



HAL
open science

Dynamics of Infragravity Waves Across the Southern Reef Barrier of Mayotte, Indian Ocean

Xavier Bertin, Héloïse Michaud, Marc Pezerat, Aline Aubry, Matthieu Jeanson

► **To cite this version:**

Xavier Bertin, Héloïse Michaud, Marc Pezerat, Aline Aubry, Matthieu Jeanson. Dynamics of Infragravity Waves Across the Southern Reef Barrier of Mayotte, Indian Ocean. Coastal Dynamics 2025, Apr 2025, Aveiro, Portugal. hal-04924854

HAL Id: hal-04924854

<https://hal.science/hal-04924854v1>

Submitted on 5 Feb 2025

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Dynamics of Infragravity Waves Across the Southern Reef Barrier of Mayotte, Indian Ocean

Xavier Bertin¹, Heloise Michaud², Marc Pezerat³, Aline Aubry⁴ and Matthieu Jeanson⁴

¹ UMR 7266 LIENSs, CNRS/La Rochelle Univ., La Rochelle, France.

² Shom, 42 Av. Gaspard Coriolis, 31100 Toulouse Toulouse, France.

³ Shom, 13 Rue de Châtellier, 29200 Brest, France.

⁴ Univ. Mayotte, Dombéni, Mayotte, France

Espace-Dev, Univ Montpellier, IRD, Univ Guyane, Univ la Réunion, Univ Antilles,
Montpellier, France
xbertin@univ-lr.fr

Abstract. Due to climate change, tropical islands are being increasingly exposed to coastal hazards. Under energetic incident swells, infragravity (IG) waves can have a key contribution to extreme water levels and flooding, but their dynamics at barrier reef remains little studied. In this context, this study analyses IG wave generation mechanisms and transformations across a barrier reef to the southwest of Mayotte (Indian Ocean), combining a new comprehensive field dataset with phase resolving wave modelling. This analysis reveals that IG waves are mostly breakpoint-forced and suffer a substantial dissipation by bottom friction, particularly at low tide. Numerical experiments with reduced bottom friction representing a degraded coral reef suggest that IG waves would grow by about 20% across the reef at high tide. This study highlights the key role of coral reefs to dissipate IG waves and hence limit extreme water levels and subsequent coastal hazards.

Keywords: Infragravity waves, coral reef, bottom friction, Mayotte, phase-resolving modelling.

1 Introduction

Tropical islands are currently facing an increase in coastal hazards, due to the combination of global sea-level rise, natural subsidence, the possible intensification of cyclonic activity and the degradation of coral reefs. In tropical volcanic islands, the absence of continental shelves usually causes extreme water levels and subsequent flooding to be controlled by the effects of atmospheric pressure gradients and short wave dissipation, which drives a wave setup. In addition to these processes controlling still water levels, energetic swells can induce large infragravity waves (hereafter IG, see [1] for a review), which correspond to long waves associated with the presence of groups in the incident short waves and can drive intermittent flooding. Yet, over the last decades, this phenomenon has mostly been studied at sandy beaches, and the analysis of the processes controlling IG wave generation and transformations across coral

reef/lagoon environments has been limited to a few studies, mostly focusing on fringing reefs (e.g. [2], [3]). In this context, this study investigates the generation of IG waves and their transformations and dissipation across a complex coral reef lagoon system to the south-west of Mayotte, in the Indian Ocean.

2 Study site

The study area corresponds to the barrier reef to the Southwest of Mayotte, a French archipelago located in the Mozambique Channel (Fig. 1-A). This area is exposed to a macrotidal regime, with a tidal range reaching 4 m during spring tides. The sea state is often multimodal and combines local wind seas from E to SE and distant source swells (hereafter DSS), generated south of Africa and propagating through the Mozambique Channel. Tropical cyclones are rare but can have devastating effects, as it was tragically reminded during cyclone Chido, which hit Mayotte on December 14, 2024.

