Aaron Richmond-Crosset and Abigail Phillips
GEOG 293: Intro to Remote Sensing
Professor John Rogan
18 December 2024

Title

Assessing Shoreline Changes in Funafuti Atoll, Tuvalu

Research Question and Hypothesis

The research question of this project is: How has the shoreline changed in Funafuti Atoll between 2015 to 2023-2024? We hypothesize that the shoreline has decreased in some areas and increased in others, with an overall net decrease.

Research Goals

- Identify shoreline dynamics for the islands of Funafuti Atoll
- Assess the extent to which shoreline change has occurred between 2015 & 2023
- Update the work of Mischino Hibayashi from 2015

Study Area

Tuvalu is an island nation in the Southwestern Pacific Ocean. It is one of over 50 Small Island Developing States (SIDS) locales that experience disproportionate environmental and socioeconomic challenges compared with other countries of the world due to their small size, low economic resilience, and frequency of storm events given the tropical climate (Hisabayashi 2017). The nation of Tuvalu comprises reef islands and atolls, including Nanumea, Nui, Nukufetau, Funafuti, and Nukulaelae. Atolls are a group of islands surrounding a shallow lagoon. This project focuses on Funafuti Atoll (Hisabayashi 2017).

Funafuti is made up of at least 29 low-lying reef islets (only 2-3 feet above the average sea level) and is the location of the capital city of Tuvalu (Hisabayashi 2017). It is also where over half of the country's population lives in small villages across the islands, although many islands are entirely uninhabited (Hisabayashi 2017). The atoll has a 25 km length north-to-south and a 17.5 km width (Hisabayashi 2017). Figure 1 shows a map of the study site.

Funafuti and the whole nation of Tuvalu are vulnerable to extreme weather events. There are an average of 8 cyclones per decade in the region. It is also important to note that the rise in sea level is not equal in all parts of the world. In fact, Funafuti Atoll experienced some of the highest rates of sea level rise in the world from 1950 to 2009, with a rate of ~5.1 ± 0.7 mm/yr (Hisabayashi 2017). This is three times the global average, likely due to regional variability and vertical ground motion (Hisabayshi 2017).

Data Description

Name	Source	Type
Planet Labs 2024	Planet Labs	.tif
Island area data for 2015	Mischino Hisabayashi	Table

The primary data for this study is high-resolution satellite data for July 2024. The resolution of the dataset is 2 meters. The spectral bands of the dataset are RGB and near-infrared.
To compare rates of change in 2015-2024 to 2005-2015, this study uses Mischino Hisabayshi's data on island shoreline change.

Methods

We ran a Random Forest classification of Funafuti atoll using Google Earth Engine. The classes used in this study were Land Vegetation, Water Vegetation, Sand, and Water. We also included an urban class for Fongafale. Land Data Training and testing points were selected manually based on a false-color composite from the Planet Labs file. We calculated validation/accuracy metrics for both a Random Forest classification and a Minimum Distance classification and confirmed that the Random Forest had less error than the Minimum Distance algorithm.

Because the big island, Fongafale, varies widely in size and land cover from the other islands on the map, we ran separate Random Forest Classifications for Fongafale and the rest of the smaller, less inhabited islands. Fongafale needed a different training and testing data set to account for relatively high amounts of urban land cover compared to other islands.

Next, we created geometries for each Island based on a map from Hisabayashi. We ran the Random Forest Classification for the whole area, clipped the classifications to each island geometry, and calculated the area of Land Vegetation for each island. From there, we compared our starting and ending values and percent loss to Hisabayashi's values from 2015.

We measured the Edge of Vegetation (EoV) because it is resistant to changes based on seasonality or daily tidal variation and gives a better idea of long-term patterns of sea-level rise.

Results

Figure 1 shows the actual area in hectares and percent change in land area between 2015 and 2024. It also shows the percent change in land area between 2005 and 2015 to compare rates of change. The majority of islands (25) experienced shoreline loss from 2015-2024 (See Figures 2 and 3). Three islands experienced shoreline gain, but there was a 9.18% net decrease in area. Net decrease for 2015-2024 has accelerated from 0.13% in the 2005-2015 interval. There is a much faster rate of loss of shoreline in the years 2015-2024.

