

An investigation into edge-wave generation by wind

EGU General Assembly, 19–30 April 2021

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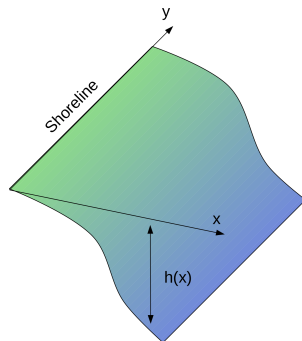
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Linear Edge waves on a cylindrical beach (1)

- x = cross-shore, y = alongshore, $h = h(x)$.
- SWE for velocity potential $\varphi(x, y, t)$

$$\varphi_{tt} + (c^2 \phi_x)_x + c^2 \varphi_{yy} = 0; \quad c = \sqrt{gh}.$$
- With $\varphi(x, y, t) = F(x, k)e^{i(ky - \omega t)}$,
 $F(x, k)$ satisfies the differential equation

$$(c^2 F_x)_x + (\omega^2 - c^2 k^2) F = 0, \quad (1)$$
- Solutions of equation (1) determined by boundary conditions.



Cylindrical beach

Linear edge waves on a cylindrical beach (2)

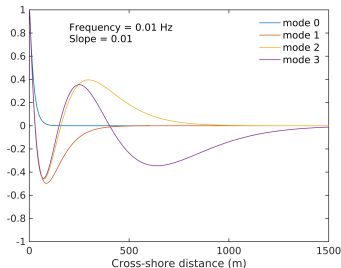
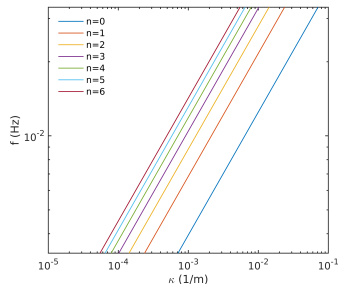
- Equation (1) with edge-wave BCs

$$(c^2 F_x)_x + (\omega^2 - c^2 k^2) F = 0, \quad (1)$$

$$F(0) < \infty, \quad \text{and} \quad F(\infty) = 0 \quad (2)$$
- BC equivalent to strong reflection:
 - on mild sloping beach $\Rightarrow$ **edge waves = infragravity (IG; periods 0.5 - 5 min);**
 - offshore $\rightarrow$ turning point $\omega^2 = c^2(x)k^2$.
- Problem (1-2) singular Sturm-Liouville problem eigenvalue $\omega(\kappa)$, eigenfunction F .
- Plane beach dispersion

$$\omega_n^2(k) = gs(2n + 1)k.$$

Examples of dispersion curves and cross-shore structure of first 4 mode for beach slope $s = 0.01$ and $f = 0.01$ Hz.



Edge waves in nearshore dynamics

- Discovered by Stokes in 1846 (Stokes, 2009, Ursell, 1952, see also LeBlond and Mysak 1978, Huthnance, 1975 and many others).
- Initial research interest in generation of beach cusps (e.g., Guza, 1975).
- Studied for simple beach profiles (Ball, 1967, Clarke, 1975, etc); barred beaches (Bryan and Bowen, 1996), with alongshore currents (Howd et al. 1992); rogue edge waves (Pelinovsky et al., 2010).
- Important for nearshore wind-wave evolution (e.g., Freilich et al. 1984, Elgar and Guza, 1985, many others); contribute to flooding (up to 3-m elevation; e.g. Stockdon, 2006; Guza, 2012, etc).

Edge-wave generation mechanisms

Edge wave generation are not well understood.

Generally assumed: As IG waves, edge waves cannot be generated by wind (IG freq. below the spectral gap).

Alternative mechanism: wave-wave interaction (e.g., Freilich, Elgar and Guza, 1984, 1985, etc).

- ① swell and leaky (nearly shore-normal) IG waves (e.g., Kirby, 1998)
 - ② leaky IG + two counter-propagating subharmonic EW (Guza & Davis, 1974)
- Implies directional symmetry with respect to the shoreline normal.
 - Confirmed by field observations (Herbers et al 1995). Statistically,
 - ratio up- to down-coast IG energy flux ≈ 1 .
 - asymmetry determined by swell direction.

