Bound and free infragravity waves over a bar

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Abstract: This study aims to investigate the changes in the infragravity wave energy under partial short-wave breaking conditions induced by a longshore bar. Field observations of near-bottom pressure records on a cross-shore array were analysed for such purpose. The bispectrum was employed to detect the phase-coupling between short and infragravity wave frequencies. This allowed to separate the infragravity wave energy in bound and free energy components.

The bar crest induced a decrease on the short-wave energy due to depth-induced breaking. At the same location, a damping on the bound infragravity wave energy was observed. This damping coincides with a negative value of the short-wave radiation stress cross-shore gradient. This provides evidence that bound infragravity wave energy decreases with a reduction in the forcing.

Key words: Infragravity waves, Bispectral analysis, Field observations, S. Jacinto

1. INTRODUCTION

Wind-generated surface gravity waves with periods between 4 s and 25 s often drive the morphological evolutions in coastal environments. Hereafter they will be denoted by short-waves (SW). The energy associated to SW is mainly dissipated by depth-induced breaking across the surf zone and near the shoreline. The swash zone is dominated by infragravity waves (IGW) with periods between 25 s and 250 s (Guza and Thornton, 1982).

Two mechanisms were proposed to generate IGW. Longuet-Higgins and Stewart (1962) proposed the so called bound wave mechanism (BWM) in which nonlinear interactions between SW frequencies can transfer energy to IGW frequencies. The result is a low-frequency fluctuation of the mean sea level that travels bounded to a SW group of high waves, commonly known as bound wave. Later, Symonds *et al.* (1982) suggested what will be known as the breakpoint mechanism (BKM), which is due to the time displacement of the breaking point location that generates a dynamic wave setup. An important difference between both mechanisms is the propagation speed of the resulting IGW. On one hand, the IGW associated to a bound wave would travel bounded to the SW group and therefore with the wave group velocity. On the other hand, the IGW generated by the BKM would travel with its free wave celerity.

The focus of this work will be on the bound wave. In particular, it aims to address what happens to the bound wave during SW breaking under intermediate water conditions using field observations.

Previous studies commonly assumed that the bound wave is released after SW breaking but they do not suggest any release mechanism. Other view point is that bound IGW energy decays with the forcing, i.e. SW groups. Baldock and Huntley (2002) distinguished two different cases. The former is the situation where SW are shallow water waves at the breakpoint (i.e. $kh < 0.314$, k is the wavenumber, h is the mean water depth and kh is the relative wavelength). In this case, a bound wave will propagates with the free wave celerity towards the shoreline. The latter, is the case where SW are not shallow water waves at the breakpoint (i.e. $kh > 0.314$). If so, a bound wave would propagates shoreward with the SW group velocity. In this situation, Baldock (2012) argued that the bound IGW energy would decay with the forcing, i.e. the SW groups.

The main purpose of this study is to assess the changes in the bound IGW energy after SW breaking using field data collected over a longshore bar. A bispectral analysis was employed to estimate fraction of bound IGW energy.

2. METHODOLOGY

2.1 Field data

A two-day field campaign took place in S. Jacinto beach in June, 2015. Eight pressure tranducers (PT) were moored on a cross-shore transect almost perpendicular to the coastline and over a longshore bar that is a distinct feature of this beach. Along the two days period, the incident SW groups arrived from the west-northwest sector. The significant SW height (H_{sw}) varied between 1 m and 1.5 m and the peak SW period (T_p) decreased from 12 s to 9 s.

2.2 Data analysis

Each time record of near-bottom pressures, with a sampling frequency of 2 Hz, was low-pass filtered with a cut-off frequency of 0.004 Hz to remove the tidal oscillations. After, three blocks of approximately 136 min (2^{14} observations) were selected around either low- or high-tide. The wave spectrum was calculated with the Welch method accounting with a linear correction for pressure attenuation over depth. The number of degrees of freedom (*dof*) was 62 with a frequency resolution (*df*) of 0.002 Hz. The SW frequency band was defined between 0.04 Hz and 0.3 Hz and the IGW frequency band was defined between 0.004 Hz and 0.04 Hz. The mean water depth (d) was defined as the mean of the tidal oscillation for each block. The peak SW wavenumber (k_p) and the mean SW wavenumber (k_m) were determined using the linear wave theory after knowing d, T_p and T_m.

2.3 Bound wave energy

The bound IGW is generated due to second-order nonlinear interactions between SW (Longuet-Higgins and Stewart, 1962). These second-order nonlinear interactions cannot be detected using first-order spectral analysis. Therefore, a higher-order spectral analysis (i.e. bispectrum) was used. The bispectrum was computed for each block. A frequency averaging on eleven frequencies was additionally performed to improve the bispectral stability, yielding 154 *dof* and a *df* of 0.0054 Hz.

