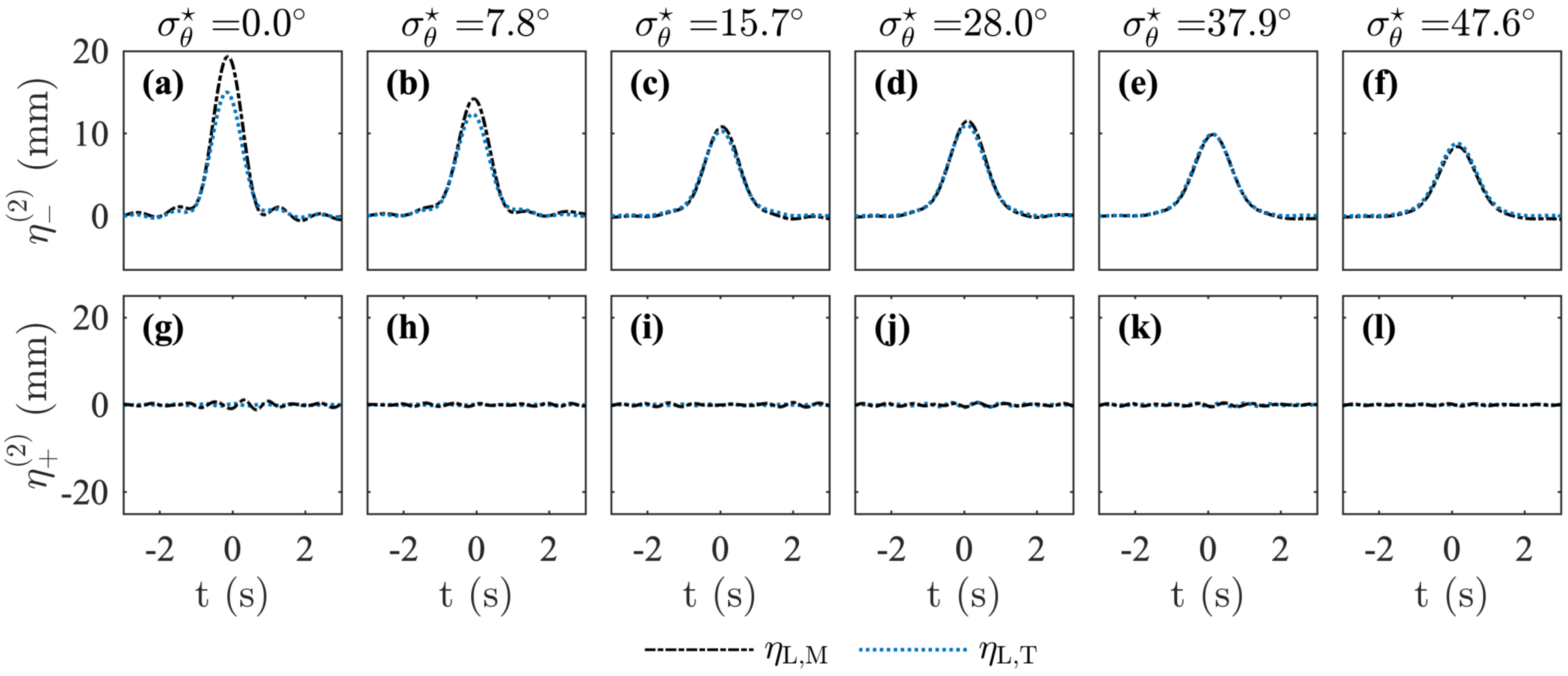
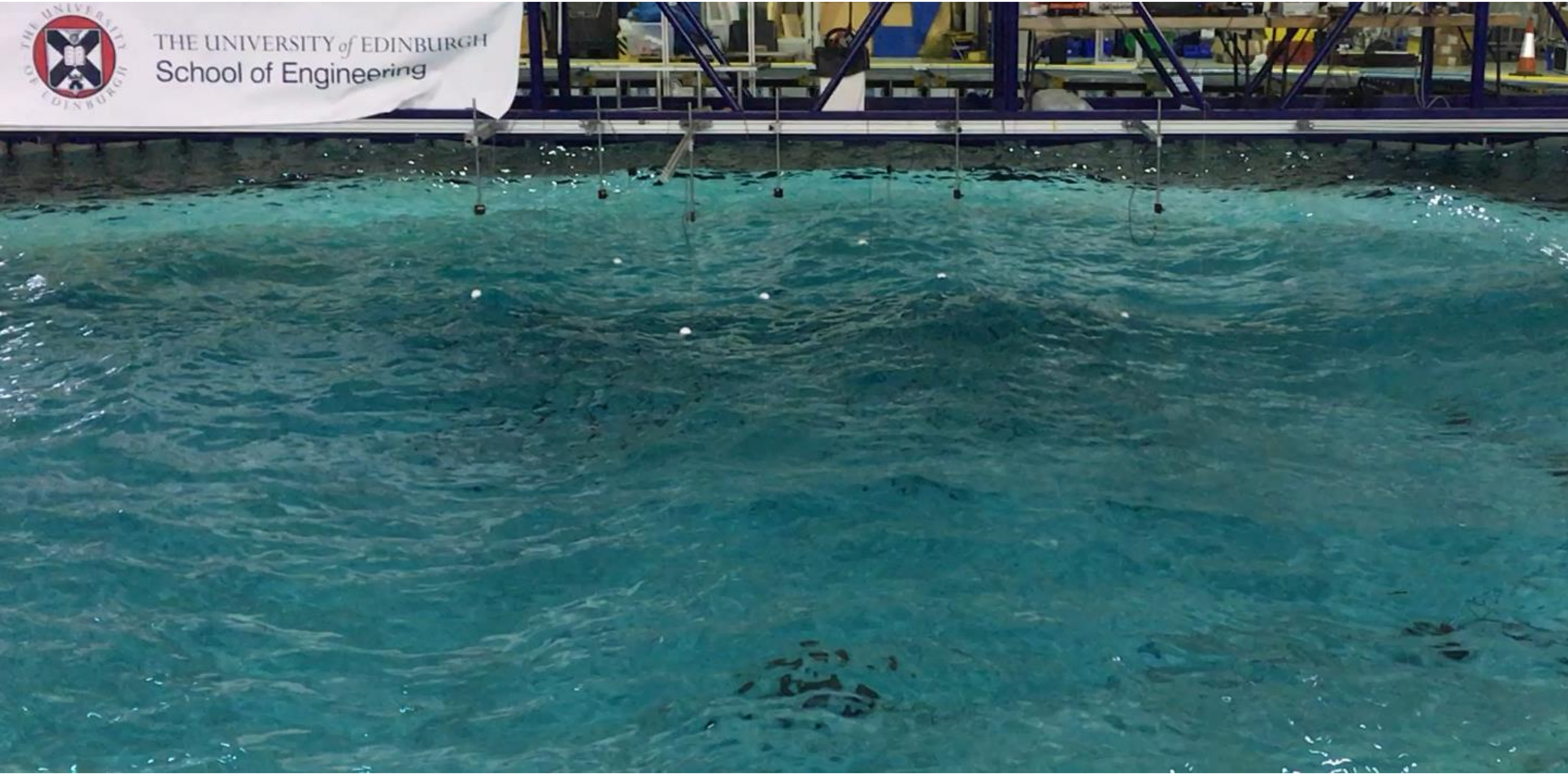
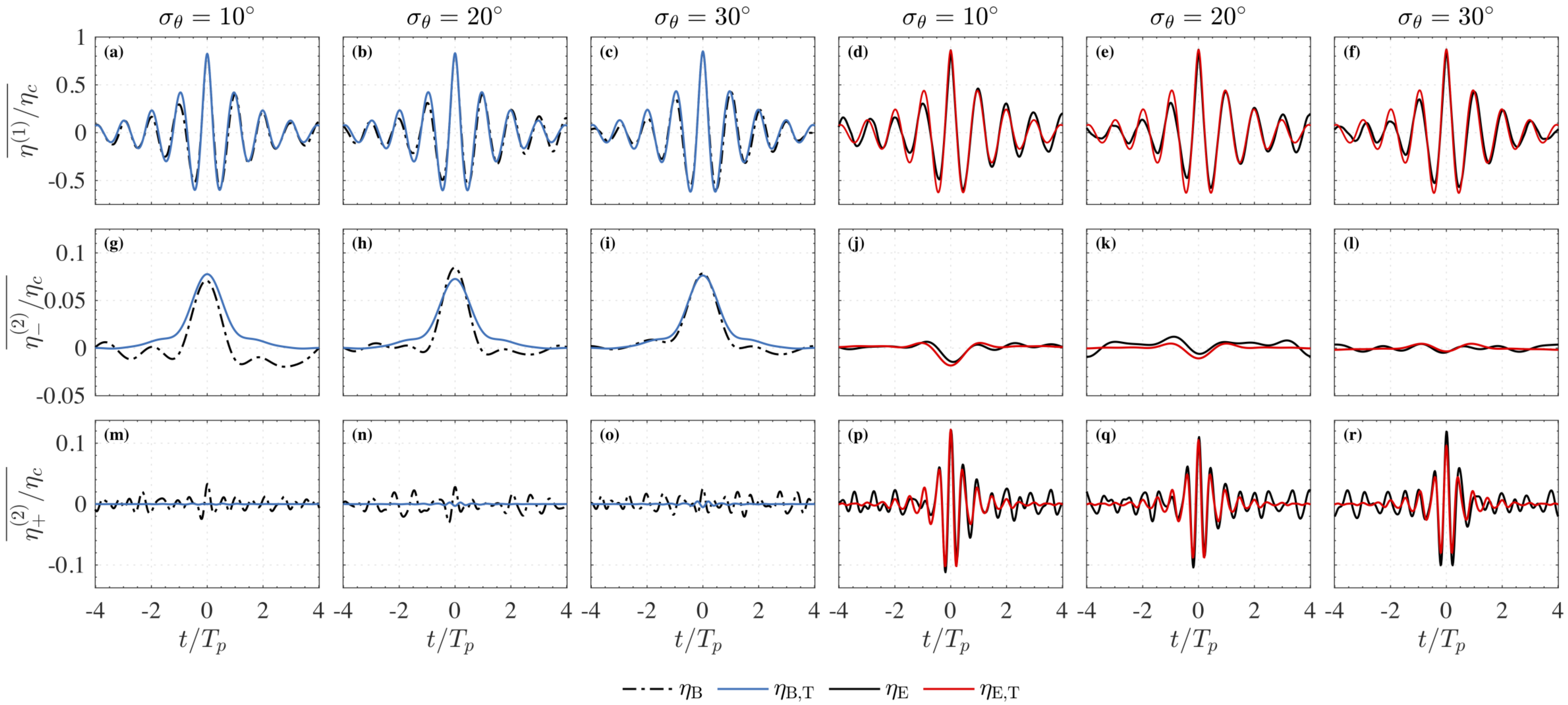