This suggests that strong directional (up-/down-coast) edge waves opposite to swell direction have a different origin.

Wind generation hypothesis

Key Question

Do directionally-asymmetric edge waves fields occur, that

- 1 do not match the swell direction,
- 2 but match the wind direction?

If they do exist, then: Generation mechanism is wind forcing rather than wave-wave interaction.

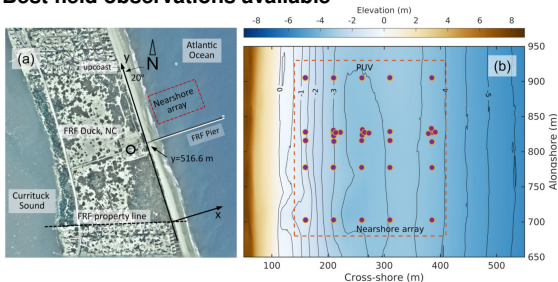
Data set

Finding directionally-asymmetric edge waves events is a challenge.

- Laboratory data cannot be used (lateral boundary conditions impose alongshore symmetry).
 - Field observations of edge waves are notoriously difficult:
 - Alongshore uniformity is an idealization, valid approximately in the field over limited spatial scales.
 - Typically arrays comprising a large number of synchronously-recording sensors distributed in alongshore lines: Intrinsically low resolution in the alongshore wave-number domain.
- ⇒ Even low resolution arrays are expensive (enough said).
- Directionally asymmetric edge-wave fields are statistically rare (e.g., Herebers et al. 1995).
 - More so directionally asymmetric edge-wave fields not matching swell direction (e.g., Herebers et al. 1995).
- ⇒ Long term observations are needed to capture such such events (more expensive).

Data analysis

Best field observations available



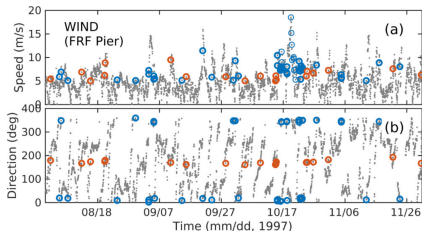
- *SandyDuck'97* nearshore array (Elgar, Herbers, O'Reilly and Guza), US-ACE FRF, Duck NC, USA.
- Recorded PUV @ 2 Hz continuously August to December 1997.
- Over 100 sensors. Using here 35 PUV clusters in alongshore lines.

- Freq. cross-spectra: 3-hr records ; 600-s segments; 50% overlap; d.o.f. = 34 ; $df = 0.008$ Hz; 26 IG modes ($f \leq 0.05$ Hz).
- Alongshore line: 46 non-redundant lags $\lesssim 200$ m; array dimensions are a severe constraint;
- e.g., mode 3 edge-waves at $f = 0.01$ Hz has $\lambda = 2341$ m.

⇒ Lowest order Max. Entropy estimate of (k, f) power spectra: single-peak distribution

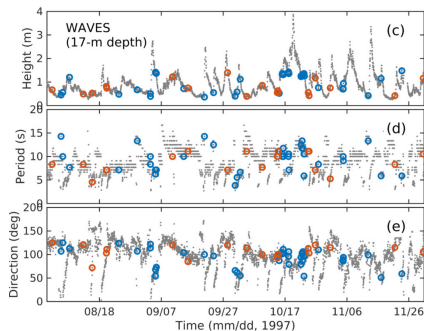
- Peak $\approx$ “center of mass” in k .

Synopsis of observations



Wind: a) speed; b) direction. Met. station at shoreline end of pier.

Wind/wave direction wind in meteorological convention (clockwise; “coming from”, w.r.t. downcoast: 20 degrees west of north)



Wave: c) significant height; d,e) peak period, direction. Dataswell buoy (4 km offshore, 17-m isobath).

Definition of possible wind generation cases: downcoast (blue) and upcoast (red):

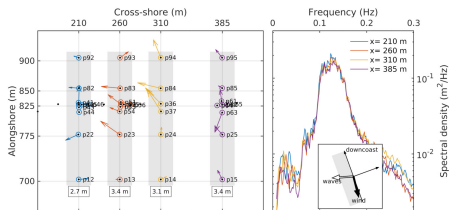
- wind ± 20 degrees alongshore;
- offshore wave heights less than 1.5 m;
- near shore-normal swell (± 40 degrees window in 17-m depth).

