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A numerical study of nonlinear wave interactions

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Objective

Nonlinear triad interactions redistribute energy which:

- Transforms the shape of sea-swell waves (SS, f = 0.05 - 2 Hz)
- Generates energy at infragravity frequencies (IG, f = 0.005 - 0.05 Hz)

IG waves are found to be important in the erosion of beaches and dunes during storms. Recently, it has been suggested that IG waves may loose energy by:

- Transferring it back to (former) SS spectral peak
- IG-IG transfers that cause IG waves to steepen and to eventually break

Here, we investigate energy transfer patterns for different types of beaches, using the model SWASH.

Model validation

Governing equations of SWASH are the non-linear shallow water equations and account for non-hydrostatic pressure (Zijlema et al. 2011). We validated (Figure 1) SWASH using the high-resolution, small-scale, Globex lab dataset with a 1:80 sloping beach (Ruessink et al. 2013).

- Onset of SS wave breaking and dissipation amount captured well
- IG wave height increase and arrest in good agreement
- IG dissipation slightly overestimated

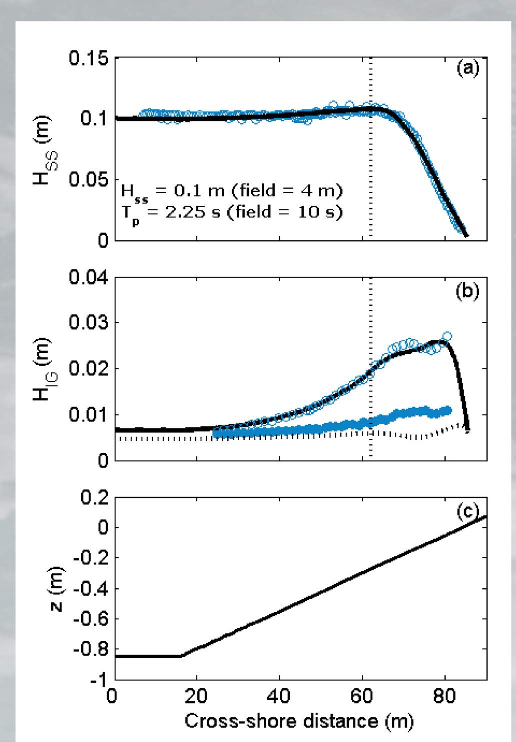
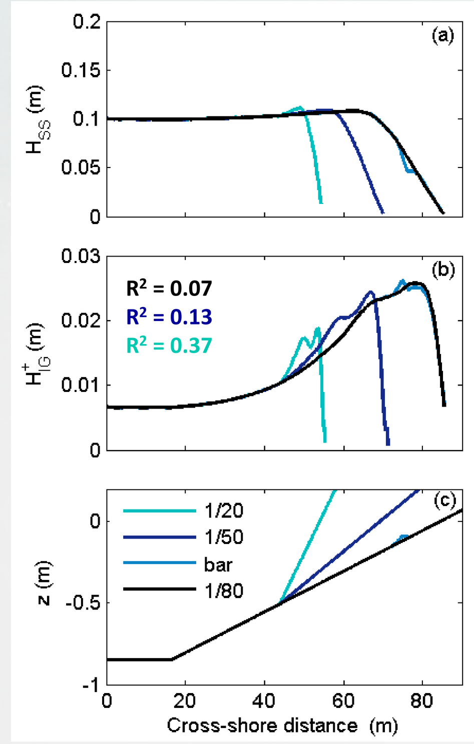


Figure 1: Measured (dots) and modelled (lines) significant wave height H_s versus cross-shore distance x, for (a) SS waves and (b) incoming (circles) and outgoing (dots) IG waves.

Variable bathymetries

We use SWASH to simulate wave propagation over a low (1/80), mild (1/50) and steep (1/20) sloping beach, and a 1/80 beach with a sandbar, with H_s = 0.1 m, and T_p = 2.25 s.



- Low slope, strong IG wave growth, low R^2
- Steep slope, weak IG wave growth, high R^2

Figure 2: (a) H_{SS} and (b) H_{IG}. Panel (c) shows corresponding bottom profiles. Reflection R^2 in inner surf (h = 5 cm). Sand bar dimensions correspond to Δh = 70 cm, Δx = 80 m, h = 1.80 m in the field.

