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An investigation of wave-dominated coral reef hydrodynamics

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Abstract

The coastal zone is of great societal and economic value. Understanding anthropogenic impacts and natural processes is a prerequisite to effective management of coastal resources, and a key part of this understanding is the prediction (both past and future) of the coastal zone's hydrodynamics. Methods of predicting the hydrodynamics of coral reef systems, which tend to be morphologically complex and subject to a variety of oscillatory and non-oscillatory motions over a large range of space and time scales, remain poorly developed.

Recent advances in numerical modeling have allowed the practical solution of the two- and three-dimensional shallow water Navier-Stokes equations at spatial scales on the order of tens of meters. This has allowed unprecedented prediction of coastal hydrodynamics, and its use is expanding, particularly in mid- to high latitude continental margins regions. Few researches have yet applied these advances to coral reef systems, however.

The goal of this work is to improve the understanding and prediction of relevant hydrodynamic processes in coral reef systems. This is accomplished by the combined analysis of in situ oceanographic instrument data and climate information, as well as the application of a coupled wave-flow numerical model at two different study sites. The study sites, Hanalei Bay and Midway Atoll, both in the Hawaiian Islands (Figure 1.1), constitute two fundamentally different reef morphologies, a fringing reef embayment and an atoll, respectively. Both are subjected to a wide range of wind-wave energy, which is shown to force the most energetic hydraulic motions at both sites.

Results include an evaluation of the numerical models used, a statistical analysis of wind-wave climate that identifies major modes of coastal circulation, and the calculation of flushing times and other coastal hydrodynamic metrics under different conditions. Model evaluation shows that if the spatially varying hydraulic roughness and wave dissipation approximations presented here are used, coupled wave/flow numerical model skill for steep and morphologically complex coral reefs may approach that of milder sloped mid-latitude continental margin coasts. The results also highlight important hydrodynamic differences between prevailing (wind and wave) conditions and episodic storm wave events. These events incur water

levels, current velocities, flushing rates, and inferred sediment transport several orders of magnitude greater than those of prevalent conditions. For instance, flushing (residence) times at both study sites are on the order of 1-3 days during prevalent conditions, whilst during large storm wave events flushing time may reduce to several hours. The high near-bed flows and associated shear stresses episodically mobilize and transport seafloor sediment and heavily impact the benthic biological community.

The number and magnitude of these episodic events are shown to exhibit high interannual variability linked to climate indices for El Niño/Southern Oscillation (ENSO) and the North Pacific Index (NPI). The historically small (but variable) number of these events (between 0 and approximately 20) indicate that annual differences in net sedimentation and water quality are very large at both sites, and most likely sensitive to long-term changes in annual recurrence. Additionally, large changes in sea level anomaly during these large wave events, evident in model predictions and confirmed by tide gauge data at Midway Atoll, introduce an unaccounted for variable in contemporary sea-level trend analyses, possibly at many *in situ* sea level monitoring sites in the Pacific and Indian Oceans.

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