Herbers *et al.* (1994) proposed an indirect measure to obtain the bound IGW energy. In this formulation, the bound IGW energy is equal to the product between the zeroth moment IGW energy and a double integration of the bispectrum [Herbers *et al.* (1994) for details]. Hereinafter, it is assumed that the total IGW energy is equal to the sum between bound IGW energy and free IGW energy. For the remaining of this study, the total IGW energy is denoted by E_t, the bound IGW energy is denoted by E_b and the free IGW energy is denoted by E_f.

3. RESULTS AND DISCUSSION

3.1 Cross-shore evolution of the significant wave height

Fig. 1 displays H_{sw}, H_{ig} and d for each of the three blocks at each cross-shore position. The horizontal axis is the distance between each PT and the most offshore PT, thereby increasing to the coastline. H_{sw} decreases from 1.45 m to 1.2 m between $60 < X < 140$ m (Fig. 1 – panel a, diamonds) for the first low-tide. This decrease can be explained by depth-induced breaking over the bar crest as in Roelvink and Stive (1989). Similar but milder decreases in H_{sw} are also observed for the other scenarios (high-tide and second low-tide).

The H_{ig} increases shoreward as expected because it is inversely proportional to the water depth until the inner surf zone. A small decrease is observed during the first low-tide (diamonds – Fig. 1b, $X \sim 120$ m). This decrease will be further investigated below after separating the IGW energy in bound and free IGW components.

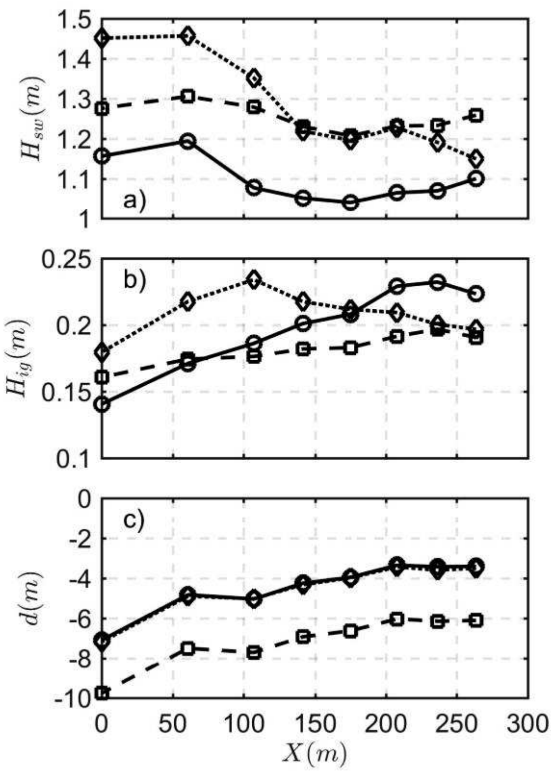

Fig. 1. Cross-shore evolution of the significant short (top) and infragravity (middle) wave height and total water depth (m). Symbols are representative of the first low-tide (diamonds), first high-tide (squares) and second low-tide (circles).

3.2 Cross-shore evolution of the bound wave energy

Fig. 2 displays the ratio between bound and total IGW (E_b/E_t), the relative water depth (k_ph) and d. During both low-tides, shallow water conditions ($kh < 0.314$) are reached at $X \sim 190$ m. Consequently, the decrease in E_b/E_t at $X \sim 60$-110 m is not due to the release of the bound IGW energy. If so, shallow water wave conditions ($kh < 0.314$) would be satisfied for the SW energy. The bound IGW energy, previously propagating with the SW group velocity, would start to propagate with its free wave velocity in shallow waters, i.e. the bound IGW would be released as free IGW. This is not the case.

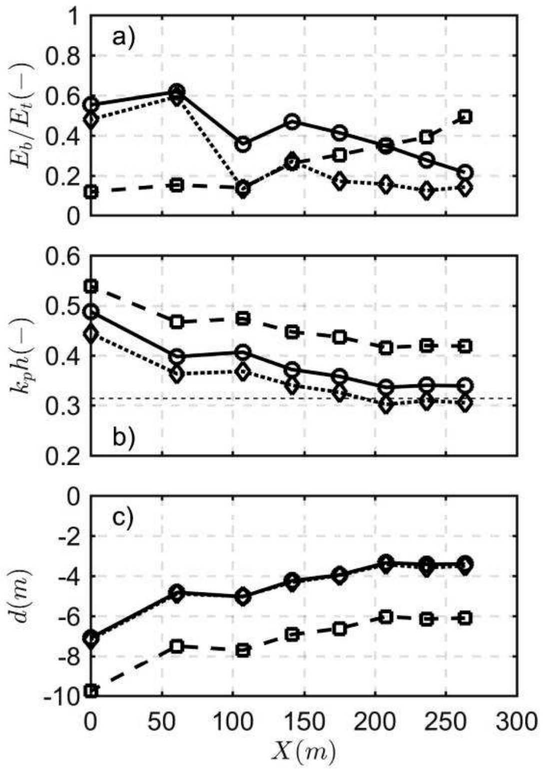

Fig. 2. Cross-shore evolution of the ratio between bound and total infragravity wave energy (top), relative water depth (middle) wave height and total water depth (m). Symbols are representative of the first low-tide (diamonds), first high-tide (squares) and second low-tide (circles).