- Low slope, IG frequencies dominate inner surf zone
- Steep slope, SS frequencies dominate inner surf zone

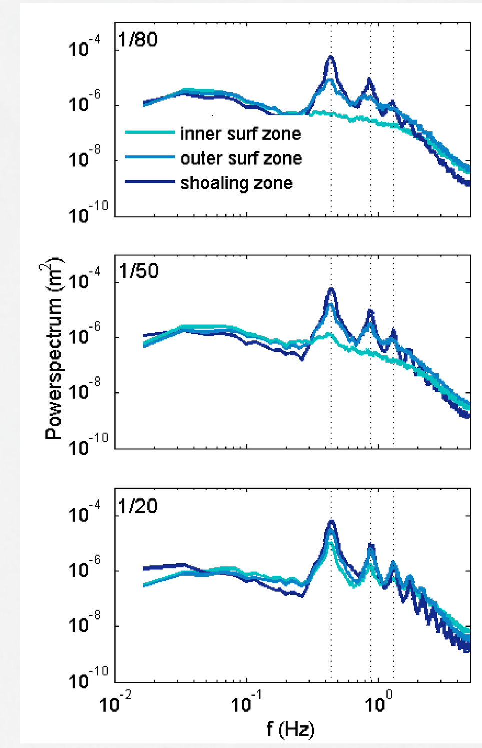
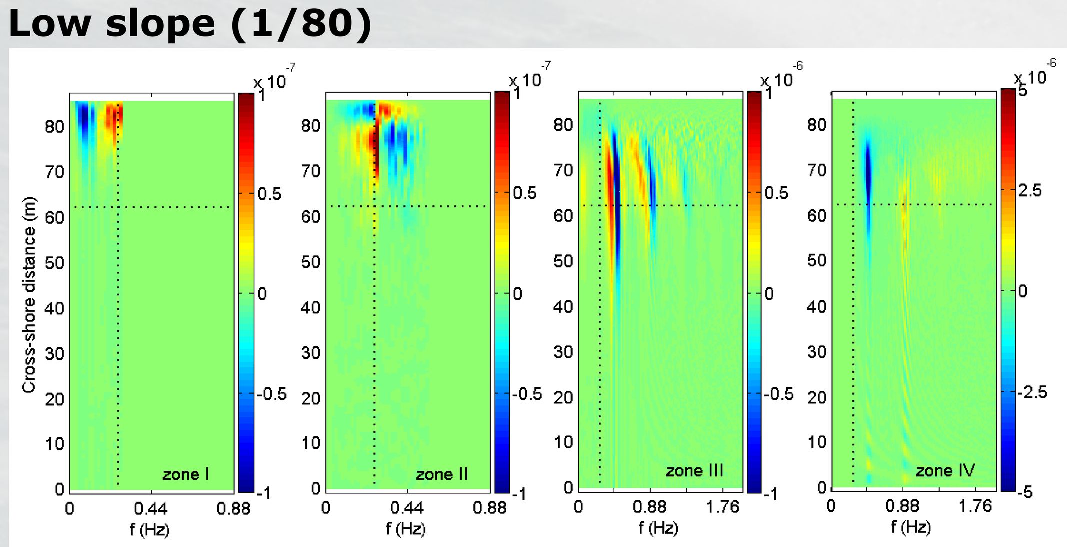


Figure 3: Powerspectra in shoaling (h = 25 cm), outer surf (h = 12.5 cm) and inner surf zone (h = 5 cm) for the three beach types. Vertical lines indicate offshore power spectral peak (0.44 Hz) and its first (0.88 Hz) and second (1.32 Hz) harmonic.

Energy transfers

The nonlinear source term S_{nl} accounts for energy transfers to and from a frequency f. S_{nl} is estimated by integrating the product of the imaginary part of the bispectrum and a coupling coefficient following Herbers et al. 2000. Figure 5 shows the S_{nl} term for each of the four bispectral zones as defined in the box *'Bispectral analysis'*, for the 1/20 and 1/80 slopes.

Low slope (1/80)



Steep slope (1/20)

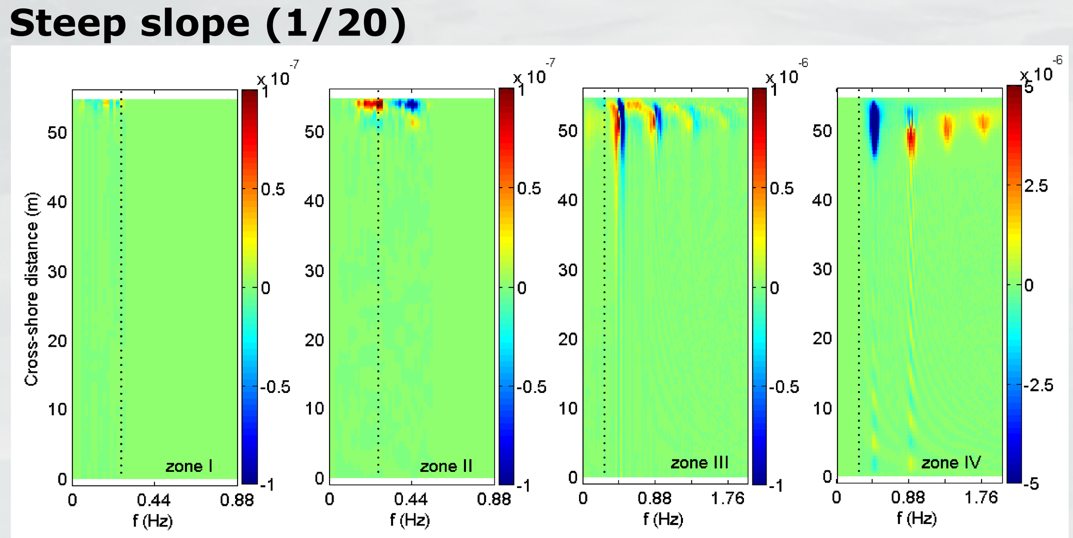


Figure 5: S_{nl} terms plotted versus f and x. Vertical dashed line is the cut-off between IG and SS frequencies. Horizontal dashed line is the edge of the surf zone.

