PROJECT TITLE: Predicting the Impact of Storm Waves and Sea-Level Rise within the Papahānaumokuākea Marine National Monument (PMNM).

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RESEARCH STATEMENT

Recent storms and a tsunami (11 March 2011) have underscored the intrinsic potential for sea-level rise to damage wildlife populations and ecosystems of the low-lying Papahānaumokuākea Marine National Monument (PMNM). The goal of this study is to provide maps of wave impact and storm-induced inundation levels for islands of high conservation value. Vulnerability will be assessed for Midway Atoll and Laysan Island using historical data and new high resolution Digital Elevation Models (DEMs) for a variety of sea-level rise scenarios. Research to date forecasts sea-level rise with only passive flooding scenarios, and until now, was limited by a lack of topography data for Hawaii's remote atolls. Predicting impacts of flooding and storm-induced waves is needed to develop climate-change adaptation plans for the biological communities and resident endangered species. This information is also needed for managers to understand risks and determine emergency responses for the range of parameters where natural, historical, and cultural resources and remotely stationed personnel may be threatened from sea-level rise and storm-induced waves.

NEED

Scenarios of projected global climate change predict that sea level rise may inundate coastal and low elevation Pacific islands. The Northwestern Hawaiian Islands (NWHI) include 300,000 sq. km of ocean waters and 10 sub-tropical islands and atolls of high conservation value. Designated as Papahānaumokuākea Marine National Monument (PMNM) and a World Heritage Site, the islands provide habitat for the largest and most important assemblages of tropical seabirds in the world, with 14 million birds and 11 endangered species of terrestrial birds and plants. Many of the wildlife species' foraging, haul-out, foraging and nesting habitats (e.g., coral reefs and, beaches, freshwater seeps, and coastal ecosystems) are very sensitive to sea level. Sea-level rise will significantly modifying not only water levels, but also storm wave run up, the mixing of salt and fresh water, and the resulting transport of sediment, nutrients, contaminants, and flooding of terrestrial and coastal communities. On low, flat atolls, a small rise in sea level may cause large horizontal migrations of the shoreline, and in some locations may result in the loss of freshwater lens supporting migratory and endangered water birds. Increased sea level will shift the elevation of intertidal habitat upwards, in some cases onto unsuitable substrate or cause loss of habitat. Climate change also may increase the frequency of storm overwash and extreme events that will affect seabird and endemic bird population dynamics by increasing the mortality rates of eggs and chicks. Nesting habitat may also be negatively influenced by overwash events. Shrubs and grasses intolerant of saltwater may die off. An increased frequency of overwash events, as forecast in many scenarios of climate change, may weaken or slow the rebound of vegetation.

All of the beaches and many of the low-lying atoll islets in PMNM are subject to inundation from storm-induced waves. Until recently, no information existed from which to predict the likelihood of wave damage under present and predicted sea-level rise scenarios. For example, just this year storm wave-induced overwash and inundation caused significant damage to terrestrial habitats and seabird chicks and nests on both Midway Atoll (12 January 2011) and Laysan Island (11 February 2011).

Observations show that global sea level is rising at a rate almost double the Intergovernmental Panel on Climate Change's 2007 report (Fig. 1). Recent estimates and syntheses that include rise due to thermal expansion and ice melting suggest sea level will exceed 1.0 m, and may reach 2.0 m, above 2000 levels by the end of the 21st century. Sea-level rise is particularly critical for the unconsolidated low-lying coral atoll islets, especially those in the NWHI, many of which have maximum elevations of less than 3 m above present sea level. Because published vertical coral reef flat accretion rates for coral reefs exposed to open-ocean storm waves (1-4 mm/yr) are up to an order of magnitude smaller than the rates of sea-level rise projected for the years 2000-2100 (8-16 mm/yr), projected sea-level rise will outstrip potential new reef flat accretion, resulting in a net increase in water depth overexposed coral reef flats on the order of 0.4-1.5 m during the 21st century. Rising sea levels will exacerbate the impacts of storms and wave action coastlines and coral reefs by reducing wave-energy dissipation, primarily by reducing wave breaking at the reef crest and increasing the water depth relative to the hydrodynamic roughness over the reef flat.

