

AN EXAMINATION OF THE RELATIONSHIP BETWEEN
RAPA NUI *AHU* AND TOPOGRAPHY USING STRUCTURE
FROM MOTION AND GIS

by

ELIZA PEARCE

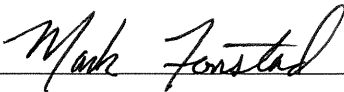
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Title: An Examination of the Relationship between Rapa Nui *Ahu* and Topography
using Structure from Motion and GIS

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Associate Professor Mark Fonstad

Recent studies about Rapa Nui (Easter Island) have shed a new light upon the movement of the island's giant statues (*moai*) and platforms (*ahu*) showing that they were purposeful projects created by small communities around the island. What remains unclear, however, is the full meaning and purpose of the giant structures created by the ancient Rapanui. A current working theory is that the structures were costly signals to other clans on the island as a way to mark rare fresh water resources. For this study, imagery was collected of the south coast of the island and then used in conjunction with Structure from Motion to create topographic data for the area. Various GIS analyses were then run on different aspects of the landscape around the different types of *ahu* (those with *moai* and those without). None of the statistics run on the data acquired from running these analyses indicate any significant difference between the topographic placement of the two types of *ahu*. This lack of significance shows that topography does was not an influential factor in the placement of these features and whatever factors were involved, they did not have a topographical relationship. This means that other relationships like water sources were perhaps more important for *ahu* placement.

Acknowledgements

I would like to thank my advisors Dr. Mark Fonstad, Dr. Terry Hunt and Dr. Nick Kohler for taking the time to be on my thesis board and advise me during this process. I would especially like to thank Dr. Fonstad for his consultation and help with all the data. An additional thanks needs to be made to Dr. Hunt and Drs. Lipo and Lee from CSULB for accepting me as an undergraduate research assistant on their trip to Rapa Nui in early January 2015. This thesis is meant to tie into their continuing research about Rapa Nui and is based off of data and research conducted on the island. The work I have done would not have been possible without the amazing opportunity they provided me.

I would also like to thank my amazing parents, Josie and Ken, who have stood by and supported me throughout my time here at the University of Oregon and in the Clark Honors College. Their help, encouragement, and engagement with all I do has been invaluable.

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Accompanying Materials

I have made all of my data and work files available to Drs. Terry Hunt and Carl Lipo in case any work I have done for this paper may be of use in their future research on Rapa Nui. Copies of my data and files will be kept with them in their Network Attached Storage.

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Part 1: Introduction

In November of 2014, I was selected for an amazing opportunity to travel to the remote island Rapa Nui (Easter Island) as an undergraduate research assistant for Professors Carl Lipo and Christopher Lee from CSU Long Beach (CSULB) and Dean Terry Hunt of the Clark Honors College at the University of Oregon. Thus, I spent the first twenty days of January 2015 on an island in the Pacific helping to conduct research. Carl Lipo and Terry Hunt have been working on Easter Island for several years now and have made some ground-breaking discoveries regarding the movement of the giant stone statues on the island (*moai*) and the cultural dynamics of the island's pre-historic people.¹ In their continuing research on the Rapa Nui, they have been able to bring out students through Research Experiences for Undergraduate (REU) funding through the National Science Foundation (NSF) to help with various projects.

The project I helped the professors work on while on Rapa Nui was collecting areal imagery of the island's South Coast. This was done via the use of a drone and the result was incredibly high-resolution photos. From these images and structure-from-data technology, three-dimensional reconstructions of the landscape can be created along with composites of all the images that allow information and data to be gleaned regarding the topography of the ground and features upon it.

Using this collected data, I was able to search out and identify pre-historic man-made features such as the *moai* and *ahu*. *Moai* are the famous stone statues placed around the island and *ahu* are long, low platforms made of stone that were built by the

¹ Hunt, Lipo. *The Statues that Walked*. 2011

prehistoric Rapanui. Some *ahu* have *moai* placed on top of them (image ahu) and there are also others that do not (ahu). While most of the *moai* are mapped and documented, *ahu* without associated statues are more likely to be accidentally overlooked from a ground perspective since they can simply look like a pile of stones. It is much easier, however, to identify their unique, long form from aerial photographs. In addition to locating these features, my study focuses on their locational relationship to the topography of the area.

