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# **RELEVANCE OF INFRAGRAVITY WAVES IN A WAVE-DOMINATED INLET**

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## **ABSTRACT**

This study investigates the relevance of infragravity (IG) waves at Albufeira Lagoon Inlet, a shallow wave-dominated inlet located on the Western Coast of Portugal. A field experiment carried out in September 2010 revealed the occurrence of low-frequency oscillations (i.e. 25 to 300 s) in water levels and current velocities. While these fluctuations were present over the ebb-tidal delta along the whole tidal cycle, they only appeared between the beginning of the flood and up to two hours after high tide inside the lagoon. The XBeach modeling system was applied to Albufeira Lagoon Inlet and reproduced the generation and propagation of IG waves and their blocking during the ebb. This behavior was explained by blocking due to opposing tidal currents reaching  $2.5 \text{ m.s}^{-1}$  in shallow water depths. Numerical results suggest that the breakpoint mechanism and the long bound wave shoaling mechanisms contributed significantly to the generation of IG waves in the inlet. IG waves induced fluctuations in flood currents inside the lagoon reaching temporarily 100 % of their magnitude. The fact that these fluctuations occur mostly at flood and not at ebb could promote flood dominance in the lagoon. This hypothesis will have to be verified, namely under storm wave conditions.

## **KEYWORDS**

Infragravity waves, wave-dominated inlet, low frequency waves, wave blocking.

## **Keypoints**

- Measurements revealed energetic IG waves in a wave-dominated inlet.
- Breakpoint generation and bound-wave shoaling both contributed significantly to IG wave generation.
- IG waves were blocked by opposing ebb-currents.

## **1. INTRODUCTION**

Tidal inlets are transition zones between the ocean and back-barrier lagoons or estuaries where constant exchange of water, sediments, nutrients and larvae occurs. Hydrodynamics and morphological changes in tidal inlets have strong ecological and socio-economic repercussions, since they affect navigation safety, flooding extent, erosion of adjacent beaches, water renewal and material exchange between the lagoon (orestruary) and the open ocean. Due to the complex interactions between tides, wind waves, river outflows, sediments transport and morphology, understanding the resulting hydrodynamics and sediment transport patterns is still a challenge.

47 Nonetheless, an increased knowledge of these processes is needed to improve the management  
48 and maximize the resilience of these coastal systems.

49  
50 In the last decade several studies (e.g. Siegle et al., 2004; Bertin et al., 2009; Olabarrieta et al.,  
51 2011; Dodet et al., 2013; Orescanin et al., 2014; Wargula et al., 2014; Olabarrieta et al., 2014,  
52 Chen et al., 2015) have emphasized the relevance of surf-zone processes in mixed-energy and  
53 wave-dominated tidal inlets. Shallow water depths over the ebb-tidal delta can induce wave  
54 breaking and subsequent surf-zone circulations. Wave-breaking accelerations can also affect the  
55 extension and direction of ebb currents, as well as impact the hydrodynamics inside the estuary.  
56 For example, wave breaking over the ebb-tidal delta can induce a wave setup and increase water  
57 levels at the scale of the whole lagoon or estuary (e.g. Malhadas et al. 2009; Bertin et al., 2009;  
58 Olabarrieta et al., 2011; Dodet et al. 2013; Arnaud and Bertin, 2014; Bertin et al., 2015).  
59 Moreover, due to the interaction between the wave bottom boundary layer and tidal currents,  
60 bottom friction increases (e.g. Grant and Madsen 1979, Soulsby et al., 1997) and, consequently,  
61 can affect the overall tidal propagation (Olabarrieta et al., 2011 and Dodet et al., 2013).

62  
63 The relevance of oceanic infragravity waves (hereafter, “IG waves”) in the nearshore is well  
64 recognized and many studies have been conducted in the last four decades to ascertain their role  
65 in coastal morphodynamics (e.g. Guza et al., 1984; Masselink, 1995; Baldock and Huntley,  
66 2002; Baldock et al., 2004; Pomeroy et al., 2012). IG waves are ocean waves with periods from  
67 25 to more than 300 seconds associated with the presence of groups in gravity waves. To date,  
68 two main mechanisms for the generation of infragravity waves have been proposed. Longuet-  
69 Higgins and Stewart (1964) suggested that the observed free infragravity wave or “surf beat”  
70 may be due to the shoaling, release and subsequent reflection of bound long waves after the  
71 gravity waves break in the surf-zone. Bound waves result from 2nd-order non-linear wave-wave  
72 interactions between wind waves (“forced” IG waves: [Hasselmann, 1962; Longuet-Higgins and  
73 Stewart, 1962; Okihiro et al., 1996]). An alternative mechanism for the generation of surf beat  
74 was presented by Symonds et al. (1982) and Schäffer (1993), who considered the temporal  
75 variation of the breakpoint as a wave maker, generating surf beat both seaward and shoreward.  
76 The moving breakpoint mechanism can also be thought as a “dynamic set-up” in the surf-zone.  
77 Large waves break earlier and produce larger set-up than small waves in the wave group, which  
78 introduces oscillations in the set-up at the group frequency. The first mechanism was shown to  
79 be dominant on gently sloping beaches due to the shoaling of the bound-wave (e.g. List 1992;  
80 Herbers et al., 1995; Pomeroy et al., 2012) while the second mechanism occurs preferably when  
81 gravity waves break within a narrow zone, which condition is preferentially met over a steep  
82 bottom (Battjes et al, 2004; Van Dongeren et al., 2007; Baldock, 2012; Pomeroy et al., 2012).

83  
84 Despite being known that mixed-energy and wave-dominated tidal inlets share characteristics of  
85 beach and tidally dominated areas (e.g. Siegle et al., 2004; Bertin et al., 2009; Olabarrieta et al.,  
86 2011), the dynamics and effects of IG waves in tidal inlets have not yet been addressed  
87 according to the author’s knowledge IG wave generation, propagation, and dissipation  
88 mechanisms in tidal inlets might differ substantially from those observed in beach environments  
89 for several reasons. First, the inlet morphology, characterized by the presence of an ebb-tidal  
90 delta, a main channel and secondary channels, is usually more complex than a beach  
91 morphology. Moreover, ebb-tidal deltas combine gentle slopes in their central part and steep  
92 slopes in their terminal lobes so that both generation mechanisms for IG waves can be active

93 along a tidal cycle. Second, while in a beach all incoming IG wave energy is dissipated or  
94 reflected, in a tidal inlet part of the IG energy might, depending on the tidal phase, propagate  
95 through the main channel and into the inner part of the lagoon or estuary. Finally, IG waves in  
96 tidal inlets can be affected by strong flood and ebb currents.

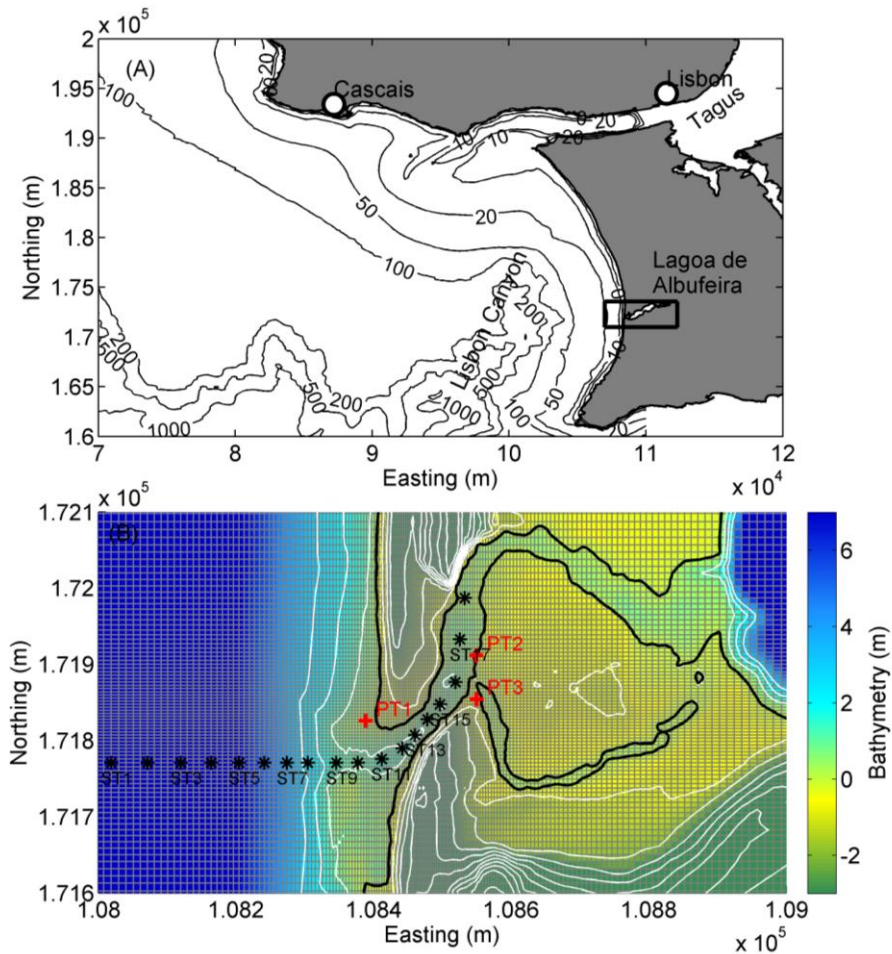
97  
98 Different types of approaches and numerical models have been considered to numerically model  
99 the generation and propagation of infragravity waves. Two main approaches or types of models  
100 can be distinguished: 1) phase-resolving (e.g, Herbers et al. 1995; Madsen et al., 1997; Kennedy  
101 et al., 2000; Torres- Freyermuth et al., 2010; Bonneton et al., 2011; Zijlema et al., 2011; Ma et al.,  
102 2012; Ruju et al., 2012; Rijnsdorp et al., 2015; Sheremet et al., 2016) and 2) phase-averaged  
103 models (e.g. Reniers et al. 2004, 2006, 2010; Uchiyama and McWilliams, 2008; Long and  
104 Haller, 2009; Roelvink et al., 2009, Eldeberky et al., 2015). Phase-resolving models account for  
105 the non-linear gravity wave transformations and possible non-linear energy transfer from the IG  
106 band to the gravity band. Because of the high computational cost, the application of phase-  
107 resolving models is limited to areas of hundreds of meters and time periods shorter than a tidal  
108 cycle. On the other hand, coupled models are computationally more efficient, but they disregard  
109 the aforementioned non-linear processes.

