EOS
EOS, TRANSACTIONS, AMERICAN GEOPHYSICAL UNION

VOLUME 93 NUMBER 17
24 APRIL 2012
PAGES 169–176

Sea Level Rise and the Ongoing Battle of Tarawa

PAGES 169–170

At dawn on 20 November 1943, U.S. marines launched an assault on Tarawa, a Japanese-held atoll in the British Protectorate of the Gilbert and Ellice Islands. The water in the lagoon was only 3 feet deep that morning, less than the 4–5 feet required by a fully loaded personnel carrier to navigate the waters. As a result, marines saddled with equipment were forced to wade almost a mile across the lagoon under heavy Japanese fire.

The United States won the Battle of Tarawa, but it proved to be one of the bloodiest battles of the war; almost 6000 Japanese, Americans, and Gilbertese were killed in just 3 days of fighting. Of the American fatalities, almost half occurred because U.S. military planners ignored warnings about the local tides on the morning of the assault [e.g., *Wright,* 2000].

Today, Tarawa Atoll (Figure 1, top left), capital of the independent Republic of Kiribati and home to 40% of the country's 103,500 people, receives public and political attention because of a very different battle. Along with the Maldives and Tuvalu, Kiribati is broadly considered to be one of the countries most threatened by sea level rise. In the growing discourse on the effects of sea level rise on places like Kiribati, scientists and educators can learn from the Battle of Tarawa: Like the weather, the sea and the shoreline are constantly changing.

The distinction between weather—what you "get"—and climate—what you "expect"—is consistently confusing to the public. As scientists often explain in the media, the weather at a particular location on a particular day is not proof of a global climate trend, nor is a global climate trend a good predictor of the local weather at a particular location on a particular day.

This same nuance is important in discourse about sea level rise. As the global average sea level rises, the response of any one location at any given time will depend on the natural variability in regional sea level and the effects of local human activities on coastal processes. As with climate warming, the state of an individual shoreline or the extent of flooding on a given day is not proof of a sea level trend, nor is a global sea level trend a good predictor of individual flooding or erosion events.

By Simon Donner

Natural Variability and Sea Level

Much like the weather, the local sea level and the shoreline vary over multiple time scales. In addition to the diurnal, weekly, and annual cycles of the astronomical tides, the local sea level is sensitive to the weather and to ocean dynamics. On an hourly to weekly time scale the sea level can rise during periods of low atmospheric pressure (e.g., the "storm surge"