THE UNIVERSITY of EDINBURGH
School of Engineering

Statistical Properties of Directionally Spread Ocean Waves Measured by Buoys



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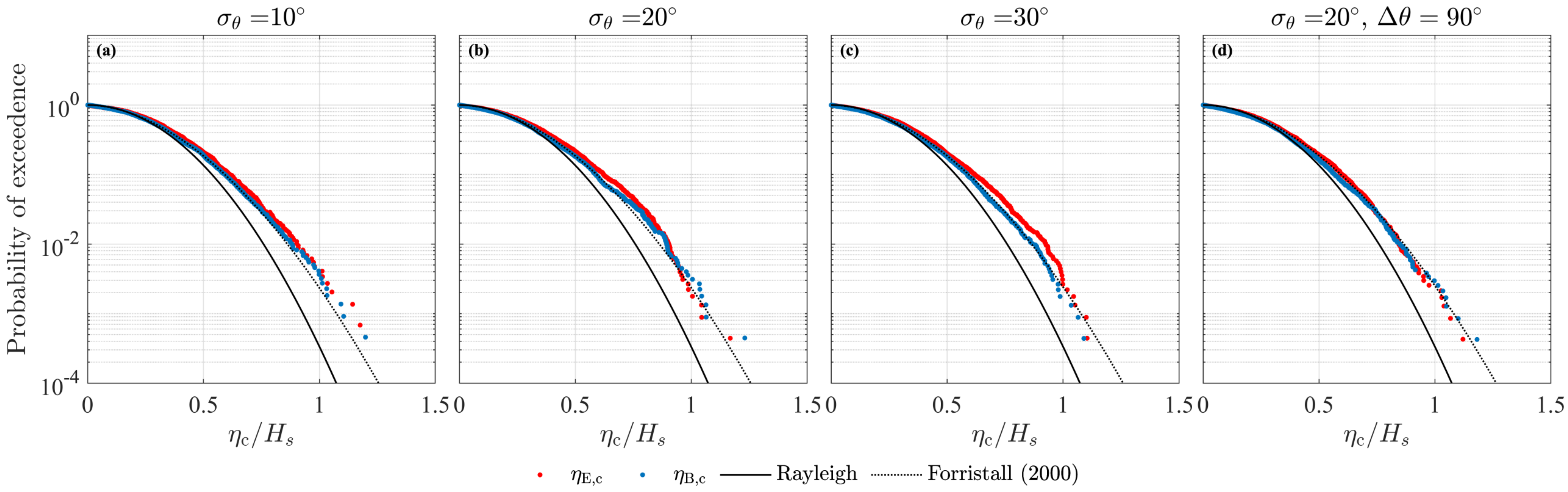