Purpose

Almost all *ahu* and finished *moai* are found close to the coast. While it is sometimes thought that the *moai* face outwards towards the ocean (as a means of protection and look out), in reality they all face inwards towards the land. This is because rather than warriors or guardians, the statues represent ancestors meant to watch over and be respected by the people.² For this study, I analyzed the relationship between the locations of *ahu* with their surrounding topography in order to see if there is a significant relationship between the two; to see if topography was a deciding factor in terms of where the ancient Rapanui decided to place and build these giant architectural feats, whether building locations were chosen randomly along the coastline or not.

This is an important and relevant study because not much is known about the spatial reasoning behind why various features are placed where they are. A significant relationship between low topography and anthropogenic features would help support

² Hunt, Lipo. 2011

ideas that the *ahu* and *moai* serve additional functionality rather than simply being ancestors to respect. Drs. Hunt and Lipo have a working hypothesis that the statues and platforms relate to freshwater and other resources. Proving coastal access is near these sites, would thus tie my research into further data being collected and studied about coastal freshwater. Lower coastal elevation and slope generally indicate better ocean access, features placed in such locations could have been demarcations or claims to the area and the resources such an area provided.

In order to fully analyze and understand this relationship, I asked a few broad questions: How are *ahu* structures positioned on the landscape? Is there a locational difference between *ahu* and image *ahu* structures that denotes a difference in purpose? Are these features near where water resources are more accessible? Are these features in places that make them more visible? These broad questions I later broke down into seven more specific questions related to the tests I was running:

1. Are image *ahu* at higher elevations than *ahu*?
2. Do image *ahu* have a larger viewshed than *ahu*?
3. Are image *ahu* closer to the coast than *ahu*?
4. Is the coastal slope near image *ahu* less steep than the coastal slope near *ahu*?
5. Is the coastal slope near image *ahu* less steep than the general slope of the coast?
6. Is the coastal slope near *ahu* less steep than the general slope of the coast?
7. Is the ground slope around image *ahu* steeper than the ground slope around *ahu*?

I used all of these questions to guide my research and methods in examining the relationship between the *ahu* and topography on Rapa Nui.

the Pacific, Rapa Nui is volcanic and the three points of its roughly triangular shape consist of the extinct volcanoes whose activity formed the island: Rano Kau, Poike, and Terevaka (fig. 1). The general landscape is that of rolling grassy hills interspersed with rough lava fields and old volcanic craters and parasitic cones. Given the island's volcanic origins, the island is mainly basalt and andesitic rock as well as some scoria and obsidian. The soil on the island consists mainly of loams and clays.⁴

Just south of the Tropic of Capricorn, Rapa Nui's climate is subtropical with an annual average temperature of 68.5°F and some rain falls 140 days out of the year. March to June are the rainiest months and August to December the driest but heavy rainfall, often in squalls, can occur any time during the year.⁵ While the island sees a good amount of rainfall throughout the year, it is quickly absorbed by the porous volcanic bedrock so the land rarely remains wet. There are also no permanent natural sources of freshwater on the island; no perennial rivers and only two lakes, both standing water and located in the craters of volcanoes, though stagnant water can also collect in lava tubes.

Unlike many tropical islands, Rapa Nui has no barrier reef. This leaves the island exposed to the ocean whose rough seas have, over time, created cliffs along much of the shore line. There are three sandy beaches on the island but all are on the two more northern sides of the island. The southern coast has spots where coastal access is easier but these remain rocky.

4 "About Rapa Nui." Easter Island Statue Project Official Website RSS.

5 "Easter Island Travel Guide."