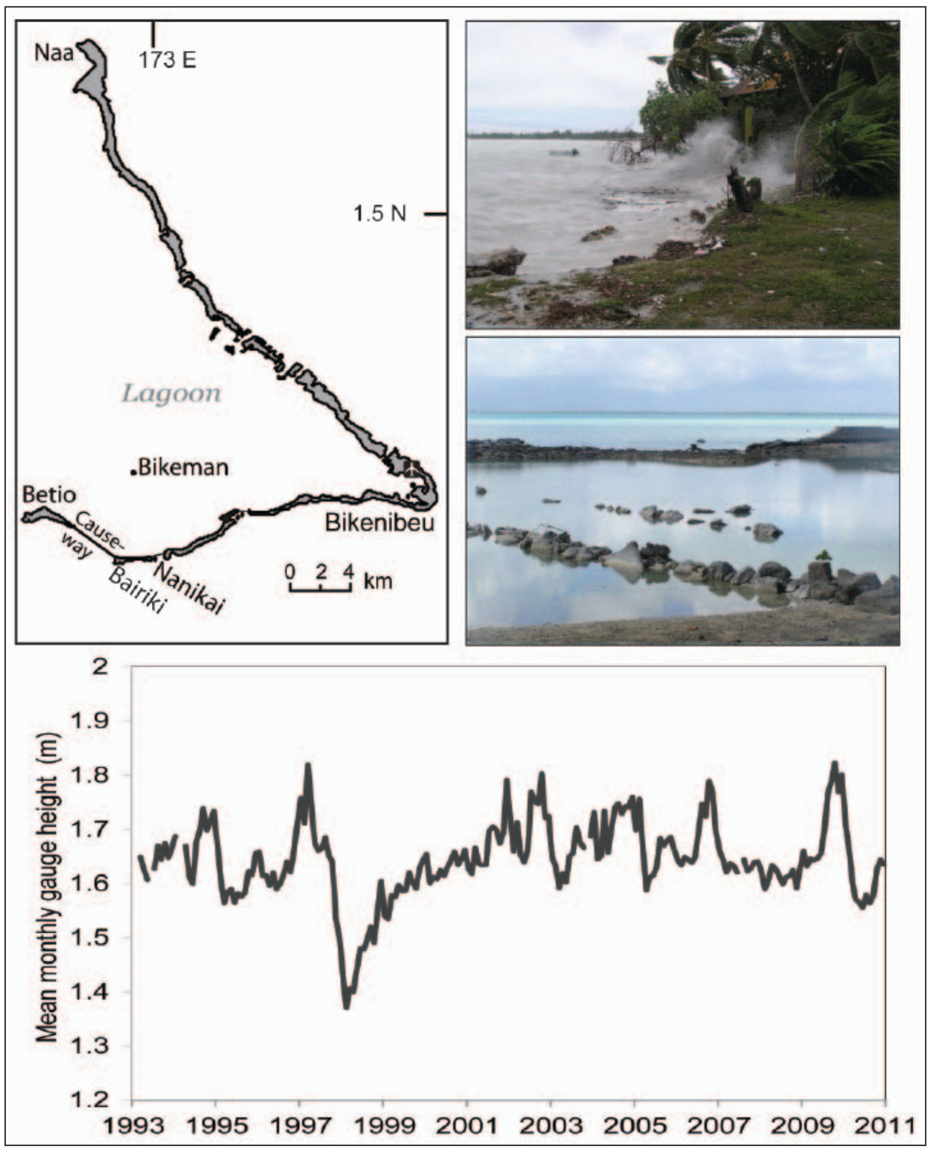

Fig. 1. (counterclockwise from top left) Map of Tarawa Atoll; monthly mean sea level at Betio, Tarawa, from Australian Tidal Facility data; inundation behind a failed sea wall in South Tarawa; and flooding on the lagoon shoreline of Bikenibeu during a 2005 storm.

driven by a tropical cyclone). On weekly to monthly time scales the local sea level can vary because of atmosphere-ocean oscillations like the El Niño–Southern Oscillation (ENSO).

The importance of natural variability in sea level on shorelines is most evident in central equatorial Pacific atolls like Tarawa (Figure 1, bottom). During El Niño events, slowdown or reversal of the trade winds and the South Equatorial Current raises sea surface temperatures and the sea level in the central and eastern equatorial Pacific. For example, the monthly mean sea level dropped by 45 centimeters from March 1997 to February 1998, according to the Australian Tidal Facility gauge, due to a switch from El Niño to La Niña conditions (Figure 1, bottom). Moreover, during the three most recent El Niños centered in the central Pacific (2002–2003, 2004–2005, and 2009–2010) [*Lee and McPhaden,* 2010] the peak monthly mean sea level at Tarawa averaged 15 centimeters above the long-term gauge mean. This spike during these El Niño events is equivalent to 50 years of global sea level rise at the rate observed since 2000 of 3 millimeters per year [*Nicholls and Cazenave,* 2010].

The combination of natural weather- and climate-driven variability in sea level and the astronomical tidal cycle can lead to flooding and erosion events, particularly in sand-dominated systems like atolls and barrier islands. For example, the 2004–2005 ENSO event contributed to two major flooding events in Tarawa. During a "king" tide on 10 February 2005, water flooded several causeways between the islets in South Tarawa and damaged the hospital in the town of Betio. A second flooding event occurred 2 weeks later, despite the lower daily tidal range, because of record high winds (47 knots at Betio) and record-low surface level pressure (999.2 hectopascals). Even though the maximum gauge height was 25 centimeters below that reached 2 weeks earlier, the northwest winds generated lagoon waves that again breached sea walls, flooded causeways, and damaged homes and public infrastructure (Figure 1, top right).

These flooding events, though statistically more likely to happen as global average sea level rises, are themselves no more evidence of rising sea level than an individual heat wave is evidence of rising global temperatures. Despite a continued global average sea level rise, the gauge height reached on 10 February 2005 in Tarawa has not been surpassed since.