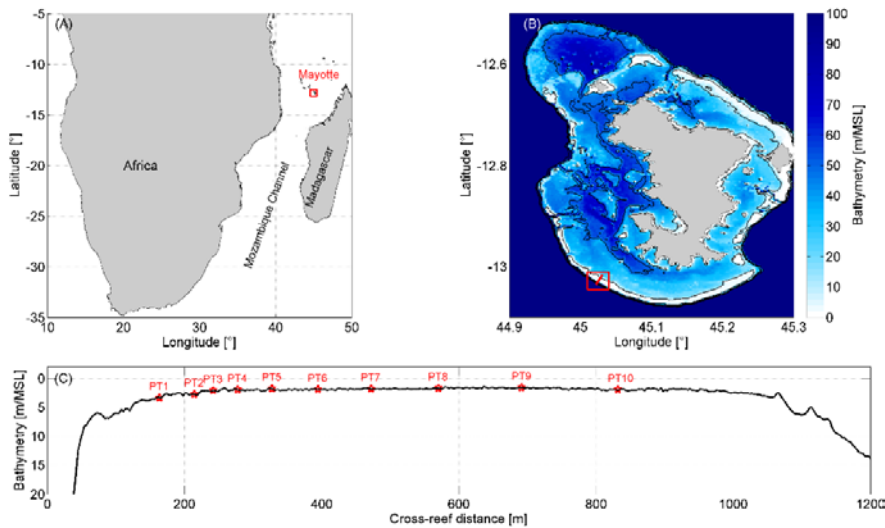


Fig 1. (A) Location of Mayotte Archipelago in the Mozambique Channel, (2) bathymetric map and location of the studied area in Mayotte and (C) zoom in on the instrumented transect across the reef barrier with location of the 10 pressure transducers used in this study.

This studied barrier reef is about 1 km-wide, with a reef slope combining a very steep lower part (1:8) below 10 m and a moderately-steep upper part (1:20) from 10 m up to the reef crest (Fig. 1-C). The reef flat is gently sloping with a mean slope of the order of 1:1000. The first 200 m of the barrier reef are characterized by a strong roughness due to the combination of a spur and grooves patterns and a high density of corymbose and branch coral. The remaining part of the reef is much smoother and corresponds to coral skeletons and patches of sediments. Applying a 1D frequency-integrated wave energy model over pairs of adjacent sensors from the same dataset as in

the present study, [4] (this volume) estimated roughness lengths K_s ranging from over 1.0 m at rough part of the reef and 0.01 m at the smooth part.

3 Data and methods

3.1 Field data

A comprehensive field campaign was organized from late August 2023 to November 2023 across the barrier reef/lagoon system to the southwest of Mayotte (Fig. 1). During this field campaign, 10 pressure transducers were deployed across the barrier reef, and several current profilers were deployed around this transect (Figure 1C). Bottom pressure was converted to surface elevation using linear wave theory and the frequency cutoff between short and IG waves was adaptive and defined as half the peak frequency of the short waves.

3.2 Numerical modelling

In order to complement data analysis and better understand IG wave generation and propagation across the barrier reef, the phase resolving model SWASH [5] was implemented over the studied reef barrier. The modeled domain extends over 1200 m in the cross-reef direction and 400 m in the along-reef direction and is centered on the instrumented transect (Fig. 1). The realistic bathymetry starts by 25 m water depth and follows a 150 to 200 m wide plateau after the numerical wave maker. The horizontal grid has a spatial resolution of 2 m in the cross-reef direction and 5 m in the along-reef direction. Two layers are used in the vertical, which allows for small dispersion errors up to frequencies of 0.3 Hz for the considered water depths [5]. Based on roughness length estimates of [4] at the instrumented transect, the bottom friction coefficient C_d was set to 0.02 at the rough part of the reef and 0.005 elsewhere, which also matches the values used by [6] at an Australian fringing reef (2022).

Along the southwest open boundary, SWASH is forced with directional wave spectra computed from a global application of the WaveWatchIII model, as described in [7]. In order to account for the water depth inconsistency between the closest grid point in WaveWatchIII and the open boundary of SWASH, a linear shoaling is applied to these directional spectra.

4 Results

4.1 Short and IG waves variations during the field campaign

The analysis of PT data collected along the cross-reef transect reveals firstly that the most energetic event took place around the 20/09, where H_{m0} exceeded 2.5 m (Fig. 2-B) with peak periods T_p in the range 20-25 s. This energetic event corresponded to a very long period DSS and drove IG waves with $H_{m0,IG}$ reaching 0.4 m (Fig. 2-C). During high tide, IG waves usually gain energy across the reef while during low tide, they reach a maximum around PT2-PT3 after which they continuously decrease, resulting in a strong tidal modulation (Fig. 2-C). The correlation between the IG waves and the wave

energy envelope was usually negative outside the surf zone and reverted to positive over the reef, with the strongest correlations observed at low tide (Fig. 2-D). In the following, the analysis will be complemented by phase resolving numerical modelling during the high tide of the energetic event (t_1 on Fig. 2).

