

THE GENERATION OF ROGUE WAVES FROM SURF ZONE INFRAGRAVITY MOTIONS PENETRATING A BAR-BUILT SHALLOW ESTUARY

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SUMMARY

Rogue waves have been the subject of intensive research and scientific debates over the last 20 years. In oceanographic contexts, they are defined as infrequent large waves (with heights more than 2 times the significant wave height of the carrier field) suddenly appearing among a group of smaller wind generated waves (Haver and Anderson, 2000). They have been seldom observed in nature, yet causing significant damage and casualties (Kharif and Pelinovsky, 2003).

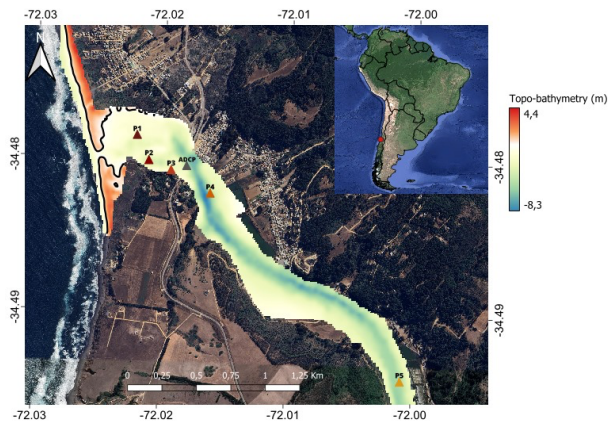


Fig.1. Overview of the “Laguna Cáhuil” shallow-bar built river estuary and its bathymetry. The location of the bottom moored pressure sensors is depicted in triangles P1 to P5).

In the present contribution, we present field measurements of infragravity waves penetrating into a shallow bar-built estuary located in the Pacific border of Central Chile (34.48°S , 72.00°W , see Figs. 1 and 2). We show that the shallow and narrow canal connecting the river to the sea acts as a natural low-pass filter for swell frequencies, as it has been previously documented (Williams et al., 2016; McSweeney et al., 2020). The quasi-periodic entrance of infragravity motions into the estuary evolve over a shallow bathymetry as highly nonlinear long-waves that fission into solitonic wave trains. The statistical analysis of the measured wave heights show that the resulting field is of strongly non-Gaussian nature, with a frequent appearance of rogue waves (see Fig. 3).



Fig. 2: An infragravity wave motion penetrating into the shallow lagoon during the tidal flood cycle of August 1st 2023.

Our results thus give a possible answer to the question posed by Haver and Anderson in 2000: "What is a freak wave: rare realization of a typical statistics or typical realization of a rare population?". Large waves emerging from a collection of interacting solitonic wave packets in our field experiment supports the latter possibility, where rogue waves appear as a typical realization of a rare population. Indeed, the empirical exceedance probabilities of the measured wave field are well above the Rayleigh distribution as shown in Fig. 3, confirming that they belong to a “different population”.

The analysis of our field dataset will be documented and discussed in light of recent findings in nonlinear physics (Suret et al., 2023) and experimental fluid mechanics (Redor et al., 2021). The possibility that these strongly nonlinear wave fields exist in real settings, open fascinating new avenues for fundamental and applied research in wave dynamics, oceanography, and engineering.

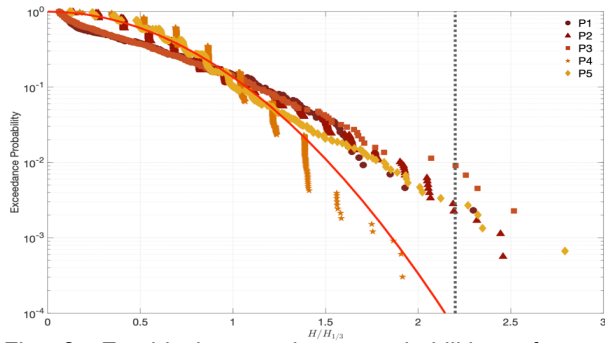


Fig. 3: Empirical exceedance probabilities of wave heights at the different measured locations. The Rayleigh distribution is plotted in red for reference, and the threshold limit for rogue waves is depicted in a black vertical dotted line.

MATERIAL AND METHODS

The field campaign presented in this work was conducted between the 1-3 August 2023. It was designed to take place during spring tides under conditions where incoming swells could penetrate a shallow bar-built estuary. The upstream river discharge was negligible over the whole duration of the experiment, so seawater inflows and estuary outflows were controlled by the tidal modulation only. During the tidal flood cycle, infragravity motions could propagate inside the shallow lagoon, while during the ebb cycle, almost no wave penetration from the ocean could be observed, in agreement to what was shown in the numerical experiments conducted with a set of Serre-Green-Naghdi partial differential equations by Cienfuegos (2023).

The reported set of wave measurements were sampled at 1 Hz using 5 bottom moored pressure sensors (1 Aqualogger310 and 4 Nortek Vector ADVs; see their locations in Fig. 1). The pressure time series were high-pass filtered with a cutoff frequency of 0.001 Hz (16 minutes) to damp out tidal modulations. The exceedance probability distributions of wave heights presented in Fig. 3 are computed for pressure signals recorded during the flood tide cycle of August 2nd 2023 (nearly 390 minutes) using a zero up-crossing analysis.

A high-resolution video camera recorded wave propagation within the surf-zone and long-waves penetrating into the shallow canal at 7Hz. The images were rectified following the methodology of Holland et al. (1997) using 58 measured ground points (Trimble R3 GPS). Pixel time-stacks of wave front trajectories were useful to characterize the periods of incoming swells and infragravity motions entering into the shallow lagoon.

Incident wave climates are obtained from hindcast data computed with the model WW3 v6.07 (WW3, 2019) at node located in front of the study site in 18 m depth.

Tidal levels in a nearby station (nearly 20 kms south of the site) are available at the Boyeruca station accessible in the [IOC-Sea Level Monitoring Facility](#). River discharges can

be downloaded from the station “Estero Nilahue en Santa Teresa” from the [Dirección General de Aguas](#) (DGA).

REFERENCES

Cienfuegos, (2023). Surfing Waves from the Ocean to the River with the Serre-Green-Naghdi Equations. *Journal of Hydraulic Engineering* 149.9: 04023032.

Haver and Andersen (2000). Freak waves: rare realizations of a typical population or typical realizations of a rare population? in: *The Tenth International Offshore and Polar Engineering Conference*, Seattle, USA, 27 May-2 June 2000, International Society of Offshore and Polar Engineers, ISBN 978-1-880653-46-3.

Holland, Holman, Lippmann, Stanley, Plant (1997). Practical use of video imagery in nearshore oceanographic field studies. *IEEE J. Ocean. Eng.* 22, 81-92.

Redor et al. (2021). Experimental study of integrable turbulence in shallow water. *Physical Review Fluids* 6.12: 124801 (2021).

McSweeney, Stout, and Kennedy (2020). Variability in infragravity wave processes during estuary artificial entrance openings. *Earth Surface Processes and Landforms* 45.13: 3414-3428.

Suret et al. (2023). Soliton Gas: Theory, Numerics and Experiments. arXiv preprint arXiv:2304.06541.

Williams, and Stacey (2016). Tidally discontinuous ocean forcing in bar-built estuaries: The interaction of tides, infragravity motions, and frictional control. *Journal of Geophysical Research: Oceans* 121.1: 571-585.

WW3 (2019). The WAVEWATCH III® Development Group User Manual and System Documentation of WAVEWATCH III ® Version 6.07, Tech. Note 333 NOAA/NWS/NCEP/MMAB.