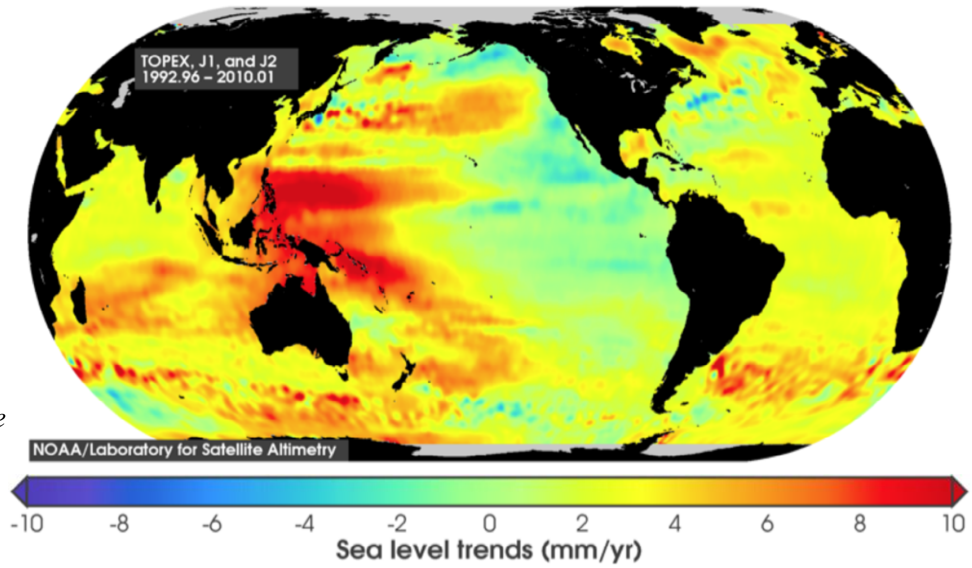

FIGURE 1. *Observed trends in sea level between 1993 and 2010 (Laboratory for Satellite Altimetry, 2011). Note the high rates (5-10 mm/year) in the central and western North Pacific Ocean where US Federally-managed atolls (e.g., Midway, Laysan, and Wake) are located.*

By reducing wave energy dissipation at the reef crest and over the reef flat, sea-level rise will cause larger waves to directly impact the coastline and potentially drive coastal erosion. These larger waves at the shoreline will also increase the resulting wave-driven run-up, which is the maximum vertical extent of wave uprush on a beach above mean sea level; run-up is primarily a function of the incident wave height, incident wavelength, and slope of the coastline. Because the corals reefs that form atolls are spatially heterogeneous and storm wave heights and wavelengths vary in space and time, the wave-driven run-up and inundation that will result from sea-level rise also varies both spatially and temporally, especially Pacific Ocean atolls that are exposed to >5 m-high waves numerous times each year. It is important to note that these resulting temporal and spatial variations in wave-driven run-up and inundation driven by sea-level rise have not yet been addressed; our studies to-date could not even use simple geographic information system (GIS)-based "bath tub" models of sea-level rise that simply "flood" the islands because there were DEMs of PMNM's land surface.

Because most of the islands within the Monument are low-lying atolls surrounded by deep ocean or extensive coral reefs, the extent and type of impact from storm wave-driven run-up and inundation is likely much different from high volcanic islands such as the Main Hawaiian and Mariana Islands. Refuge managers need to know the possible damage of intense storm events on their personnel, natural resources, and infrastructure, as wells as the most appropriate response to that danger; lack of information makes planning for protection and recovery of the Monument's resources less effective and more costly. What are the probable effects and appropriate responses to the threat of a large storm? How will these probabilities change under current sea-level rise scenarios? Furthermore, how managers plan to accommodate the stresses on natural resources and infrastructure imparted by sea-level rise? Until 2011, high resolution digital elevation models needed for making these predictions did not exist. A USGS grant from the National Climate Change and Pacific Island Ecosystem Research Centers, along with support from the U.S. Fish and Wildlife Service (USFWS) and National Oceanic and Atmospheric Administration (NOAA), allowed for acquisition of new topographic data in the NWHI using aerial LiDAR. These data, along with improved bathymetry, permit us to determine critical values for storm-induced inundation of Midway Atoll and Laysan Island. This information will be integrated with geospatial habitat and population analysis in progress (USGS Preventing Extinctions due to Sea level Rise in the NWHI).

Significant storm-induced waves impact the Hawaiian chain roughly every decade; it is imperative that we are able to realistically assess and plan for these events and how the intensity and frequency of damage to natural resources and infrastructure may change under sea-level rise scenarios. Currently this information is not available from which to make informed management decisions. The current project proposes to model the run-up (inundation) of storm waves generated by a climatic end-members, and how these patterns may change under sea-level rise scenarios, in order to provide managers with quantitative information needed for protection and adaptation of these resources. While there are a number of islands and atoll islets throughout PMNM (Fig. 2), this investigation will be focused on two sites that characterize two atolls with the largest land area: (1) Midway Atoll (28°12'N and 177°22'W), which is comprised of three islands: Sand (451 ha), Eastern (135 ha), and Spit (6 ha) with a well-defined reef crest, shallow lagoon, with islets near the atoll rim; and (2) Laysan (25º46' N, 171º44' W), which is approximately 415 ha and located in the center of the atoll that has neither a reef crest nor central lagoon. Midway Atoll and Laysan Island are home to three endangered bird species (Laysan Duck, Laysan Finch, and Short-tailed Albatross) and the largest populations of migratory seabirds in the Pacific (Black-footed Albatross, Laysan Albatross, and Bonin Petrels). Endangered Hawaiian monk seals, as well as the threatened Hawaiian green sea turtles, rest and breed on the beaches of PMNM. The islands also provide refugia for culturally significant marine resources. By identifying areas and species most vulnerable, resource managers can plan for management and climate change adaptation scenarios with new understanding of the impact of climate change on Hawaii's atoll systems. Additionally, this study will provide new understanding of the impact of climate change on atoll systems globally and the potential geopolitical consequences caused by the relocation of atoll island-states.

