Fall | 16

Mapping the Island of Wotto

Evaluating Flood Risk from Sea Level Rise

Prepared for Wotto Atoll Resources Management Plan

by Joseph Muhlhausen (CielMap, L.L.C.)
Mark Stege (Marshall Islands Conservation Society)
Bill Labilja (Ministry of Internal Affairs—RMI Lands & Survey)

Funding support from
International Union of Conservation of Nature
Micronesia Conservation Trust
CielMap and MICS and Ministry of IA

Insert IUCN and other logos here

Table of Content

Executive summary

The Republic of the Marshall Islands *Reimaanlok* Community-Based Resource Management Planning Framework entails a comprehensive data gathering process inclusive of topographic and bathymetric mapping for flood risk analysis. Various methods are being explored which meet stringent cost, replicability, and timeliness criteria. This report is a synthesis of one such method from start to finish.

The Island of Wotto (also referred to as Wotho), and the Marshall Island more generally, do not possess adequate elevation models for meaningful study of sea level rise nor for storm surge impact. This project is one of the first to use drones to collect data and use that data to build an elevation model suitable for sea level rise risk assessment.

With co-financing support from IUCN via the German International Climate Initiative and MCT via the Margaret Cargill Foundation, this pilot entailed having MICS and the Ministry of Internal Affairs Lands & Survey establish high accuracy GPS coordinates as ground control points, followed by MICS and CielMap LLC to collect data (aerial images) using drones in order to catalog and model the Island of Wotto. The Wotto Island digital terrain model and the associated flood risk model have numerous applications, including long term resource management planning.

Island height mapping results indicate flooding due to sea level rise beginning in 2055 and increasing in magnitude through to 2100. Some households and the northern end of the airstrip in particular are highly vulnerable to significant flooding occurring twice or more per year. These infrastructural assets are projected to be significantly affected by sea level rise and increased storm intensities in the future, even at lower-end emissions scenarios. If supported and properly managed, however, trees can serve as a coastal protection agent by providing critical natural structure especially when interwoven with engineered structures and barriers.

Mission Team and Logistics

The mission required two trips to Wotto aboard the Air Marshall Island Dornier 228 aircraft. The first trip took one full week during January 2016, while the second trip (originally planned for one week) took ten hours due to Air Marshall Islands flight cancellations on the front end of the trip. By flying at a higher altitude, we were able to shorten the flying time to 3 hours while still meeting mission objectives and gained critical insight for rapid-assessment mission scenarios.

Figure 1: Trip # 2 route map on Air Marshall Islands. Leg (1) Majuro Atoll to Kwajalein Atoll; Leg (2) Kwajalein to Wotto Atoll including three hours ground time on Wotto; Leg (3) return to Majuro via Ujae Atoll and Lae Atoll.

Mission Goal and Phases

The mission goal was to conduct a vulnerability assessment on Wotto Atoll that included island height analysis and flood risk assessment as per *Reimaanlok* data gathering protocols. The mission consisted of two main parts:

1. One week on Wotto to conduct GPS survey to position the elevation model in space using geographic coordinates; and
2. Three hours on Wotto collecting data (aerial images) for the production of the Wotho Island elevation model.

Figure 2: Lands & Survey equipment during the mission on Wotto and CielMap's equipment during equipment and flight plan testing on Majuro

GPS Survey

RMI Lands & Survey conducted the GPS survey of Wotto in January of 2016. Nine geodetic benchmarks were set at specific locations throughout the island following the Ground Control Points (GCPs) priority workplan (Figure 3). Two of the eight benchmarks were established by digging into the soil and forming a foundation of quickset cement on which bronze plates were affixed. Equipment used to establish the other six benchmarks included battery-powered drill, concrete drill bits, concrete screws and galvanized steel washers. Once established, a survey-grade GPS base station and rover combination were used to observe each benchmark for at least 45 minutes, and later post-processed to an estimated cross-referenced accuracy of 8 cm horizontal and 10 cm vertical. The eight set GCPs are shown in Figure 4.

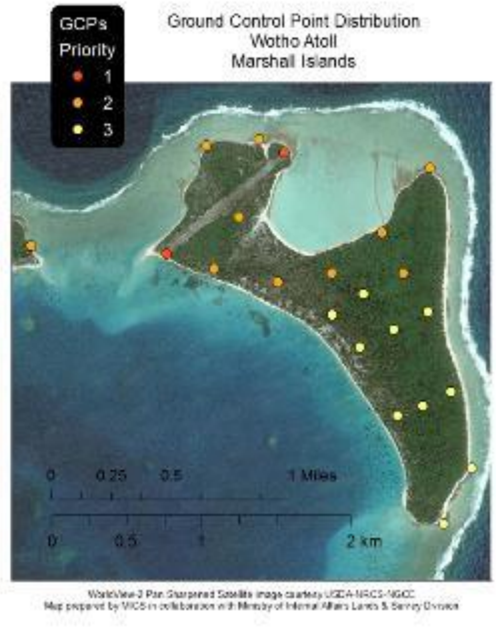


Figure 3: Initial GCP distribution

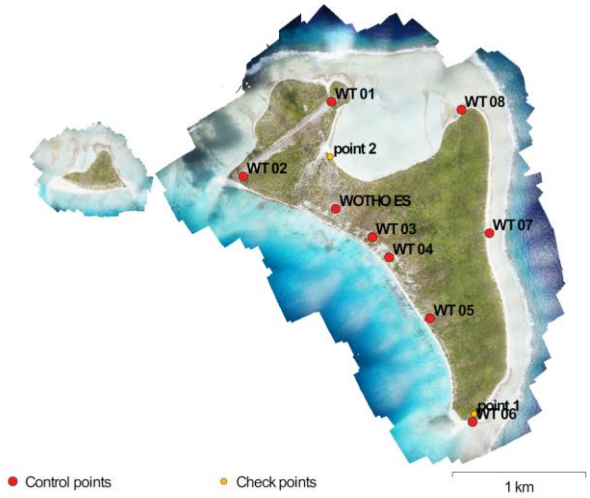


Figure 4: Final GCP distribution

Data Collection

The data collection plan was to collect aerial images using a drone over the course of an entre week on the Island of Wotto. Due to Air Marshall Islands flight cancellations, the decision was made to modify the flight plan to only three hours; by flying at a higher altitude, we were able to shorten the flying time while still meeting mission objectives.

During the first half hour of the three-hour window of time, the measured GCPs were highlighted using various colored tiles and paint to make it visible within the aerial photograph. The markings were centered towards the benchmark in order to maintain best accuracy.