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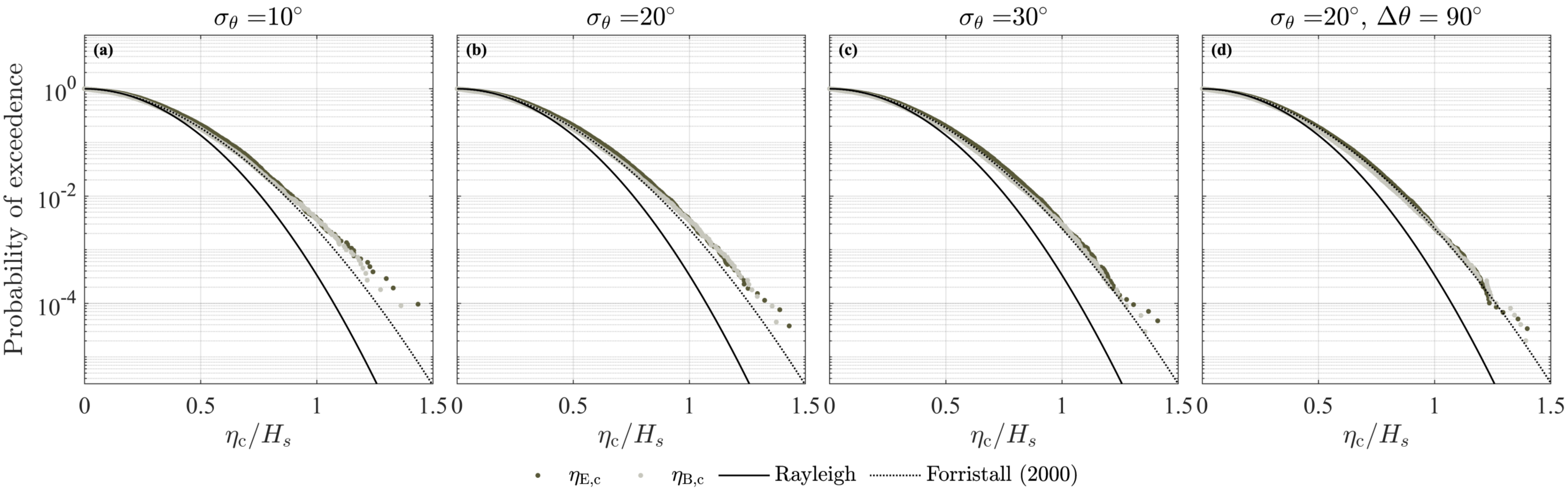
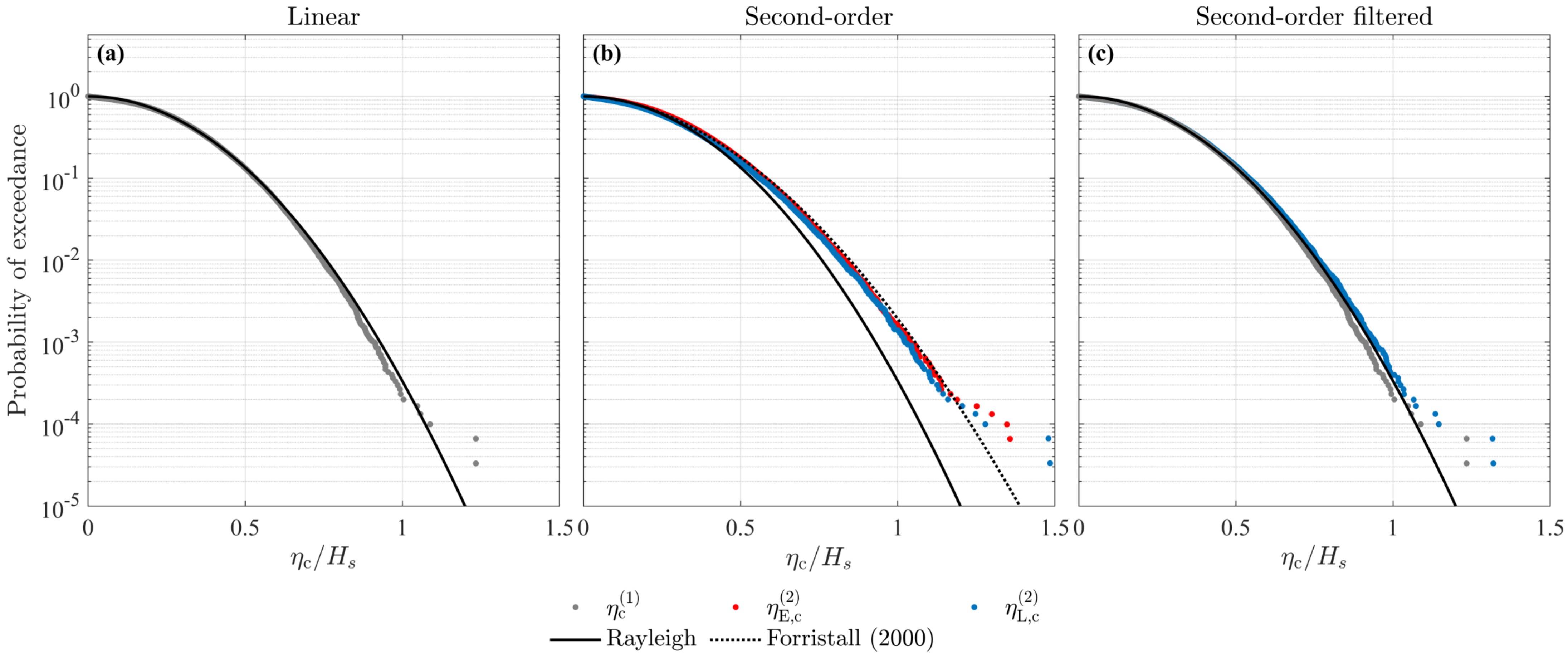


