The Impact of Sea-Level Rise and Climate Change on Department of Defense Installations on Atolls in the Pacific Ocean (RC-2334)

Objective

The U.S. Geological Survey (USGS), National Oceanographic and Atmospheric Administration (NOAA), Deltares, and University of Hawaii (UH) conducted a study to provide basic understanding and specific information on the impact of climate change and sea-level rise on Roi-Namur Island on Kwajalein Atoll in the Republic of the Marshall Islands, which is part of the Ronald Reagan Ballistic Missile Test Site. The primary goal of this joint investigation was to determine the influence of climate change and sea-level rise on wave-driven flooding and the resulting impacts to infrastructure and freshwater resources on atoll islands.

Technical Approach

This investigation focused on Roi-Namur Island, which is on the northernmost tip of Kwajalein Atoll in the Republic of the Marshall Islands. Physics-based numerical oceanographic and hydrogeologic models were used to forecast how future sea-level rise and climate change will affect wave-driven flooding of the island and evaluate its resulting impacts to infrastructure and freshwater resources. In order to make accurate projections, such modeling requires physical process formulation and field-data collection for validation and calibration. First, the morphology and benthic habitats of the atoll were mapped to determine the influence of spatially varying bathymetric structure and hydrodynamic roughness on wave propagation over the coral reefs that make up the atoll. Second, historic meteorologic and oceanographic data were analyzed to provide historical context for the limited in situ data and comparison to previous seawater overwash and flooding events. These data were then used to calibrate and validate physics-based, dynamically-downscaled numerical models to forecast future atmospheric and oceanic forcing for a range of climate change scenarios. Third, in situ observations were made to better understand how changes in meteorologic and oceanographic forcing controlled wave-driven water levels, seawater flooding of the island, and the resulting hydrogeologic response. These data were then used to calibrate and validate physics-based, numerical hydrodynamic and hydrogeologic models of the island. The hydrodynamic model was used to forecast future wave-driven island overwash and seawater flooding for a range of climate change and sea-level rise scenarios. The output of those hydrodynamic simulations were then used as input to the hydrogeologic model to evaluate the impact of projected annual wave-driven flooding on the atoll island's freshwater aquifer and at what rate the aquifer can recover. Lastly, the "tipping points" – when the recurrence interval of island overwash and seawater intrusion events is shorter than the recovery times for the impact – were forecast.

Results

The future climate simulation developed projects that deep-water wave heights and wind speeds around Kwajalein Atoll will decrease slightly, resulting in a decrease in the magnitude and frequency of the threat to marine operations. The decrease in the frequency of tropical storms and typhoons will also reduce the frequency of weather-based disruptions to marine and terrestrial operations, although the slight increase in intensity of typhoons may result in greater impact of a given storm despite their much less frequent occurrence. The projected slight decrease in rainfall will cause a small reduction in freshwater availability. The potential effects of these changes, however, will likely be insignificant in comparison to the impact of projected increases in sea level in the region. These increases in sea level will result in greater wave-driven runup and island flooding.

The impact of sea-level rise inundation combined with annual wave-driven flooding will begin to significantly negatively impact Roi-Namur when mean sea level is 0.4 meters higher than at present. At this point, without active management measures, the annual amount of seawater flooded onto the island during storms will be of sufficient volume to make the groundwater non-potable year-round. At this level of sea-level rise, much of the isthmus that connects Roi and Namur will be flooded annually, negatively impacting the facilities in those locations. Thus the “tipping point” – the time at which potable groundwater on Roi-Namur will be unavailable – is projected to be reached before 2035 for the RCP8.5+icesheet collapse climate scenario, the 2030-2040 time frame for the RCP8.5 climate scenario, and 2055-2065 for the RCP4.5 scenario. Although active management practices such as post-flood short-term intensive withdrawal and artificial recharge will allow for 3-4 months of potable groundwater on Roi-Namur during the rainy season at higher sea levels, it is not clear as to the sustainability of such operations over the long term with increasing frequency and intensity of wave-driven flooding and island overwash.

Even if the groundwater supply was supplemented or replaced with another source (e.g., desalinization or delivery of freshwater from elsewhere), the annual wave-driven flooding will disrupt operations on Roi-Namur. When mean sea level is 1.0 m higher than at present due to sea-level rise, at least half of the island is projected to be flooded annually; the areas that will not experience annual flooding include just the runway, the southern portion of the isthmus and associated infrastructure, and the northern portion of Roi where the housing is located. This “tipping point” – at which the majority of Roi's land would be flooded annually – is projected to be reached in the 2055-2065 time frame for the RCP8.5+icesheet collapse climate scenario, the 2060-2070 time frame for the RCP8.5 climate scenario, and sometime after 2105 for the RCP4.5 scenario. Many of the adjacent islands on Kwajalein Atoll that are inhabited and/or have DoD facilities (Ebeye, Ennylabegan, Ebadon, Ennubirr, Gagan, Gellinam, Gugeegue, Illeginni, Legan, Meck, Omelek) will face a similar fate. Together, these results provide an improved understanding of the planning and management strategies necessary to protect infrastructure and natural resources on low-lying atoll islands globally in the face of future climate change.

Although the focus of the effort presented here was on low-lying atoll islands, there is high relevance of the findings presented here to other tropical, reef-lined islands. Because the majority of housing and critical infrastructure (ports, roads, airports, hospitals, power plants, water treatment plants, etc.) on most tropical high islands such as the Hawaiian Islands, Guam and the Commonwealth of the Northern Mariana Islands, American Samoa, Puerto Rico, and the US Virgin Islands are located within a few meters of current sea level, they, too will confront threats similar to those faced by atolls resulting from increased wave-driven flooding of coastal zones due to sea-level rise. The results presented here, therefore, provide coastal managers an estimate of the effect of different oceanographic, geomorphic, geologic, and hydrologic characteristics on potential coastal hazards caused by wave-driven flooding of coral reef-lined coasts globally and how these may change in the future.

Benefits

This study provided new understanding of how atoll islands may be affected by projected rises in global sea level and climate change; such information has broad application to atolls and coral reef-lined coastlines worldwide. These results provide an improved and updated timeline of the threats these low-lying atoll islands face to their infrastructure and natural resources due to future climate change. A next step is to comprehensively identify atoll islands managed by the US Department of Defense (DoD), both active (e.g., Kwajalein, Wake, Diego Garcia) and decommissioned (e.g., Midway and Johnston), that are most vulnerable to sea-level rise and associated impacts over the next 20 to 50 years using these results and those from theoretical simulations covering the range of reef island morphologies and climate forcing conditions so that managers can prioritize funding for further place-based studies and/or restoration and adaptation efforts. Further, this information, when applied broadly to all islands, will be critical to political leaders globally because it will enable them to identify which island nations and human populations will be displaced and when this displacement is likely to occur. If these impacts are not addressed or adequately planned for, as it becomes necessary to abandon or relocate island nations, significant geopolitical issues could arise.

Points of Contact

Principal Investigator
Dr. Curt Storlazzi
U.S. Geological Survey

Phone: 831-427-4721
cstorlazzi@usgs.gov

Program Manager

Resource Conservation and Resiliency
SERDP and ESTCP
rc@noblis.org