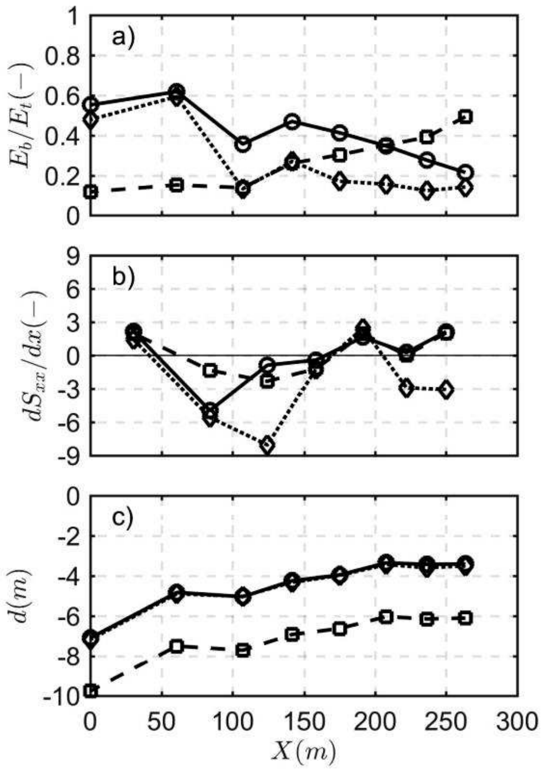

Fig. 3. Cross-shore evolution of the ratio between bound and total infragravity wave energy (top), radiation stress gradient (middle) and total water depth (m). Symbols are representative of the first low-tide (diamonds), first high-tide (squares) and second low-tide (circles).

In the following, we will assess the hypothesis that the decay on E_b/E_t at $X \sim$ 60-110 m, associated to the bound IGW, is due to a reduction in the forcing, i.e. SW groups.

Fig. 3 shows E_b/E_t, the cross-shore gradient of the radiation stress (S_{xx}) and d. S_{xx} was estimated with the linear wave theory and the cross-shore gradients were estimated using centred finite-differences. During the first low-tide (diamonds – Fig. 3b), dS_{xx}/dx displays negative values over the bar trough. These negative values imply a reduction in the forcing, i.e. the SW groups.

An interesting observation is the behaviour E_b/E_t for X > 110 m during both low-tides (Fig. 3a). A small increase on E_b/E_t occurs between X = 110 m and X = 140 m followed by a decrease shoreward.

Looking now to Fig. 2b, k_ph is close to the shallow water limit (0.314), i.e. the SW group velocity is asymptotically close to the free wave velocity in shallow waters. We therefore attribute the decrease on E_b/E_t as a result of the bound IGW transformation. The bound IGW starts to propagate with the free wave velocity, becoming a free wave. Following (Baldock, 2012), interactions between free waves are weak. Consequently, the E_b/E_t would decrease shoreward.

It is important to note that other sources of free IGW energy are possible. As an example, a SW group propagating over a bar under breaking conditions will generate a time-varying wave setup with a time scale similar to the SW group (BKM generation mechanism, see Section 1). This can explain why H_{ig} increases shoreward despite the damping in the bound IGW energy (compare Fig. 1 and 2).

In summary, our results indicate two different types of damping in the bound IGW energy. The former is associated to a decay in the SW forcing. The latter is attributed to the release of the bound IGW energy as free IGW energy in shallow water conditions.

The decay of the bound IGW energy associated to a decay on the radiation stress gradient supports the studies of (Baldock, 2012; Baldock and Huntley, 2002). A forced IGW would reduce in energy due to the decay in the forcing if depth-induced breaking occurs before shallow water conditions, i.e. kh < 0.314.

4. CONCLUSION

Field observations of near-bottom pressure records collected over a longshore bar were analysed to understand the cross-shore propagation of the bound IGW energy. The results corroborate the hypothesis of Baldock (2012) that if SW breaking occurs before shallow water conditions (kh > 0.314), the bound IGW energy would decay with the forcing, i.e. SW groups.

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