The islands that experienced the largest loss of land are Motuloa and Motugie. Nukusavali disappeared entirely from 2015-2024. The islands that experienced increases in land are Mulitefala, Luamotu, and Telele-Motusanapa, all of which are on the Eastern side of the atoll. The types of islands that experienced the most change were islands that were already small, but this could be due to pixel error. Bigger islands experienced less loss than smaller islands. Figure 3 shows the size of the islands compared to the percent change they experienced. There is a concentration of loss in the southwestern part of the atoll. Figure 3 shows the spatial distribution of percent change from 2015-2024 in Funafuti Atoll.

Discussion

Shoreline loss significantly accelerated between 2015 and 2024 (9.18% net decrease) compared to the slower loss (0.13%) in 2005-2015. Potential drivers of this acceleration, like climate change, lead to sea level rise and warmer ocean temperatures, which increase storm intensity and frequency. The king/spring tides (Feb 2024), Cyclone Tino (2020), and Cyclone Pam (2015) could all contribute to island loss.

Some islands (e.g., Motuloa and Motugie) experienced severe loss, while others (Mulitefala, Luamotu, Telele-Motusanapa) gained land area. This could be explained by sediment deposition: sediment moving from one island to another. However, because the islands in Funafuti Atoll are so small, capturing accurate land area values to quantify shoreline change with satellite imagery takes a lot of work. This study remotely sensed imagery at a resolution of 2 meters from Planet Labs. Due to pixel size limitations, the islands' small size contributed to the calculated high-loss values. Pixel area is more significant in smaller islands due to less land, which may lead to high numbers for area loss. Despite this, some smaller islands are more susceptible to land loss. Small islands, like Motugie, had an area of 23.58 m^2. (This is the equivalent of 2.5 parking spots.) As a result, they are more vulnerable to land loss because of their higher shoreline-to-area ratios, which expose a more significant percentage of their land to erosive processes. As a result, they are more susceptible to storm surges, tidal fluctuations, and wave action. Smaller islands have little to no protection from coastal erosion, unlike bigger islands, which frequently have protected interiors. This problem is made worse by rising sea levels since even slight rises can erode or submerge large areas of their whole land area. Furthermore, they frequently have less vegetation, so they lack the root structures that stabilize soil and lessen erosion from wind and water.

On the contrary, larger islands have buffering capability against erosive forces and structural stability, and they seem more resilient to land loss. Because of their more significant landmass, they are less susceptible to the effects of waves, tides, and storm surges, which gives them a more stable base. Larger islands' interiors are frequently shielded from these forces, so erosion mainly affects the outer margins without seriously endangering the island. Furthermore, more abundant vegetation may help stabilize the soil and lessen erosion on bigger islands. Because they frequently have higher elevations and more land area to absorb such impacts, these islands are less likely to be overtaken by storm surges or rising sea levels.

The study's conclusions demonstrate how seriously vulnerable low-lying atolls like Funafuti are to increasing sea levels and climate change. The growing hazard of coastal erosion, inundation, and habitat loss brought on by rising sea levels and more intense storm activity is highlighted by the accelerated land loss, especially among smaller islands. Because atolls depend on delicate shorelines and sediment dynamics to preserve their structure, these effects are especially severe for them. This study dramatically influences adaptive management and mitigation solutions for atolls and similar habitats. It offers essential information for setting priorities for conservation initiatives like strengthening shorelines at risk, improving sediment deposition, and protecting vegetation by spotting erosion patterns and resilient regions. It also emphasizes how urgent it is that the world take action on climate change to prevent sea level rise and save these delicate ecosystems and the communities that depend on them.

Figures:

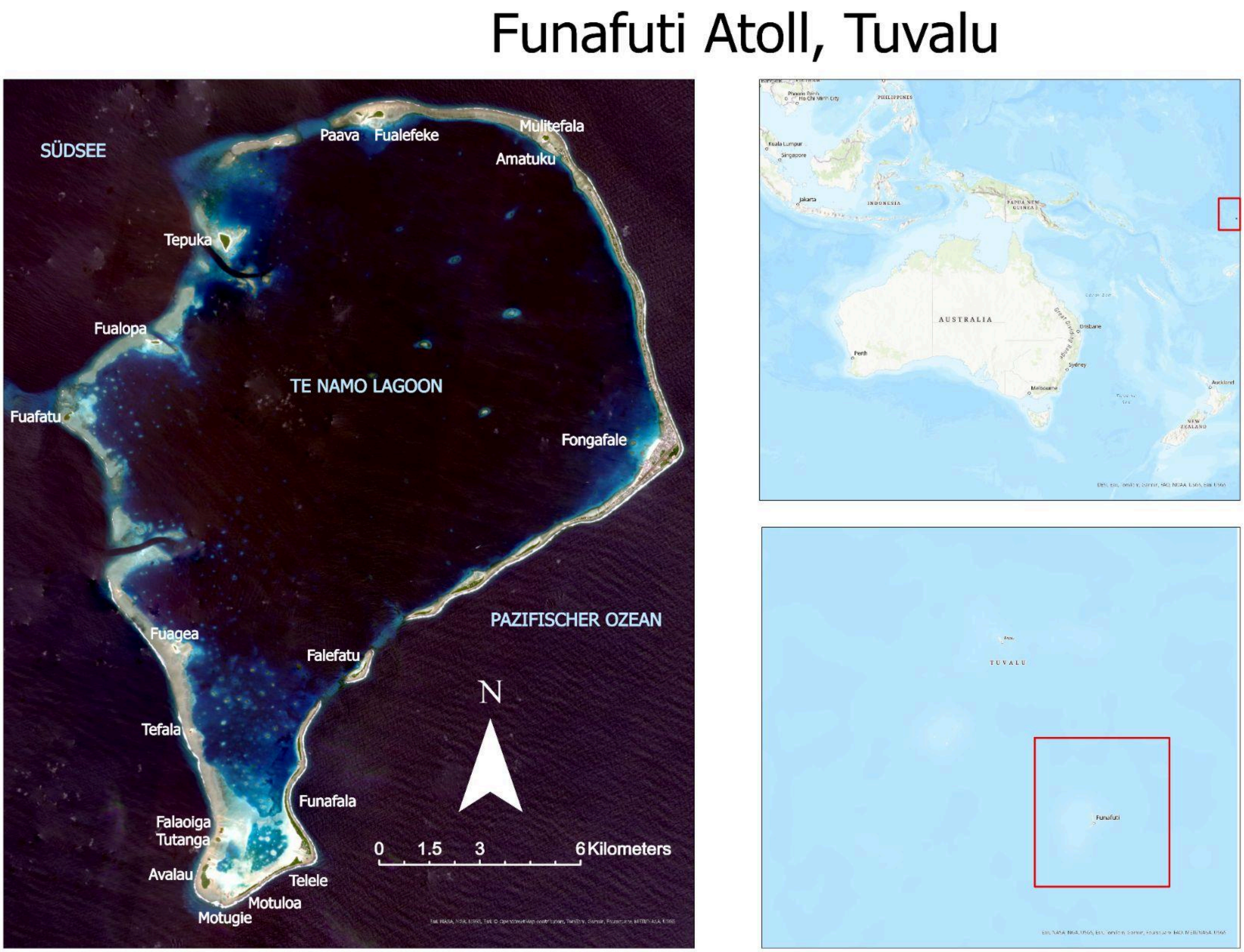

Figure 1: Study area map of Funafuti Atoll, Tuvalu.

Island	2024 Area (m)	2024 Area (ha)	2015 Area (ha)	Differenace (ha)	% change 2015-2024	% change 2005-2015
Nukusavalivali	---	---	0.52	-0.52	-100.00%	4.14%
Motuloa	491.16	0.05	4.44	-4.39	-98.89%	-3.41%
Motugie	23.58	0.00	0.18	-0.18	-98.69%	0.01%
Te Afualiku	723.37	0.07	0.22	-0.15	-67.12%	-17.96%
Tefala	1430.43	0.14	0.43	-0.29	-66.73%	-43.86%
Fuagea	982.49	0.10	0.25	-0.15	-60.70%	-78.33%
Fualopa	10114.01	1.01	2.31	-1.30	-56.22%	-1.95%
Tegasu	3123.87	0.31	0.59	-0.28	-47.05%	-5.92%
Amatuku	35071.47	3.51	6.02	-2.51	-41.74%	-17.96%
Paava	10913.70	1.09	1.62	-0.53	-32.63%	0.58%
Tutaga	11466.13	1.15	1.64	-0.49	-30.08%	1.90%
Fualefeke	46061.28	4.61	6.28	-1.67	-26.65%	-7.94%
Falaoigo	10216.63	1.02	1.39	-0.37	-26.50%	2.85%
Tepuka	78378.29	7.84	9.76	-1.92	-19.69%	-1.73%
Funafala	207697.38	20.77	24.20	-3.43	-14.17%	3.56%
Avalau-Teafufou	107251.32	10.73	12.45	-1.72	-13.85%	2.74%
Falefatu	32763.70	3.28	3.79	-0.51	-13.55%	5.05%
Fatao	49729.49	4.97	5.72	-0.75	-13.06%	1.78%
Fuafatu	32156.39	3.22	3.48	-0.26	-7.60%	-0.89%
Tefota	1387.08	0.14	0.15	-0.01	-7.53%	0.87%
Metiko	42888.75	4.29	4.63	-0.34	-7.37%	3.80%
Funagongo	103854.23	10.39	11.18	-0.79	-7.11%	0.15%
Funamanu	31393.45	3.14	3.32	-0.18	-5.44%	3.72%
Fongafale	1539122.66	153.91	159.06	-5.15	-3.24%	-0.04%
Mulitefala	24675.92	2.47	2.43	0.04	1.55%	-3.06%
Luamotu	19648.15	1.96	1.80	0.16	9.16%	1.50%
Telele-Motusanapa	117397.24	11.74	9.52	2.22	23.32%	3.59%
Vasafua	39.30	0.00	0.00	0.00	----	-100%
Net Total	**2519001.46**	**251.90**	**277.38**	-25.48	-9.19%	**0.13%**

