PREDICTING INFRAGRAVITY WAVES IN HARBOURS – AN EVALUATION OF PUBLISHED EQUATIONS AND THEIR USE IN FORECASTING OPERATIONAL THRESHOLDS

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BACKGROUND
Infragravity (IG) waves have received considerable study since the 1950s (Munk, 1949, Bertin, 2018), allowing their generation, propagation and impacts to be more effectively quantified. Here, we are concerned with the frequencies that directly excite motion in moored ships, thereby creating problematic and often unsafe conditions. Operational knowledge gained in surge-affected ports in Australia and New Zealand revealed IG height thresholds common to all locations (McComb, 2011), with wave periods from 25 to 120-150s being causative. A further observation that the IG spectral shapes at berths remain relatively constant regardless of the incident short wave spectra (McComb, 2014) allows robust predictive methodologies to be developed to forecast the onset and the passing of these empirically-derived values. The governing IG height thresholds are: Hs<0.10m is safe and manageable for a well-tendered vessel; at Hs 0.10-0.15m caution is advised and additional management is recommended, and at Hs>0.15m active management is required. Management options include shore moorings, pneumatic fendering, ShoreTension, MoorMaster etc. Without intervention, IG conditions >0.20m are universally considered dangerous. Further, IG heights are strongly modulated by tide at certain locations (Thomson, 2006), which creates rapidly changing conditions that compound the difficulties ensuring safe and effective operations.

AIM AND METHODS
We selected five published methods to predict nearshore IG height (Lara 2004, McComb 2005, Okihiro 1992, Arduin 2014 and Cuomo 2017) and undertook an evaluation of their efficacy at two energetic ports on opposite sides of the Earth. The ports of Gijon in Spain and Taranaki in New Zealand both experience problematic moored ship motions and have been subject to numerous studies of their wave dynamics over previous decades. Consequently, there is a body of knowledge, operational experience and local data to make an evaluation. The purpose of this work is to offer pragmatic guidance to the developers of operational forecasting systems on the optimal method to predict IG heights for safe mooring of ships at berth. At each port, offshore wave spectra were measured by wave buoys, while co-temporal long wave data were obtained from water level recorders (RBR-*solo*) deployed at the problematic berths.

Around 2 months of continuous data were analysed. The significant height (Hs) of the IG waves was derived from 60-minute data records, with a low- and high-pass spectral filters applied to isolate the specific frequencies of interest for ship agitation (in this case 25s<T<120s), the low frequency partition was determined from a mean power spectra (e.g. Fig. 1), showing a clear saddle around 120s. An example of the effect of changing spectral partitioning is given in Fig. 2, showing a doubling of Hs when the low frequency cutoff is extended from 120 to 200s; highlighting the need to isolate just the energy that is problematic for ships and not the wider IG range.

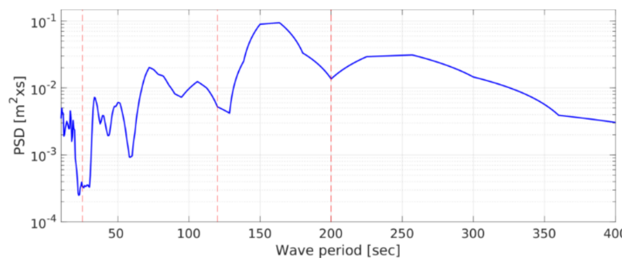

Figure 1 – Mean power spectra measured at Port Gijon, with annotation at 25, 120 and 200s period.

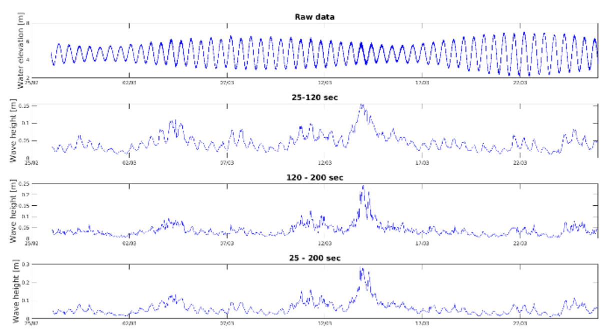

Figure 2 – Time series of raw and processed IG wave heights at Port Gijon for different spectral partitioning ranges.

Four of the methods have a semi-empirical basis; using observations to modify the wave energy flux approximation described by Inch (2017). These modifications attempt to replicate the non-linear nearshore and surfzone transformations as well as the processes within the harbour itself. The method of Okihiro (1992) however, applies the analytical solution for the IG wave spectrum to resolve a long wave boundary condition outside the harbor; deployed here with further coefficients defined to describe a transformation to the berth. Notably, the IG heights exhibit strong modulation by tide (see Fig. 2), and modulation coefficients were determined by the linear regression method described by McComb (2005).