Approximate retrospective correction method for crest heights



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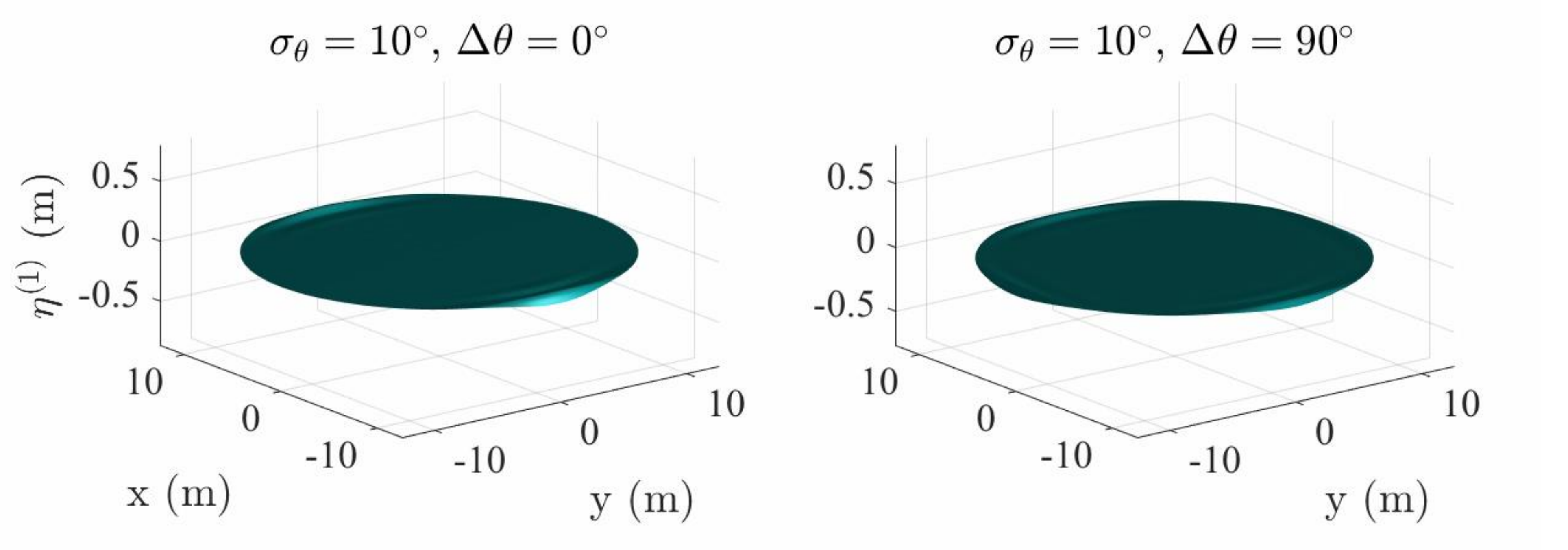
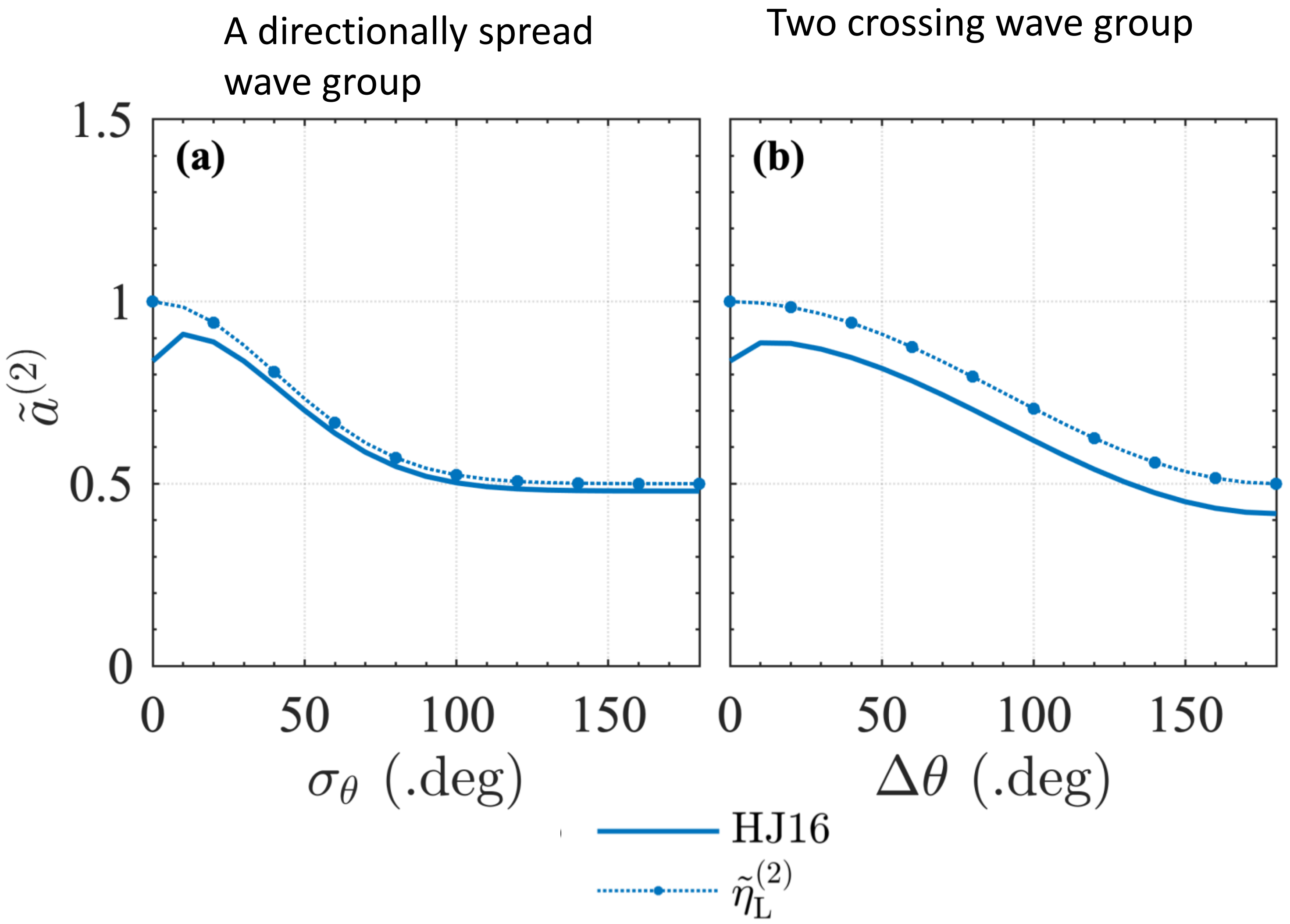


$$\tilde{\eta}^{(2)}(\sigma_\theta) = \frac{1}{2}\left(1 + e^{-\sigma_\theta^2}\right)$$

$$\tilde{\eta}^{(2)}(\Delta\theta) = \frac{1}{2} + \frac{1}{4}(1 + \cos(\Delta\theta))$$

