Wave transformation and wave-induced currents on a submerged barrier reef: Field observations and Boussinesq-type modelling

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1- Introduction

Waves breaking on a reef create a radiation stress gradient that drives wave-setup and wave-induced currents (e.g. [1], [2], [3]). These phenomena exert a major influence on the hydrodynamics of shallow submerged coral reefs, as well as on the circulation and flushing of lagoons. The tidal evolution of water depth over a reef may have a strong impact on the wave-induced processes. However, only few field experiments have been devoted to this problem. Depending on (tidal) water depth and offshore wave height, waves propagating over a submerged barrier reef may decompose into shorter components, referred to as secondary waves. This process can strongly affect wave dissipation and consequently the wave-induced circulation. In this communication we present new results about the **tidal modulation** of both wave-setup and wave-induced current on a submerged barrier reef. We also study the "high frequency" dynamics of **secondary waves** and present preliminary comparisons between field data and a **Boussinesq-type model** ([5], [6]).

2 - Field experiment

A 3-week field experiment was conducted on the Aboré coral reef (southwest lagoon of New Caledonia, fig. 1) in October 2005 ([4]).

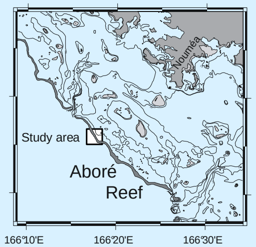

Fig. 1. Study area in the southwest lagoon of New Caledonia

Instrument deloyment (fig. 2) :

- Offshore wave and tide conditions: WTR 9, Aanderaa, 2-Hz (A0 in fig. 2)
- Reef flat: two sets of ADV Vector (Nortek) coupled with two pressure sensors sampled synchronously at 8 Hz
- Lagoon: S4 InterOcean electromagnetic current meter 2-Hz ($S4_l$ in fig. 2)

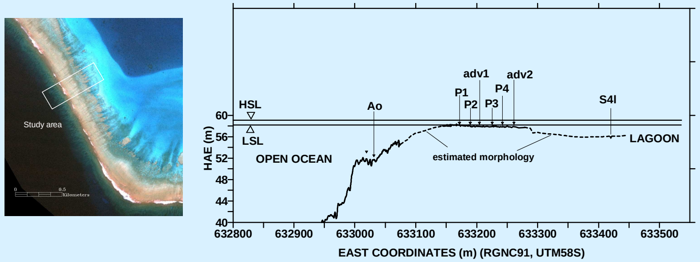

Fig. 2. Reef profile and instrument deployment. P1-4: pressure sensors; adv1-2: ADV velocimeters; $S4_l$: electromagnetic current meter; Ao: wave and tide recorder.

Tide and wave conditions (fig. 3) :

The tides are semidiurnal, with a tidal range on the reef between 0.6 and 1.4 m at neap and spring tides respectively. At low water spring, the reef-top is located just below the sea surface. In this poster, our analysis will be focused on data between days 2 and 7, characterized by westerly waves propagating normally to the reef, with $H_s \in [0.5\text{ m}, 1.8\text{ m}]$) and $T_{02} \in [5\text{ s}, 8\text{ s}]$.

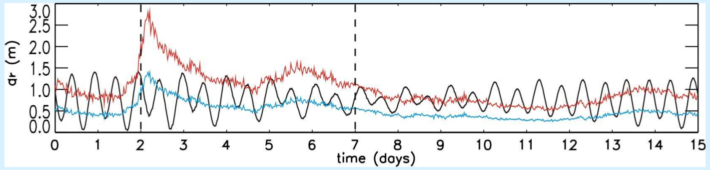

Fig. 3. Tide and wave conditions. Black line: mean water depth at the reef top d_r; red line: breakpoint water depth h_b; blue line: $h_b/2$.