110  
111 This study is focused on the Albufeira Lagoon Inlet located on the western coast of Portugal.  
112 This wave-dominated inlet closes seasonally in autumn/early winter, usually after energetic swell  
113 conditions. Dodet (2013) simulated its morphodynamic evolution under tides and gravity waves  
114 and, although the fast morphological changes of the inlet were in overall well captured, its  
115 closure was not reproduced, as if one or several relevant processes were not accounted for in  
116 these simulations. This study tackles, for the first time, the role of infragravity waves on the  
117 hydrodynamics in a wave-dominated inlet. In particular, attention is given to the main IG wave  
118 generation mechanisms and to their interactions with tides. Possible impacts of these long waves  
119 in sediment transport and morphodynamics are also discussed.

120  
121 The paper is organized as follows. A brief description of the study area is provided in Section 2.  
122 The methods, including the data acquisition and post-processing, as well as the numerical model,  
123 are described in Section 3. Observed and modeled tides, gravity and IG waves are described and  
124 compared in Section 4. Model limitations, IG wave generation and propagation mechanisms, and  
125 implications on sediment transport and morphodynamics are discussed in Section 5. The main  
126 conclusions are summarized in Section 6.

## 127 128 **2. STUDY AREA**

129 Albufeira Lagoon is located on the Western coast of Portugal, about 20 km South of Lisbon. The  
130 width of the continental shelf in front of the inlet is limited to 5 km due to the Lisbon Canyon  
131 (Figure 1A). The lagoon covers an elongated surface area of 1.3 km<sup>2</sup> SW-NE orientated and is  
132 connected to the sea through a small and shallow intermittent inlet. The inlet exhibits a strong  
133 seasonal behavior, leading to its natural closure in autumn/early winter, after which it is  
134 artificially opened in spring (Dodet et al., 2013; Fortunato et al., 2014). The inlet is bordered by  
135 steep beaches (slope of the order of 0.10) made of coarse sands ( $d_{50} = 0.0007\text{-}0.0018$  m).



136  
 137 Figure1. (A) Regional bathymetry of the study area and (B) Detailed bathymetric map of  
 138 Albufeira Lagoon Inlet, computational grid used for XBeach (grey frame), location of the  
 139 pressure sensors (red crosses), model stations (black stars). At PT2 current velocities were also  
 140 measured with an electromagnetic current-meter. The black solid line corresponds to mean  
 141 sea-level contour line. The bathymetric map of the Albufeira Lagoon Inlet shown in panel B  
 142 does not represent the whole computational domain. The model grid covers the whole lagoon.

143 This area is subjected to semi-diurnal tides, the amplitude of which ranges from less than 1 m to  
 144 more than 3.5 m. The mean tidal prism during spring tides is of the order of  $80 \cdot 10^4 \text{ m}^3$  (based on  
 145 the numerical estimates of Fortunato et al., 2014). Tides are strongly distorted throughout their  
 146 propagation across the inlet, semi-diurnal tidal constituents are severely damped while quarter-  
 147 diurnal and fortnightly non-linear constituents develop. Inside the lagoon, the amplitude of the  
 148 semi-diurnal constituents experiences a seasonal cycle, with a maximum in late summer after  
 149 which it decreases until the lagoon closes. This behavior is commonly observed at other  
 150 Portuguese shallow inlets and was explained by the shoaling of the inlet due to several wave-  
 151 induced processes (Bertin et al., 2009; Dodet et al., 2013).

152  
 153 The study area is exposed to an energetic wave climate, particularly in winter. Based on a 57-  
 154 year wave numerical hindcast (Dodet et al., 2010), the mean annual deep water ( $10.0^\circ\text{W}$ ;  $38.0^\circ\text{N}$ ;  
 155  $\sim 3000 \text{ m}$  deep) significant wave height ( $H_{m0}$ ), mean direction (MWD) and peak period ( $T_p$ ) are

156 respectively 1.9 m, 312 °, and 10.5 s. During winter (resp. summer) the corresponding values are:  
 157 2.5 m, 305 °, and 12.1 s (resp. 1.3 m, 319° and 8.4 s). The drainage basin of the Albufeira Lagoon  
 158 covers a surface area of around 106 km<sup>2</sup>, but the freshwater discharge is only significant under  
 159 heavy rain, which usually occurs when the lagoon is closed.

160  
 161 **3. METHODS**

162 IG wave dynamics and their relevance in Albufeira Lagoon are analyzed combining field  
 163 measurement analysis and numerical modelling. Water levels and currents were measured in the  
 164 field experiment described by Dodet et al. (2013). The experiment was not specifically designed  
 165 to study IG waves, and, therefore, the location of the instruments prevents the understanding of  
 166 the main generation and propagation mechanisms from the data analysis. To complement the  
 167 analysis and ascertain the main IG wave generation and propagation mechanisms, we applied the  
 168 modeling system XBeach (Roelvink et al., 2009), version 1.21.3866M, ‘Groundhog Day’  
 169 release.

170  
 171 **3.1 Field measurements**

172 During the Albufeira Lagoon Inlet field experiment, water levels and currents were measured on  
 173 the ebb-tidal delta (PT1), on the flood-tidal delta (PT2) and at the tip of the sand-spit (PT3)  
 174 located on the southern margin (Figure 1B). A high-resolution Acoustic Doppler Current Profiler  
 175 (ADCP) was collocated at PT1, while and electromagnetic current-meter was collocated at PT2.  
 176 Pressure measurements were first corrected from the atmospheric pressure variations. The entire  
 177 record was split into consecutive bursts of 30 minutes and the bursts in which the sensor was  
 178 alternatively dry were not considered. Bottom pressure energy density spectra  $Ep(f)$  were  
 179 computed using Fast Fourier Transform, with 2 Hanning-windowed segments (32 degrees of  
 180 freedom). Considering that the spectral integrals are Chi-square distributed, confidence intervals  
 181 (hereafter CI) for a given level  $\alpha$  were computed according to Bendat and Piersol (1971):  
 182

183 
$$CI = \left[ \frac{\nu}{\chi_{\nu, 1-\alpha/2}^2}; \frac{\nu}{\chi_{\nu, \alpha/2}^2} \right]$$

184  
 185 These pressure spectra were then converted into elevation spectra  $E(f)$  considering the linear  
 186 wave theory. The significant wave height ( $H_{m0}$ ) was computed as:

187  
 188 
$$H_{m0} = 4\sqrt{m_0} \quad (1)$$

189 Where,

190 
$$m_0 = \int_{f_{min}}^{f_{max}} E(f) \partial f \quad (2)$$

191 Where  $f_{min}$  and  $f_{max}$  were set to 0.04 and 0.5 Hz for the gravity band and 0.002 and 0.04 Hz for  
 192 the infragravity band, respectively.

193

194 **3.2 Numerical model**

195 XBeach is a two-dimensional modelling system that couples the St. Venant equations with a  
196 simplified wave-action conservation model, a sediment transport and bed update model. To  
197 simulate the generation and propagation of IG waves, XBeach can be forced with time varying  
198 directional wave spectra defined at the boundaries. Since the wave spectra do not contain the  
199 phase information, the model assumes random phases and applies a single summation technique  
200 to reconstruct the free surface elevation time series at the boundaries. A Hilbert transform is  
201 applied to derive time series of the gravity wave energy (that varies at the wave group scale) and  
202 these are imposed as boundary conditions for the wave-action balance equation. The incoming  
203 bound-wave is computed following Herbers et al. (1994), and is imposed along the open  
204 boundary of the flow model.

205  
206 In this study, depth-induced wave breaking energy dissipation was computed using the  
207 parameterization proposed by Daly et al. (2012). Wave-current interactions are also considered  
208 in the model. The interaction between currents and gravity waves is included in the gravity wave  
209 dispersion relation modified by the Doppler Effect and in the eikonal equation. Dissipation of  
210 gravity waves by whitecapping induced by opposing current is not considered. The dynamics of  
211 IG waves, including their generation and propagation, are implicitly considered by the St. Venant  
212 equations. Therefore, the effects of currents on IG wave propagation, including their possible  
213 blocking, are represented by the equations and do not need to be explicitly included. The reader  
214 is referred to Roelvink et al. (2009) for a detailed description of XBeach.

215  
216 A rectilinear grid (with variable grid size) covering the whole lagoon and extending to offshore  
217 water depths of 20 m was implemented. The spatial resolution ranged from 20 m along the open  
218 boundary to 3 m at the inlet (Fig. 1B). Such a fine resolution was required to adequately  
219 represent the inlet channel and resulted in a 210 by 380 nodes grid. Along the open boundaries,  
220 XBeach was forced with time-series of water levels recorded at the nearby Cascais tide gauge  
221 (Fig 1A) and the time varying directional wave-spectra originated from an application of SWAN  
222 (Booij et al., 1999) at the scale of the Cascais Bay as described in Dodet et al. (2013). This  
223 SWAN run was forced along its open boundaries with time series of wave energy spectra  
224 computed from an application of the WaveWatchIII model (Tolman, 2009) at the scale of the  
225 Atlantic Ocean (Crawford et al., 2015) and forced with wind fields originating from the ERA-  
226 INTERIM reanalysis (Dee et al., 2011).

227  
228 Bottom friction was represented by a non-linear quadratic bottom shear stress with a constant  
229 Chezy coefficient (equal to  $30 \text{ m}^{0.5} \cdot \text{s}^{-1}$ ). The horizontal eddy viscosity was assumed constant ( $0.5$   
230  $\text{m}^2/\text{s}$ ). The minimum water depth was set to 0.2 m and 0.25 m for the computation of the Stokes  
231 velocities. The breaking parameter  $\gamma$  was set to 0.4 and  $\gamma_2$  to 0.3. These values provided the best  
232 agreement between measured and modeled free-surface elevations and velocity magnitudes.

233  
234 The model was run for the duration of the field experiment (2 days), and time series of surface  
235 elevation, current velocities were archived at a 5 s interval. Spectral estimates were computed  
236 following the same methodology as for the field observations (section 3.1). To analyze the IG  
237 wave generation mechanisms and their relevance different simulations were run (Table1). In all  
238 of them tidal propagation was taken into account. Run 0 did not consider gravity waves, only  
239 tides. Run 1, considered tides and gravity waves but wave groups were not taken into account.

