ADVANCES IN PHASE-RESOLVED MODELING FOR MAPPING AND FORECASTING OF WAVE-DRIVEN COASTAL PHENOMENA

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INTRODUCTION

Phase-resolving coastal wave models have become an integral tool for predicting wave-driven phenomena such as run-up (Barnard, 2009; Grilli, 2020), and coastal flooding (Kennedy, 2012; Anderson et al., 2018). Since these models require time-consuming computations to cover sufficiently large domains, applications often involve modeling over numerous one-dimensional (1D) shore-normal transects, where the results are then interpolated onto a two-dimensional (2D) grid. This approach requires little computational time and is well suited for cases where the underlying elevation models show little alongshore variation. However, by adding 2D wave dynamics the simulation can account for phenomena that in complex environmental settings have important influence on wave-driven processes such as wave run-up and flooding.

To take advantage of the full capabilities of this modeling approach, several mapping and near real-time prediction tools were developed using a phase-resolving model in two-dimensional horizontal (2DH) mode. The results of this work show that phase-resolving models can drastically improve the assessment of coastal wave processes and even produce results in near real-time through the strategic development of code that dramatically improves computational efficiency.

METHODS

Well-validated Boussinesq-type models (Roeber & Cheung, 2012; Mihami, 2023) are employed. The project has focused on the creation of the following three products: (i) a 6-day run-up forecast ; (ii) a 6-day harbor surge forecast , and; (iii) mapping of wave-driven flooding at future sea level rise (SLR) scenarios. Creation of the 6-day forecasts (first two products) is challenging since large modeling domains are required to adequately account for key processes. Further, multiple forecasts over several days would normally require computations on the order of days, while we need to complete these computations within hours. Although the time constraint does not apply for the creation of the flood mapping product, fast turnaround times are still crucial, since often a large number of realizations is required to account for various wave directions, heights, and sea levels. The modeling work mentioned here starts with setup of the model for each of our computational domains, followed by test runs with real gravity wave directional spectra, then validation with in situ measurements of sea level. The validation is accomplished by auto- and cross-spectra comparisons of the computed and observed data, which were specifically collected during field campaigns at several nearshore sites.

For the 6-day run-up forecast, the offshore boundary of the models is forced with directional spectra from a regional SWAN forecast. Each day, the phase-resolved models with various prediction periods are run simultaneously in order to reduce the overall computation time. Model output at numerous nearshore virtual sites is converted to energy flux and then to a run-up metric, using an empirical relationship. The simulations are repeated each day to produce a new set of 6-day forecasts. For the 6-day harbor surge forecast, the energetic content of the free surface and horizontal velocities was analyzed in various infragravity period bands relative to the wave directional spectra forcing. From these analyses the value of the surge metric for each of the forecast days was determined (Azouri, 2016). To map wave-driven flooding, long wave hindcasts and water level records were used to determine the appropriate wave and water level inputs for scenarios of different return periods (i.e., 1-year, 30-year, wave event, etc.). Simulations for a given wave scenario are repeated for a suite of SLR values, and maps representing the “flood depth” are created.

RESULTS

The run-up (Figure 1) and surge forecasts are accessible on the Pacific Islands Ocean Observing System website (PacIOOS, http://www.pacioos.hawaii.edu; choose Shoreline Impacts). Each day, the computations involve multiple hours of simultaneous model simulations in order to obtain results for all 6 forecast days. The corresponding run-up and surge metrics are displayed as a function of time together with several thresholds that represent the impact levels from historical wave events. This way, the public receives easily understandable information on a daily basis. The threshold levels are determined from photographs of these historical wave events, with impact level determined subjectively. The flood maps (Figure 2) are also accessible via PacIOOS’s website (e.g., under Sea Level Rise in the Shoreline Impacts menu). The modeling results are presented as a suite of “flood depth” layers for each of the computed wave and SLR scenarios and can serve as practical guidance for planners and coastal zone managers.

SUMMARY

The novel approach presented here for mapping and forecasting wave-driven coastal phenomena is motivated by the ability of phase-resolving models to simulate the complex dynamics of wave processes that is inherent to a realistic, non-idealized, coastal environment. Furthermore, development of a more efficient phase-resolving modeling approach enabled significant speed-up of the computations. With these advancements, the creation of highly-needed tools to bolster the resilience of coastal communities can be expanded, especially to locations where the geomorphology requires 2D modeling with high-resolution grids.

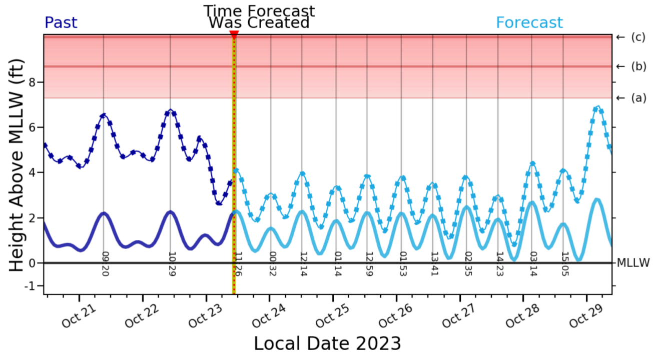

Figure 1 - Six-day forecast of wave run-up forecast for Nāpili region in West Maui, Hawai'i. The three threshold levels for that region are indicated as (a), (b), and (c), representing light, hazardous, and critical impact levels.

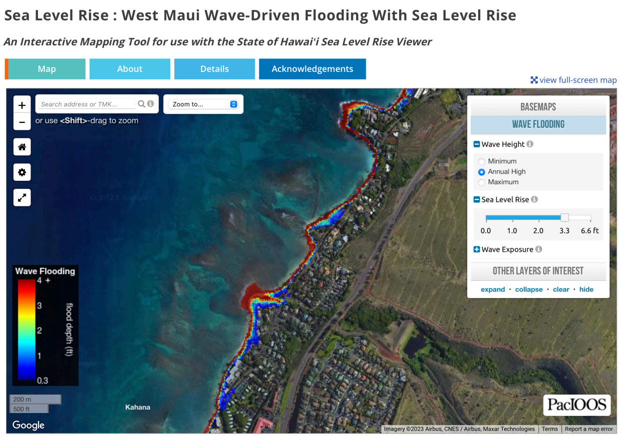

Figure 2 - Map of wave-driven flooding for Kahana region, West Maui, Hawai'i, for the annually high wave scenario plus 1 m of SLR. Map colors indicate the flood depth.

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