RESULTS
The timeseries of measured and predicted IG wave height is presented in Fig.3 for both Taranaki and Gijon. All five equations replicate the general trends in IG energy, however the equations of McComb (2005) and Lara (2004) provide the most robust outcomes over the range of events observed (see the Q-Q plots in Fig. 4).

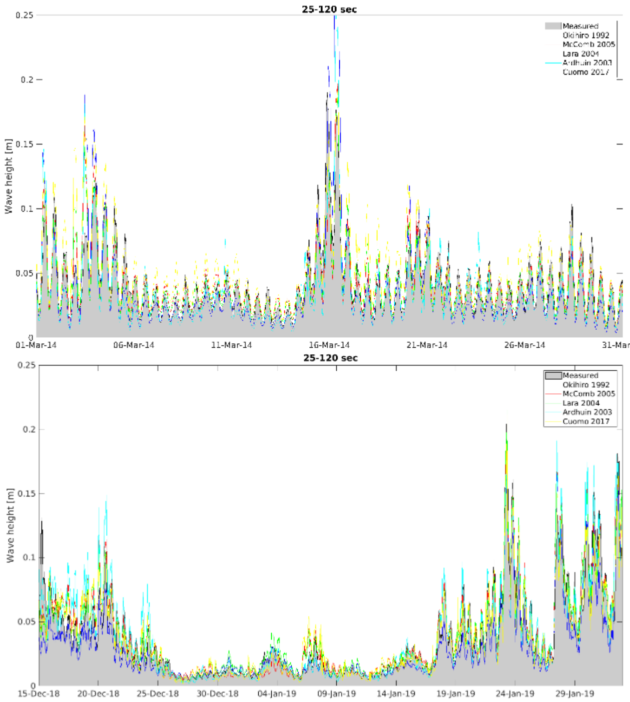

Figure 3 – Timeseries plots showing the measured and predicted IG significant wave heights for the five equations at Port Taranaki (upper) and Port Gijon (lower).

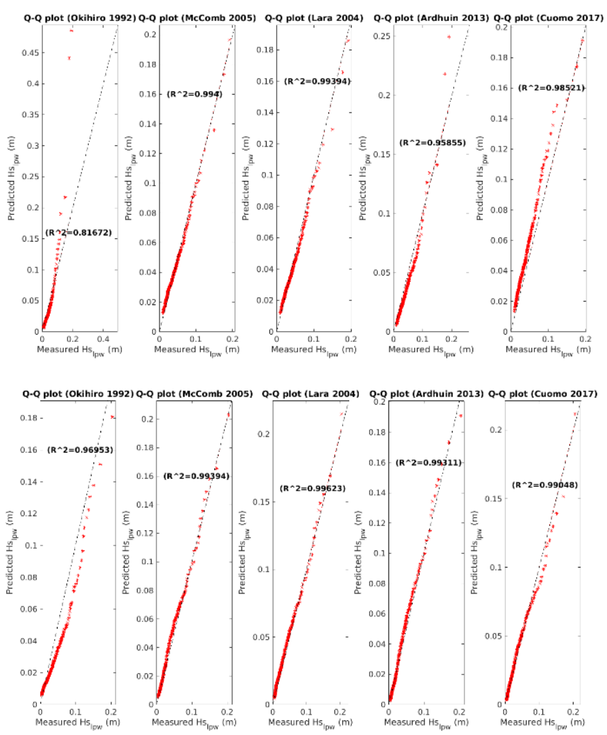

Figure 4 – Q-Q plots and associated linear regression coefficients for measured and predicted IG significant wave heights using the five equations at Port Taranaki (upper) and Port Gijon (lower).

SUMMARY

The standard accuracy metrics show the best predictors are defined with the equations of McComb (2005) and Lara (2004). The former is better in the bimodal sea states where local seas and far-field swells coexist (i.e. benefitting from a high-pass spectral filter as the data indicate that short waves with T<8s do not contribute to the port IG climate). However, the technique of Lara (2004) is very simple to apply as it uses the standard spectral parameters that are readily available from a wave forecast model. The Cuomo (2017) technique was more difficult to deploy (i.e. requiring boundary spectra) and did not perform as well over the full range of conditions in New Zealand and Spain. Both the Arduin (2014) and Okihiro (1992) methods were not able to adequately replicate the time varying IG conditions for meaningful operational guidance. Based on this analysis, Lara (2004) is proposed as a generic prediction equation; suitable for global use as a coastal IG boundary condition, effectively capturing the main non-linear components of IG generation over the frequencies of interest. However, if spectral partitioning is available, the McComb (2005) equations can be applied for a slight improvement. Coefficients need to be tuned for each berth, and well-established technique to tune the equations and modulate for tide is described in the presentation.

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