240 Run 2 included the effect of tides, gravity waves and wave groups. Run 3 is the same  
 241 configuration as Run 2 (considers the same random phases to reconstruct the wave envelope  
 242 signal) but wave forces were turned off when the gravity waves were breaking. In Run 4, wave  
 243 forces were turned off outside the surf-zone and the incoming bound wave at the boundaries  
 244 were turned off, so that only the wave breaking variation at the scale of the wave groups  
 245 contributes to the IG wave generation. Run 5 did not include any wave forces and it only  
 246 propagated the tide and the incoming bound wave defined at the boundaries. Runs 3 to 5 were  
 247 designed to analyze the relative contribution of the different IG wave generation mechanisms. To  
 248 ensure that runs 1 to 5 had the same model setting, we first ran Run2 and we stored the wave-  
 249 group changing energy and flux boundary conditions. These were directly used in runs 3 to 5.  
 250 Since Run1 did not account for the gravity energy modulation, the previously stored energy  
 251 boundary condition was low-pass filtered and imposed in Run 1. For model/measurement  
 252 comparison shown in section 4, 7 more simulations (Run 6 to 12) were done considering tides,  
 253 gravity and IG waves (same configuration as run 2). The ensemble-mean of these realizations  
 254 was used for the model verification.  
 255  
 256

	Run0	Run1	Run2	Run3	Run4	Run5	Runs 6-12
Tides	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Gravity waves	No	Yes	Yes	Yes	Yes	No	Yes
IG waves	No	No	Yes	Yes	Yes	No	Yes
Radiation stress inside surf-zone	No	Yes	Yes	No	Yes	No	Yes
Radiation stress outside surf-zone	No	Yes	Yes	Yes	No	No	Yes
Bound wave at offshore boundary	No	No	Yes	Yes	No	Yes	Yes

257 Table 1. Characteristics of the numerical simulations.

258  
 259 **4. RESULTS**

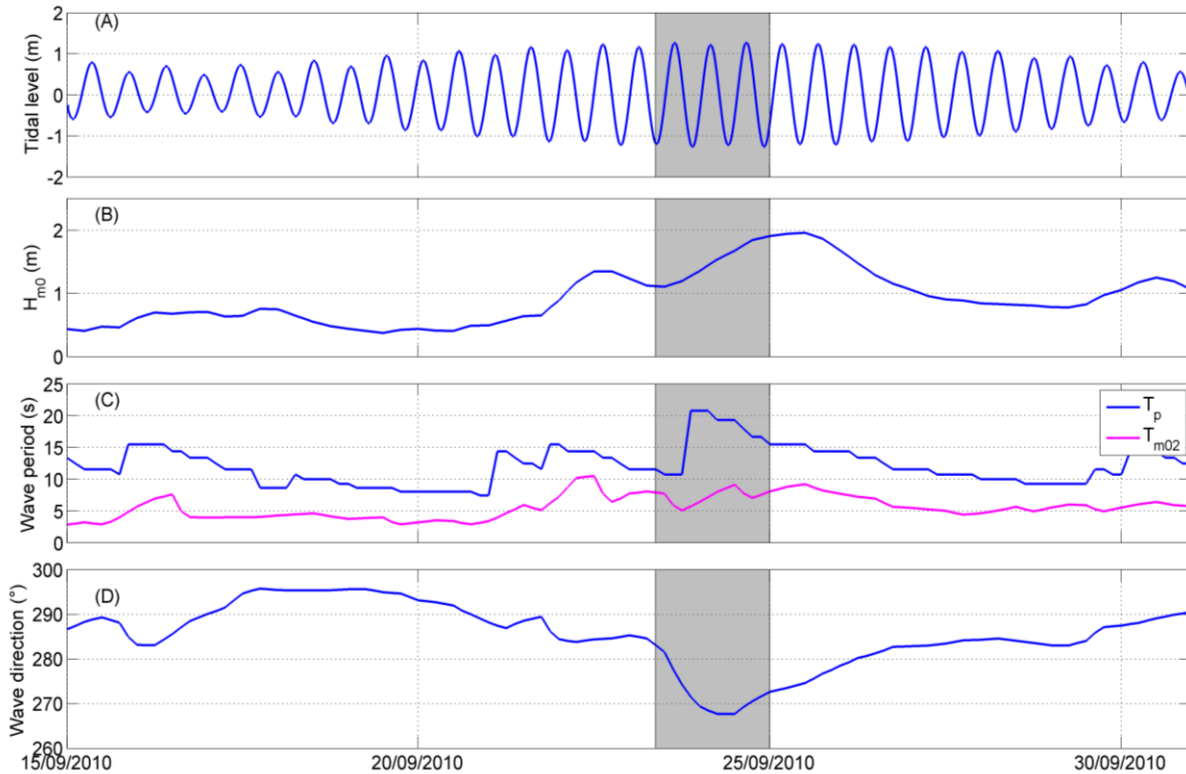
260 Tidal and gravity wave characteristics during the field experiment are described by Dodet et al.  
 261 (2013) and will not be the main focus of this section. However, since gravity waves and IG wave  
 262 propagation and generation can be affected by water levels and tidal currents model results are  
 263 going to be dependent on how well water levels and currents are reproduced by the model.  
 264 Therefore, it is necessary to verify modeled water levels and currents and to show the  
 265 comparison between modeled and measured tidal and gravity waves for a correct interpretation  
 266 of the results.  
 267

268 **4.1 Tidal propagation across the inlet**

269 The field experiment covered 3 tidal cycles and took place during spring tide conditions (Figure  
 270 2). The mean tidal range was 2.45 m, with a minimum of 2.31 m and a maximum of 2.54 m. The  
 271 tidal wave offshore the Albufeira Lagoon is symmetric, but the non-linear tidal propagation  
 272 through the inlet produces significant distortion (see Figure 3.a). As a consequence, the tidal  
 273 range inside the lagoon was reduced by more than 50% compared to the ocean. As usually



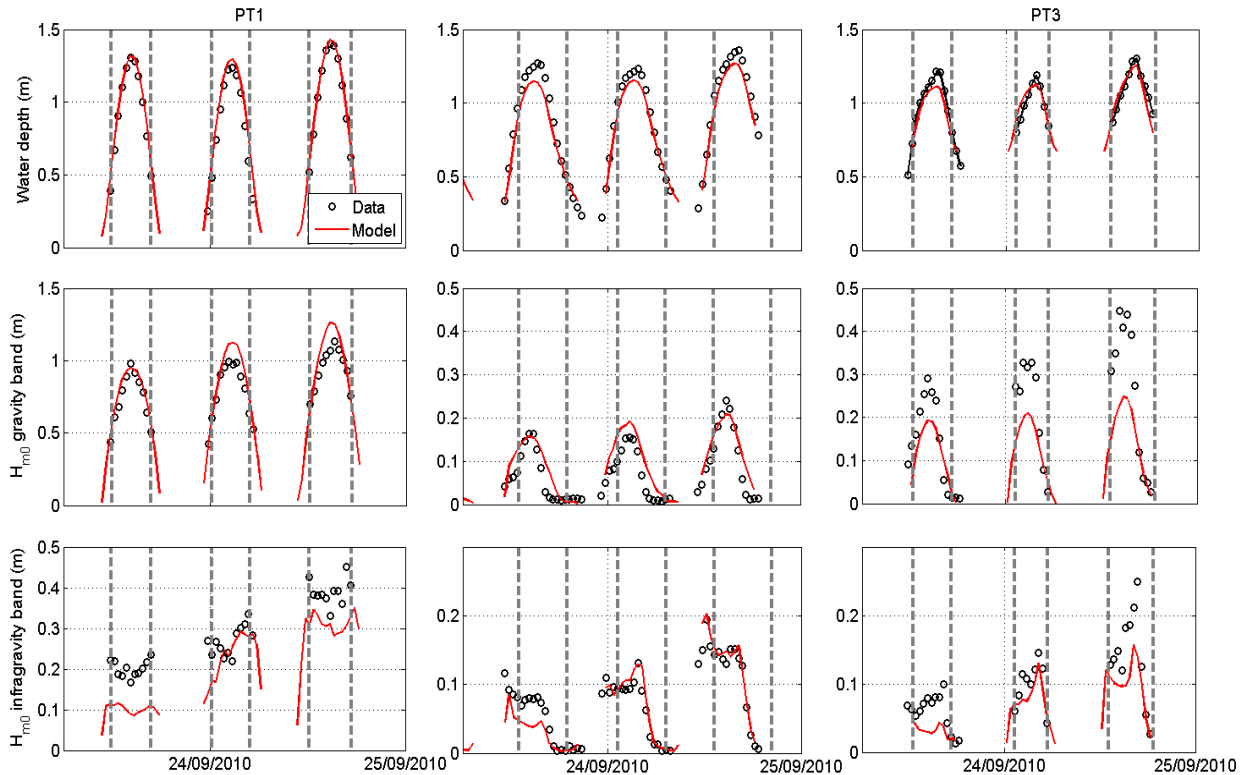
274 observed in friction-dominated tidal inlets, the mean water level inside the lagoon increased  
 275 compared to the ocean, although mean water levels inside the lagoon were also affected by wave  
 276 induced forces (Dodet et al., 2013). In overall, tidal propagation was well reproduced with the  
 277 numerical model as reflected in the model skill values (see Table 2).



278

279 Figure 2. Offshore hydrodynamic conditions during the 15<sup>th</sup> and 31<sup>st</sup> of September 2010, (A)  
 280 tidal level measured at the tidal gauge nearby Cascais, (B) deep water significant wave height,  
 281 (C) deep water wave periods, and (D) deep water mean wave direction. Deep water wind wave  
 282 characteristics were computed with Swan model, offshore the inlet at a water depth of 100 m.  
 283 The shadowed area represents the period of the field experiment.

