Towards a better description of sea states

Susanne Støle-Hentschel

Ecole normale supérieure Paris-Saclay
Centre Borelli

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- Load characterization for ship and offshore industry
- Exchange of energy and momentum between atmosphere and ocean

Motivation II – Coastal processes

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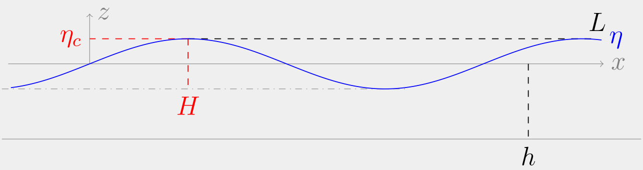
- Mixing of bacteria, nutrients



$$\nabla^2 \Phi = 0 \qquad -h < z < \eta(x,t)$$

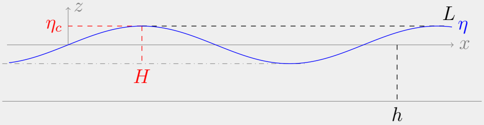
$$\Phi_z = 0 \qquad \text{at } z = -h$$

$$\Phi_z - \eta_t - \Phi_x \eta_x = 0 \qquad \text{at } z = \eta$$

$$\eta + \frac{1}{2g}\left(\phi_x^2 + \phi_y^2\right) + \frac{1}{g}\phi_t = 0 \qquad \text{at } z = \eta$$

$$\Phi_x(0,z,t) = \Phi_x(L,z,t), \eta_x(0,t) = \eta_x(L,t) \qquad -h < z < 0$$

Following Svendsen, I. A. (2005). Introduction to nearshore hydrodynamics (Vol. 24). World Scientific Publishing Company.



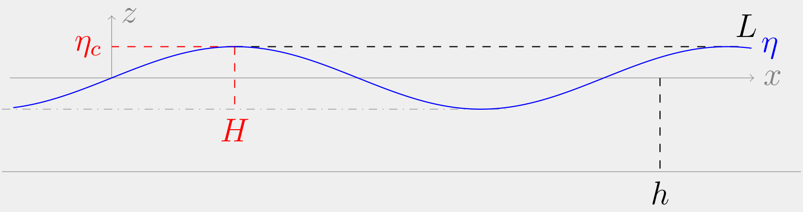
$$\epsilon = H/L \qquad \epsilon \ll 1$$

H waveheight

L wavelength

$$\Rightarrow \Phi_z - \eta_t \qquad \text{at } z = \eta$$

$$\eta + \frac{1}{g}\phi_t = 0 \qquad \text{at } z = \eta$$



Taylor approximation of potential, neglecting higher order terms just as for ϵ

$$\begin{aligned}\Phi_z(x,\eta,t) &= \Phi_z(x,0,t) + \eta\Phi_{zz}(x,0,t) + \cdots \\ &= \Phi_z(x,0,t) - \eta\Phi_{xx}(x,0,t) + \cdots\end{aligned}$$

Solution

$$\eta = a\cos(\theta)$$

$$\Phi = ac\frac{\cosh k(z+h)}{\sinh kh}\sin(\theta)$$

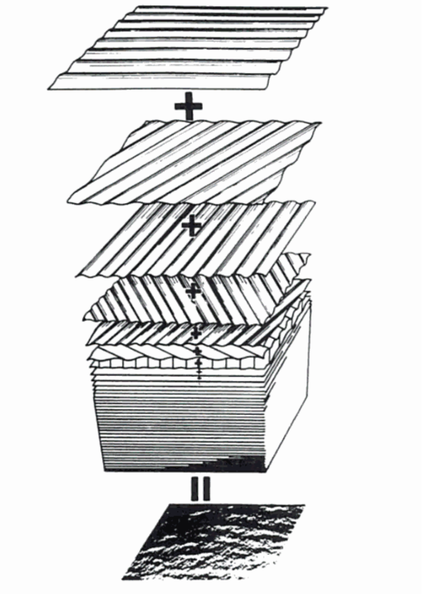
with

$\theta = \omega t - kx$	phase of the wave
ω	angular frequency
k	wave number
$c = \frac{\omega}{k}$	phase speed (= crest speed)
a	wave amplitude

Dispersion relation:

$$\omega = \sqrt{gk\tanh(kh)}$$

The sea surface in oceans can often be represented by a superposition of infinitely many waves of different waves, amplitudes, and phases oriented in different directions. Higher order solutions are also studied numerically.