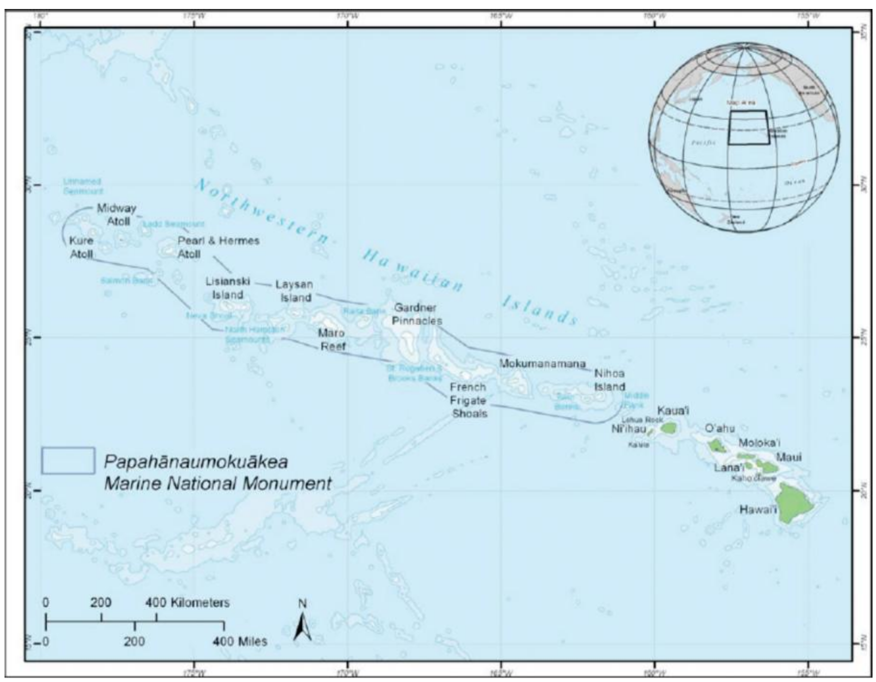

FIGURE 2. Map of Papahānaumokuākea Marine National Monument showing the location of the two study areas: Laysan Island and Midway Atoll.

METHODS

The potential impact of storm waves and sea-level rise on coastal habitats and infrastructure in PMNM will be investigated quantitatively by the USGS-PCMSC staff using the Delft3D numerical model. Delft3D is a three-dimensional coupled hydrodynamic model that handles waves using the WAVE module. Storm-induced surface gravity waves will be simulated via the 3rd-generation Delft3D-WAVE module. The WAVE module is based on discrete spectral action balance equations, computing the evolution (growth, propagation, and decay) of random, short-crested waves. Physical processes such as bottom friction and depth-induced breaking, and non-linear quadruplet and triad wave-wave interactions are included.

There are a very large number of potential combinations of storm sources, and so we will not model waves generated by specific storms. Rather, we will develop a number of simulations of varying wave height and wave period around the primary wave sources (North Pacific, Trade Wind, South Pacific and those generated by Kona storms), as well as hurricanes. There exists a general lack of wave buoys with long directional records for the areas of interest. Accordingly, we will use US Army Corps of Engineers' Wave Information System model hindcast wind and wave data. These data sets will be analyzed for both average and end-member (top 1%) storm conditions. These different sets of conditions will help to better constrain the combinations of wave heights, periods, and directions above which possible damage to terrestrial habitats and infrastructure may occur. Sea-level rise scenarios (+0.25 m, +0.50 m, +0.75 m, +1.00 m, +1.50 m, +2.00 m) will be based on ranges defined by Intergovernmental Panel on Climate Change and others. The scenarios will be conducted by running each of the wind and wave sources for each combination of present and future wave and sea-level rise.