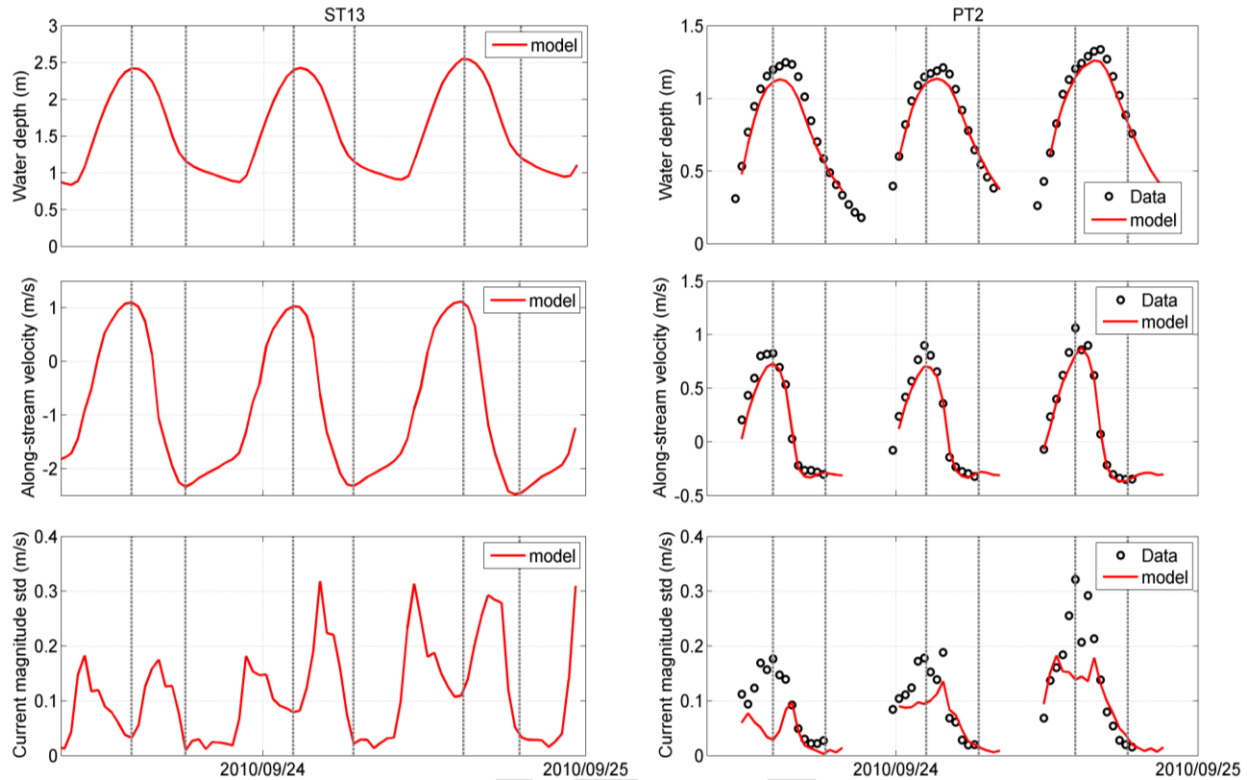
284 The Root Mean Square Error (RMSE) between modeled and measured water level variations at  
 285 the ebb-tidal delta station (PT1) was 0.07 m, at PT12 0.08 m and 0.06 m at PT3. These values  
 286 were still smaller than 10% of the tidal range at each station, which indicates that the model  
 287 reproduced adequately the tidal distortion as its propagation through the inlet and inner lagoon.



288

289 Figure 3. Measurement (black circles) and model result for Run2 (red curve) comparison at the  
 290 three measurement stations. Top panels show the low-pass filtered ( $f < 0.002$  Hz) free surface  
 291 elevation time series, middle panels  $H_{m0,IG}$  time series and bottom panels  $H_{m0,IG}$  time series. The  
 292 grey dashed vertical lines indicate a similar water level at ebb and flood and help identifying  
 293 large differences in short and IG waves between ebb and flood. Model results represent the  
 294 ensemble-mean of 8 numerical simulations, statistically equivalent to Run2.

295 Currents were also measured at PT2 by means of an electromagnetic current meter, located 0.4 m  
 296 above the bed. The comparison with modeled currents averaged over 30 minute samples at this  
 297 sensor reveals a fair agreement, with a RMSE of 0.10 m/s and only a slight underestimation of  
 298 the flood peak, leading to a -0.05 m/s negative bias (Figure 4) and a 0.98 Willmott Skill Score  
 299 (WSS) (Table 3). However, since this sensor was located on the ramp of the flood-delta (Figure  
 300 1), it was sheltered from ebb currents. In the main channel (ST 13) modeled ebb currents were  
 301 twice as strong as flood currents and temporarily reached 2.5 m/s (Figure 4).



302

303 Figure 4. Modeled (red) against measured (black circles) water depth (top row), along-stream  
 304 current velocity (middle row) and standard deviation of the current magnitude computed over  
 305 30 minute samples (bottom row) in the inlet main channel (ST13, Figure 1) and at PT2. The grey  
 306 dashed lines indicate the time where maximum flood and ebb currents occurred. The standard  
 307 deviation of the current magnitude computed over 30 minute samples has been previously low-  
 308 pass filtered with a 25 s window to remove orbital motions of gravity waves.

309

#### 310 4.2 Characterization of gravity waves

311 Deep-water gravity wave energy and the peak period ( $T_p$ ) increased during the field experiment  
 312 (Fig2). The 23<sup>rd</sup> of September  $T_p$  was 12.5 s and the significant wave height ( $H_{m0,G}$ ) 1 m. At the  
 313 end of the experiment swell waves propagating from the west hit the inlet, and consequently  $T_p$   
 314 and  $H_{m0,G}$  increased to more than 20 s and 1.8 m respectively.

315 In all the stations, gravity waves were depth limited and, therefore, tidally modulated (Figure 3).  
 316 Maximum  $H_{m0,G}$  were observed during high tide at PT1, especially in the last tidal cycle, when  
 317 values over 1.2 m were measured. This station became dry from mid to low tide. At PT1 the  
 318 model RMSE was 0.09 m (see Table 2), and the tidal modulation was well captured. The  
 319 Willmott Skill Score (defined in Appendix A) was larger than 0.92 at PT1 and PT2, and  
 320 decreased to 0.76 at PT3, mostly due to a negative bias.

321 Gravity waves damped when propagating from the ebb-delta to the inner lagoon (Figure 3).  
 322  $H_{m0,G}$  decreased from PT1 on average ~91% at PT2 and ~76% at PT3 during high tide. Modeled

323  $H_{m0,G}$  mean reductions were ~86% at PT2 and ~84% at PT3. The highest RMSE (~0.10 m) was  
324 obtained at PT3, where the model underestimated  $H_{m0,G}$ , especially during the last high tide.

325 During the ebb,  $H_{m0,G}$  at PT2 decreased sharply and at mid-ebb  $H_{m0,G}$  was lower than 0.025 m  
326 (Figure 3). This fast reduction after the beginning of the ebb up to low tide was already explained  
327 by wave blocking at the inlet (Dodet et al., 2013). The  $H_{m0,G}$  tidal modulation observed in the  
328 measurements was well reproduced with the numerical model. However, the blocking during the  
329 mid-ebb was underestimated by the model.

### 330 **4.3 Characterization of IG waves**

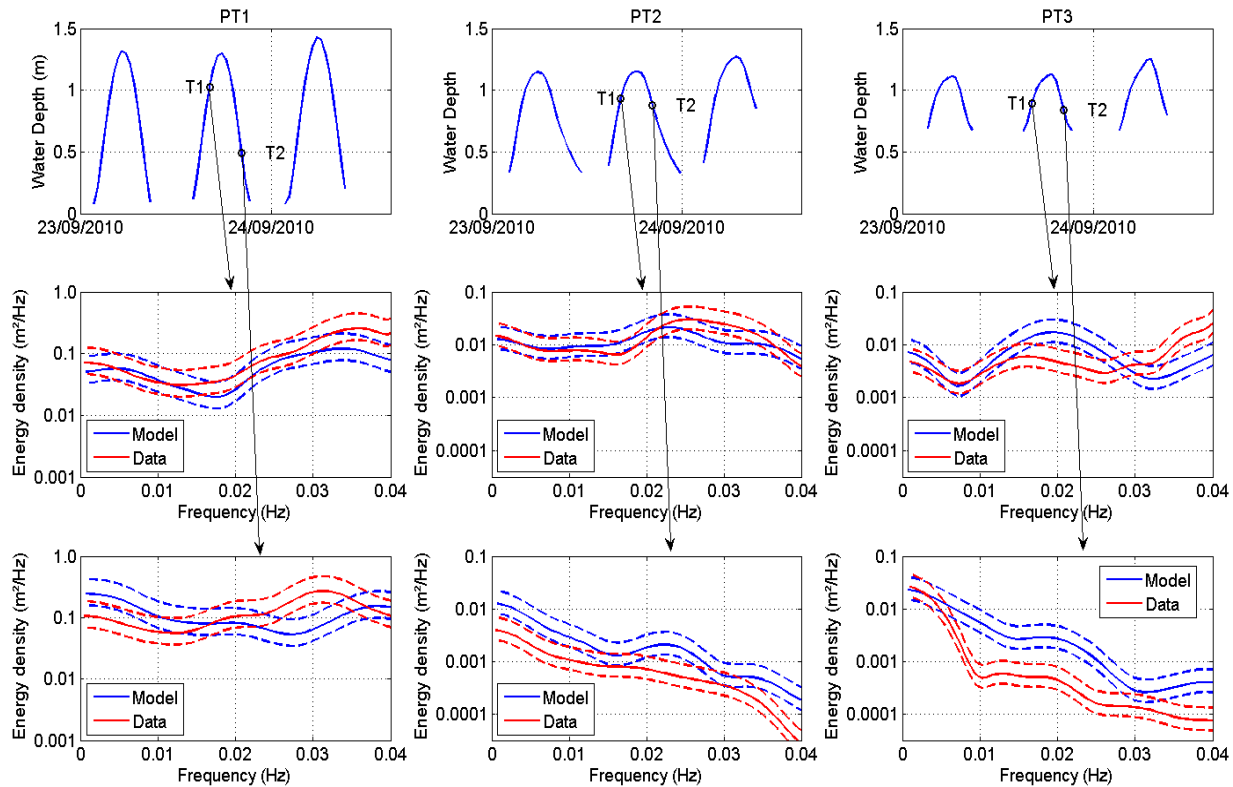
331 Measurements revealed the occurrence of low frequency oscillations (i.e. 25 to 300 s) in the ebb-  
332 delta (PT1) and interior stations (PT2 and PT3). During the experiment, IG wave significant  
333 wave height ( $H_{m0,IG}$ ) increased from 0.2 m to more than 0.5 m at the ebb-tidal delta (PT1). The  
334 largest  $H_{m0,IG}$  was observed during the last tidal cycle of the 24<sup>th</sup> of September, when offshore  
335 wind waves were most energetic and the period was largest (see Figure 2). This swell originated  
336 from a remote storm (Dodet et al., 2013).

337 Mirroring the behavior of the gravity band, IG waves were tidally modulated and  $H_{m0,IG}$   
338 decreased from the ebb-tidal delta (PT1) to the inner part of the lagoon (Figure 3). Due to the  
339 shallow water levels at PT1, the station became dry during half of the tidal cycle. In the three  
340 tidal cycles covered by the experiments, two local maxima of  $H_{m0,IG}$  could be identified at PT1,  
341 the first before and the second after high tide. Between these two local maxima, specifically  
342 during high tide, a local minimum of  $H_{m0,IG}$  was observed.