Sampling variablity

Swell and wind sea

Wave breaking

- Current research topic
- Detection of wave breaking by remote sensing (dissipation, onset of breaking)

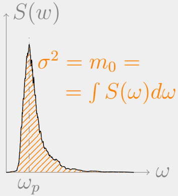
Obtaining wave statistics from measurements

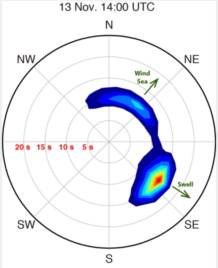
Significant wave height H_s

- 4σ, standard deviation
- Traditionally the mean of the highest third of the waves

Spectra with Directional distribution

- Peak Period
- Mean wave direction
- Directional spreading





- Satellite microwave radars
- Ground-based HF radars
- Buoys
- ADCPs (Acoustic Doppler current profilers)
- Radar altimeter
- Nautical Radars

- Floates on the waves
- Most trusted wave height measurement device in open ocean (error: 0.5%η)
- Wave direction
- Surface current
- Point measurement
- Suspected to underestimate extreme waves

Acoustic Doppler current profilers (ADCPs)

- Common in-situ sensors for oceanic currents
- Provide three-dimensional current vectors for the whole water column
- Can reside on the bottom for many days and provide long time series
- Not well suited for surface current measurements (wave motion causes large errors)

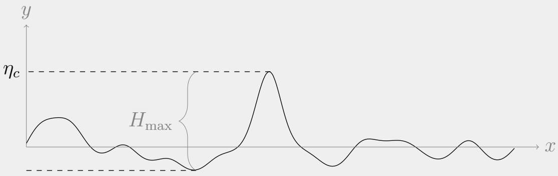
- Instrument deployment and retrieval can be difficult and time consuming
- Data of bottom-mounted devices are not immediately accessible for near-real time analsyis

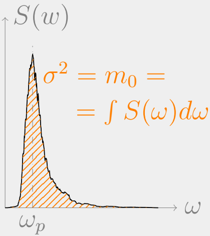
[Romeiser et al., 2002]

Extreme waves in crossing seas

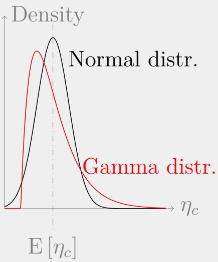
Large number of accidents in crossing seas

- Analysis of ship accidents shows large number occurred in crossing seas Toffoli et al. [2005]
- Speculations about increased amount of freak waves in crossing seas
- Hydrodynamic laboratory allows study of counter-propagating and following sea states



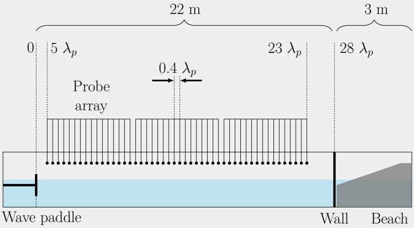


- Wave height H_{max}
- Crest height η_c
- Significant wave height $H_s = 4\sigma$
- Probability distributions, exceedance, kurtosis

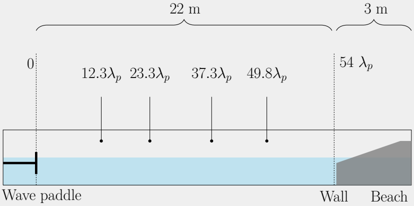


Criteria for freak waves

$$H_{max}/H_s > 2, \quad \eta_c/H_s > 1.25$$



Counterpropagating

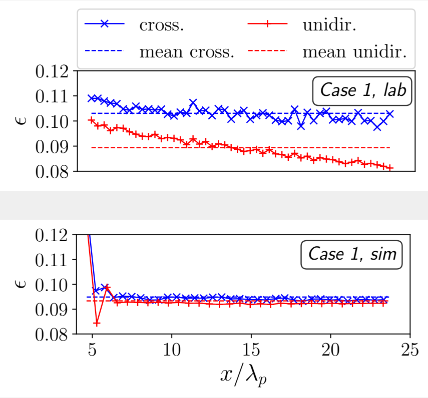


Following

- The wave maker generated random waves according to given spectra
- The amplitudes were chosen such that wave breaking would not affect the results