Approximate retrospective correction method for crest heights



Approximate retrospective correction method for crest heights

$$\eta_c \approx \eta_c^{(1)}$$

$$\eta_{Corr,c} = \eta_c + \eta_{c-}^{(2)}$$

Approximate retrospective correction method for crest heights

$$\eta_c \approx \eta_c^{(1)}$$

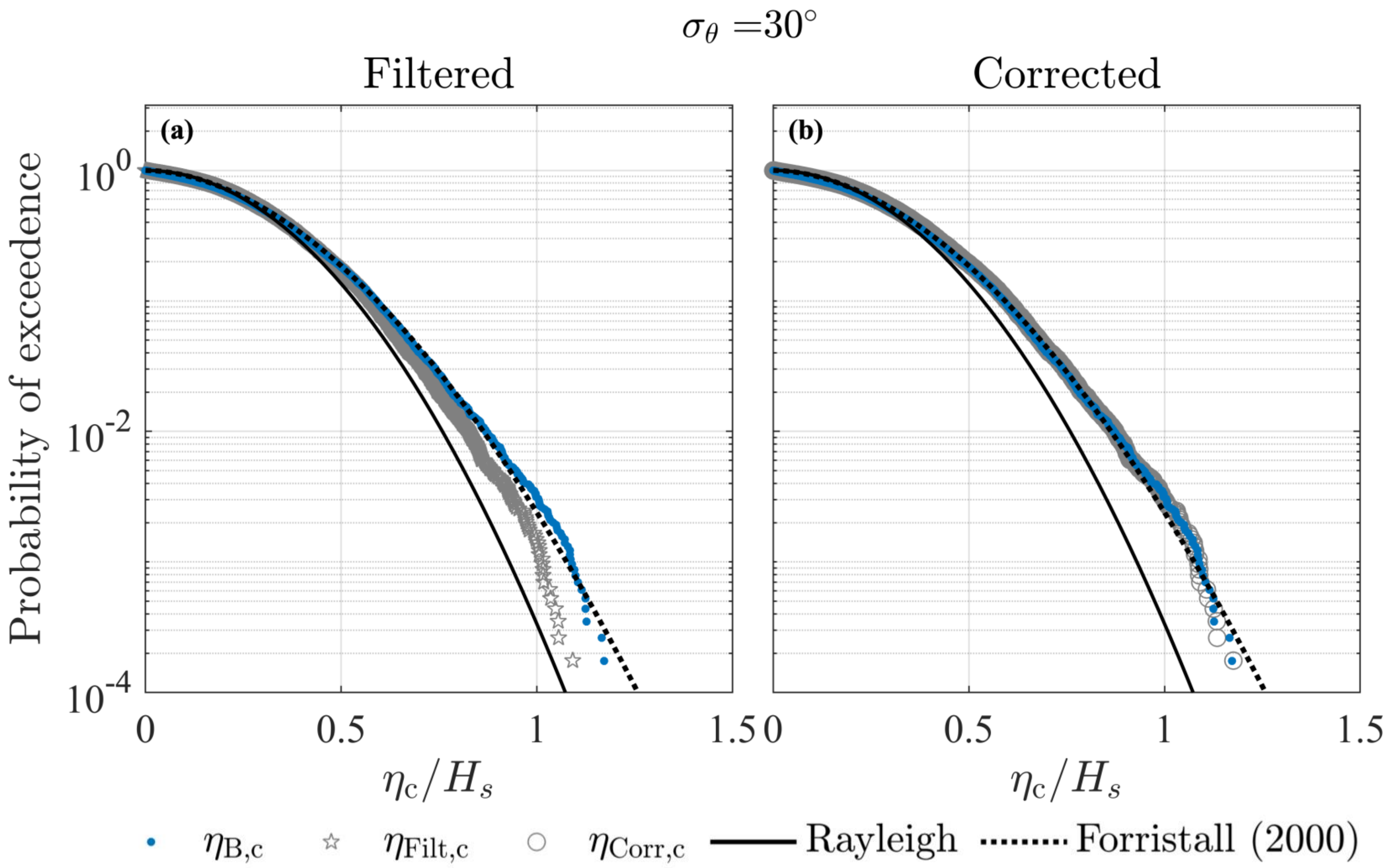
$$\eta_{Corr,c} = \eta_c + \eta_{c-}^{(2)}$$

$$\eta_{c-}^{(2)} = \frac{1}{2}(\eta_c)^2\, k_0 \tilde{\eta}^{(2)}(\sigma_\theta, \Delta\theta)\left(1 - \varepsilon_{hpf}\right)$$

$$\tilde{\eta}^{(2)}(\sigma_\theta) = \frac{1}{2}\left(1 + e^{-\sigma_\theta^2}\right)$$

$$\tilde{\eta}^{(2)}(\Delta\theta) = \frac{1}{2} + \frac{1}{4}(1 + \cos(\Delta\theta))$$

Approximate retrospective correction method for crest heights



Conclusions

- In deep water (ocean waves), second-order Lagrangain motion causes the cancelation of super-harmonic (sigma theta -> 0) and an increase in sub-harmonic contribution to crest height
- O(2) effects alone will not result in a change to crest height, however, this constitutes a shifting of bound energy from low to high
- For deterministic extreme (non breaking) wave groups buoy motion is essentially purely Lagrangian

- Spectral parameters (Hs, Tp. Etc.) are not significantly different between buoys and gauge measurements
- Filtering slightly affects measured Hs, and significantly reduces measured skewness λ^3
- Wave and crest height measured by buoys and gauges follow the same distributions

- Simplified expressions for second-order contribution to crest height can be used to retrospectively correct measurements and remove the effects of filtering