343 At PT2 and PT3, the observed tidal modulation was not related to the drying of the stations,  
344 since they only became dry at the lowest tidal levels. After mid-ebb, IG wave energy levels at the  
345 inner stations were very low ( $H_{m0,IG}$  decreased by more than 90% with respect to the maximum  
346 values observed during each tidal cycle), suggesting a possible blocking of IG waves. As an  
347 example, Figure 6 depicts the water elevation measurements at PT2. The water elevation time  
348 series, showed fluctuations both in the gravity and IG bands, especially during late flood, high  
349 tide and at the begin of the ebb. After high tide, as the water elevation decreased,  $H_{m0,G}$  and  
350  $H_{m0,IG}$  decreased drastically.  $H_{m0,G}$  reduction occurred on average 20-25 minutes before the  
351 decrease of the IG band.

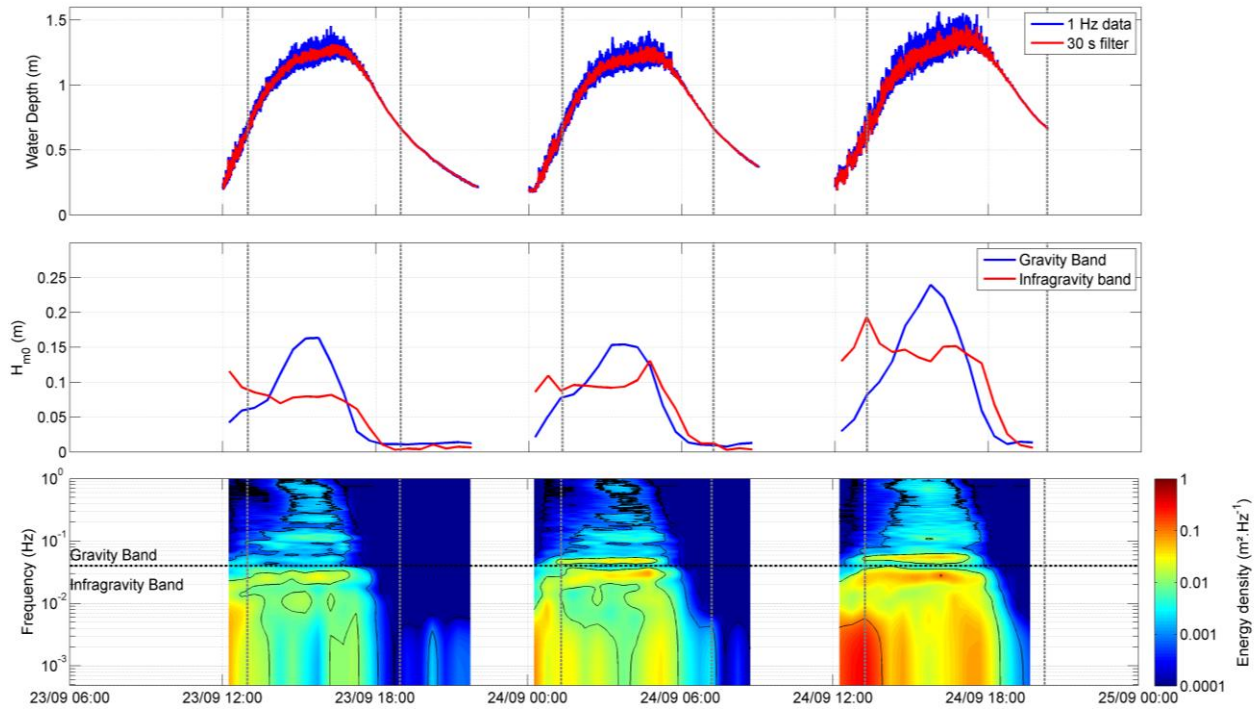
352 XBeach captured both the IG wave energy decrease from the ebb-tidal delta to the inner part of  
353 the lagoon and the tidal modulation (see Table 2). At PT1 the model tended to underestimate the  
354 observed IG wave energy levels, particularly during the first tidal cycle (RMSE=0.08 m), while  
355 at PT2 and PT3  $H_{m0,IG}$ , model results were closer to the measurements (RMSE=0.02 and 0.04 m  
356 at PT2 and PT3 respectively). As indicated by the Willmott Skill Score the model performance  
357 was good in all the stations. As observed in the measurements, model results showed an increase  
358 of the  $H_{m0,IG}$  just before and after the high tide, with a local minimum at high tide. Although this  
359 tendency was observed in all the stations, it was more pronounced at PT3, especially during the  
360 last tidal cycle. As observed in the measurements, modeled IG waves almost disappeared after  
361 mid-ebb at PT2 and PT3.

362 In addition to bulk parameters, measured and modeled frequency distributions of the energy  
 363 associated with IG waves were also compared during the flood (T1) and during the ebb periods  
 364 of the second tidal cycle (Figure 5). At PT1, the frequency distribution of the IG wave energy  
 365 was well captured by the model, although the energy level of the gravity band was  
 366 underestimated by the model. In particular, the maximum of energy was found in the same  
 367 frequency band in the model and in the measurements (0.02-0.04 Hz). The wave spectrum during  
 368 flood and ebb did not change significantly. Inside the lagoon (PT2 and PT3), the frequency  
 369 repartition of energy was also well captured by the model during the flood, particularly at PT2,  
 370 which mirrors the good agreement between model and data for  $H_{m0,IG}$  (Figure 3). During the ebb,  
 371 the two orders of magnitude drop of energy at the highest frequencies was well captured by the  
 372 model, particularly at PT2.



373  
 374 Figure 5. Water depth (top row), IG wave energy density spectra of energy at T1 (middle row)  
 375 and IG wave energy density spectra of energy at T2 (bottom row) at PT1 (left column), PT2  
 376 (middle column) and PT3 (right column). Measured and modeled spectra are depicted in red  
 377 and blue respectively. Dotted lines represent the 95% confidence interval of the spectra.

378  
 379 Low frequency fluctuations in the range 25 to 300 s were also observed in the currents velocities  
 380 recorded at PT2 (Figure 4). The largest current fluctuations in the infragravity band occurred  
 381 nearly in phase with maximum flood currents and rapidly dropped after the beginning of the ebb.  
 382 After mid-ebb, these current fluctuations were almost inexistent. XBeach captured reasonably  
 383 the time evolution of these velocity fluctuations, although with a substantial underestimation of  
 384 the peak (Figure 4).



385  
386 Figure 6. Time series of the measured free surface elevation (top),  $H_{m0,G}$  and  $H_{m0,IG}$  (middle), and  
387 frequency repartition of energy density (bottom) at PT2.

	Free surface elevation (tides+ wave setup)				$H_{m0,G}$				$H_{m0,IG}$			
	RMS E (m)	NRMS E (%)	BIAS (m)	WSS	RMSE (m)	NRMS E (%)	BIAS (m)	WSS	RMSE (m)	NRMS E (%)	BIAS (m)	WSS
PT1	0.07	6.7	0.06	0.98	0.09	11	0.07	0.95	0.08	28	-0.07	0.79
PT2	0.08	8.5	-0.06	0.98	0.03	44	0.02	0.92	0.02	24	-0.004	0.96
PT3	0.06	6	-0.03	0.94	0.1	48	-0.07	0.76	0.04	41	-0.03	0.805

388 Table 2 Root Mean Square Error (RMSE), Normalized Root Mean Square Error (NRMSE), bias  
389 and model skill (Willmott Skill Score, WSS) for free surface elevation (tides+ wave setup),  
390  $H_{m0,G}$  and  $H_{m0,IG}$ . For a perfect model that reproduces the observation exactly, the WSS is one.  
391

	RMSE (m/s)	Bias (m/s)	NRMSE (%)	WSS (-)
Along-stream current magnitude	0.10	-0.05	21	0.98
Current magnitude standard deviation	0.07	-0.04	53	0.76

392  
393 Table 3 Root Mean Square Error (RMSE), bias, Normalized RMSE and model skill (Willmott Skill  
394 Score, WSS) for current magnitude and standard deviation.  
395

## 396 5. DISCUSSION

397 This section points out the limitations of the considered modeling approach, and describes the  
398 main mechanisms that trigger IG waves in Albufeira Lagoon and the propagation processes  
399 along the tidal inlet. In the absence of water level measurements outside the surf-zone, it was not  
400 possible to analyze the dominant IG wave generation mechanism based on the observations.  
401 Considering that XBeach reproduced IG energy evolution reasonably both inside and outside the  
402 lagoon, we used model results alternatively. The section also discusses the possible implications  
403 of IG waves on sediment transport and morphodynamics in wave-dominated inlets.

404

### 405 5.1 Limitations of the modeling approach

406 The comparison between modeled and measured water levels showed a good agreement, with  
407 RMSE lower than 0.1 m. Wave heights in the gravity band ( $H_{m0,G}$ ) were also reasonably  
408 reproduced, with RMSE ranging from 0.04 to 0.10 m. On the ebb-tidal delta  $H_{m0,G}$  were slightly  
409 overestimated at high tide. This problem was also pointed out by Dodet et al. (2013) and  
410 explained by limitations in the available bathymetric data. Inside the lagoon, the model  
411 overestimated wave heights at the beginning of the ebb, although the total blocking that occurred  
412 after mid-ebb was well captured. The fast drop of wave height at the beginning of the ebb was  
413 explained by Dodet et al. (2013) by an increase in wave steepness due to strong opposing  
414 currents, which induces dissipation by whitecapping. The increase in wave steepness is due to  
415 shoaling induced by opposing currents. This hypothesis was corroborated by time series of wave  
416 energy spectra (Figure 6), which shows that the highest frequencies were dissipated first. Since  
417 XBeach considers a single frequency in the gravity band, this process cannot be accurately  
418 represented, and could explain the overestimation of wave height at the beginning of the ebb.  
419 The under prediction of  $H_{m0,G}$  at PT3 and over prediction at PT2 during the flood and high tide  
420 could also be due to the fact that we are not considering any diffraction effects.