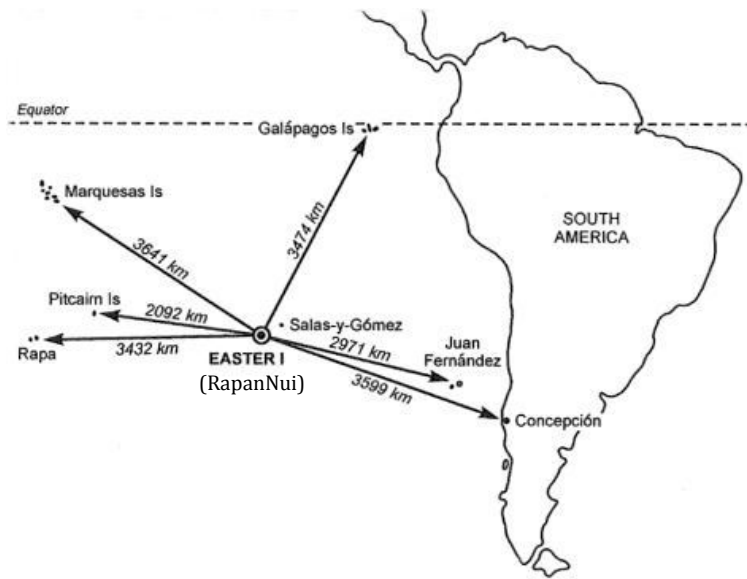


Figure 2: Rapa Nui Isolation

This image shows Rapa Nui (Easter Island) and its distance to other inhabited lands. The island labelled “Rapa” refers to Rapa Iti not Rapa Nui.

Source: http://www.bibliotecaplayades.net/arqueologia/easter_island/easter01.htm

History and the Conventional Narrative

Despite the island’s isolation, Rapa Nui is home to some of the most fantastic prehistoric architectural feats known, the *moai*. There are hundreds of these large statues placed all around the island, with each one carved from a quarry on the side of a volcano called Rano Raraku and then transported, sometimes all the way across the island, until they reached their final permanent destination (fig. 1).

The earliest radio carbon dating places initial settlement of Rapa Nui by Polynesians around 1200 CE and Europeans first came in contact with the island in

1722 when the Dutch explorer Jacob Roggeveen stayed for a few days on the island.⁶

Roggeveen and subsequent explorers and scientists observed the large statues and relatively small number of indigenous people (a few thousand) and wondered how such monumental structures could have been created.⁷ As the chief pilot of Cpt. Don Felipe González's 1770 voyage wrote:

“That a people lacking machinery and materials for constructing any should be able to raise the crown or headpiece on to a statue of such height causes wonder, and I even think that the stone of which the statues are made is not a product of the island, in which iron, hemp, and stout timber are absolutely unknown. Much remains to be worked out on this subject.”⁸

The base assumption underlying this and following ideas about the statues, is that ingenious tools and a large population must have been needed to create them. Thus, there must have been must have once been a great, ancient Rapanui civilization which, after having made hundreds of statues, for some reason collapsed consequently when Europeans arrived they encountered the “depleted” population. This in turn has given rise to speculation as to what caused this population collapse. Some look to various aspects of native oral traditions or use pieced bits or evidence while others like go to the extreme to explain *moai*.

The idea that no one knows how the *moai* were constructed and moved or by whom has resulted in the majority of those uneducated in the subject believing that Easter Island is a bare and desolate place with no people, just statues. The truth, however, is that there has been continuous occupation of the island throughout its

6 Corney; Roggeveen. The Voyage of Captain Don Felipe González. 1908

7 Corney; Roggeveen. The Voyage of Captain Don Felipe González. 1908

8 Corney; Felipe González De Haedo. The Voyage of Captain Don Felipe González. 1908

known history, and while its population was diminished due to disease and slaving to a mere 110 people at one point, there are still decedents of the indigenous people living on the island today.⁹ There is a common misconception among the general public that the *Moai* are simply large stone heads due to years of their depiction in popular culture as such. This idea has been propagated by the classic stock image from the quarry Rano Raraku (fig. 3), where the statues were carved, as well as their portrayal as simply heads in various media forms, from comics to cartoons to movies (fig. 4). In reality though, the statues are full-bodied and when properly placed, stand upright and erect (fig. 5).