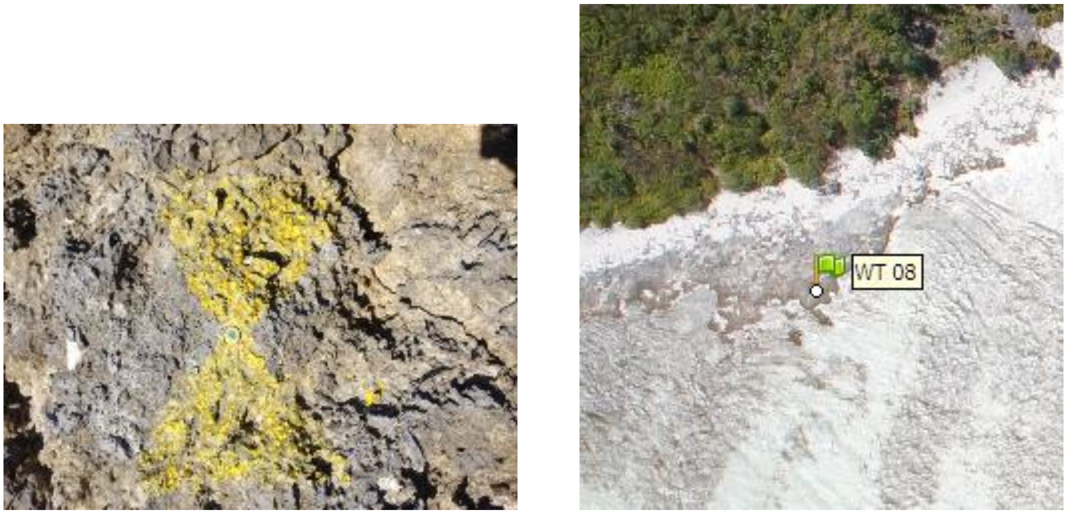


Figure 5: View of GCP 08 from aerial photographs GCP 08 marker with yellow paint

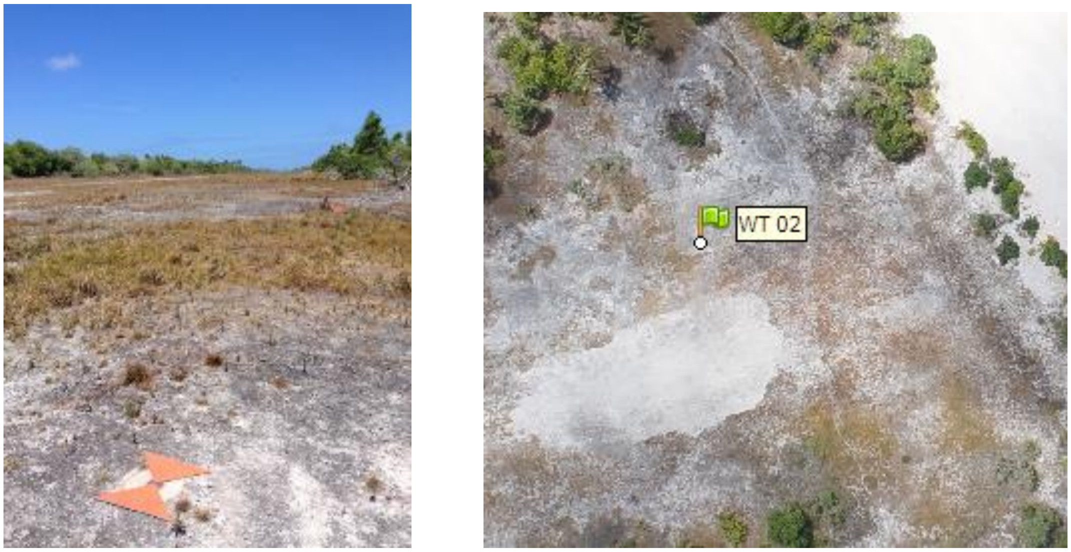


Figure 6: GCP 02 with orange tile and view from aerial photographs

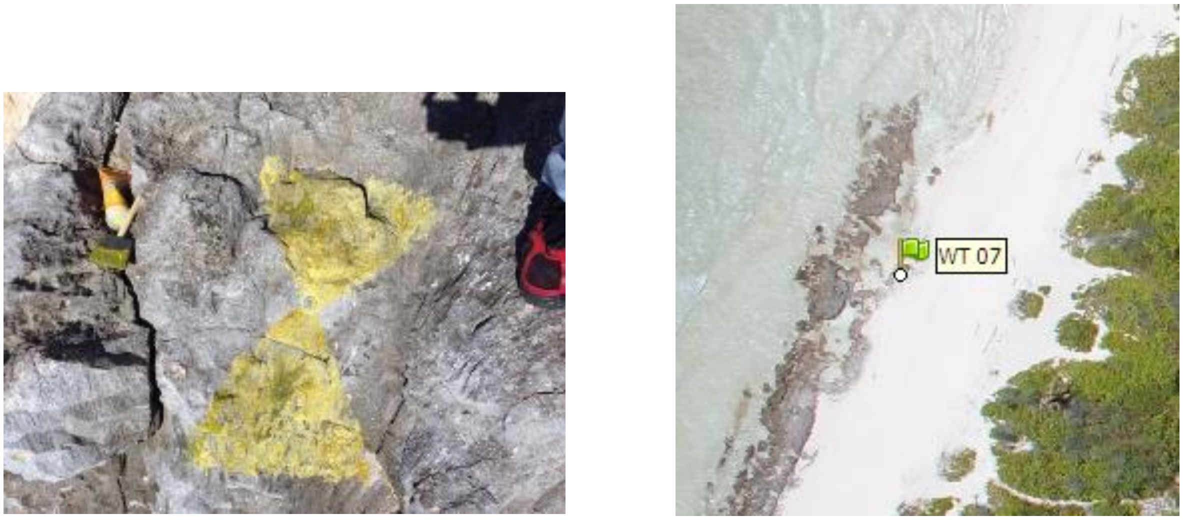


Figure 7: GCP 07 marker with yellow paint and view from aerial images

After the image data collection, some paint marks did not appear visible on the aerial image collected. For future missions, we recommend using a larger paint mark of 1.2x1.2 meters with a higher contrast (black/white or red/white). Moreover, if the sky is cloudless as it was on that day, we recommend the aperture settings on the camera be calibrated accordingly to optimize image capture.

Weather conditions

The drone chosen for the mission was selected based on its ability to collect data in winds up to 25 knots. During the 3-hour period on Wotto, visibility was excellent with wind gusts of up to 20 knots.