Figure 2: Area in hectares in 2015 (Hisabayashi)

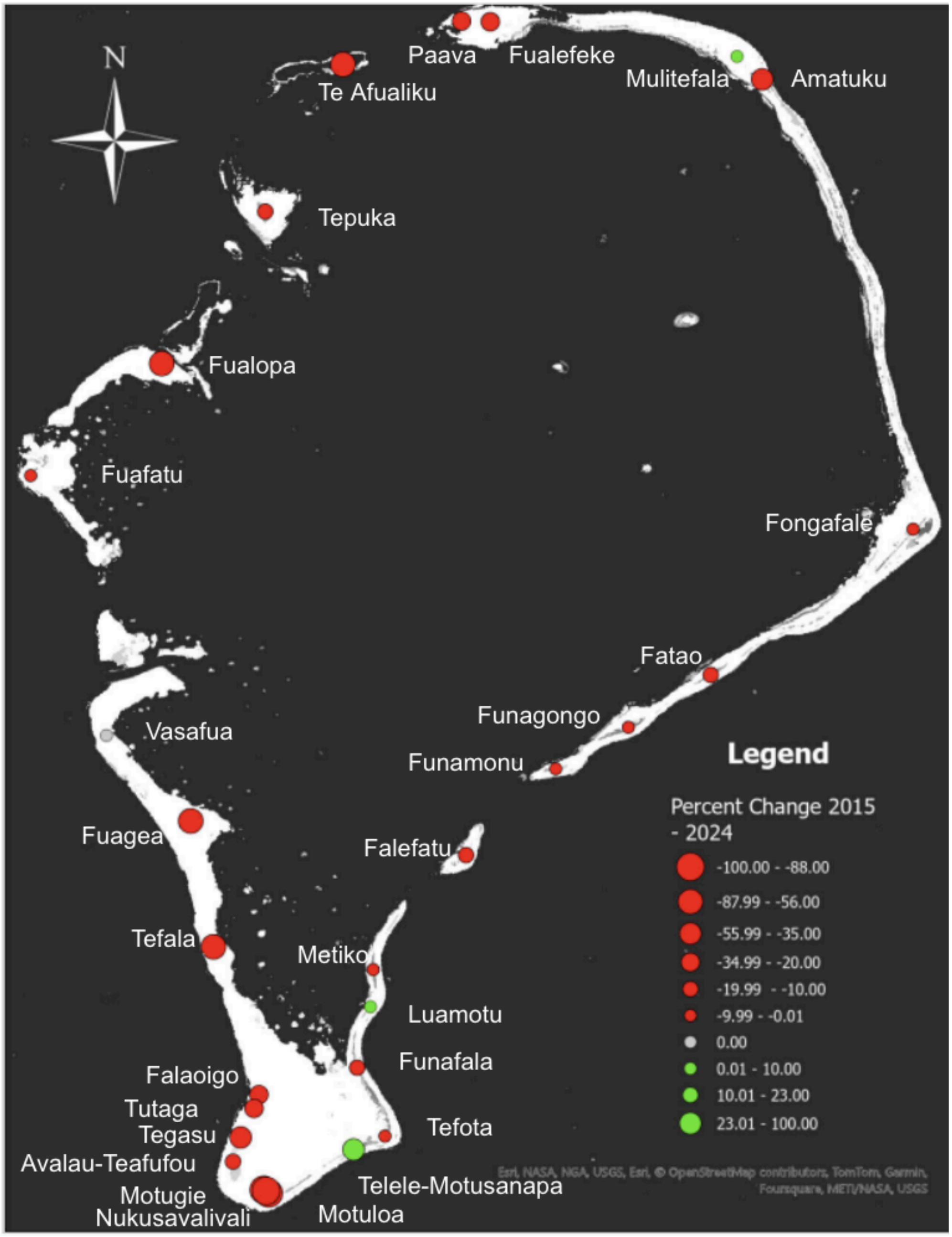

Figure 3: Spatial distribution of percent change by island in Funafuti Atoll.

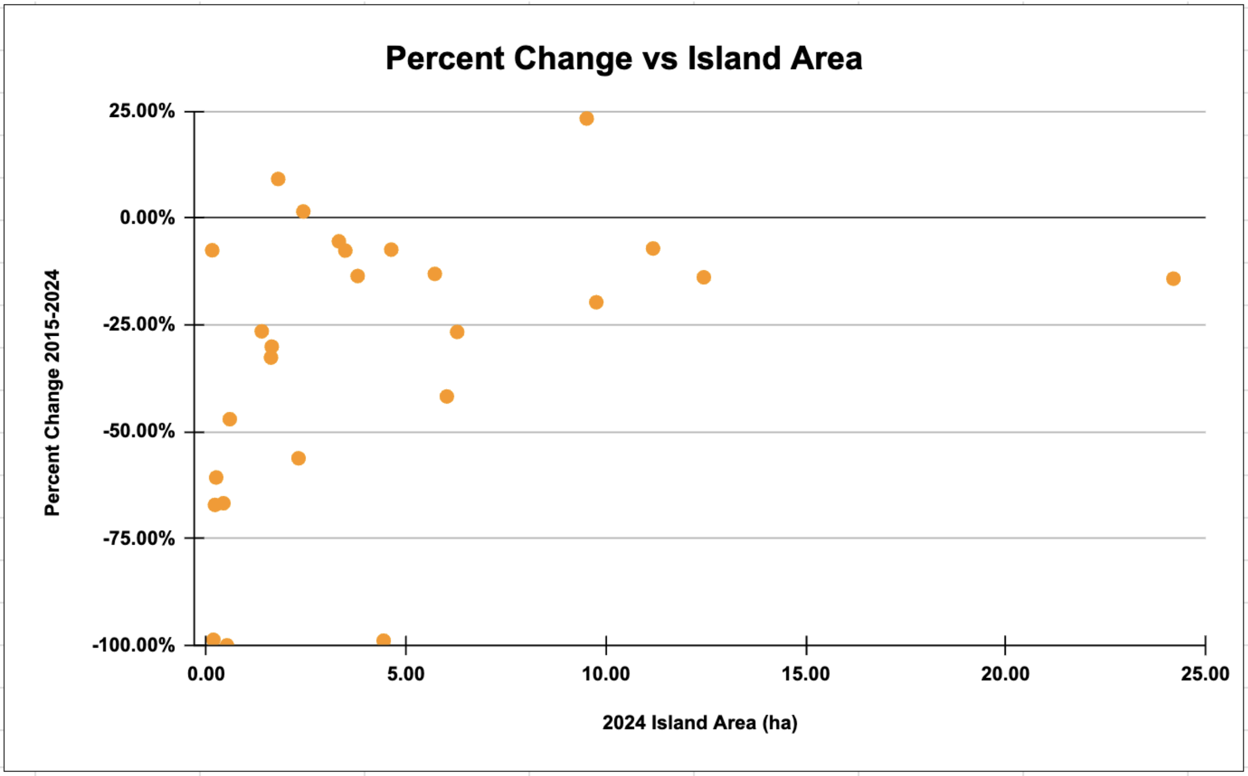

Figure 4: Percent change experienced in 2015-2024 on the vertical axis vs. Island Area in hectares on the horizontal axis.

Reference List

Hisabayashi, M., Rogan, J., & Elmes, A. (2017). Quantifying shoreline change in Funafuti Atoll, Tuvalu using a time series of Quickbird, Worldview and Landsat data. GIScience & Remote Sensing, 55(3), 307–330. https://doi.org/10.1080/15481603.2017.1367157