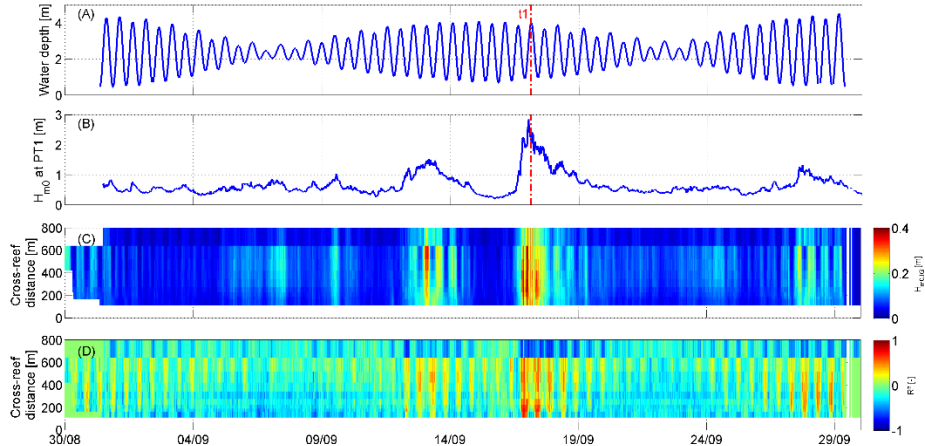


Fig. 2. Observed mean water depth (A) and H_{m0} (B) at PT1, IG wave height across the reef (C) and correlation between the IG waves and the wave energy envelope (D). Times t_1 corresponds to the high tide during the energetic event considered for numerical modelling.

4.2 Evolution of short and IG waves across the reef under storm conditions

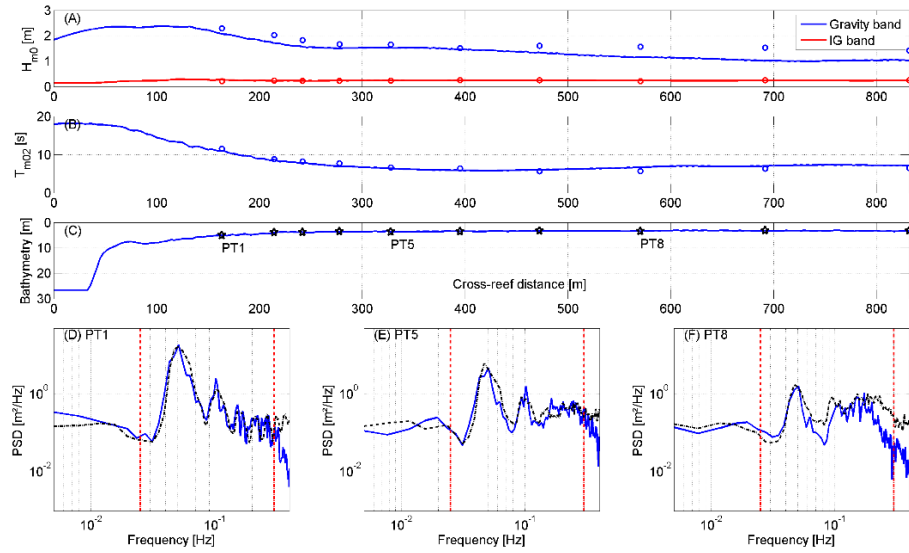


Fig. 3. Observed (circles) and modeled (solid lines) H_{m0} (A), t_{m02} (B), bathymetric profile and location of the PTs (C) and modelled (blue) and observed (black) spectra at PT1 (D), PT5 (E) and PT8 (F) at high tide on the 19/09/2023 (t_1 on Fig. 2).

Modelling results reveals firstly that, during high tide and energetic conditions, short waves grow due to shoaling over the reef slope and start to break just before PT1, after which they smoothly decrease across the reef barrier (Fig. 3-A). This behavior is overall well captured by SWASH, although wave height is underestimated after PT7. The mean wave period T_{m02} decreases by a factor of 2 across the surfzone (Fig. 3-B), due to the development of higher harmonics (Fig. 3-D to 3-F). These energy transfers are well captured by SWASH, although energy over 0.2 Hz is strongly underestimated after PT7 (Fig. 3-F), which will be discussed later. IG waves continuously grow until PT3, after which they reach a plateau at $H_{m0,IG} \sim 0.25$ m. The spectra in the IG band are rather flat, with the maximum of energy found between 0.007 and 0.02 Hz and these patterns are also well reproduced by SWASH.