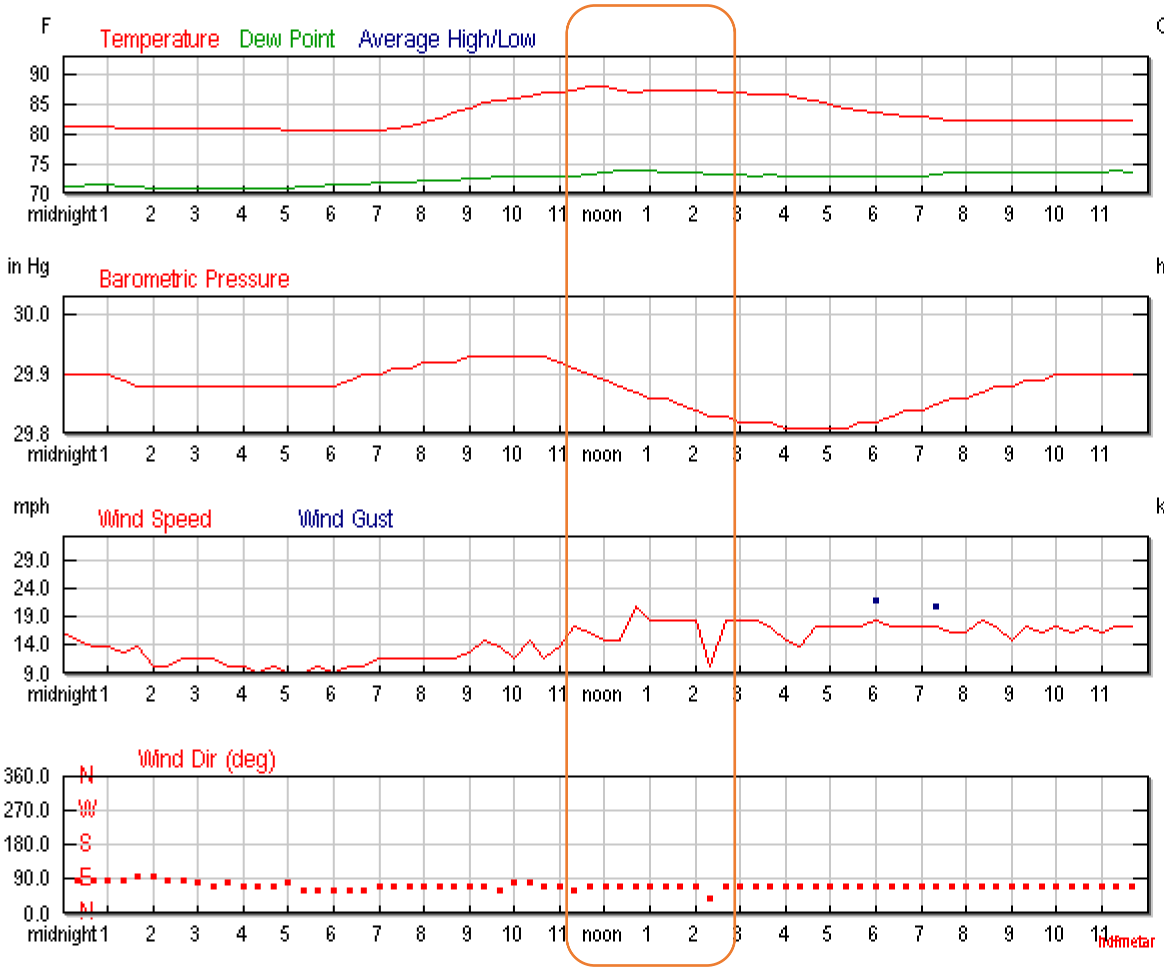


Figure 8: Weather conditions during 3-hour flight plan on Wotto

Flight pattern

The original mapping plan was to fly at an altitude of 150 meters in blocks of 1 sq. km. Due to the 3-hour turn around time, the flight plan was modified to fly at 400 meters. By flying at a higher altitude, we were able to shorten the flying time while still meeting mission objectives. A total of 462 images were collected on the first 400-meter flight. The flight covered the whole island at a resolution of 12 cm/pixel. A second flight, over the populated area and the small island northwest of Wotto called Eneopñak, collected 509 images at an altitude of 150 meters.

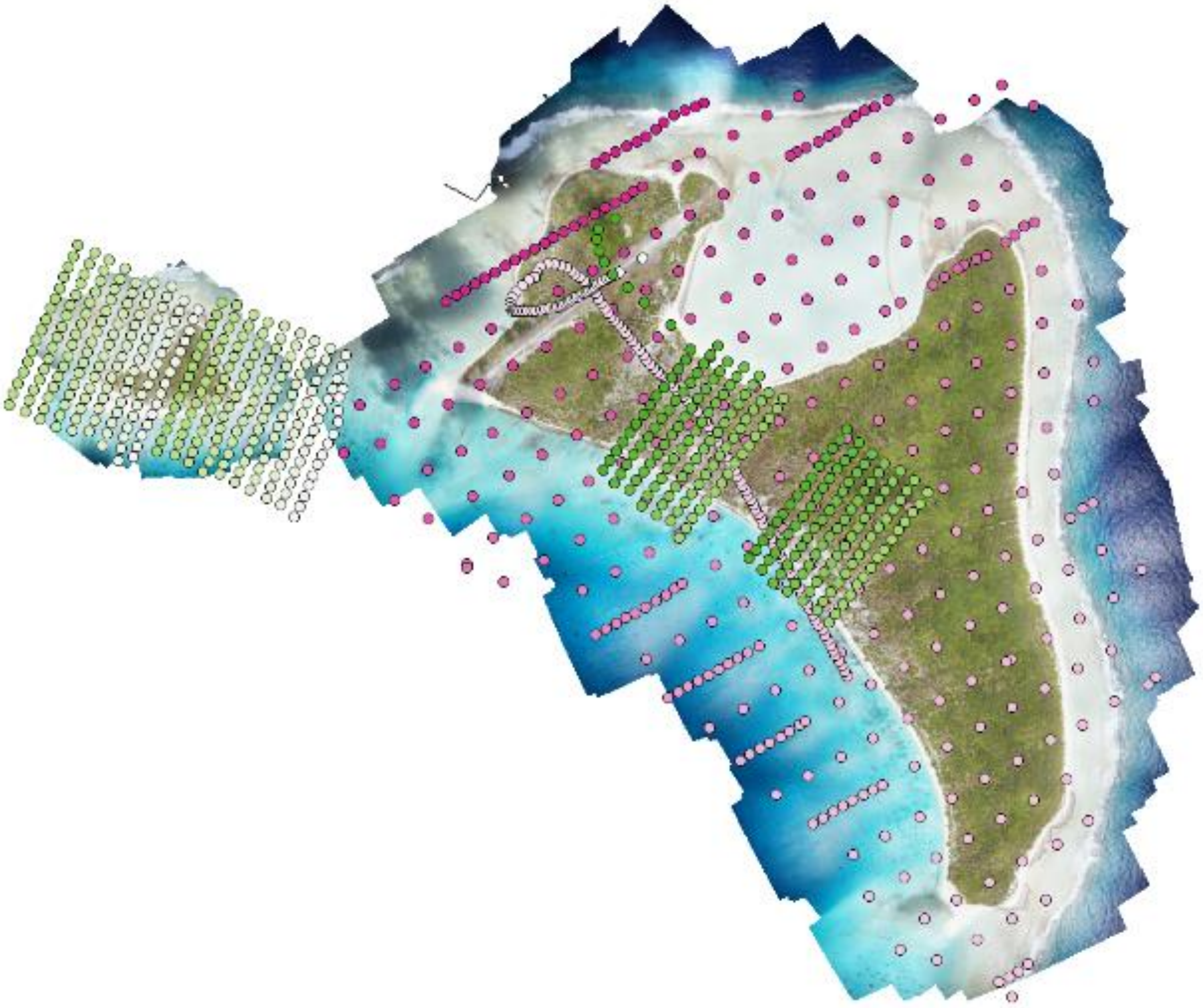


Figure 9: Flight paths. Flight 1 is in pink, flight 2 is in green

Image samples

Figure 10: Over the populated area

Figure 11: Over the dense canopy forest

Figure 12: Over the airstrip

Camera coordinates

During the data collection, an onboard GPS collected the geographic coordinates for each image. These coordinates were later used to geo-reference the topographic model, in conjunction with the Ground Control Points.

Topographic model reconstruction

Images collected were used to build various geospatial datasets including an ortho-photo, a digital surface model, a digital terrain model, and a 3D model.

The method used to build the different geospatial datasets is photogrammetric reconstruction. Photogrammetric reconstruction creates topographic models using overlap between images; geographic coordinates of images; and Ground Control Points.

Pix 4D and Agisoft Photoscan are softwares used for topographic model reconstruction. Photoscan was selected for its better vegetation removal capabilities, a key part of creating a Digital Terrain Model for flood risk assessment.

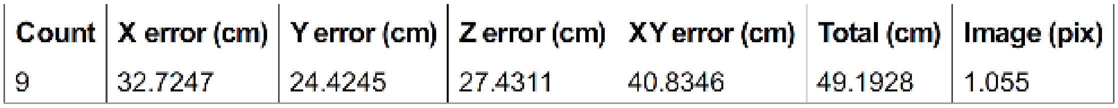
Photogrammetric reconstruction summary

Number of images:	1,039	Camera stations:	735
Flying altitude:	274 m	Tie points:	420,925
Ground resolution:	7.19 cm/pix	Projections:	1,568,493
Coverage area:	6.74 km²	Reprojection error:	0.958 pix

Positional Accuracy

The accuracy of the photogrammetric reconstruction depends on the image quality, as well as the number of GCPs and their accuracy. In order to get best accuracy, 15 to 20 GCPs is usually necessary. Due to battery power limitations, RMI Lands & Survey was able to collect only nine Ground Control Points.

The resulting model accuracy (RMSE) is 27cm vertically, and 40cm horizontally.