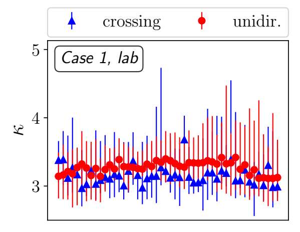
- Open source code HOS-NWT developed by Bonnefoy et al. [2009] and Ducrozet et al. [2012].
- Higher order spectral method with a numerical wavemaker and a numerical beach

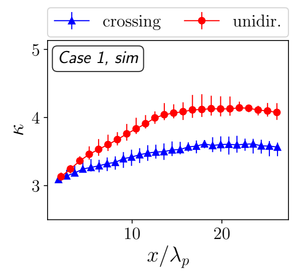
Significant waveheight H_s for JONSWAP waves



- The steepness in crossing seas is not well defined
- Special case with the same peak wavelength and separation angle of 180°
-

$$\{\epsilon(x), \overline{\epsilon}, \overline{\epsilon_r}, \overline{\epsilon_l}\} = \\ = \frac{k_p}{\sqrt{8}} \{H_s(x), \overline{H_s}, \overline{H_{sr}}, \overline{H_{sl}}\}$$

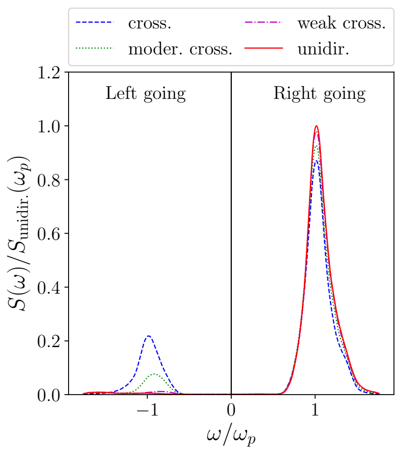


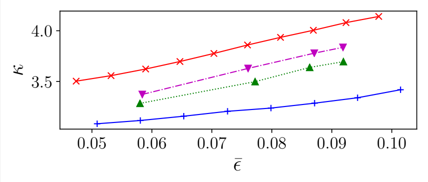


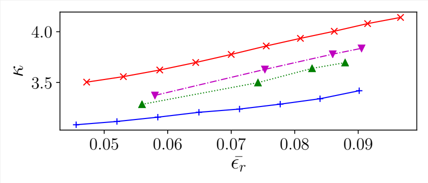
- The kurtosis of unidirectional waves is higher
- The kurtosis of reflected waves is lower

Average kurtosis

for different degrees of reflection



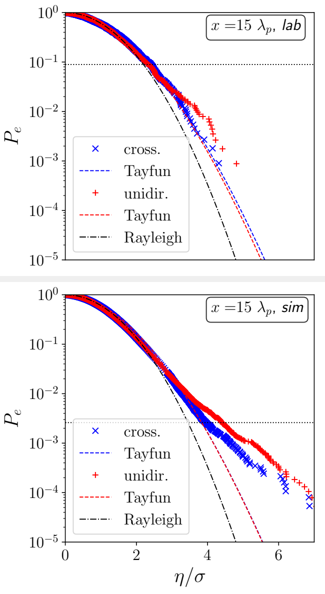




- The kurtosis is reduced by the reflection.
- A minor reflection has a strong effect.

Exceedance probability

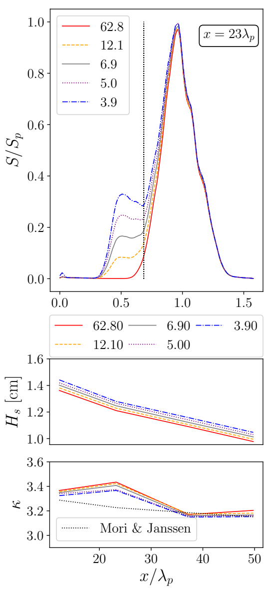
of crest height



- Too little data in the laboratory
- Both cases show more extreme waves than second order Tayfun
- Counter-propagating waves appear to reduce the amount of extreme waves