Direct Human Impacts on Shorelines

Coastal development, including land reclamation, erosion control efforts, wetland drainage, and flood management, is increasing worldwide at the same time that the sea level is rising. Just as human modification of the land surface can influence the temperature and moisture budget of a region by altering the surface albedo, surface roughness, and atmospheric composition, human modification of the coastal environment can affect flood magnitude, flood frequency, and even island shape by altering hydrodynamics and sediment supply. Together, these practices can create the geomorphic equivalent of an "urban heat island" effect, where instead of the urban environment altering the local temperature, it alters the coastline.

Three types of shoreline modification that are typical in low-lying island nations have altered sediment supply and island shape in South Tarawa [*Webb,* 2005]. First, land reclamation, accomplished by infilling behind a constructed sea wall, has increased land area in some locations but exacerbated erosion and inundation in others. The shoreline of islets like Bairiki has been extended lagoonward through the construction of government facilities, landfills, maneabas (community meeting houses), and individual homes [*Webb and Kench,* 2010]. At the same time, poor engineering of sea walls has led to erosion at the airport and the hospital [*Webb,* 2005] on the islet of Bikenibeu and also led to inundation of reclaimed lands along the lagoon shoreline in Abarao (Figure 1, middle right) and other islets.

Second, the practice of mining of beaches and barrier reefs for construction materials, common in Kiribati, Tuvalu, and other atoll nations, can make the shoreline more vulnerable to tidal extremes and storms [*Webb,* 2005]. Almost three quarters of the households in South Tarawa mine sand, gravel, and reef rock from the lagoon or the ocean reef, with one third doing so more than once a week [*Greer Consulting Services,* 2007]. Although the effect of beach mining on the shoreline is difficult to distinguish from that of other coastal processes, concern is sufficient to warrant European Union investment in a midlagoon dredging project to provide an alternative source of fill.

Last, the construction of causeways between islets has altered islet evolution. Unlike a bridge, a solid, hard-topped causeway limits or blocks the natural flow of sediment between the ocean and the lagoon. Causeway construction allowed nearshore currents to deposit sediment along the lagoon beaches of South Tarawa islets like Bairiki and Nanikai [*Solomon and Forbes,* 1999]. These densely populated islets have actually grown in area over the past few decades [*Webb and Kench,* 2010] because of the unintentional impacts of local development on sediment supply, land reclamation, and natural processes. This accretion, however, came at the cost of other islets. The lagoon islet of Bikeman, which was dotted with coconut trees during the Battle of Tarawa, is now a sandbar that disappears from view at high tide. Despite some claims to the contrary by climate activists, the loss of this once popular resting spot for fishermen is primarily due to the construction of the Betio-Bairiki causeway, which redirects sediment flow [*Solomon and Forbes,* 1999].

Communicating About Sea Level Rise

The failure to consider the contribution of natural variability and direct human modifications can lead to misattribution of flooding events or shoreline changes to sea level rise. Tarawa, the most easily accessible atoll in Kiribati, is a popular destination for journalists and activists interested in observing and communicating the impacts of sea level rise on a low-lying nation. For example, a Greenpeace slide show within an explanation of what sea level rise means that depicts the 2005 flooding remains among the top responses to an Internet query of "Kiribati" and "sea level rise." These common images of flooded homes and waves crashing across the causeways—collected during an anomalous event on islets susceptible to flooding due in part to local modifications to the environment—can provide the false impression that Tarawa is subject to constant flooding because of sea level rise.

The attribution problem is further magnified by the political situation. The Kiribati government faces the difficult challenge of raising international awareness about the local impacts of climate change to support adaptation and mitigation efforts. Interpreting the causes of shoreline changes or flood events, as well as predicting the local impacts of sea level rise, is challenging for a developing country with limited resources for scientific investigations. Many individual observations of erosion, flooding, or groundwater salinization, recorded in community consultations for internationally funded climate change adaptation programs, are thus attributed to climate change without scientific analysis [e.g., *Mackenzie,* 2004]. These events are presented as examples of climate change impacts in promotional materials and at international events (e.g., "Our Road to Copenhagen," a Kiribati side event at COP15 in Copenhagen), without any mention of ENSO-driven natural variability or local shoreline modification.