Count	X error (cm)	Y error (cm)	Z error (cm)	XY error (cm)	Total (cm)	Image (pix)
9	32.7247	24.4245	27.4311	40.8346	49.1928	1.055

Model accuracy

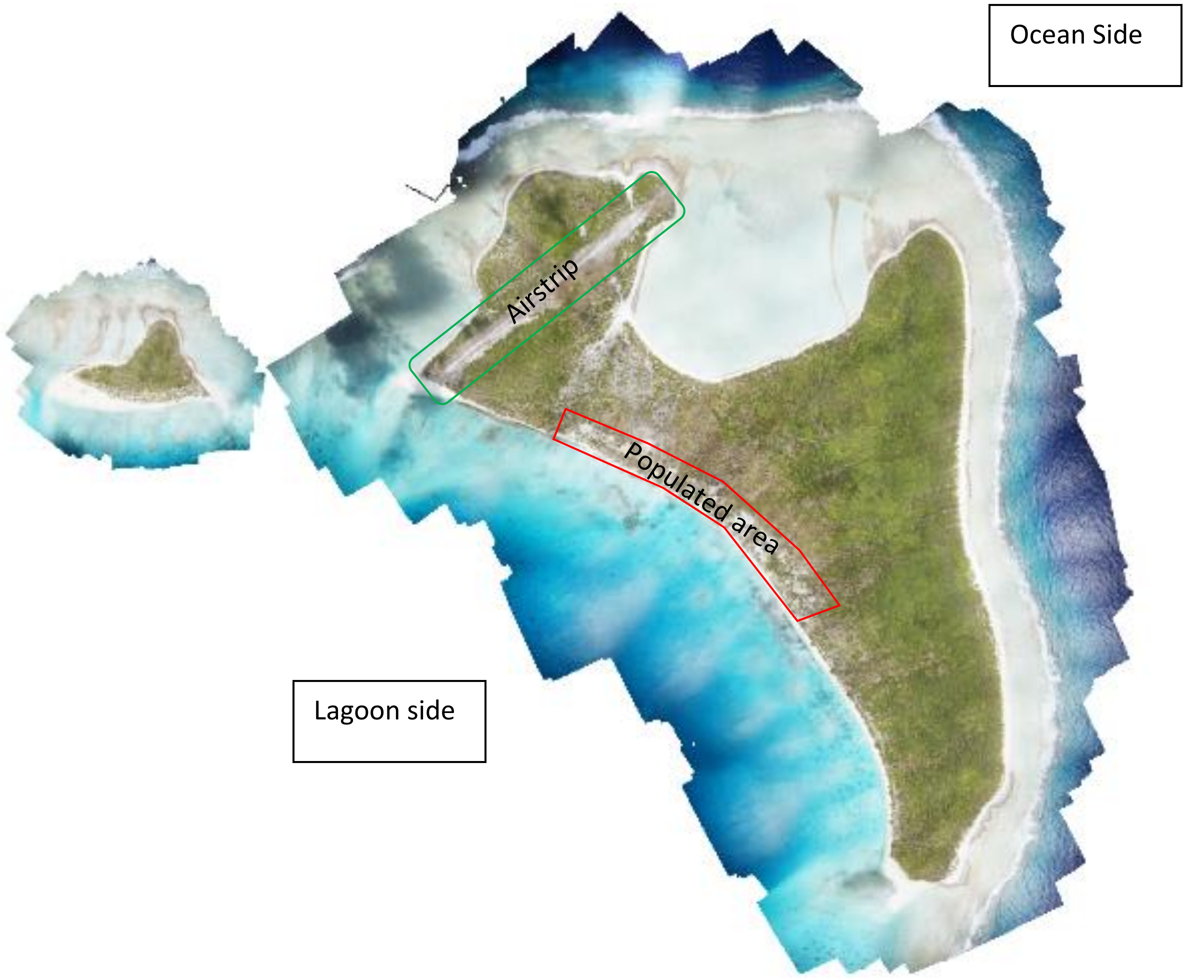
While positional accuracy is about absolute location of the model in the geographic space, model accuracy is about positional accuracy of model objects relative to each other. Model accuracy is 0.9pixels, which translates to 6.8cm (given a model resolution of 7cm/pixel). In other words, any object's position relative to any other object on the photogrammetric reconstruction will be within a margin of error of 6.8cm.

Main Geospatial products

The photogrammetric reconstruction was used to generate a series of geospatial products. Each product includes data collected from flight 1 and 2.

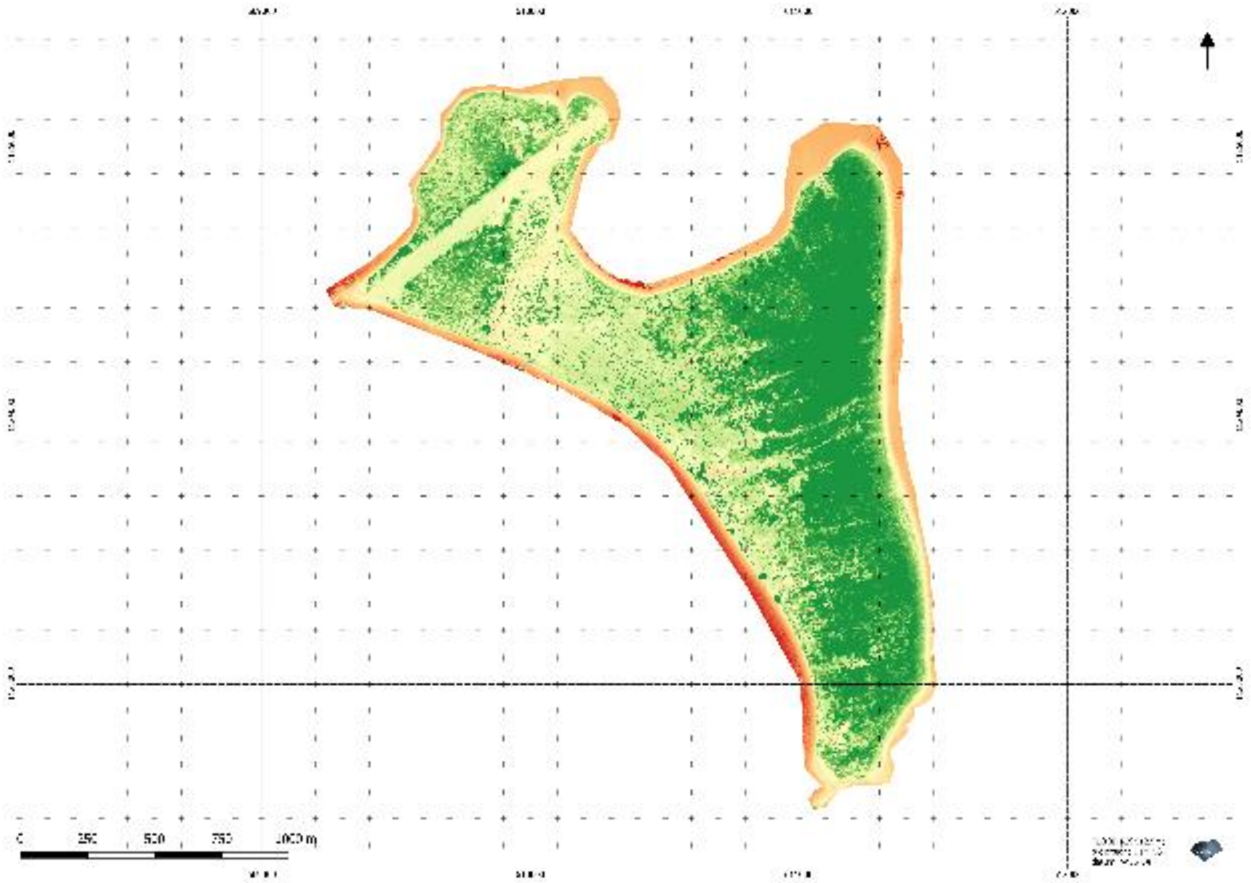
Ortho-photo

The ortho-photo can be used for visual assessment of the landscape, as a historical record, as a distance measurement tool, or as a way to position important sites.