Modeled wave heights, wave periods, wavelengths, and wave-driven set-up under both present and future climate-change scenarios will be extracted from the model grid points adjacent to the shoreline. These data will then be used to compute run-up heights using a parametric run-up equation under both present and future climate-change scenarios. These run-up heights will then be added to modeled sea-level (present [+0.00 m] and +0.25 m, +0.50 m, +0.75 m, +1.00 m, +1.50 m, +2.00 m of sea-level rise) to compute total water levels and thus the limit of inundation. These total water levels will then be projected onto a detailed LiDAR digital elevation models and GIS maps by USGS-PIERC staff as a series of contours detailing the limit of inundation under the given sea-level rise scenarios for specific islands (Laysan Island and Midway Atoll's Sand, Spit, and Eastern Islands) relative to the location of important natural resources previously mapped by USFWS and USGS. Analyses of these map results will also provide understanding as to the number of natural resources and infrastructure impacted by different sea-level rise scenarios, and also provide insight into "tipping points", where the frequency of inundation of a resource becomes so frequent that the resource is no longer viable. Since these are all numerical modeling studies we do not anticipate field collection, or permits are required.

While the current proposal is limited to modeling the effects and timing of storm-induced waves and sea-level rise on resources within PMNM, and provides critical and independent deliverables, related work for additional islands should be considered if additional funding becomes available. The same information and modeling provided for PMNM is also needed for the Pacific Remote Islands, and could be run at the same time if staff funding were available. These models could also provide the basis for future efforts to predict the potential effects of tsunamis (as occurred during the March 2011 Japan event) on terrestrial resources or to better constrain impacts on marine resources and their distributions using data on wave shear stresses.

DELIVERABLES

The following products will be produced for both Midway Atoll and Laysan Island:

1) Wave climatology (long-term characterization of wave patterns) delineating the different end-member wave conditions that impact the islands.
2) GIS maps of wave parameters (significant wave height, wave period, wavelength) for the different wave climatologies at present sea level.
3) GIS maps of wave parameters (significant wave height, wave period, wavelength) for the different wave climatologies at potential future sea levels.
4) GIS maps showing the limit of inundation for the different wave climatologies at present sea level relative to the locations of natural resources and infrastructure.

5) GIS maps showing the limit of inundation for the different wave climatologies at potential future sea levels relative to the locations of natural resources and infrastructure.
6) Plots showing percentage of natural resources potentially inundated for the different wave climatologies at potential future sea levels.

The results of this study will be documented in digital maps and a scientific report to be disseminated to PMNM Managers, National Wildlife Refuges, and Federal, State, and academic researchers, and project cooperators. The new advances in understanding of sea-level rise and storm-wave impacts to atolls will be presented at the Hawai'i Conservation Conference. These products will document the range of conditions that would result in inundation of the atoll islets, impacting natural resources, both at present and for future sea-level rise scenarios. The products generated will compliment and greatly enhance ongoing research projects (funded in part by USGS-PIERC and the USGS-National Climate Change Wildlife Science Center) to evaluate management options to prevent wildlife extinctions in the NWHI due to sea level rise. Products generated will also utilize historic monitoring data collect by project cooperators were appropriate (NOAA, USFWS). This project will also provide the essential baseline and understanding for potential future efforts to predict the potential effects of (a) tsunamis on natural and cultural resources, (b) wave-induced forces on structures and predictions of coastal erosion and accretion, and (c) sea-level rise's influence on waves to better define impacts to Federally-managed marine resources (e.g., coral reefs).

SCHEDULE

Major events and timelines by project quarter.

Events	**FY2011** 07/2011 - 09/2011	**FY2012** 10/2011 - 09/2012			
	Q4	Q1	Q2	Q3	Q4
Planning	X				
Bathymetric and topographic data assimilation	X				
Oceanographic data assimilation and analysis	X				
Laysan model development	X	X	X		
Midway model development		X	X	X	
Data analysis and synthesis			X	X	X
Final GIS and report production				X	X

BUDGET

USGS-PCMSC

Salary*:	$34,900
Travel for coordination and data dissemination meetings:	$2,000
Publication costs:	$1,000
Subtotal:	$38,000
USGS-PCMSC 40.9% facilities overhead:	($15,542)
Total USGS-PCMSC budget request:	$53,542

USGS-PIERC

Salary**:	$32,376
Publication costs:	$1,000
Subtotal:	$33,376
Research Corporation University of Hawaii 8% indirect costs:	($2,590)
Total USGS-PIERC budget request:	$35,966

USGS-PCMSC cost share (researcher salary, 3 months):	$33,600
USGS-PIERC cost share (resesarcher salary, 3 months):	$21,500
USGS-PIERC cost share (publication costs):	$1,000
USGS-PIERC cost share (Digital Elevation Models acquisition and processing):	$125,000
USGS-PIERC cost share (travel for data dissemination meetings):	$2,000

*Numerical Modeling Specialist, USGS-PCMSC, 3 months
**GIS Specialist, USGS-PIERC, 6 months

PICCC Project Total Request:	$89,508
USGS Total Cost-Share:	$183,100