While there have been many different narratives regarding the island's pre-history over the years, most have since been dismissed by the general public, that the statues were made by aliens¹⁰ or that they were the work of white Egyptians and Incans¹¹. In their place is the current conventional narrative of the island, an idea presented by Jared Diamond in his book *Collapse*. By his account, when the Polynesians first arrived on it Rapa Nui was a lush paradise and a prosperous civilization was established. As time went on, a ruling class forced their people to create *moai* in order to honor the ancestors and encouraged a so-called *moai* cult of intense building competition. In order to build and move these *moai* wood and plant materials were required and so the Rapanui cut down all of the trees that once existed on the island. With no more trees, the topsoil washed away and food became scarce. The Rapanui were then unable to sustain themselves on the island and they turned to

9 Hunt, Lipo. 2011

10 Däniken. Chariots of the Gods?: Unsolved Mysteries of the Past. 1970

11 Holton "Heyerdahl's Kon Tiki Theory and the Denial of the Indigenous Past." 2004

cannibalism as their civilization collapsed. They caused their own demise through ecocide.¹²

Diamond's theory, like the ones before, though, still labors under the assumption that there must have once been a great civilization under which the *moai* were constructed that disappeared before the Europeans arrived. There is a new explanation as to how the *moai* were moved, however, that goes against this idea. Using the physical characteristics of the *moai*, Drs. Carl Lipo and Terry Hunt have constructed a new fact-based and clarified narrative for the island, one where the pre-historic population remained stable and that the populace encountered by the Europeans was, in fact, a healthy and thriving community, one which only began to collapse post-contact due to disease and slavers. Lipo and Hunt were able to show that *moai* were not moved in a completely finished state. Rather, when the *moai* were initially carved, they had a much further forward center of gravity. The resulting forward lean meant that through the use of three ropes tied around the head area, if the *moai* was rocked back and forth while twisting it forward, it could be moved by relatively few people.¹³ If the *moai* could be moved this easily, there would have been no need for a big population to supply the laborers needed to move the statues and thus there would be no need to try to explain some sort of disappeared society. With this revealed, the changes in landscapes and land cover become less important to the overall story, with palm tree loss being explained by the introduction of rats that ate the palm seeds and saplings instead of clearing for

12 Diamond. "Twilight at Easter." Collapse: How Societies Choose to Fail or Succeed. 2005

13 Hunt, Lipo. 2011

agriculture by the natives.¹⁴ This is supported by the observations of Jacob Roggeveen in 1772:

“Nor can the aforementioned land be termed sandy, because we found it not only not sandy but on the contrary exceedingly fruitful, producing bananas, potatoes, sugar-cane of remarkable thickness, and many other kinds of the fruits of the earth; although destitute of large trees and domestic animals, except poultry. This place, as far as its rich soil and good climate are concerned, is such that it might be made into an earthly Paradise, if it were properly worked and cultivated; which is now only done in so far as the Inhabitants are obliged to for the maintenance of life.”¹⁵

Hunt and Lipo’s explanation shows that the indigenous Rapanui were smart and well aware of their surrounding environment, unlike their depiction in previous narratives. Rather than labor being forced upon people, Hunt and Lipo show that *moai* making and moving was a group activity of choice and there was deliberation behind the making and moving of each one.

14 Hunt, Lipo. 2011

15 Corney; Roggeveen. 1908



Figure 2: Classic photo of just the *moai* heads

Buried *moai* in Rano Raraku. Photo taken by author



Figure 3: *Moai* in Pop Culture

From left to right: depictions of *moai* in the movie *Night at the Museum*, *The Simpsons*, and a *Batman* comic. Source: <http://www.moaiculture.com/popculture.html>



Figure 4: *Moai* standing on an *Ahu*

Ahu Nau Nau. Once scattered, this *ahu* has been reconstructed and these *maoi* with their *pukau* re-erected to stand on top as they once did. Photo taken by author