5 Discussion and conclusions

5.1 Predictive skills and limitations of the model

The spatial patterns of both short and IG waves are overall well reproduced by the model, although short wave heights remain underestimated after PT7. As energy is transferred towards higher harmonics through triad interactions (see section 4.2), a finer spatial resolution may be required to better capture the resulting shorter waves. Next, the wave boundary conditions may suffer inaccuracies as wave modelling in this part of the Indian Ocean is particularly challenging due to the presence of the Agulhas current at the entrance of the Mozambique Channel (e.g. [8]). Yet, IG waves are accurately reproduced by SWASH, so that modelling results can be used with confidence to further analyze their dynamics.

5.2 Importance of IG waves dissipation by bottom friction

The fate of coral reefs in a context of global change is a major concern worldwide (e.g. [9]). In order to evaluate the importance of coral reef for IG wave dissipation, SWASH was launched with a uniform friction coefficient set at 0.005, which corresponds to a reef covered by coral skeletons and patches of sediments. This simulation shows that IG waves are increased by about 20% across the reef barrier compared to the present-day situation where the first 200 m of the reef are characterized by a high roughness. IG waves crossing the reef barrier propagate through the lagoon as free waves and reach the coast of the main island, where they can contribute to extreme sea levels and subsequent coastal hazards. This study demonstrates the key role coral reefs in dissipating IG waves and stresses the importance of protecting these environments to mitigate the impacts of ongoing global changes.

Acknowledgements

This research is funded by the France 2030 PPR Ocean and Climate project FUTURISKS (ANR-22-POCE-0002). Permanent pressure data are collected to the

Southwest of Mayotte in the scope of the National Observation Service DYNALIT, part of the Research Infrastructure ILICO. The developing teams of the codes WaveWatchIII and SWASH are warmly acknowledged for making their source code available. Finally, Nicolas Lachaussée and Yann Merky provided unvaluable help during the field campaign of 2023.

References

1. Bertin, X., de Bakker, A., van Dongeren, A., Coco, G., et al.: Infragravity waves: From driving mechanisms to impacts. *Earth-Science Reviews*, 177, 774–799 (2018).
2. Pomeroy, A., R. Lowe, G. Symonds, A. Van Dongeren, and C. Moore: The dynamics of infragravity wave transformation over a fringing reef. *Journal of Geophysical Research*, 117, C11022, doi:10.1029/2012JC008310 (2012).
3. Bruch, W., Cordier, E., Floc'h, F., & Pearson, S. G.: Water Level Modulation of Wave Transformation, Setup and Runup Over La Saline Fringing Reef. *Journal of Geophysical Research: Oceans*, 127(7), Article 7. <https://doi.org/10.1029/2022JC018570> (2022).
4. Geindre, M., Sous, D., Floc'h, F., Michaud, H., Martins, K., Pézerat, M., Bertin, X., Jeanson, M., and Aubry, A.: Frictional dissipation of incident waves over a spatially-varying rough barrier reef in Mayotte, Indian Ocean. *Proceedings of the Coastal Dynamics Conference, Aveiro, Portugal*. (2025).
5. Zijlema, M., Stelling, G., & Smit, P.: SWASH: An operational public domain code for simulating wave fields and rapidly varied flows in coastal waters. *Coastal Engineering*, 58(10), 992–1012. <https://doi.org/10.1016/j.coastaleng.2011.05.015> (2011).
6. Rijnsdorp, D. P., Buckley, M. L., da Silva, R. F., Cuttler, M. V. W., Hansen, J. E., Lowe, R. J., et al.: A numerical study of wave-driven mean flows and setup dynamics at a coral reef-lagoon system. *Journal of Geophysical Research: Oceans*, 126, e2020JC016811. <https://doi.org/10.1029/2020JC016811> (2021).
7. Gaffet, A., Bertin, X., Sous, D., Michaud, H., Roland, A., & Cordier, E.: A new global high resolution wave model for the tropical ocean. *EGUsphere*, 1–26. <https://doi.org/10.5194/egusphere-2024-2610> (2024).
8. Marechal, G., and Ardhuin, F.: Surface currents and significant wave height gradients: Matching numerical models and high-resolution altimeter wave heights in the Agulhas current region. *Journal of Geophysical Research: Oceans*, 126, e2020JC016564. <https://doi.org/10.1029/2020JC016564> (2021).
9. Walker, A. S., Kratochwill, C. A., & van Woesik, R.: Past disturbances and local conditions influence the recovery rates of coral reefs. *Global Change Biology*, 30 (1), e17112 (2024).