Edge waves (wave-wave generation...)

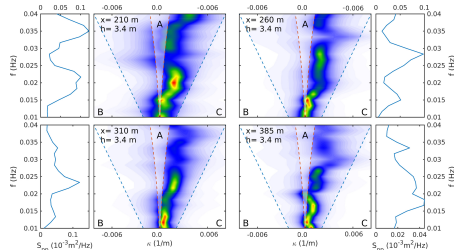
August 24th, 05:00 hours; edge waves propagating downcoast.

Edge wave direction matches swell direction but is opposite to wind direction.

Although not directionally symmetrical, this case is consistent to the wave-wave interaction mechanism.



Nearshore array; Pressure spectra. Circles = pressure and velocity sensors. Gray rectangles = lines used for (k, f) analysis.



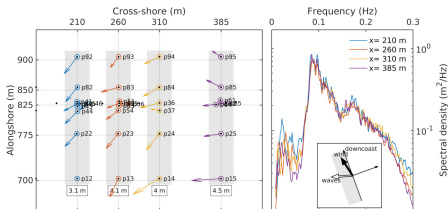
IG (k, f) spectra at alongshore array lines. Dashed red-blue = edge wave domain.

Downcoast edge waves (wind generation?)

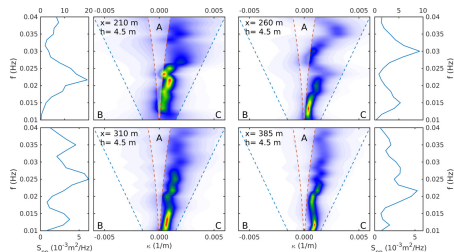
November 30th, 16:00 hours: edge waves propagating downcoast.

Edge wave direction matches wind direction wind;

Swells normally incident: wave-wave interactions should produce directionally symmetric edge waves.



Nearshore array; Pressure spectra. Circles = pressure and velocity sensors. Gray rectangles = lines used for (k, f) analysis.



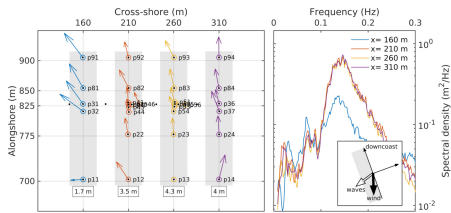
IG (k, f) spectra at array lines. Dashed red-blue = edge wave domain.

Upcoast edge waves (wind generation?)

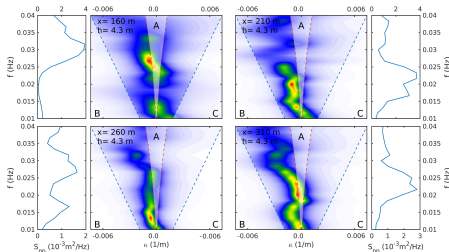
September 5th, 11:00 hours: edge wave propagating upcoast;

Edge wave direction matches wind direction wind.

Swells normally incident: wave-wave interactions should produce a directionally symmetric edge waves.



Nearshore array; Pressure spectra. Circles = pressure and velocity sensors. Gray rectangles = lines used for (k, f) analysis.



IG (k, f) spectra at alongshore array lines. Dashed red-blue = edge wave domain.

Summary

On mildly sloping beaches, with near uniform alongshore profile:

- Edge waves are alongshore propagating waves trapped by reflection at the shoreline and offshore turning point.
- The strong reflection at the shoreline implies that edge waves belong to the IG wave family.
- Generally agreed that IG waves are generated through wave-wave interaction.

The implication, confirmed statistically by field observations is that

- the directionality of edge wave fields is strongly correlated to offshore swell direction
- edge wave fields are typically directionally symmetric.

Using observations of IG waves collected during *SandyDuck*'97 field experiment, we identify edge-wave events with

- strong directional asymmetry, matching wind direction, and
- nearly shore-normal swells.

The existence of such anomalous events suggests that direct generation by wind is plausible.