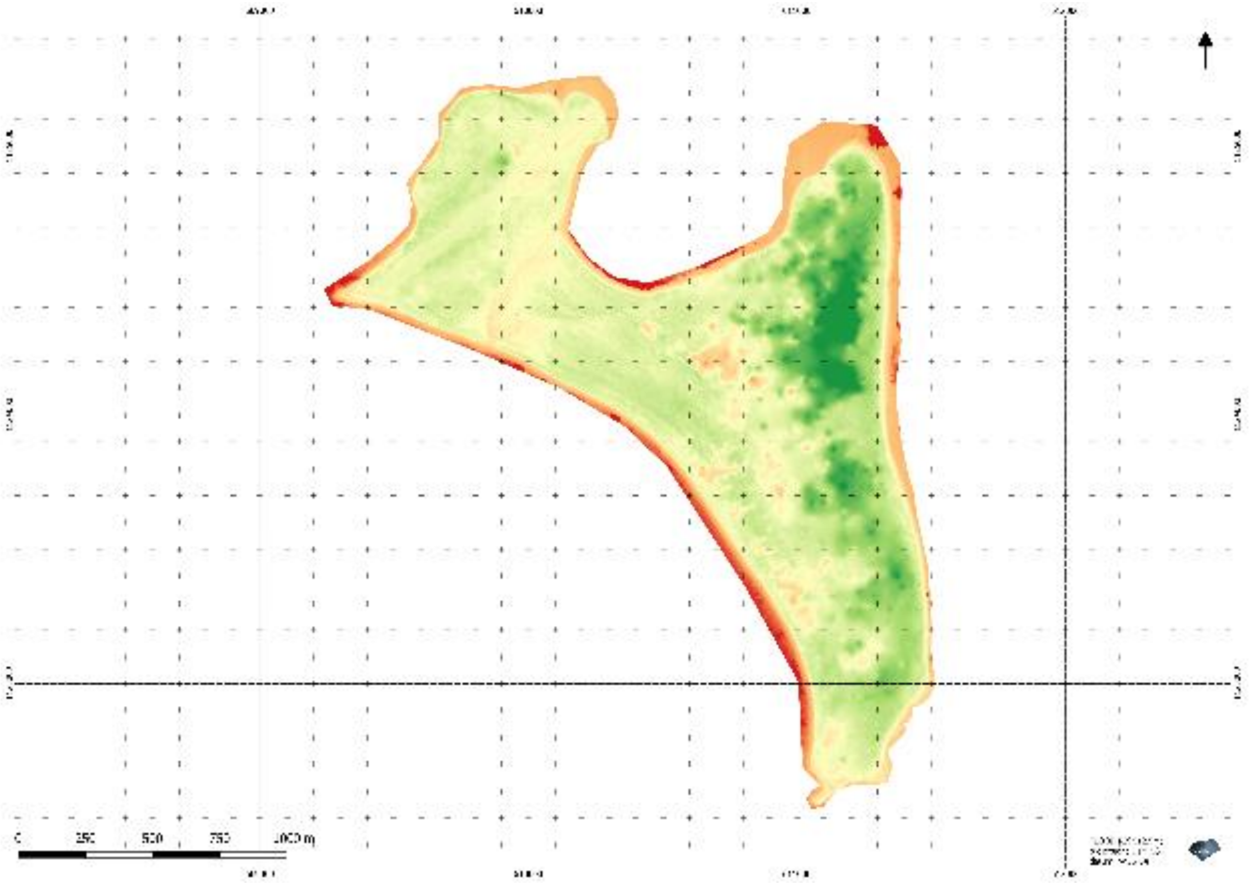
Digital Surface Model

The digital surface model can be used to measure the absolute and relative elevation of surfaces, including land, shorelines, infrastructure, rooftops, tree canopy, etc..



Digital Terrain Model

Vegetation and other non-terrain objects (e.g. houses) were removed from the Digital Surface Model in order to obtain the Digital Terrain Model. The Digital Terrain Model can be used for flood risk modeling, soil erosion risk and other applications where only ground elevation is necessary. Although vegetation and buildings were removed to provide a bare earth elevation model, the elevation in unpopulated and densely vegetated sections of the island shown in green is likely overestimated due to the high vegetation density.



Sea level rise assessment

Orthometric height and water level

All heights measurements provided by Lands and Survey were orthometric. The digital surface and terrain models heights, which are based on the GCP reference system, are orthometric as well. Figure 13 provides a brief summary of this important distinction in relation to the water level.

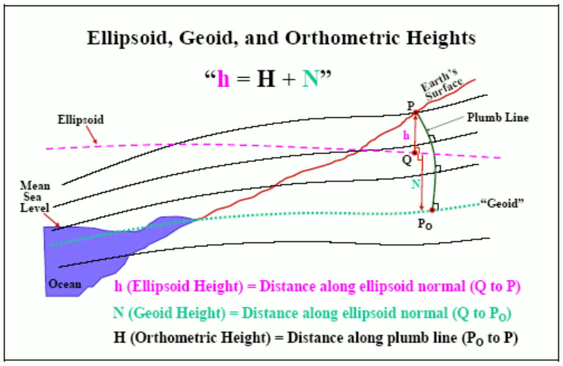


Figure 13: Relationship between the different height definitions (source: NOAA)

To link the water level to the orthometric heights, the height value of WT 07 was converted from orthometric height to Mean Higher High Water[1]. This was done by first determining the tidal height on January 19 at 3:00 PM (i.e. the time of data collection shown in Figure 14), based on tide gauge data on Kwajalein Atoll located 250 km southeast of Wotto. As shown in Figure 15, at 3:00PM the water line is -0.40 centimeters in Mean Higher High Water (MHHW)[2].

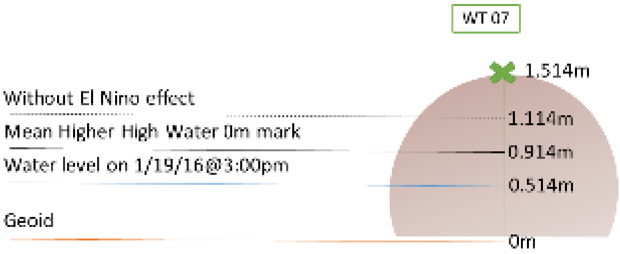


Figure 14: WT 07 measured at 1.514 m orthometric height by the RMI Lands and Survey Division. Note position of WT 07 is approximately 1 m above the water level.

---

[1] Mean Higher High Water (MHHW) is defined as the average of all high water heights observed over the National Tidal Datum Epoch (19 years), which in this analysis was derived from tide gauge services on Kwajalein on the NOAA website. Sea level rise, as discussed below, shall be considered as the advancement of the MHHW mark over time.

[2] In the MHHW datum, 0 meters represents the average of high water heights.

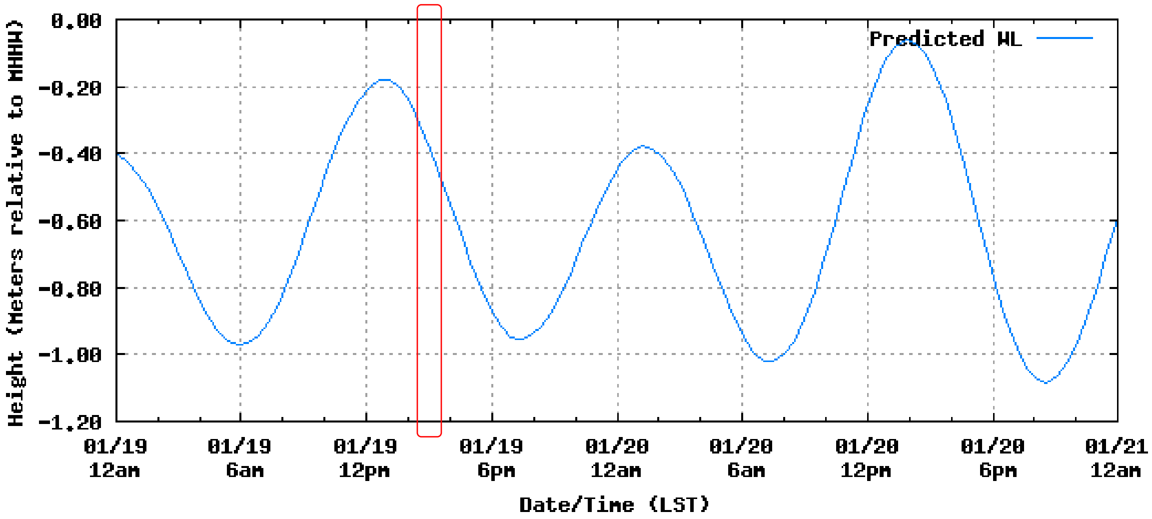


Figure 15: Tidal variation on April 2nd. In red the timestamp period of the reference images

