THE RESPONSE OF HARBOR ENVIRONMENTS PROTECTED BY IRREGULAR FRINGING REEF SYSTEMS TO STRONG GRAVITY WAVE FORCING - A CASE STUDY

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INTRODUCTION

Three high-resolution, dispersive nearshore numerical models (BOSZ - Roeber & Cheung, 2012; FUNWAVE - Shi et al., 2012; XBeach - Roelvink et al., 2009) are compared and contrasted with observations from fringing-reef and harbor environments, in an attempt to test their ability to reproduce the wave transformation processes in a complex Hawaiian reef-system environment forced by highly energetic sea/swell wave conditions. Hale'iwa Harbor, located on Oahu's North Shore (Figure 1), is a small boat harbor that faces serious operational problems resulting from water level fluctuations and currents during periods of strong swells. These oscillations are predominantly at infragravity periods (rather than swell periods), and, nearly every winter season, their amplitude levels are sufficiently large to trigger significant surges in the harbor. These surges can cause damage to harbor infrastructure and boats, and threaten the safety of mariners who attempt to enter or exit the harbor.

The model outputs, when obtained from simulations using a sufficiently large domain (Figure 2), and observations of sea level and currents are found to be in generally good agreement, as all three models successfully reproduce the correct spectral levels and capture much of the observed auto- and cross-spectral details. This modeling effort (i) provides performance metrics of several high resolution nearshore models; (ii) improves our understanding of the origin of infragravity (IG) wave energy in small harbors under strong sea/swell wave forcing; (iii) identifies the importance of an irregular reef structure in the vicinity of the harbor for accurate IG simulation; and, (iv) provides improvements to wave runup and harbor surge forecasts for reef-protected and unprotected shorelines.

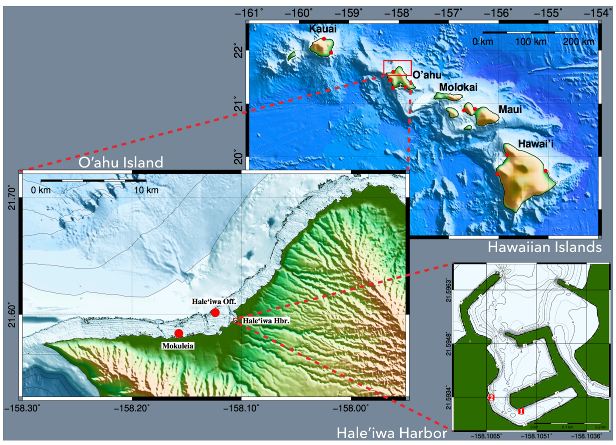

Figure 1 - Maps of the Main Hawaiian Islands, O'ahu's North Shore, and Hale'iwa Harbor.

In addition, our observations from other coastal sites across the Hawaiian Islands emphasize the great spatial variability of the locally dominant suite of IG oscillations, including resonant oscillations at periods of as much as 60 minutes that arise from the multiply-connected island geometry. It's now quite clear that when studying the dominant IG oscillations of a given harbor, it is not sufficient to only consider the local modes defined by the harbor's geometry, as larger scale modes that are dependent upon processes distant from the harbor also contribute significantly to the observed IG variability inside the harbor.

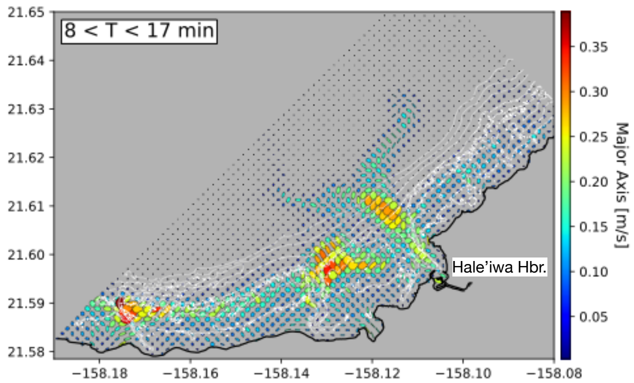

Figure 2 - Modeled infragravity current ellipses in the 8-17 min period band, along O'ahu's North Shore coast. White contours indicate bathymetry (5m interval).

METHODS

The harbor oscillations and nearshore processes are studied through data analyses of sea levels and currents obtained from historical and recent observations, as well as through high-resolution numerical modeling inside the harbor and at the coast. The use of the numerical models for the wave processes in the harbor and along the coast under the same forcing conditions and with similar parameter settings confirm their ability to reproduce real nearshore ocean conditions. The modeling effort also extends the observational findings, as the models can be used to reconstruct the spatial distribution of the IG wave field for swell conditions where no data is available. Furthermore, analyses of the model output from several cross-shore and alongshore sites have improved the understanding of the generation mechanisms and dynamics of IG waves at the coast. Maps of wave energy, phase, and other wave properties in several IG period bands serve as tools for identifying critical processes such as resonant standing waves.

RESULTS

The simulations and observations on O'ahu's North Shore demonstrate the generation of strong currents oscillating at IG periods from 0.5 to 17 minutes. The highest IG current amplitudes close to shore occur at the shortest periods, while near the outer edges of several deep channels the strongest currents are tied to the longest IG periods (Figure 2). The simulations also reveal standing IG wave patterns modified by coastal morphology, with alongshore symmetry varying with frequency. The existence of such standing wave patterns may result in strong currents near the nodal lines of sea level amplitude.

Even though Hale'iwa Harbor is very small (approx. 250 m x 250 m at 3-4 m depth), the observations reveal resonant IG oscillations at periods between 1 and 23 min. As was shown in previous modeling studies (e.g., Munger & Cheung, 2008; Cheung et al., 2013), it is evident that some of these observed long period IG waves are trapped to sections of the coast and result in resonant oscillations that are coherent along the coast and into the connected harbor. Our observational analysis also reveals various coastal sites across the Hawaiian Islands where island-scale and inter-island scale oscillations reach significant amplitudes. At times, such oscillations can be more energetic than the local modes of a given harbor. These findings suggest that when studying the dominant IG oscillations of a given harbor, it is not sufficient to consider only the local modes defined by the harbor's geometry, as larger scale modes that are dependent upon processes distant from the harbor also contribute significantly to the observed IG variability inside the harbor. This has important implications on how numerical models should be used to reproduce the dominant variability of harbors. Conventional studies are typically focused on a small domain, which isolates the harbor from the coastal environment. This unintentionally eliminates the contribution of any oscillations that may potentially originate along the coast outside the harbor.

The investigated wave processes are typical for tropical and subtropical islands in the Pacific and elsewhere, and help to improve efforts on coastal hazard mitigation and mariners' safety.

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