Such unverified attribution can inflame or invite skepticism of the scientific evidence for a human-caused increase in the global sea level. After *Webb and Kench* [2010] reported that the area of 23 atoll islets in Kiribati and neighboring countries had remained stable or increased over the past 20–60 years, some of the international news media reported that the effects of sea level rise on atoll nations were exaggerated and that Kiribati is not threatened by future sea level rise (e.g., R. Callick, Coral islands left high and dry, *The Australian,* 2010, http://www.theaustralian.com.au/news/features/coral-islands-left-high-and-dry/story-e6frg6z6-1225878132101). Though the study did show evidence that atoll islets were dynamic and do not necessarily decrease in area in response to sea level rise, the islets in question remain vulnerable to inundation from global mean sea level rise in the future, as the authors stressed in a subsequent briefing note (see http://dev.sopac.org.fj/WebDoc/Island Vulnerability Arthur Webb Brief_lbedit.pdf).

The challenge of differentiating between observed changes in the coastal environmental and the projected impact of sea level rise is not unique to Kiribati. For example, the Carteret Islanders of Papua New Guinea have been migrating from their home atoll for decades because overpopulation, human development, and natural disasters, in addition to sea level rise, have caused coastal erosion and reduced water availability [*Connell,* 1990]. Nevertheless, the Carteret Islanders are commonly called the world's first climate change "refugees" in outreach and documentary films (e.g., *The Rising Tide;* see http://www.risingtidethemovie.com/).

Navigating Rough Waters

The coastal environment, like the weather, is evolving because of natural climate variability and direct human disturbance, as well as a global trend. A particular flood event, whether it occurs in a low-lying atoll like Tarawa or in New York City, cannot be blamed on global sea level rise any more than a particular heat wave can be blamed on climate warming.

Instead of incorrectly attributing individual flood events or shoreline changes to global sea level rise, scientists and climate communicators can use such occurrences to educate the public about the various natural and human processes that affect sea level, the shoreline, and the shape of islands. This would better prepare the public and policy makers for the changes that societies are likely to experience as global sea level rises in the coming decades.

Acknowledgments

The author thanks T. Kirata, A. Tekiau, the Kiribati Adaptation Project, and the Kiribati Meteorological Service for assistance during field research. This work is funded by a NSERC Discovery grant.

References

Connell, J. (1990), The Carteret Islands: Precedents of the greenhouse effect, *Geography,* 75, 152–154.

Greer Consulting Services (2007), Kiribati technical summary—Report of economic analysis of aggregate mining on Tarawa, *Proj. Rep. 71b,* 19 pp., South Pac. Appl. Geosci. Comm., Suva.

Lee, T., and M. J. McPhaden (2010), Increasing intensity of El Niño in the central-equatorial Pacific, *Geophys. Res. Lett., 37,* L14603, doi:10.1029/2010GL044007.

Mackenzie, U. N. (2004), Kiribati Adaptation Project: Social assessment final report, 97 pp., Gov. of Kiribati, Tarawa, Kiribati.

Nicholls, R. J., and A. Cazenave (2010), Sea-level rise and its impact on coastal zones, *Science, 328,* 1517–1520, doi:10.1126/science.1185782.

Solomon, S. M., and D. L. Forbes (1999), Coastal hazards and associated management issues on South Pacific Islands: A reconnaissance survey, *Ocean Coastal Manage., 42,* 523–554, doi:10.1016/S0964-5691(99)00029-0.

Webb, A. P. (2005), Technical report—An assessment of coastal processes, impacts, erosion mitigation options and beach mining, *Proj. Rep. 46,* 47 pp., South Pac. Appl. Geosci. Comm., Suva.

Webb, A. P., and P. S. Kench (2010), The dynamic response of reef islands to sea level rise: Evidence from multi-decadal analysis of island change in the Central Pacific, *Global Planet. Change, 72,* 234–246, doi:10.1016/j.gloplacha.2010.05.003.

Wright, D. (2000), *Tarawa 1943: The Turning of the Tide,* 96 pp., Osprey, Oxford, U. K.

Author Information

Simon Donner, Department of Geography, University of British Columbia, Vancouver, Canada; E-mail: simon.donner@ubc.ca