Another height adjustment made took into account the state of ENSO in January 2016. Specifically, observed water levels in January 2016 were depressed by an estimated -0.20 centimeters due to a strong El Nino phase.[3]

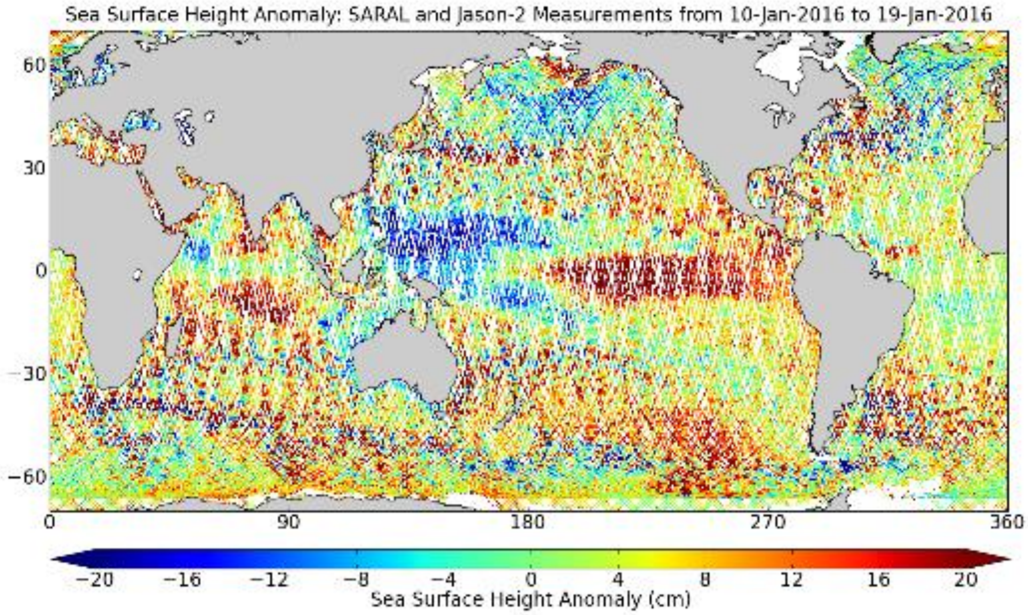


Figure 16: Sea Surface Height Anomaly on week leading up to January 19. Wotto located in dark blue area of the Pacific Ocean.

The elevation model was therefore shifted down by 1.1 meters (-51.4cm – 40cm – 20 cm).

---

[3] NASA Jet Propulsion Laboratory. Website accessed October 13, 2016 http://sealevel.jpl.nasa.gov/images/latestdata/ssh/2016/SSHA_20160119_144509.png

Sea level rise model

Projected sea level rise values adopted in this analysis come from the Pacific Climate Change Science Partnership (PCCSP). Projected sea level rise for the Marshall Island are as follows: 16 cm by 2030, 30cm by 2055 and 62 cm by 2090.[4] Moreover, a global sea level rise of 98 cm by 2100 is adopted from the IPCC 2013 Report to project an upper bound scenario.

Sea level rise scenarios

The flood risk scenarios are based on a simple “bathtub” model. These scenarios approximate the image of sea level rise over time when tides are the highest. Analysis of flood risk is provided below within time increments of 2030, 2055, 2090, and beyond.

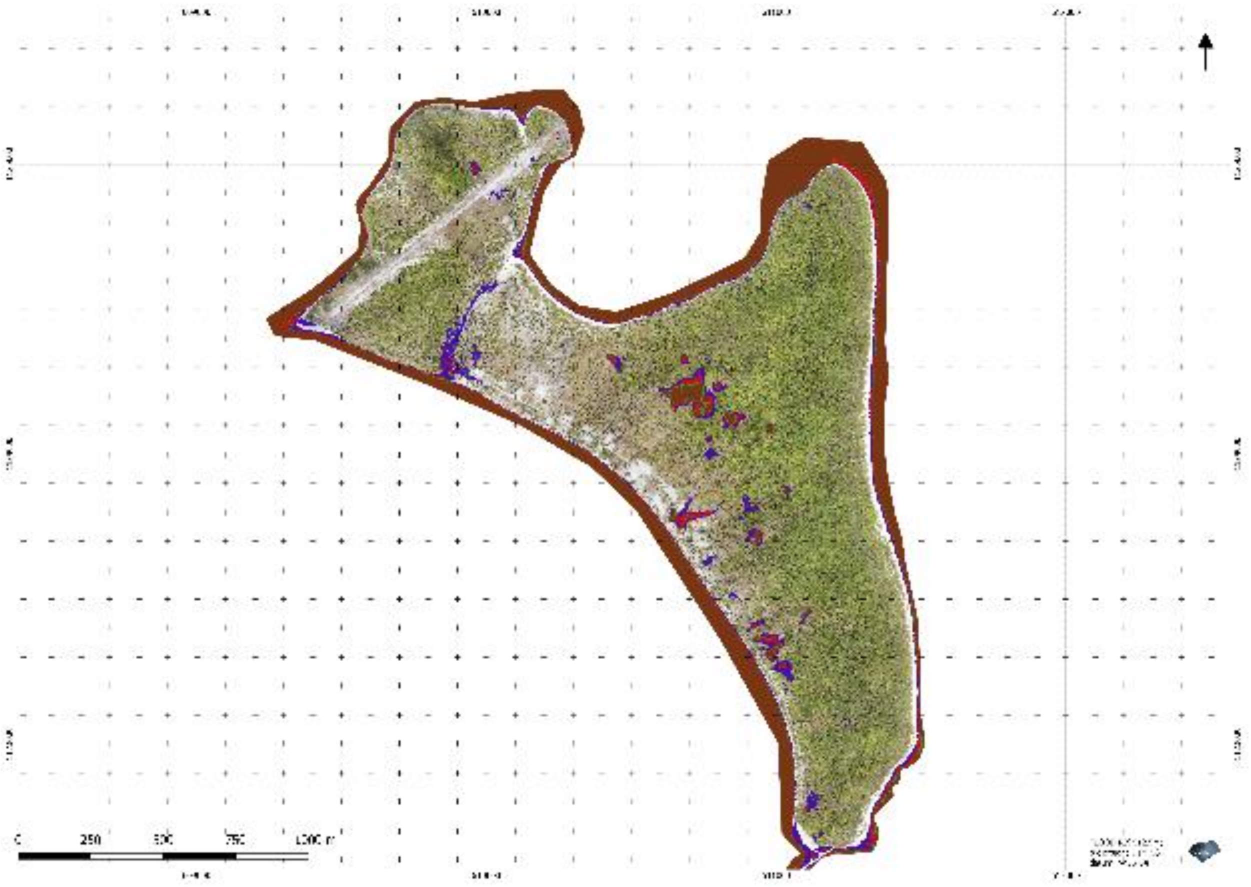


Figure 17: Sea level rise scenario for 2030 (brown), 2055 (green) and 2090 (red), and 2100 (Blue)

Given that the model is adjusted to MHHW as a datum, areas that appear to be flooded in the various scenarios can be identified as frequent flooding areas, i.e. areas likely to flood at least two times per year.

---

[4] Australian Bureau of Meteorology and CSIRO, 2011. Climate Change in the Pacific: Scientific Assessment and New Research. Volume 2: Country Reports. Chapter 7: Marshall Islands p. 124.