Ahu

While the *moai* are generally the first thing that comes to mind when “Easter Island” is mentioned, there are also other large archeological structures that can be regularly seen throughout the landscape, *ahu*. These are long low platforms upon which the *moai* were placed. These places are considered to have once been ceremonial locations and gathering places for the prehistoric Rapanui, community locations for local “clans” or family groups. Rather than simply being ceremonial sites, people would live and farm in the areas around the *ahu* with the large stone statues placed with their backs to the sea and looking down on them. Even with this understanding, the *ahu* and their purpose could have meant many things to the ancient Rapanui and whatever the

original intent, it is well documented that burials took place there at least during historical times. As Captain Cook, leader of the third European party to disembark on Rapa Nui, noted in 1774:

“The gigantic statues, so often mentioned, are not, in my opinion, looked upon as idols by the present inhabitants, whatever they might have been in the days of the Dutch; at least I saw nothing that could induce me to think so. On the contrary, I rather suppose that they are burying-places for certain tribes or families. I, as well as some others, saw a human skeleton lying in one of the platforms, just covered with stones.”¹⁶

Visitors to the island continued to note the remains found near *ahu* and a century later in 1886, William Thompson, the paymaster of the U.S.S. Mohican recorded this description of *ahu*:

“The platforms differ greatly in dimensions, but the general plan and characteristics are inevitably the same. Many of them are in a fair state of preservation, except that the images have been thrown down and the terraces in the rear obliterated or strewn with rubbish, while others have been reduced to a state of complete ruin. The platforms are usually located near the beach, and on a high bluff some of them are quite near the edge, overlooking the sea. The general plan consists of a front elevation composed of blocks of stone fairly squared and neatly fitted together without cement, a parallel wall forming the inside boundary, built of uncut stone, inclosing small chambers or tombs placed at irregular intervals. [Thompson’s reference’s to “front” and “rear” are opposite as, when confronted with all of the *moai* fallen over, he assumed that the *moai* faced outwards towards the sea when they’d originally stood rather than inland] Loose boulders [*sic*] fill the spaces between the tombs and form the horizontal plane of the platform, into which are let the rectangular stones which constituted the base upon which the statues stood. The façade stones are large and heavy, and in some cases the smooth surface presented could not well be attributed to the ride implements at the command of the builders and must have been produced by friction or grinding. Long wings composed of uncut stone extend from the platform proper, built up to the summit at the ends. In the rear of the platform a few steps descend to a gently sloping terrace,

16 Cook and Furneaux. A Voyage towards the South Pole and round the World. 1777

which terminates in a low wall and is bounded by a squarely built wall raised above the ground so as to join the top of the platform.”¹⁷

William Thompson is considered to have conducted the first archeological investigation on the island during his two week stay and many others would follow, noting the *ahu*, describing their features and categorizing them. There remains a general similarity throughout these descriptions, all noting the same general rectangular form and winged ends with the large wall in back and sloping ramp in front (fig. 5).¹⁸

While *ahu* that supported *moai* (*image ahu*) were the main subject of investigation and note for those initial explorers and archeologists to the island, there are structures on the Rapa Nui that have a largely similar basic shape to the *image ahu*, being low and long, but are generally simpler in their construction and have no associated statues. These *ahu* are also found near the coast but they tend to have a much greater variation in size, and, rather than the wings and squared ends of the *image ahu*, their ends tend to taper (fig. 6). Sometimes there is a front slope and strong back wall associated with them but this is generally not the case. Captain Cook described some of these features in his journal:

“Besides the monuments of antiquity, which were pretty numerous, and nowhere but on or near the sea-coast, there were many little heaps of stones, piled up in different places along the coast. Two or three of the uppermost stones in each pile were generally white, perhaps always so, when the pile is complete. It will hardly be doubted that these piles of stone had a meaning; probably they might mark the place where people had been buried, and serve instead of the large statues.”¹⁹

17 Thompson. *Te Pitot e Henua, or Easter Island*. 1886

18 Beardsley. *Spatial Analysis of Platform Ahu on Easter Island*. Dissertation. 1990

19 Cook and Furneaux. 1777

As Cook noted, it is impossible to understand exactly what these different forms of *ahu* meant to the Rapanui but they undoubtedly served some purpose.