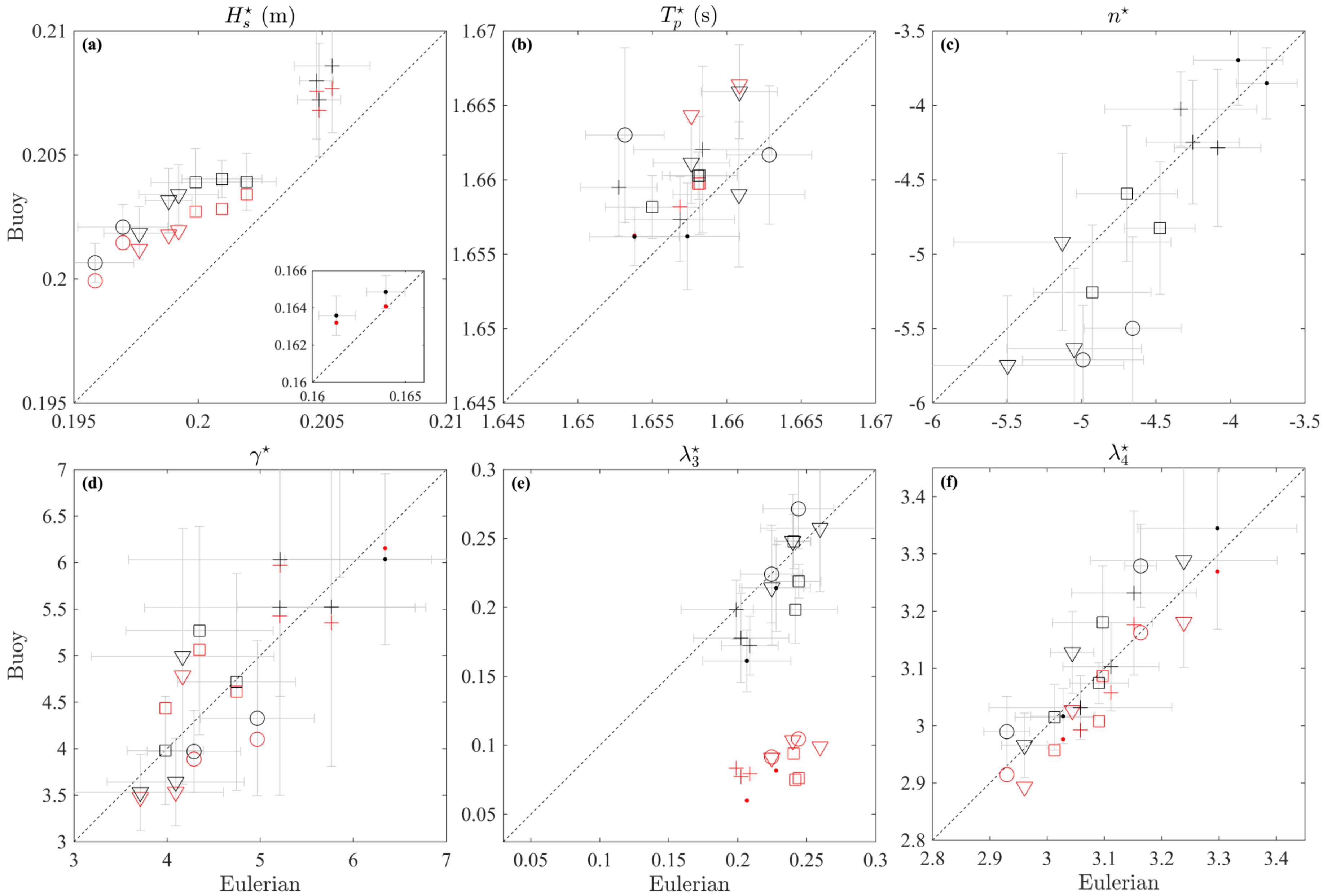
- These experiments do not consider a realistic mooring configuration, however, if a lack of mooring compliance was to cause an underestimation of crests we believe this would also affect measured wave heights

Thanks for your attention!

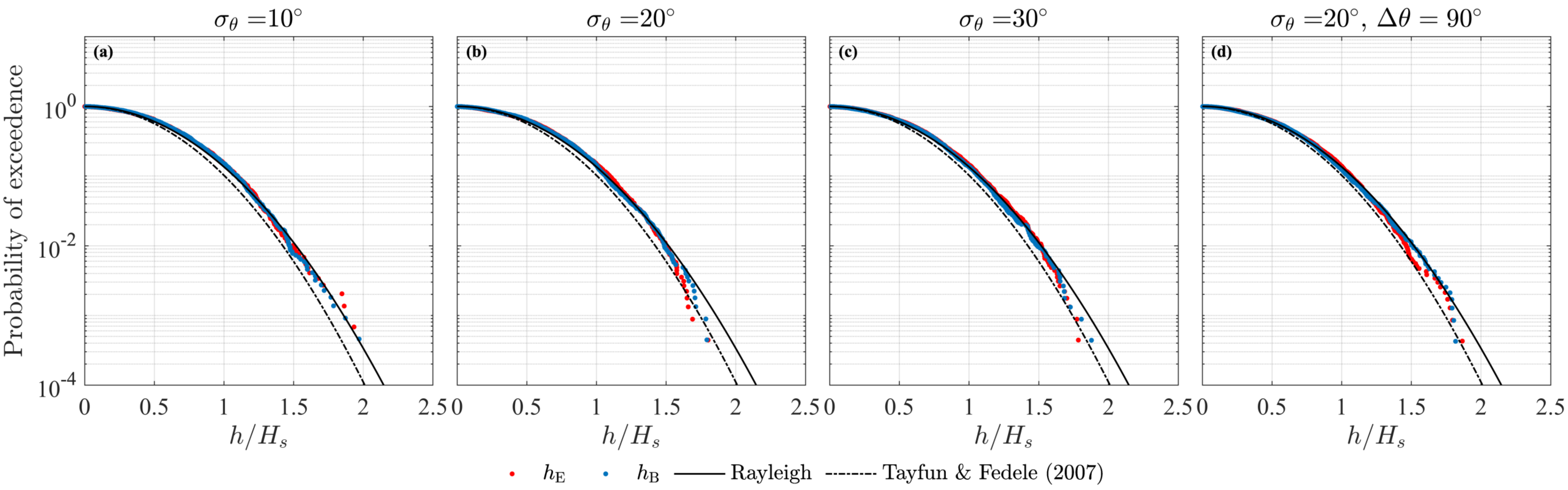
1. M. L. McAllister, and T. S. van den Bremer “Lagrangian Measurement of Steep Directionally Spread Ocean Waves: Second-Order Motion of a Wave-Following Measurement Buoy” **J. Phys. Oceanogr. (in press)**
2. M. L. McAllister, T. S. van den Bremer “Experimental Study of the Statistical Properties of Directionally Spread Ocean Waves Measured by Buoys” **J. Phys. Oceanogr.** (under review)

