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Are beach erosion rates and sea-level rise related in Hawaii?

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ABSTRACT

The islands of Oahu and Maui, Hawaii, with significantly different rates of localized sea-level rise (SLR, approximately 65% higher rate on Maui) over the past century due to lithospheric flexure and/or variations in upper ocean water masses, provide a unique setting to investigate possible relations between historical shoreline changes and SLR. Island-wide and regional historical shoreline trends are calculated for the islands using shoreline positions measured from aerial photographs and survey charts. Historical shoreline data are optimized to reduce anthropogenic influences on shoreline change measurements. Shoreline change trends are checked for consistency using two weighted regression methods and by systematic exclusion of coastal regions based on coastal aspect (wave exposure) and coastal geomorphology. Maui experienced the greatest extent of beach erosion over the past century with 78% percent of beaches eroding compared to 52% on Oahu. Maui also had a significantly higher island-wide average shoreline change rate at −0.13 ± 0.05 m/yr compared to Oahu at −0.03 ± 0.03 m/yr (at the 95% Confidence Interval). Differing rates of relative SLR around Oahu and Maui remain as the best explanation for the difference in overall shoreline trends after examining other influences on shoreline change including waves, sediment supply and littoral processes, and anthropogenic changes; though, these other influences certainly remain important to shoreline change in Hawaii. The results of this study show that SLR is an important factor in historical shoreline change in Hawaii and that historical rates of shoreline change are about two orders of magnitude greater than SLR.

1. Introduction

It has not been widely documented if historical rates of sea-level rise (SLR) are an important factor in shoreline changes observed on coasts around the world. Zhang et al. (2004) document that on the U.S. east coast rates of coastal erosion are about two orders of magnitude greater than the rate of SLR. However, this has not been confirmed elsewhere and the relative contribution of SLR to regional shoreline change patterns remains debatable. Improved understanding of the influence of SLR on historical shoreline trends will aid in forecasting beach changes with increasing SLR. Globally-averaged sea-level rose at about 2 mm/yr over the past century. Studies indicate that the rate of rise is now approximately 3 mm/yr (Church and White, 2006; Merrifield et al., 2009) and may accelerate over coming decades (Vermeer and Rahmstorf, 2009).

Few datasets embody detailed multi-decadal to century-scale historical shoreline positions on sandy beaches of wave-dominated coasts, with relations to SLR. List et al. (1997) examined beach profile response to accelerated SLR on barrier coastal islands of Louisiana since the 1880s, concluding that relative SLR is not the primary factor forcing the region's shoreline change. Leatherman et al. (2000) investigated the relationship between long-term (century-scale) shoreline change and varying rates of SLR along the U.S. east coast, finding a correlation between regionally-averaged shoreline change rates and localized rates of relative SLR. Brunel and Sabatier (2009) examined historical shoreline changes on the French Mediterranean coast in comparison to theoretical predictions of shoreline change due to SLR and found that sea-level rise is one of, but not the major, factor influencing shoreline retreat on wave-dominated coasts in that region. Webb and Kench (2010) described the response of central Pacific atoll islands to SLR using historical aerial photography over a 19 to 61 yr period and concluded that reef islands are dynamic landforms that undergo a range of physical adjustments to changing SLR and other boundary conditions.

Recently completed shoreline change studies for the islands of Kauai, Oahu, and Maui, Hawaii (Fletcher et al., 2012; Romine and Fletcher, 2013) indicate substantially higher erosion rates for the beaches of Maui compared to Oahu and Kauai. Tide gage data from the individual islands indicates higher rates of localized SLR around Maui compared to Oahu and Kauai (approximately 65% higher, http://tidesandcurrents.noaa.gov/). Coincidentally, the relative rate of SLR around Kauai and Oahu (1 to 2 mm/yr) is similar to the global-average rate of SLR over

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the past century, while the relative rate of SLR around Maui is similar to the present rate of global-average SLR (2 to 3 mm/yr). Oahu and Maui Islands provide a unique opportunity to investigate shoreline trends between two adjacent islands in similar physical settings and with similar geomorphologic history (including anthropogenic changes), but with significantly differing rates of relative SLR. SLR is only one of many factors driving shoreline change. Other drivers of shoreline change that must be considered carefully include sediment availability, anthropogenic changes, littoral processes, wave conditions, and coastal and nearshore geomorphology. Because of these multiple factors, establishing a direct causative link between historical shoreline change and SLR remains a challenge.

Using historical shoreline measurements from Fletcher et al. (2012), augmented with new data for the north and west coast of Maui, we provide further investigation of trends for the islands of Oahu and Maui to determine if there are significant differences between the islands and if SLR is an important factor in observed shoreline changes. We control for influences other than SLR to determine if SLR remains as the best explanation for observed changes. We also utilize a series of consistency checks to determine if results are significant and to eliminate other possible explanations.

2. Regional setting

The Hawaii archipelago, including the islands of Oahu and Maui (Figs. 1 and 2), is comprised of eight volcanic islands in the tropics of the central north Pacific. The islands are fringed by carbonate reef platforms built from a complicated patchwork of fossil Pleistocene reefs during interglacial sea-level high stands of the past 500 kyr or so (Fletcher et al., 2008).