Torsethaugen spectra and statistics

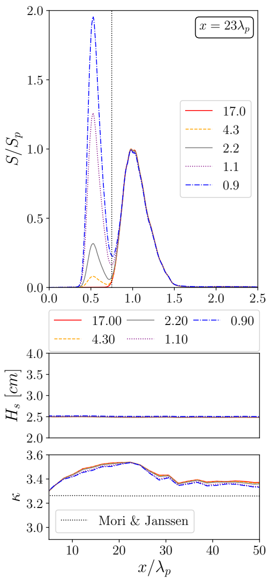
along the laboratory tank



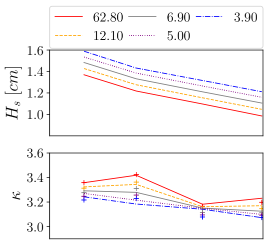
- Windsea waves have behave similarly with and without swell present
- Decay of H_s attributed to dissipation (short waves)
- Results in decrease of κ
- Comparison to Mori and Janssen [2006].

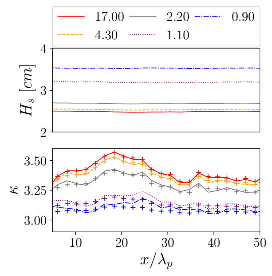
Ochi & Hubble spectra and statistics

for the numerical simulation



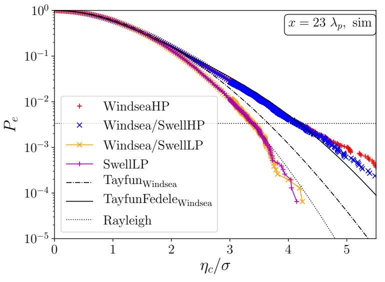
- Windsea waves have behave the same with and without swell present
- Windsea spectra are almost identical
- Comparison to Mori and Janssen [2006].



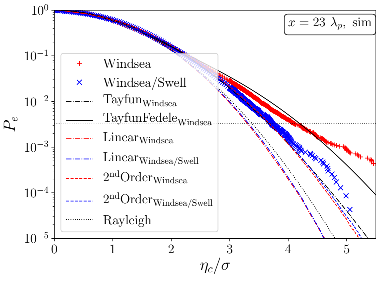


- Assuming windsea (*W*) and swell (*S*) are independent, κ of the combined sea states (*SW*) is

$$\kappa_{\mathrm{SW}} = \frac{\kappa_{\mathrm{S}}\sigma_{\mathrm{S}}^4 + 6\sigma_{\mathrm{S}}^2\sigma_{\mathrm{W}}^2 + \kappa_{\mathrm{W}}\sigma_{\mathrm{W}}^4}{(\sigma_{\mathrm{S}}^2 + \sigma_{\mathrm{W}}^2)^2}$$



- The swell and windsea have the same probability distributions if they are simulated together or alone.

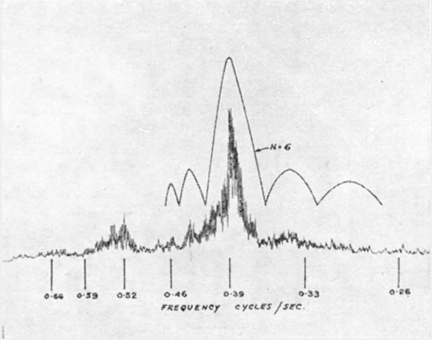


- The analysis of the combined sea state gives the impression of a weakly nonlinear sea state since it gives the average between a linear and a nonlinear system.

Conclusion of crossing sea analysis

- Established representation of sea states is not adequat for defining warning criteria
- In addition to the shown problems in multi-modal seas NON-STATIONARY is not taken into account

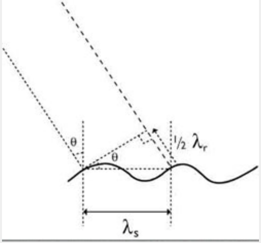
Wave observations with radars



- Crombie [1955] observed two peaks of different amplitude symmetrically placed around the carrier frequency f_c
- The peaks must result from different targets
- The spikes are discrete hence the targets must move with constant velocity

Crombie's core observation

"Waves act as diffraction gratings" [Crombie, 1955]

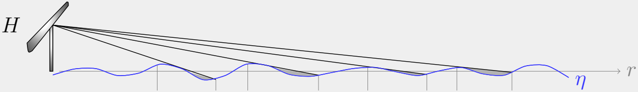


- William Henry Bragg and Lawrance Bragg
- Nobel price in physics in 1915
- Determined crystal structures
- Surprising reflection patterns from X-ray