421  $H_{m0,IG}$  time series were reasonably reproduced, with RMSE of the order 0.02 to 0.08 m. In  
422 particular,  $H_{m0,IG}$  were underestimated by up to 25%, and even 50% at the first tidal cycle at  
423 PT1 (Figure 3). Among the different possible reasons, the fact that IG and gravity waves are  
424 represented in different models doesn't allow a proper representation of all the non-linear  
425 interactions that can affect the generation, propagation and dissipation of IG waves. For instance,  
426 the merging of bores in the surf-zone (e.g. Senechal et al., 2001; van Dongeren et al., 2007)  
427 cannot be represented in such modeling approach, which would lead to an overestimation of  
428 energy in the gravity band and an underestimation in the IG band, as observed here. These model  
429 limitations, together with the limitations in the available bathymetric data could explain why at  
430 PT1 the WSS indicates a lower model performance. This underestimation of IG waves can also  
431 explain the underestimation of low frequency fluctuations in the currents observed at PT2  
432 (Figure 4). In addition, the relationship between  $H_{m0,IG}$  at the entrance of the lagoon and the  
433 magnitude of the current fluctuation inside the lagoon doesn't appear to be linear. This non-  
434 linearity could be related with the rapidly changing bathymetry around the flood delta but this  
435 hypothesis will have to be verified in future studies.

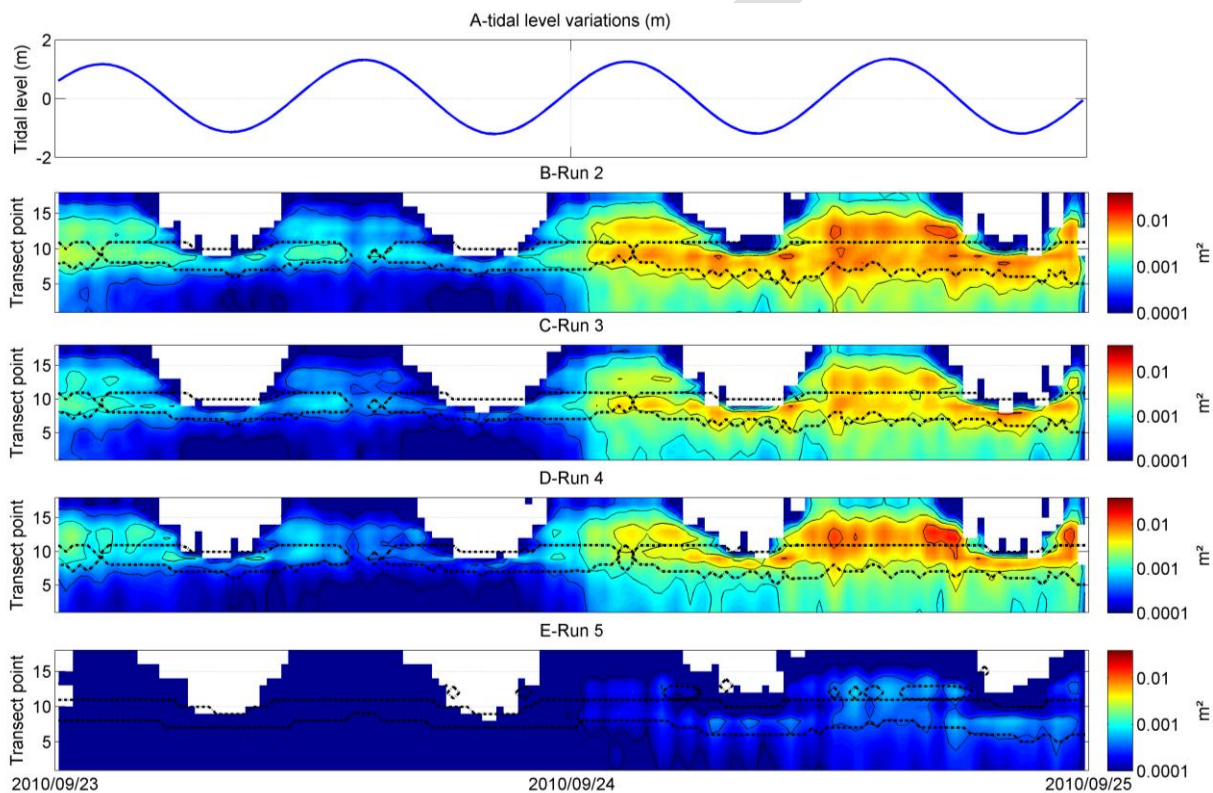
436 However, despite these limitations, the low RMSE and acceptable model skills values would  
437 suggest that XBeach captures the main processes responsible for IG wave generation and  
438 propagation during the experiment. Therefore, the following points of the discussion rely on

439 numeric results and experiments, intended to better understand the relevance of IG waves on  
 440 tidal inlet dynamics.

441

## 442 5.2 IG wave generation

443 With the free surface elevation stored at each computational node with a 5 s interval, for each  
 444 model simulation, the time variation of the IG energy variance was computed every 10 minutes.  
 445 The energy variance evolution, through a transect that extended from offshore of the inlet (at  
 446 water depths of 10 m), along the main channel, to the interior part of the lagoon, was analyzed  
 447 and compared between the considered simulations (Figure 7). Model stations (hereafter ST)  
 448 chosen for the data analysis are shown in Figure 1.



449

450 Figure 7.A) Time series of the tidal free surface elevation at ST2, and time series of the  
 451 simulated IG wave energy along the transect shown in Figure 1: B) Run2: with incoming bound  
 452 wave and wave forces activated everywhere, C) Run3: same as 2 without wave forces in the  
 453 surf-zone, D) Run4: no incoming bound-wave nor wave forces outside the surf-zone, E) Run5:  
 454 with incoming bound-wave and without wave groups. The locations of stations along the  
 455 selected transect are shown in Figure 1. The dashed lines delimit the surf-zone.

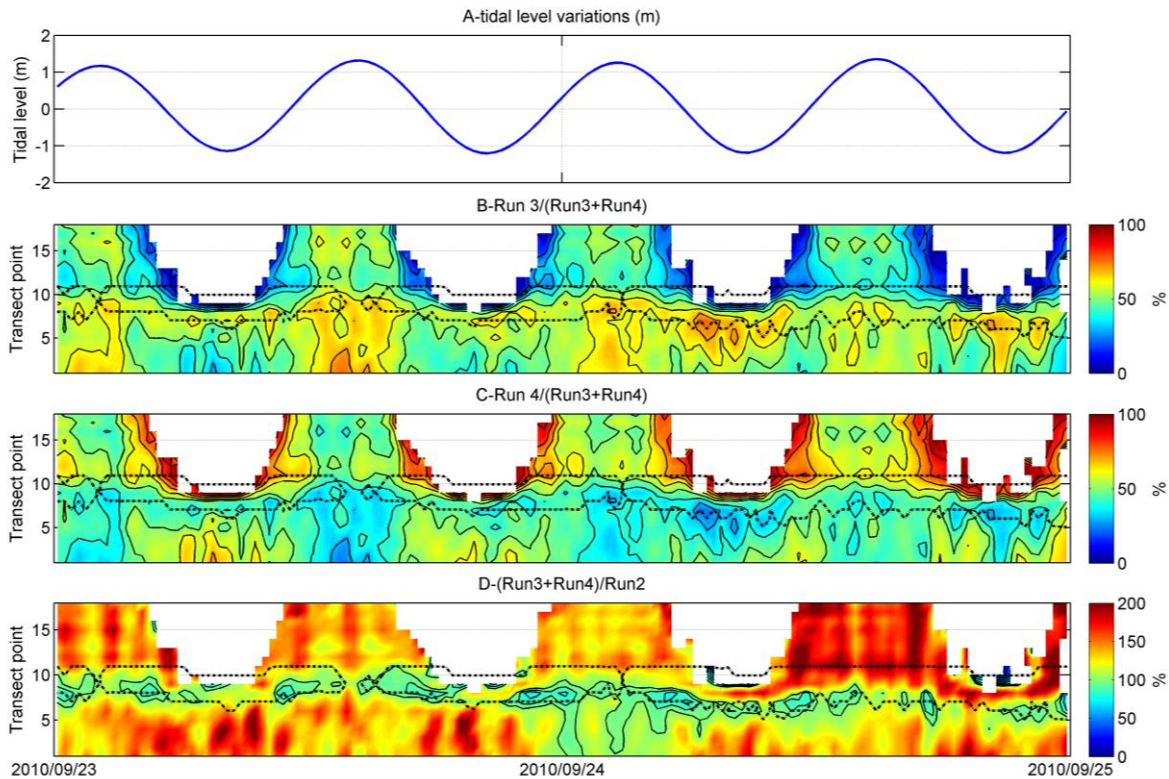
456 In general, energy levels at Run 2 and 4 were higher than at 3 and 5. In Run 2 the maximum  
 457 energy levels were  $0.012 \text{ m}^2$ , which is equivalent to  $H_{m0,IG}$  of 0.45 m. In all simulations energy  
 458 increased from offshore to the ebb-tidal delta (ST 7-11), where maximum values were reached.  
 459 When water levels exceeded mean water levels two local maxima were observed. The first one  
 460 was located in the offshore edge of the ebb-tidal delta, between ST 8 and 10. The second was



461 located in the inlet mouth, between ST 12 and 14. During the rest of the tidal cycle only one  
462 maximum, at the edge of the ebb-tidal delta, was observed. The location was tidally modulated,  
463 closer to the inlet at high tide and more offshore at low tide. Energy was higher inside the surf-  
464 zone for run 4 and conversely, slightly higher outside the surf-zone for Run 3. Run 5 was  
465 designed to investigate the contribution of the incoming bound wave and its shoaling across the  
466 domain without any further forcing mechanism (Figure 7E). The IG energy variance in Run 5  
467 was one order of magnitude smaller than in the rest of the runs, which indicates that this  
468 mechanism is not dominant, therefore it will not be further discussed.

469 Run 3 was designed to compute the contribution of the bound wave mechanism in IG wave  
470 generation while Run 4 was designed to isolate the contribution of the breakpoint mechanism. In  
471 order to better quantify the contribution of each mechanism, we also computed the ratio between  
472 IG energy variance from Run 3 (resp. Run 4) normalized by the linear sum of the IG energy  
473 variance from Run 3 and 4 (Figure 8B and 8C, respectively). Outside the surf-zone and up to the  
474 middle of the surf-zone, the bound wave mechanism is responsible for 40 to 70 % of the IG  
475 energy variance, while from the inner part of the surf-zone to the shoreline and the inlet mouth,  
476 the breakpoint mechanism turns dominant at the lower stages of the tide and is responsible for 50  
477 to 90% of the IG energy variance. During high-tide, the relevance of the breakpoint mechanism  
478 decreases, which could be due to less intense wave breaking over the steepest part of the ebb-  
479 shoal. This behavior would also explain the shapes of the observed time series of  $H_{m0,IG}$   
480 measurements, with two local maxima (one at flood and the other at ebb tide) and a local  
481 minimum during high-tide.