Some archeologists have tried to classify Rapa Nui prehistory into various periods and fit various types of *ahu* construction within these time frames but in their study of the inland *image ahu* complex of A Kivi-Vai Tekā, Mulloy and Figueroa found that:

“From the point of view of *image ahu* architecture, a single, coherent, continuously developing pattern of ideas is represented. In terms of general conception and apparent cultural function as well as detailed architectural characteristics this sequence of structures demonstrates a clear and detailed, unbroken chronological progression such as might be expected from the architectural reflection of the activities of a single continuously developing society. No evidence is interpreted as revealing a chronological break in the sequence such as might suggest a population replacement, the intrusion of a new cultural pattern or even a period of sudden cultural renaissance. The evidence indicates that, from the point of view of *image ahu* architecture, this part of the local history can most meaningfully be seen as a single period of uninterrupted development characterized by gradual introduction of new ideas, the expansion of themes and improvement of capacities.”²⁰

Indeed, several *ahu*, particularly *image ahu*, show signs of reworking, rebuilding and/or maintenance taking place since their initial creation. This can be noticed when there are square-ended outlines indicating where a previous *ahu* was once built or if an *ahu* angles in the middle rather than being straight (fig. 7). In addition, some of the large blocks used as the outside walls of the *ahu* can be identified as the heads and bodies of *moai* that presumably fell, broke and were then repurposed. These *moai* generally have the rounder, less long head shape that is characteristic of older *moai* styles. It should be

20 Mulloy and Figueroa. *The A Kivi-Vai Tekā Complex and its Relationship to Easter Island Architectural Prehistory*. 1978

noted, however, that the simple lack of discernable difference between features does not indicate that no timeline or chronological difference exists.



Figure 5. Image ahu

The central part of the image ahu is thicker, more solid, and rectangular and is where the *moai* (now fallen) once stood. To either side stretches out the squared “wings” while in front is the sloping ramp where evenly spaced smooth, rounded rocks were placed. A historic wall has been made using/intersecting the image ahu.



Figure 6. Ahu

A well preserved ahu with no associated *moai*. The construction is still the same with a retaining outer-wall of larger stones, but the ends of the structure are much pointier and there are less associated defining factors.



Figure 7. Image Ahu with Various Iterations

This image ahu has had several stages to it. The front rectangular outline and wings are clear as are another set behind and at a slightly different angle.

Costly Signaling and Water

The construction and moving of a *moai* would have been a long term and significant event given their size and the distance they were moved to locations around the island. While no one can know exactly the rationale behind the Rapanui's construction of the enormous *moai* and *ahu*, one concept that could have been an underlying driver to their construction is costly-signaling.

Costly-signaling is the notion that large structures and other “frivolous” visible possessions indicate a level of wealth, health, or status because those in possession of such signals must be able to handle the “cost” placed upon the individual. This cost is often the diversion of energy to create the feature, like with peacocks putting energy into growing their elaborate tails rather than getting bigger themselves (it does not have to be a conscious decision). In modern human societies, the cost is often monetary as people buy objects that have little functional value except to display the wealth of the owner.²¹ These costly signals are generally visual and *moai* and *ahu* would fall into this category, their size and scale indicating to others that those involved in their construction had enough resources and “wealth” to deal with the cost that came from erecting such features.

The *moai* could also be involved in costly-signaling by delineating members of a group. As Smith and Bliege say, “another type of collective good that may be a form of costly signaling involves punishing those who free-ride on the group's cooperative activities or otherwise violate group-beneficial norms.”²² There were once several

²¹ Hunt, Lipo. 2011

²² Smith and Bliege Bird. "Costly Signaling and Cooperative Behavior.". 2005

different family “clans” living in around Rapa Nui that were associated with specific areas of the island.²³ In talking to Dr. Lipo, he is of the opinion that rather than a top-down order to build *moai* involving specific carvers and transportation laborers (as some narratives say), these groups of people would carve, move the *moai*, and build the *ahu* themselves in addition to maintaining their other sustenance related activities.²⁴ If this were indeed the case, such action and involvement in the endeavor would help to show who was involved, invested, and a part of that particular family group. Erecting a *moai* would make it clear who was to partake in the “clan’s” resources as opposed to outsiders and freeloaders.