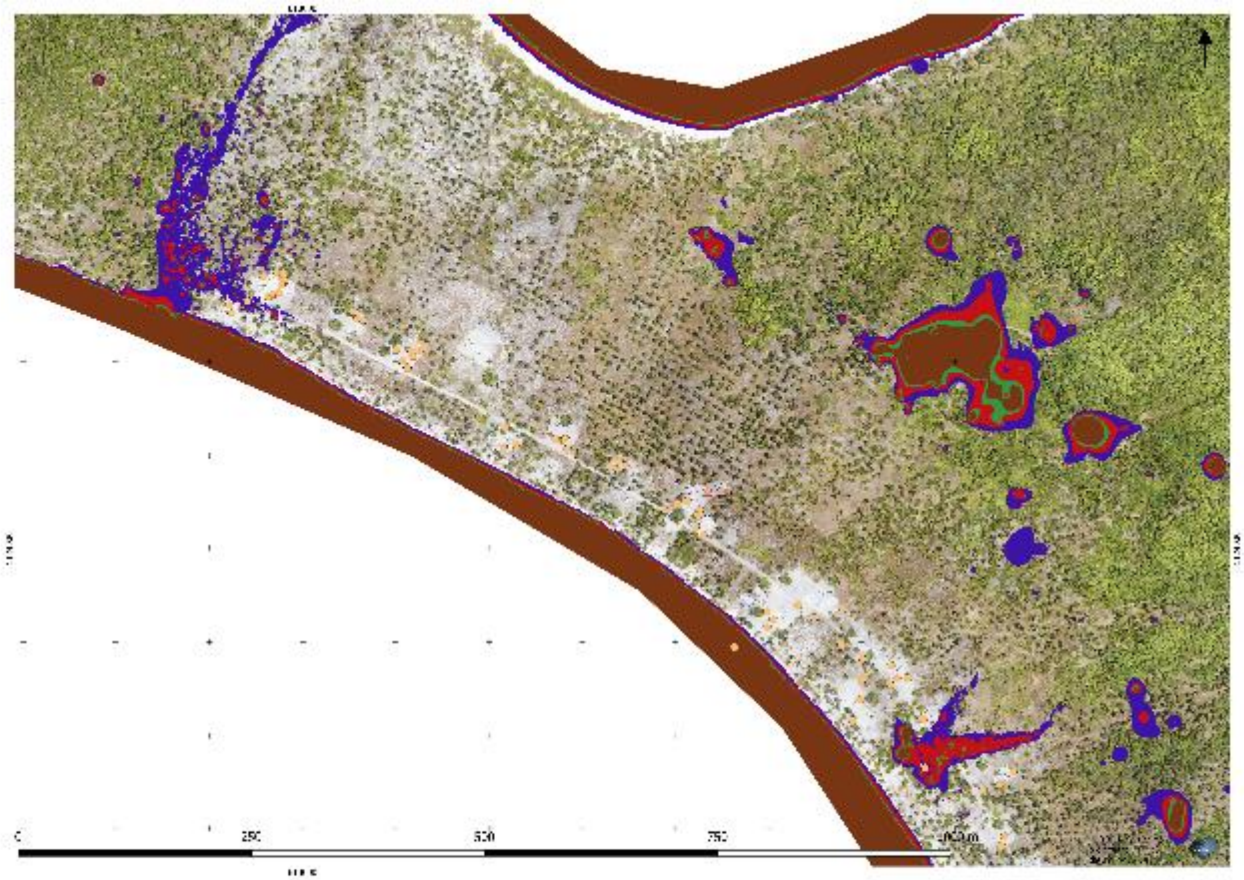


Figure 18: Population center of Wotto close-up (buildings are marked as poylgones). Sea level rise scenario for 2030 (brown), 2055 (green) and 2090 (red), and 2100 (Blue)

2030 (brown): At 16 cm sea level rise, the shoreline recedes by up to 3 meters inland, leading to greater likelihood of inundation from overtopping waves during storm events especially during westerly storms. Inland flooding begins to appear in areas corroborated by traditional knowledge (as further discussed below in the ‘Lessons Learnt’ section), and therefore is considered probable flooding areas during king tides in the near future.

2055 (green): Because of some depressions in the island topography, sea level rise impacts continue to spread to a larger inland area of Wotto and frequently flood, specifically in the central and lagoonal areas of the island. As noted above, this is consistent with the oral history of Wotto in these locations. Moreover, a channel between the lagoon and the ocean running north-southwest of the populated area and east of the airport could be of concern during storm events.

2090 (red): Water floods the channel running north-southwest between the ocean and the lagoon, with sea water reaching the vegetation and two households on the lagoon side shoreline. Specifically, 10 of 54 (about 20%) of existing breadfruit trees and 3 of 17 (about 18%) of households exposed to higher soil salinity levels and inundation, respectively, at least two times per year. One inland area appears to flood more significantly, with one household affected. Small patches of inland seawater also appear near the north tip of the airport, raising concern to air transportation during even moderate northeasterly swells.

Inland areas also appear to flood regularly from groundwater upwelling, suggesting some localized impacts to the groundwater lens in and surrounding these areas.

2100 (blue): In sea level rise scenarios of 70 cm or greater, as is the case here, very significant flooding occurs including in two populated areas of the island comprising a significant number of households, the northern side of the airport, and larger areas of inland areas. In terms of impact to food sources indicate 29 of 54 or 54% of breadfruit trees on Wotto being exposed to higher soil salinity levels at least two times per year.

Recommendations and Lessons learnt

Lessons learnt over the course of the two missions to Wotto and subsequent analysis of the data can be categorized into 1) methodological lessons learnt 2) financial across the RMI and 3) vulnerability lessons learnt specific to the Wotto community.

Methodological Lessons Learnt

Possibility of Rapid Assessment Approach: Our mission to map the island of Wotto, produce an island elevation map, and conduct a sea level rise risk analysis was successful despite a window of only 3 hours. Although additional time on site would allow for additional image collection and more detailed analysis of densely vegetated parts of an island, this methodology can be replicated in remote islands especially where time and/or cost considerations are stringent.

UAV Photogrammetry (Drone) vs Ground GPS (Conventional) Method: The rapid assessment approach has important efficiency implications for the Reimaanlok Field Guide. In 2012 when Appendix A13, A14, A15 for Island Height and Flood Risk guidance was incorporated into the Field Guide, the state of the art of surveying did not include drones. Based on the results of this drone-assisted survey on Wotto, we can confirm that substantial time and resource efficiency gains were achievable compared to a conventional survey method. Below is detailed comparison of the two methods.

	Conventional Method	**Drone Method**
Coverage	5 km^2	5 km^2
Time	2 months	3 hours
Point density	Low > 100 cm which would result in an estimated 10,000 points	Very high < 6 cm with more than 400,000 points achieved in Wotto
Precision	> 100 cm	< 6 cm
Accuracy	Highest accuracy < 10 cm	12 cm with 10 ground control points, < 50 cm (with fewer GCPs)
Cost	$100,000 (estimate based on time involved in the field plus precision equipment and trained team of surveyors, plus data analysis)	$40,000 (estimate based on actual cost of 2-person team, 1 week preparation time, grounded flight, drone and digital photo equipment, plus data analysis)

Wave and Storm Modeling Gap: The flood risk scenarios described above do not take into account the increasingly significant role that storm surges and waves will play as sea level rises. Indeed the frequency and intensity of episodic flooding events in atolls are predicted to increase exponentially with sea level rise because elevated water levels diminish wave-energy dissipation along fringing reefs and reef flats prior to waves reaching atoll shorelines. (Merrifield et al 2014, Storlazzi et al 2011, Woodroffe 2008). It is therefore recommended that further analysis be conducted using the elevation model of Wotto.

Social Impact Enhancement: Only preliminary analysis was possible given limited resources for this study, so that various flood impacts were not possible.