482 In order to detect possible interactions between both mechanisms, we computed the linear sum of  
483 the IG energy variance from Run 3 and 4 normalized by the IG energy variance of Run 2 (Figure  
484 8D). All along the considered time series, the normalized sum is close or higher than 100%, with  
485 local values reaching 200% along the shoreline. This behavior suggests that the bound-wave and  
486 the breakpoint mechanisms acted in opposite ways and resulted on a reduction of  $H_{m0,IG}$   
487 compared to a situation where both mechanisms would act independently. Since the bound-wave  
488 is out of phase with the wave envelope and the wave setup is in phase, the combination could  
489 create a destructive interaction and result on a reduction of the amplitude of the observed IG  
490 waves. In addition, Run 3 does not include wave forces inside the surf-zone and therefore the  
491 mean wave setup is not accounted for. Additional tests with a simple 1D shoaling model (energy  
492 flux conservation) suggest that considering wave setup could reduce IG wave energy by ~8 %.  
493 Therefore, this effect could also contribute to explain departures from 100 % in Figure 8D.



494

495 Figure8. A) Time series of the free-surface elevation due to tides in ST2. (B) Percentage of *IG*  
 496 *energy variance* due to bound wave mechanism compared to breakpoint mechanism, C)  
 497 Percentage of *energy variance* due to breakpoint mechanism compared to bound wave  
 498 mechanism and D) Sum of energy variance of Run 3 and Run 4 normalized by Run 2, showing  
 499 relevant interactions between both mechanisms.

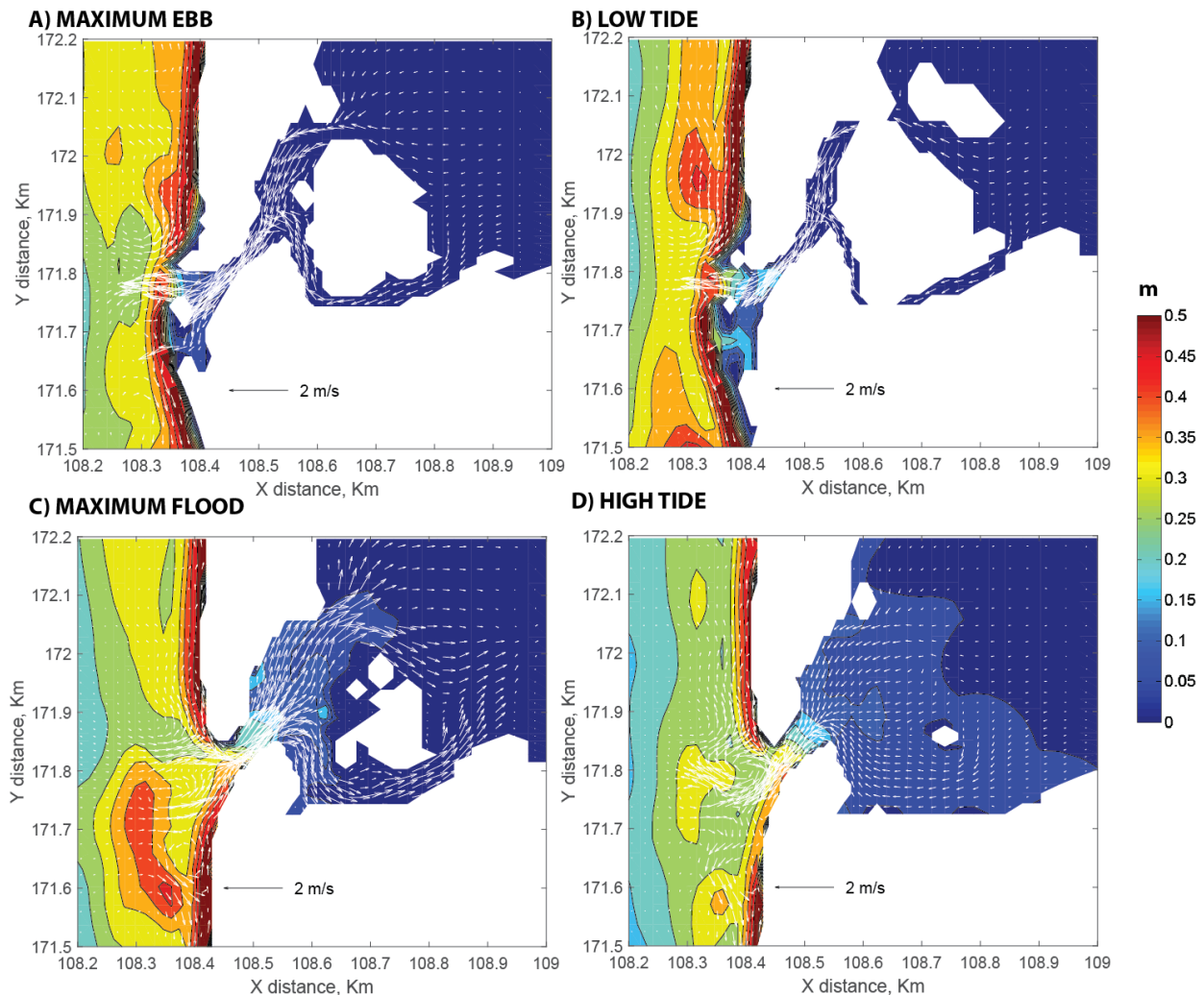
### 500 **5.3 IG wave propagation from the ebb-tidal delta to the inner lagoon**

501 IG wave propagation from the ebb-tidal delta to the inner part of the lagoon is complex and  
 502 highly dependent on the tidal phase.  $H_{m0,IG}$  variation from the offshore to the inner part of the  
 503 lagoon showed that, independently of the tidal phase, the maximum IG energy peak was obtained  
 504 over the ebb-tidal delta (Figure7). This maximum was followed by a decrease of  $H_{m0,IG}$  between  
 505 ST 10 and 12. At the inlet throat (ST 13 and 14) a second local minimum was observed during  
 506 the flood and high tide. During low and ebb tide a drastic decrease of  $H_{m0,IG}$  was detected at ST  
 507 13, in the modeling results as in the observations.

508

509 To have a better understanding of how the tidal stage can affect the IG wave propagation, we  
 510 computed the spatial distribution of  $H_{m0,IG}$  at different tidal instants during the last tidal cycle  
 511 (Figure 9), assuming stationary mean wave boundary conditions equivalent to those of  
 512 September 24 at 9:00 AM ( $H_{m0,G}=1.55$  m,  $T_p=19.3$  s and 264 degrees peak direction in nautical  
 513 convention).  $H_{m0,IG}$  was computed after splitting the modeled free-surface elevation into  
 514 consecutive bursts of 30 minutes. To be consistent with this burst, currents were also averaged  
 515 over 30 minute intervals.

516 Model results indicate that during maximum ebb and low tide, the maximum  $H_{m0,IG}$  was  
 517 restricted to the terminal lobe, whereas during high tide and mid flood infragravity energy  
 518 propagated throughout the ebb-tidal delta. During mid ebb, IG wave energy reached the inlet  
 519 mouth but the energy did not propagate into the lagoon, it got blocked. Tidal currents at the inlet  
 520 were more intense than 1.8 m/s, reaching peak values of 2.5 m/s in water depths ranging from 1  
 521 to 1.5 m (Figure 4). As the water depth decreased parts of the ebb-tidal delta became dry. IG  
 522 waves were mainly generated in the terminal lobe, where most of the wave breaking occurred.  
 523



524  
 525 Figure9. Simulated  $H_{m0,IG}$  distribution and depth-averaged current vectors during a)  
 526 maximum ebb, b) low-tide, c) maximum flood, and d) high-tide of the last tidal cycle.  
 527 Current vectors were averaged over the length of the burst (30 minutes). High tide and  
 528 low tide are defined in terms of maximum and minimum water levels inside the lagoon.  
 529

530 Gravity waves at inlets get blocked during the maximum ebb and they break at or before the  
 531 blocking point without being reflected, while losing considerable amounts of energy due to  
 532 current induced whitecapping (Chawla and Kirby, 2002). Similarly, IG waves could be blocked  
 533 at the inlet and this could explain the drastic energy damping observed during the mid-ebb and  
 534

535 blocking happens when the absolute wave group celerity falls to zero, in other words, when the  
 536 relative group celerity is equal to the opposing current speed:

$$537$$

$$538 \quad C_{g,a} = C_{g,r} + U \cos \alpha = 0 \quad (6)$$

539 where  $C_{g,a}$  and  $C_{g,r}$  are the absolute and relative wave group celerities, respectively,  $U$  is the  
 540 vertically averaged current speed and  $\alpha$  is the angle between waves and currents. When blocking  
 541 occurs, the wave energy cannot propagate against the current.  
 542