Photo credit: CDIP

Spectral Parameters

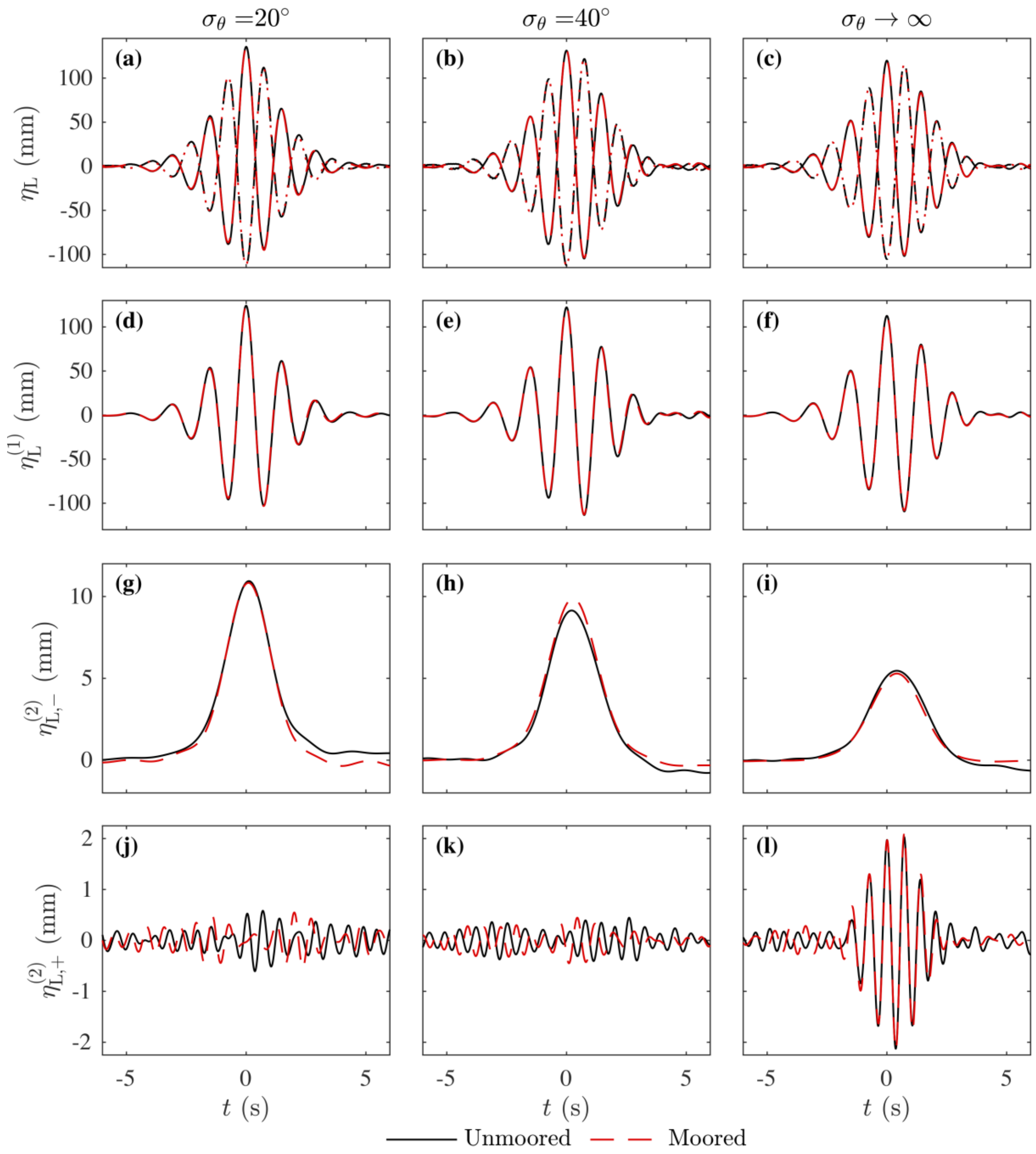


Wave height



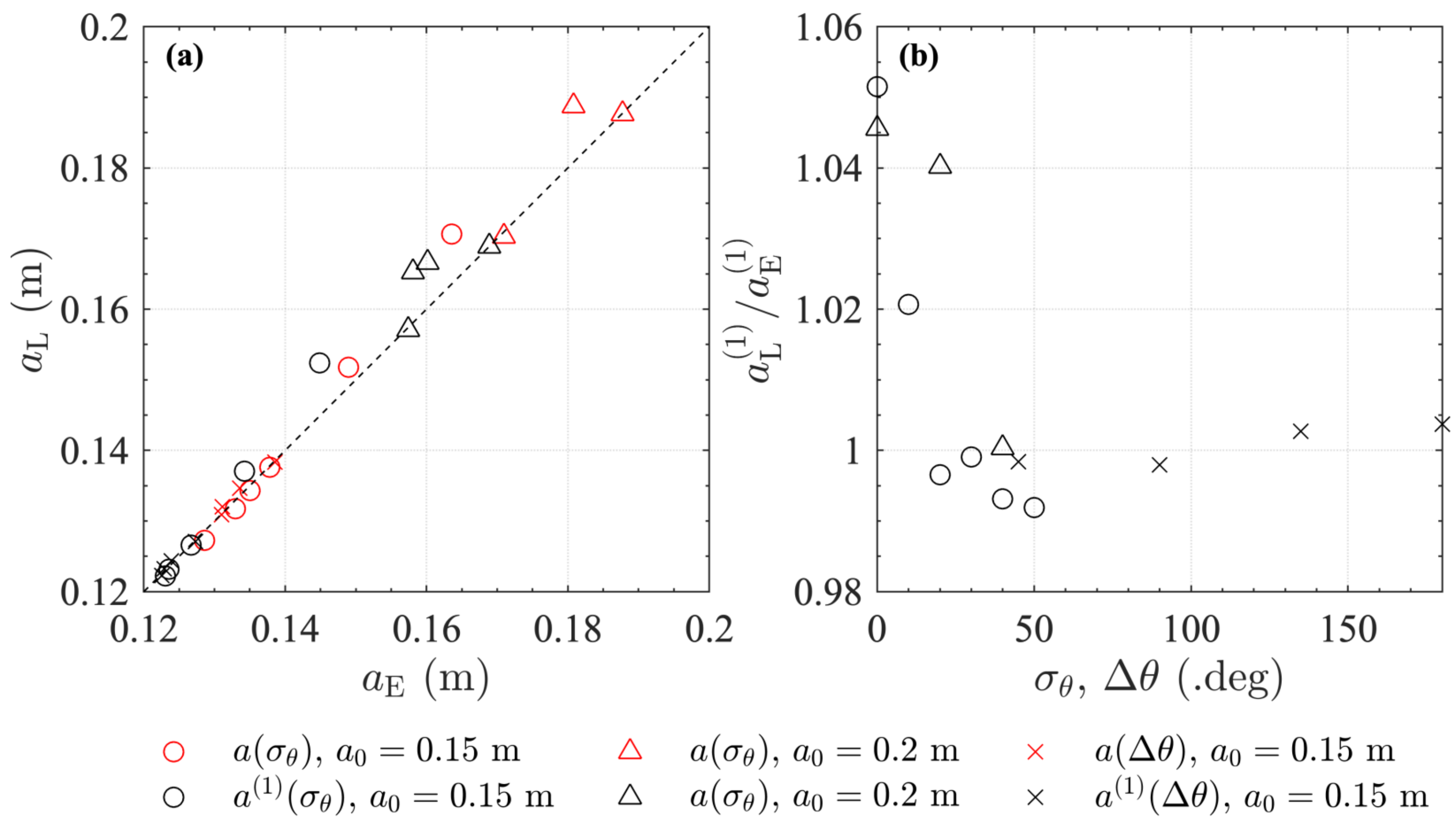
$\sigma_\theta = 10^\circ$
$\sigma_\theta = 20^\circ$
$\sigma_\theta = 30^\circ$
$\sigma_\theta = 20^\circ,\ \Delta\theta = 90^\circ$
(a)
(b)
(c)
(d)
Probability of exceedence
10^0
10^{-2}
10^{-4}
0 0.5 1 1.5 2 2.5
h/H_s
h_E
h_B
Rayleigh
Tayfun & Fedele (2007)