Fixed-Wing and Sturdy UAVs: This mission highlights the advantage of using a fixed-wing drone capable of maintaining stability in 20-25 knot wind conditions for reliable elevation and flood risk model analysis in remote areas, including ease of transport and high quality products for comparatively low cost.

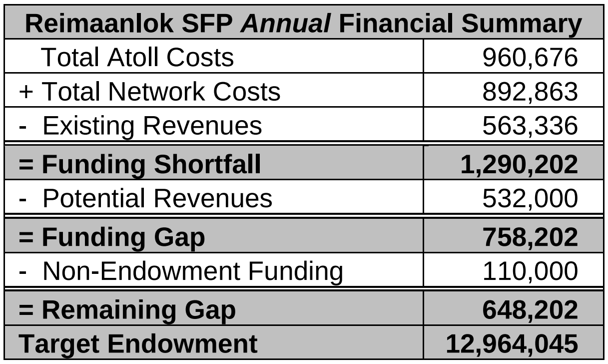
Model Accuracy Refinement: It is apparent that drone-assisted flood risk assessments can provide vital spatiotemporal information to climate risk management on a timely basis, however we note a few areas of potential improvement for the next iteration. In order to improve absolute accuracy, future missions should include additional ground control points. In addition, it is recommended to use high contrast markers in order to ensure visibility of ground control points from aerial images and to configure the aperture settings for extreme sunlight and highly reflective surfaces.

Storm Surge Addition: More immediately, additional work on the Wotto model is recommended in order to incorporate wave and storm surge contributions to flood risk and vulnerability of community livelihoods. This addition is readily available, with preliminary discussions in this regard already initiated with Dr. Curt Stollazi of the US Geological Survey who has done similar work in Kwajalein Atoll and Wake Atoll. The storm surge addition will result in a much enhanced flood risk analysis, and contribute substantially to Wotto community's understanding of its vulnerability to climate change.

Data Storage Needs: The project also has the benefit of better estimating the future digital storage capacity needs of the National Spatial Analytic Facility, which is located at the College of the Marshall Islands and is a storehouse for marine, terrestrial, and socioeconomic data to better track atoll habitability in the face of climate change.

Financial Lessons Learnt

The Reimaanlok Sustainable Finance Plan (SFP) was completed in 2010. As shown in Table 1, the SFP concludes that the remaining gap for the RMI to achieve the Micronesia Challenge goals shall be addressed by an endowment of almost $13M that issues a 5% annual disbursement. In addition, the SFP estimates a $126,250 one-off establishment cost per atoll.



Reimaanlok SFP *Annual* Financial Summary	
Total Atoll Costs	960,676
+ Total Network Costs	892,863
- Existing Revenues	563,336
= Funding Shortfall	**1,290,202**
- Potential Revenues	532,000
= Funding Gap	**758,202**
- Non-Endowment Funding	110,000
= Remaining Gap	**648,202**
Target Endowment	**12,964,045**

Table 1 Annual cost, revenue, and endowment calculations to fully achieve the Micronesia Challenge goals

Some caveats accompany these calculations.

1) The MC goals were naturally not yet fully achieved when the SFP was developed, so the

‘Total Atoll Costs’ needed to be ground truthed and extrapolated from an indicative sample of existing MC sites. The sample chosen was Ailuk Atoll.[5]

2) The Ailuk Fisheries Management Plan did not have a terrestrial component, and therefore “ground truthed” costs for Ailuk’s terrestrial protected areas were based on expert interviews.
3) A climate lens was applied to the Reimaanlok in 2011-2012, *after* the SFP was developed. Therefore the SFP calculations do not currently have any annual or establishment cost elements associated directly with climate change incorporated into its current calculation of $960,676 ‘Total Atoll Costs’. Specifically, “climate lens” features of the Reimaanlok which were developed in the five years since the SFP include the Island Height and Flood Risk Assessment (Appendix A13, A14, A15), the Vulnerability Assessment Local Early Action Planning or VA-LEAP Tool (Appendix A35), and a climatized Socioeconomic Household Survey (Appendix A6 amended)

Lessons learnt relative to the SFP from this Wotho Case Study should aim to address as much of the third caveat within the Reimaanlok SFP as feasible given available resources. This would include information of costs of assessments including the Island Height and Flood Risk Assessment (Appendix A13, A14, A15), the Vulnerability Assessment Local Early Action Planning or VA-LEAP Tool (Appendix A35), and a climatized Socioeconomic Household Survey (Appendix A6 amended). Similar to how Ailuk Atoll was chosen as the cost template for the SFP in 2010, Wotho Atoll could provide a helpful sample for the three above climate assessments within the Reimaanlok. Whether the enhanced or better-informed vulnerability assessments will further result in the additional costs of implementing the management plans in relation to assessments is not clear, much less enhanced or better-informed adaptation strategies and interventions.

Community Vulnerability Lessons Learnt

An important initial lesson learned was the interplay between community/data contexts and climate science communication. Traditional knowledge is able to validate the terrain elevation features that appear on the model, and by extension high flood risk areas. In this case, as shown in Figure 19, the legends of Likuripjen and Neen Annañ correspond to the flooded channel between the lagoon and the ocean running north-southwest and to the inland flooded area in the center of the island.

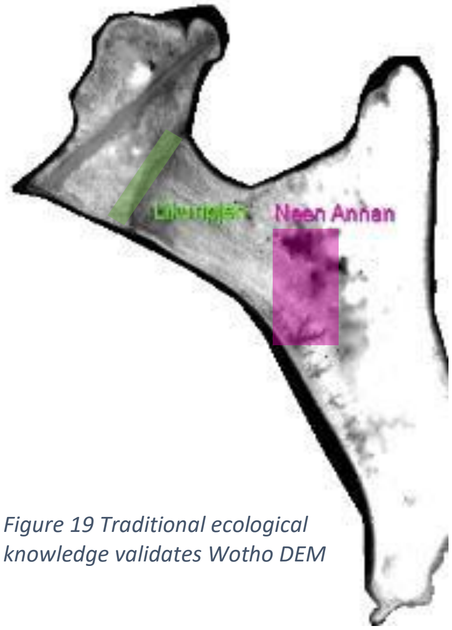


Figure 19 Traditional ecological knowledge validates Wotho DEM

Finally, although a comprehensive geospatial review of the flood risk scenarios overlaid onto natural, infrastructural, and socioeconomic features is needed to fully capture the nuances of data, certain implications for adaptation design are readily apparent, in particular as it relates to Shoreline Ecosystems and Coastal Infrastructure as well as

---

[5] Majuro Atoll was another sample, however it needn’t be considered within this analysis due to its unique SFP calculations.

Vegetation and Food Crops targets. We recommended the following next steps:

1. Develop buffer zones around flood risk areas by planting native coastal vegetation and allow space landward of such areas to enable them to adapt naturally to sea-level rise;
2. Support planting of food trees enriched by compost piles and raised earthen mounds, and where possible applying lessons learned from agroforestry program by women's group on Mejit Island; and
3. Promote resilient livelihoods development in agroforestry, including site selection for a multipurpose women's center and disaster shelter.

Acknowledgements

First of all, we express our sincere gratitude to the People of Wotto for their hospitality and continued leadership in preparing and implementing their Wotto Resource Management Plan, for which this pilot project was conducted. A special *koṃṃool tata* to Iroij Michael Kabua, Alab Namar Nashon, Senator David Kabua, Mayor Tatios Anjolok, Acting Mayor Bernie Joseph, and Executive Councilman Simpson Jelke.

We also express our appreciation to Ed Carlson and Guy Schumann for their many efforts to advance hazards science in the Marshall Islands. Without their help and support, this pilot project would not be possible.

We are also grateful to Tony Kimmet of the USDA-NRCS and DigiGlobe for satellite imagery used in the planning phases, and look forward to the opportunity to compare the results of this Wotto DTM with DG's satellite-derived elevation product.