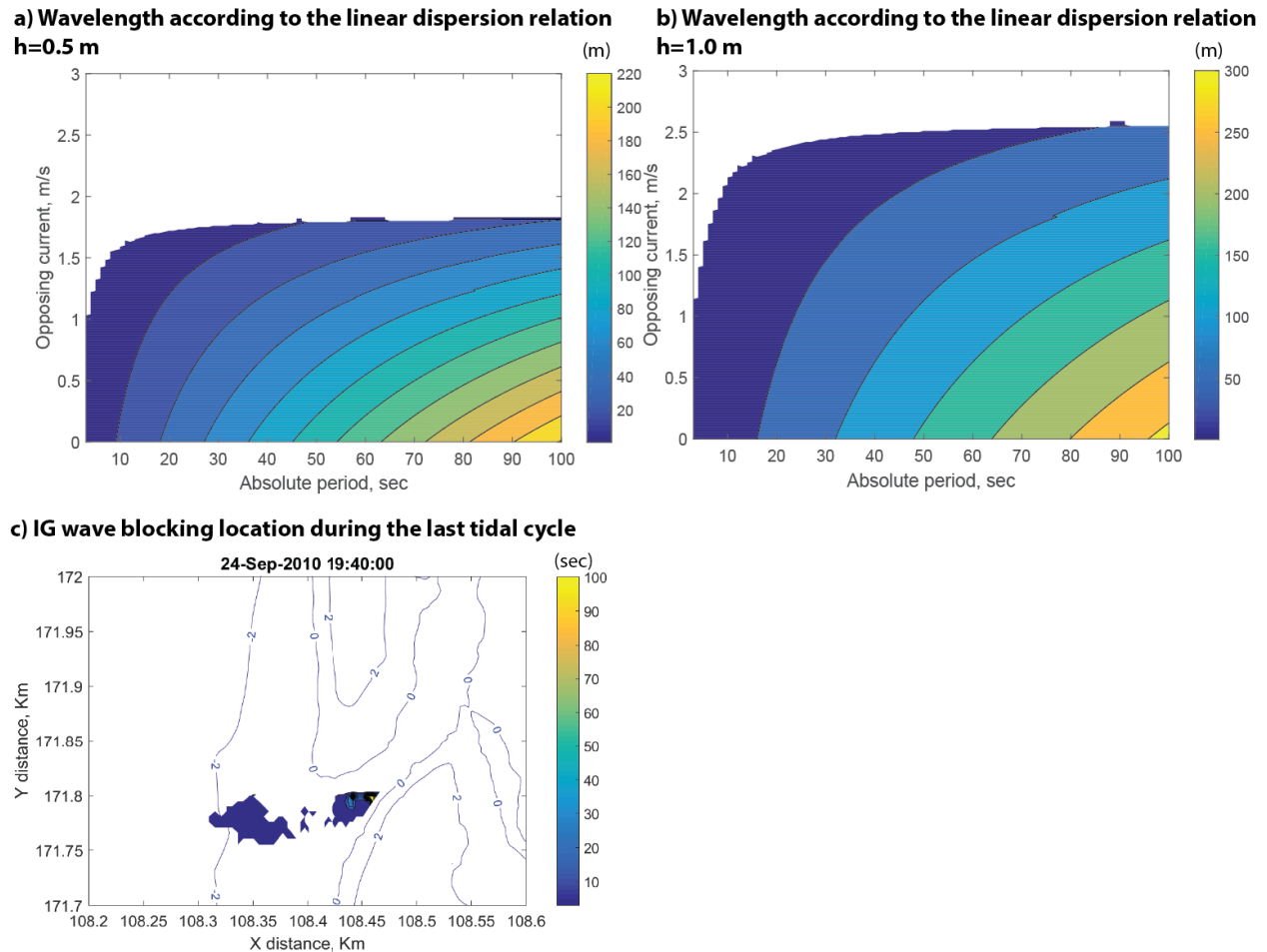
543 The linear wave dispersion relationship affected by the Doppler shift can be used to determine  
 544 the maximum period blocked by an opposing current with a given intensity:  
 545

$$546$$

$$547 \quad \sigma^2 = (w_a - kU \cos \alpha)^2 = gk \tanh(kh) \quad (7)$$

548 Where  $\sigma$  is the intrinsic or relative frequency,  $w_a$  is the absolute frequency,  $U$  the magnitude of  
 549 the depth-averaged velocity,  $k$  is the wavenumber,  $g$  the gravitational acceleration and  $h$  is the  
 550 total water depth.  
 551

552 We used the linear dispersion relation to determine, based on the computed water levels and  
 553 current speeds, where and when gravity and IG wave blocking occurred. As shown in Figure 10  
 554 (panels a and b), weaker opposing current speeds are required to block shorter period waves  
 555 according to the linear dispersion relation. For 1 m water depth, current velocities larger than 2.4  
 556  $\text{m}\cdot\text{s}^{-1}$  are theoretically required to block waves of any frequencies while for 0.5 m water depth,  
 557 this value drops to 1.7  $\text{m}\cdot\text{s}^{-1}$ . IG wave blocking in the last tidal cycle got initiated at the inlet  
 558 mouth (Figure 10c), where tidal current speeds up to 2.5 m/s were modeled from mid-ebb to low  
 559 tide, with water depths varying from 1.5 to 1 m. Gravity-wave blocking was initiated earlier and  
 560 further offshore.  
 561  
 562



563  
 564 Figure 10. Contour map of the wave length (m) as a function of the opposing current  
 565 velocity given by the linear dispersion relation, a) for a water depth of 0.5 m and b) for a  
 566 water depth of 1 m. The white area indicates that there is no real solution and the  
 567 maximum period indicates the maximum period that is blocked; c) IG wave blocking  
 568 location computed with the linear-dispersion relation during tidal cycle 3 and bathymetric  
 569 contour lines in blue. The color indicates the maximum period (s) that is being blocked.

570  
 571 Measured gravity waves at PT2 and PT3 were blocked earlier (20 minutes in average) than the  
 572 infragravity band (Figures 3, 5 and 6), mainly because lower speed currents and/or larger water  
 573 depth are required to block lower period waves (Figure 10).

#### 574 575 **5.4 Possible impacts on sediment dynamics**

576 The propagation of IG waves across the inlet induced current fluctuations that reached more than  
 577 50% of the tidal current intensity at PT2 during all the experiment, but especially in the third  
 578 tidal cycle (Figure 4). Although this behavior was reasonably reproduced by XBeach, a direct  
 579 comparison with the measured time series was not possible because the phase of the gravity  
 580 wave frequency components at the offshore boundary were unknown. Alternatively, the standard  
 581 deviation of current velocities were computed over 30 minute samples and compared. This  
 582 comparison revealed that XBeach was able to capture the temporal pattern of these low-

583 frequency fluctuations, although with a substantial underestimation of the peak, which occurred  
584 during the maximum flood currents. Because sand fluxes depend non-linearly both on water  
585 levels and currents, they may be affected by the presence of low-frequency fluctuations  
586 associated with IG waves.

587 These low frequency fluctuations associated with IG waves would tend to promote sand fluxes,  
588 but their blocking during a large part of the ebb would cause this process to be more active  
589 during the flood. Over a tidal cycle, this process would tend to limit ebb-dominance in the main  
590 channel and promote flood-dominance inside the lagoon. One should keep in mind that this  
591 experiment was carried out under low to moderate energy waves and it can be expected that  
592 under storm waves, larger IG waves would induce larger current fluctuations which could have a  
593 determinant impact on the inlet sediment dynamics. In particular, this mechanism could  
594 potentially contribute to the shoaling and closure of tidal inlets that occurs in winter along the  
595 western coast of Portugal (Bertin et al., 2009; Dodet et al., 2013; Fortunato et al., 2014). Further  
596 field measurements should be carried out under storms and under less energetic but more  
597 frequent swell conditions, with a deployment specifically dedicated at measuring IG waves and  
598 their subsequent dynamics.

## 5995 6. SUMMARY AND CONCLUSIONS

600 Field measurements conducted at the Albufeira Lagoon Inlet revealed that IG waves developed  
601 on the ebb-tidal delta and propagated inside the lagoon during flood and high tide, while they  
602 were blocked during the ebb. The field experiment covered three tidal cycles, during spring tides.  
603 Offshore significant wave height and the peak period increased due to the effect of a remote  
604 storm that generated energetic swell conditions that impacted the study zone at the end of the  
605 experiment. During the last tidal cycle, when the offshore waves were most energetic,  $H_{mo,IG}$   
606 values over 0.5 m were measured at the ebb-tidal delta. Inside the lagoon values up to 0.2 m  
607 were measured.

608  
609 The comparison between measurements and numerical simulations showed that IG wave  
610 generation and propagation were fairly reproduced with XBeach. This fact indicates that,  
611 although XBeach simplifies and neglects some physical processes that can affect both the  
612 generation and the propagation of IG waves, the model captures the main processes. The analysis  
613 of model results revealed that the two proposed IG wave generation mechanisms (the breaking  
614 point variation or dynamic set-up and shoaling and release of the bound-wave) were relevant,  
615 and contributed significantly to the IG wave generation. While the bound-wave shoaling was  
616 dominant offshore the breaking area, wave breaking contribution was slightly higher from the  
617 ebb-tidal delta to the inlet mouth. Model results also suggest that interactions between bound-  
618 wave shoaling and the dynamic set-up, produced a reduction of IG energy levels within the surf-  
619 zone.

620  
621 IG waves were shown to be blocked during the ebb, due to strong counter tidal currents in  
622 shallow water depths. IG wave blocking occurred later than the gravity-band blocking because  
623 stronger opposing currents and shallower depths are needed to block longer period waves.

624  
625 Field measurements and XBeach simulations demonstrated that, at least at this specific inlet, IG  
626 wave generation, propagation, and dissipation mechanisms differed substantially from those  
627 observed in beach environments. Due to steep bottom slopes at the terminal- lobe and gentle

628 slopes in the inner part of the ebb-tidal delta, the bound-wave shoaling and release and the  
 629 “dynamic” set-up mechanisms were both active during the analyzed period. Moreover, results  
 630 have shown another relevant difference with respect to the beach environments: while in beach  
 631 environments the IG wave energy is dissipated or reflected in the coast, in tidal inlets the energy  
 632 is partially transmitted to the inner part of the lagoon depending on the water levels and tidal  
 633 currents at the inlet.

634  
 635 Both measurements and model results showed that IG waves induced fluctuations in flood  
 636 currents inside the lagoon reaching temporarily 100 % of the low-pass filtered current  
 637 magnitudes (although the largest fluctuations were underestimated in the model). The fact that  
 638 these fluctuations occur mostly at flood and not at ebb because IG waves are blocked could  
 639 promote flood dominance in the lagoon. This mechanism could contribute the shoaling and  
 640 closure of tidal inlets, in combination to other wave-induced processes previously analyzed (e.g.  
 641 Bertin et al., 2009; Dodet et al., 2013). However, the field experiment presented in this study was  
 642 carried out under low to moderate wave energy and doesn't allow for a quantification of the  
 643 impact of IG waves on the inlet sediment dynamics. Additional field measurements designed to  
 644 measure infragravity wave propagation and transformation, the implications on the fluctuation of  
 645 currents and the subsequent impacts on sediment transport dynamics will have to be carried out  
 646 in such shallow inlets, under storm waves and mean wave conditions.

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 655 results and some of the processed data used in this paper will be made available upon request to  
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 657 improved this manuscript substantially.

#### 658 **APPENDIX A**

659  
 660 Considering that  $M_n$  and  $C_n$  are the measured data and the computed data, respectively, at  $N$   
 661 discrete points, the model performance (skill,  $S$ ) formula proposed by Wilmott (1981) is given  
 662 by:  
 663  
 664

$$S = 1 - \frac{\frac{1}{N} \sum_{n=1}^N |C_n - M_n|^2}{\sum_{n=1}^N \left( |C_n - \overline{M_n}| + |M_n - \overline{M_n}| \right)^2}$$

665  
 666 The overbar represents the mean value. This skill factor ranges from 0 (bad skill) to 1 (very good  
 667 skill).  
 668

669

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