Analysis of beach sediments in Hawaii shows they are typically comprised of biogenic calcareous debris eroded from nearshore reefs, with a minor fraction of volcanoclastic sediment eroded from adjacent watersheds (Moberly and Chamberlain, 1964; Harney and Fletcher, 2003). Grain size on beaches in Hawaii has been shown to be related to wave and current energy, which, in turn, is largely dependent on coastal aspect (wave exposure) (Moberly and Chamberlain, 1964). Beach sediments in Hawaii have been shown to typically be mid-Holocene in age (~500–2,000 yrs before present) likely due to changes in carbonate sediment production through the Holocene (Harney et al., 2000; Resig, 2004). Sediment storage on the inner reef platform in paleo-karst depressions and channels plays an important role in beach sediment supply (Bochicchio et al., 2009; Conger et al., 2009). Sediment may be lost from beaches by abrasion, longshore transport, transport offshore by wave-driven currents, landward transport by onshore winds, and human activities. Hawaii beaches, like most carbonate beaches, are, generally, narrower than siliciclastic beaches due to limited available sediment from the nearshore reef and coastal plain. We refer the reader to Fletcher et al. (2012) for a more thorough discussion of the coastal geology of Oahu and Maui on a regional basis.

While similar to global averages for SLR over the 20th century (~2 mm/yr; (Church and White, 2006)), localized rates of SLR vary along the Hawaii Island chain (http://tidesandcurrents.noaa.gov). SLR rates were similar for Kauai and Oahu (Kauai: 1.53 ± 0.59 mm/yr and 1.50 ± 0.25 mm/yr, resp.) and higher around Maui (2.32 ± 0.53 mm/yr) (Fig. 3). SLR rates for Kauai and Maui where not significantly different at the 95% Confidence Interval (95% CI) likely due to shorter time series for these tide stations compared to Oahu (~60 yrs for Kauai and Maui vs. ~100 yrs for Oahu). Fletcher et al. (2012) and Romine and Fletcher (2013) also found that island and regional shoreline trends for Kauai have high uncertainties likely due to high seasonal variability on some Kauai beaches, especially west Kauai. Kauai is excluded from this study where we are attempting to relate SLR and shoreline trends due to the lack of a significant difference between SLR trends for Kauai and Maui and high uncertainty with island-wide shoreline trends for Kauai. Historical shoreline data of comparable quality is not presently available for the other main Hawaiian Islands.

The variation in long-term SLR rates along the Hawaii archipelago may be related to variations in lithospheric flexure with distance from actively growing Hawaii Island (Moore, 1987) and/or decadal variations in upper ocean water masses (Caccamise et al., 2005). Acceleration of local SLR has not been detected in Hawaii tide gage records, likely related to climatological variability (e.g., tradewinds; (Merrifield and Maltrud, 2011)).

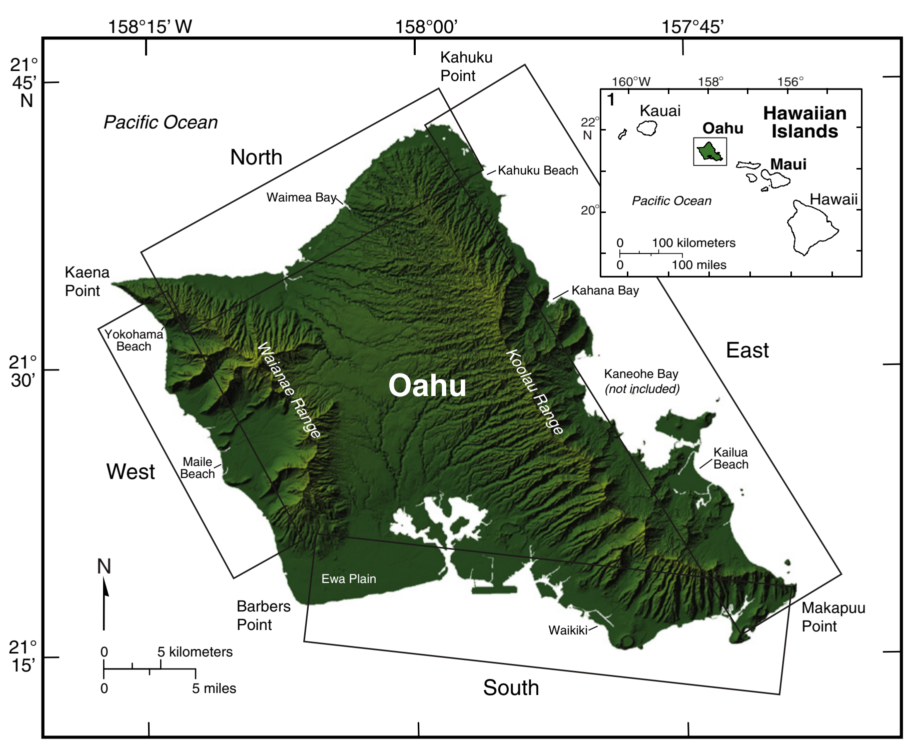

Fig. 1. Oahu island, Hawaii, showing four beach study regions: north, east, south, and west.