Inner surf zone

Low slope

- Transfers involving two or more IG frequencies dominate (I,II)
- Energy cascades from low to high IG frequencies and 'harmonics' (I,II,III)

Steep slope

- Transfers involving two or more SS frequencies dominate (III, IV)
- IG interactions are weak, small transfer/loss

Sandbar

At bar locally stronger transfers, shoreward of the bar weaker transfers

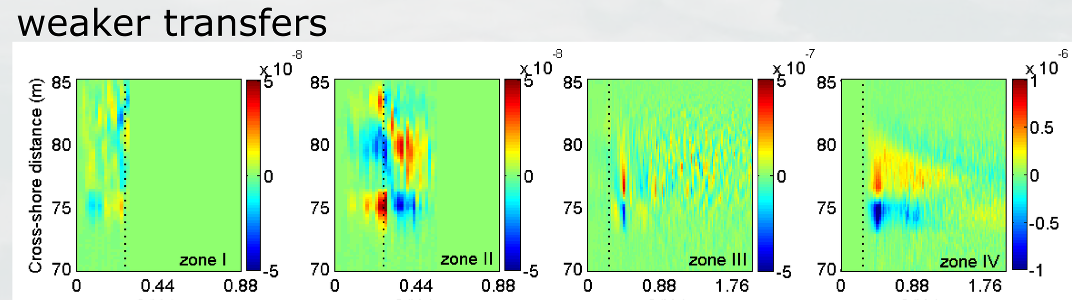


Figure 6: Difference in S_{nl} of bar minus non-barred 1/80 slope, plotted versus f and x.

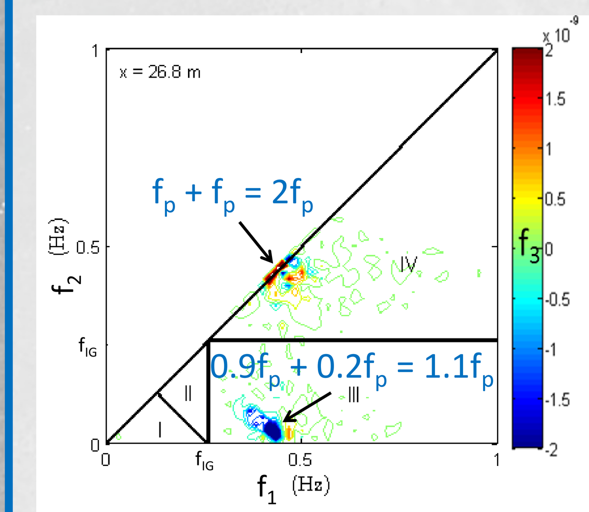
Bispectral analysis

The bispectrum $B_{f1,f2}$ detects phase-coupling between frequency components in a triad. The discrete bispectrum is defined as,

$$B_{f_1,f_2} = E[A_{f_1} A_{f_2} A^*_{f_1+f_2}]$$

$E[]$ ensemble average
A complex Fourier coefficients
$*$ complex conjugation

To obtain insight in the different triad interactions, four zones are defined, for which nonlinear energy transfers are calculated.



Zone I	**IG-IG-IG**
Zone II	**IG-IG-SS**
Zone III	**IG-SS-SS**
Zone IV	**SS-SS-SS**

Figure 4: The imaginary part of the bispectrum at x = 26.8 m.

Conclusions

- **Low slope enhances IG wave growth. IG interactions dominate in shallow water, resulting in IG energy loss.**
- **Steep slope limits IG wave growth and thereby IG interactions, resulting in less IG energy loss.**
- **At a sandbar locally stronger transfers, this is compensated by weaker transfers shoreward of the bar.**

Outlook

- Other wave conditions
- Other bar dimensions, concave/convex beach shapes

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References Herbers, T.H.C. et al., 2000. Spectral energy balance of breaking waves within the surf zone. J. Phys. Ocean. 30, 2723-2737. Zijlema et al., 2011. SWASH: An operational public domain code for simulating wave fields and rapidly varied flows in coastal waters. Coast. Eng. 58, 992-1012. Ruessink et al. 2013. Coastal Dynamics conf., 2013. GLOBEX: Wave dynamics on a gently sloping laboratory beach