Bragg's law

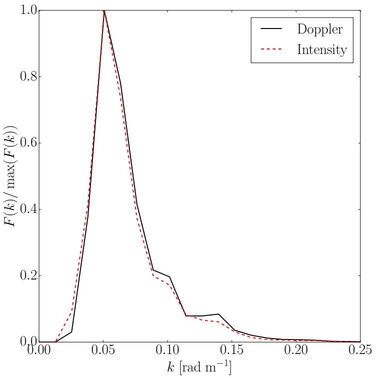
$$\lambda_s = \frac{n\lambda_r}{2\sin(\theta)}$$

- Different path lengths for different backscattering positions
- Backscattered waves are generally not in phase
- Backscatter in phase gives, amplitudes add coherently, makes a target visible

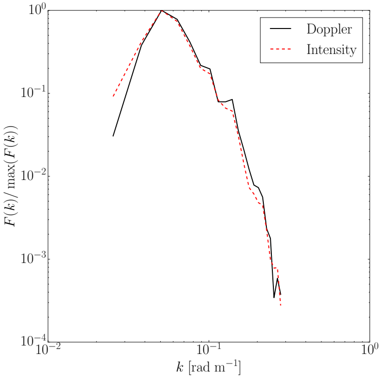


- Installed for navigation on all vessels
- Usually X-band, electromagnetic wavelength of few centimeters
- Rotating antenna collecting data in azimuth successively
- Backscatter gives image spectrum, requires a transformation to wave spectrum
- Shadowing plays an important role
- Mainly used for estimating wave spectra and directionality distributions
- Average current estimate

Spectral comparison after applied MTF

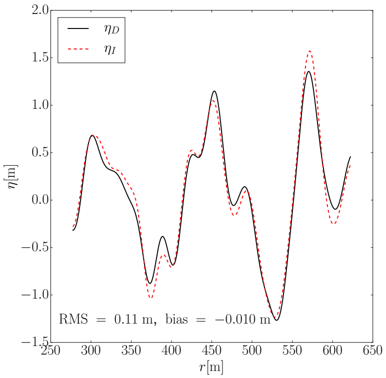


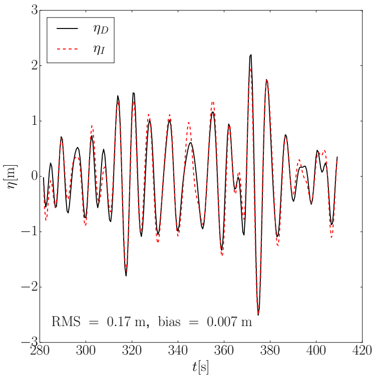
Normal scale



Log scale

Surface reconstruction

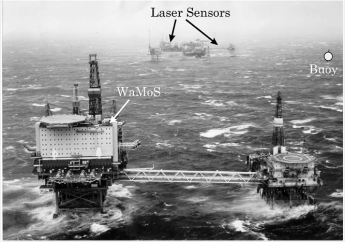




Project collaborators and plan

Head of Division for Oceanography and Marine Meteorology at The Norwegian Meteorological Institute
Professor II in Physical oceanography

My scientific work is motivated by the potential for observing systems and forecast models to improve safety and reduce the environmental impact of human activities at sea.

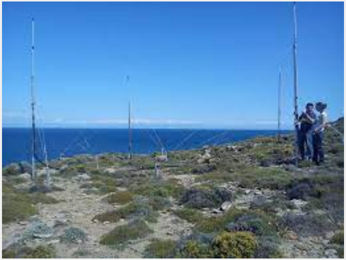


Head of the department of Radar Hydrography
Institute of Coastal Research
Helmholtz-Zentrum Hereon, Germany.

- FINO3 plattform
- Core competence coherent X-band radars
- Complementary measurements (Wind, Current, etc.)

Professor
School of Mechanical Engineering, Tel Aviv University, Israel
Affiliation with TU Hamburg

- Water waves and their interactions with the sea bottom, currents and winds
- Remote sensing of waves and surface currents



Meital Geva

Senior lecturer
Head of Wave Dynamics Laboratory at the School of Mechanical Engineering, Tel Aviv University, Israel

- Study Generation of waves by wind
- Shear flow instability
- Turbulent Boundary Layer
- Wind-Wave flume

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