Mooring

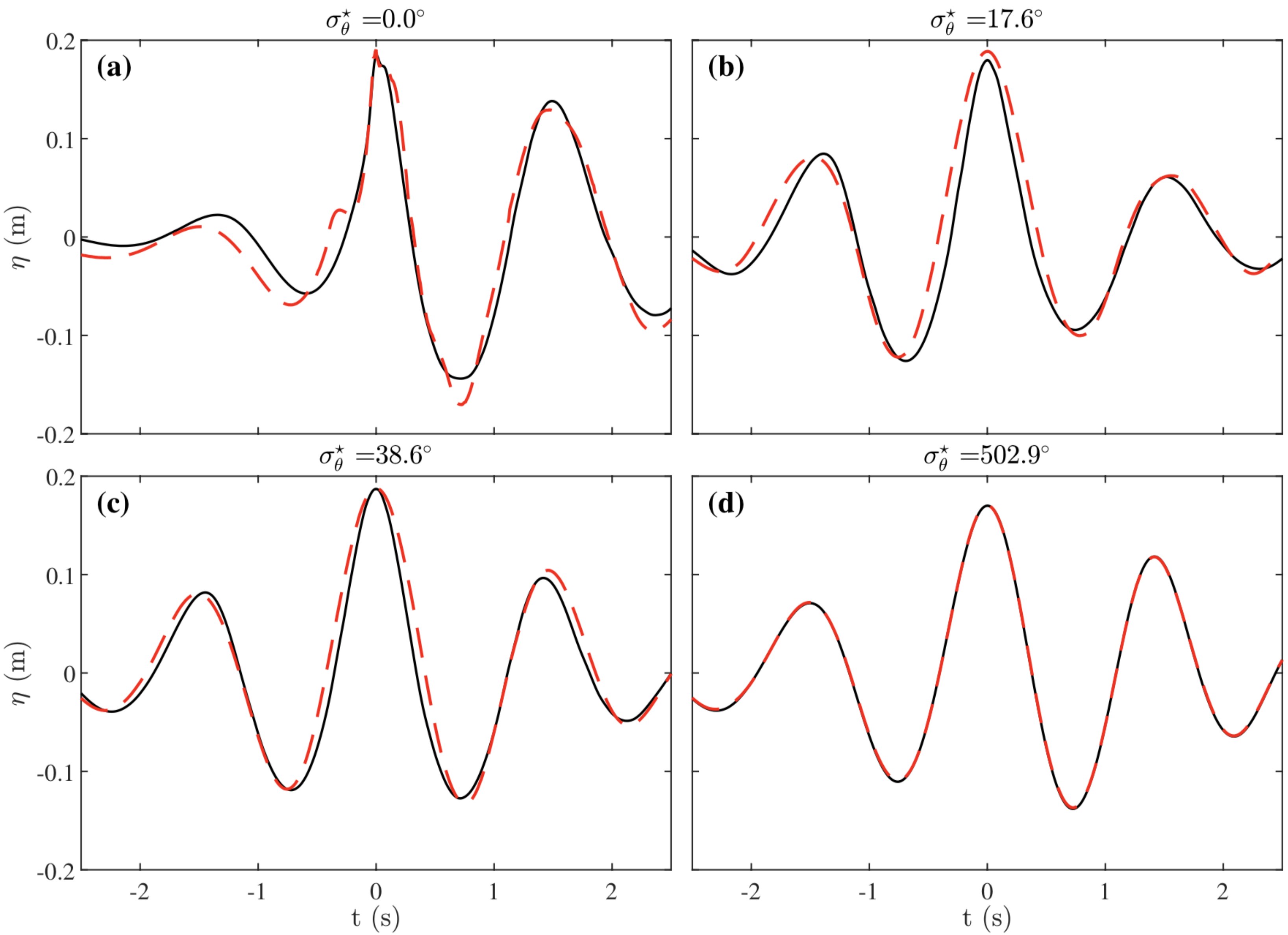


$\sigma_\theta = 20°$
$\sigma_\theta = 40°$
$\sigma_\theta \to \infty$
(a)
(b)
(c)
(d)
(e)
(f)
(g)
(h)
(i)
(j)
(k)
(l)
η_L (mm)
$\eta_L^{(1)}$ (mm)
$\eta_{L,-}^{(2)}$ (mm)
$\eta_{L,+}^{(2)}$ (mm)
100
50
0
-50
-100
10
5
2
1
-1
-2
-5
t (s)
Unmoored
Moored

Amplitude/Period



Breaking waves



Frequency attenuation