3 - Results

Tidal modulation of wave-setup and wave-induced currents

Fig. 4 shows that:

- wave setup, ζ_r, and cross-reef current at the reef top, u_r, are strongly correlated to tidal oscillations of the water depth
- ζ_r oscillates 180° out of phase with the water depth over the reef-top d_r
- u_r is positive (i.e. lagoonward directed), with a maximum value of 0.65m/s
- u_r oscillate at twice the tidal frequency, with maximum values occurring around mid-tides (see the green curve)

We show in fig. 4 that this tidal modulation is well described by Hearn's model [2]: $\zeta_r = \alpha(h_b - d_r)$ (1) $u_r^2 = K_H d_r (h_b - d_r)$ (2) where h_b is the breakpoint water depth (computed using linear shoaling theory and the breaking criteria: $Hs_b/h_b=0.7$) and with the best-fit parameters α =0.081 and K_H=0.22 s^{-2}. From equation (2), we can deduce that, for given wave conditions, the maximum u_r is reached for $d_r = h_b/2$. In fig. 3, we can see that, between days 2 and 7, the condition $d_r=h_b/2$ is generally reached twice a tide. This is in agreement with the observation (fig. 4b) of a local maximum of u_r twice a tide.

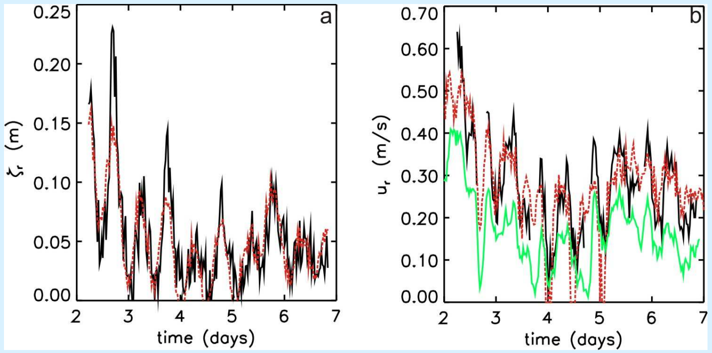

Fig. 4. Comparison between observed (solid line) and calculated (red dashed line, eq. 1 and 2) wave setup z_r (a) and cross reef current u_r (b), on the reef-top. Green line: cross reef current in the agoon at site $S4_l$.

Boussinesq modelling and secondary wave generation

We investigate the ability of a recent Boussinesq-type model, SERR-1D, to reproduce wave transformation and wave-induced current on a barrier reef. SERR-1D is a fully non-linear, weakly dispersive, finite volume Boussinesq model [5], including a new parametrization for wave breaking [6].

Fig. 5 shows computed mean surface elevation and cross-reef current over the Aboré reef for day=2.3. The offshore boundary conditions are given by the wave and tide recorder A_0. The model reproduces qualitatively well the wave-driven flow, but slightly underestimates the maximum values of ζ_r and u_r. In agreement with field observations, the model predicts that the turbulent bores (fig. 6b), propagating over the reef flat, may evolve into non-breaking oscillating bores (fig. 6c). Due to the lack of wave breaking dissipation, these secondary waves propagate far into the lagoon, and thus play a significant role in the lagoon dynamics.

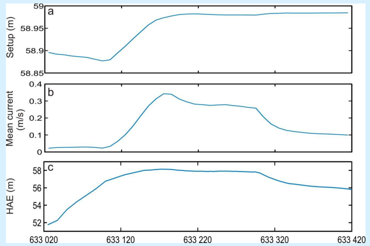

Fig. 5. Computed mean quantities, day 2.3. a : wave setup; b: cross-reef current; c: reef profile

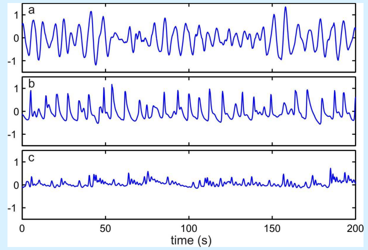

Fig. 6. Computed time series of surface elevation. a: A_0 location; b, x=633115 m; c, P3 location

4 - Conclusion

Our study presents a field experiment characterizing the tidal modulation of wave-setup and wave-induced current on a submerged barrier reef. This work is a significant contribution to the study of coral reef dynamics, because, as noted by Monismith [3], measurements of mean free surface changes have not been done in conjunction with current measurements in previous field studies. The high quality dataset collected in this study will enable us to better understand the "high frequency" dynamics of wave over a barrier reef and will be very useful for calibrating phase-averaged and Boussinesq-type models.

References

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