In regards to what the *moai* and *ahu* could be signaling, with Rapa Nui’s small size it makes sense that they could have been signaling the possession of some resource. Since lithic mulching was used as a farming method, food resources were spread out across the whole island.²⁵ Thus, as a resource, land and food were not the limiting factor. Rather, it would make sense to place these statues near a scarcer resource, a resource such as water.

Given the volcanic geology of the island, there is little to no standing water on Rapa Nui. This is a problem. There are basins carved into the rock called *taheta*²⁶ to help hold rainwater, but this is not enough. For a society to survive, a more reliable source of water is needed. There is evidence, both historical and archeological that the

23 Tilburg. Among Stone Giants. 2003

24 Talk with Carl Lipo January 2015

25 Ladefoged. “Soil Nutrient Analysis of Rapa Nui Gardening.” 2010

26 Tilburg. Among Stone Giants. 2003

wells were constructed by the ancient Rapanui. As Captain James Cook described in his journal during his 1777 visit to the island:

“[My men] could find no water except what the natives twice or thrice brought them, which, though brackish and stinking, was rendered acceptable, by the extremity of their thirst... Towards the eastern end of the island, they met with a well whose water was perfectly fresh, being considerably above the level of the sea; but it was dirty, owing to the filthiness or cleanliness (call it which you will) of the natives, who never go to drink without washing themselves all over as soon as they have done; and if ever so many of them are together, the first leaps right into the middle of the hole, drinks, and washes himself without the least ceremony... What the natives brought them here was real salt water; but they observed that some of them drank pretty plentifully of it, so far will necessity and custom get the better of nature!... On the declivity of the mountain towards the west, they met with another well, but the water was a very strong mineral, had a thick green scum on the top, and stunk intolerably. Necessity, however, obliged some to drink of it; but it soon made them so sick, that they threw it up the same way that it went down.”²⁷

It is expected that these are *puna*, wells where the ground has been cut away into the side of the slope in order to access the water table. It is obvious, however, given the brackish nature of the proffered water that many of these wells were near the coast where the sea water mixes with the water table.

It makes sense geologically that it would be easier to access freshwater near the coast because as the land comes down to meet the ocean, the water table is relatively closer to the surface. At the shoreline where they meet, fresh water discharges into the ocean but the volume depends on the tide. At high tide there is little discharge as the increasing tide creates a “hydraulic dam” blocking the fresh water, but as the tide ebbs the position of maximum discharge moves towards the ocean.²⁸ The result is less salty

27 Cook and Furneaux. 1777

28 Urish and McKenna. “Tidal Effects on Ground Water Discharge Through a Sandy Marine Beach.” 2004

brackish water. Given the water shortage on the island, it makes sense that the Rapanui took advantage and made the most of this coastal freshwater resource. In his journal Captain Cook described one such well:

“The little [water] we took on board, could not be made use of, it being only salt water which had filtered through a stony beach into a stone well; this the natives had made for the purpose, a little to the southward of the sandy beach so often mentioned, and the water ebbed and flowed into it with the tide.”²⁹

The Rapa Nui locals would have been well adapted to drinking brackish water as Cook observed and this geological phenomena can still be observed today when free roaming horses can be seen drinking ocean water at low tide. This does not happen everywhere though. For one, the water table discharges best through porous materials so while soil and sand allow for a lot of permeability, bedrock and clay are more impermeable and will generally restrict the water table. Thus, not all areas of a coastline will have the same fresh water discharge. In addition, the cliffy coastline makes it certain areas less accessible than others.

Ocean access would have made available valuable resources for the ancient Rapanui, not only water but also whatever food resources they could glean from it through fishing and harvesting.³⁰ It thus makes sense to mark and “protect” such locations, to identify and keep them for yourself and your immediate clan. Based off of diatoms in skeletons, there is evidence of regional geographic variability in the water sources of the ancient Rapanui that could be explained by a differing reliance on water sources, with individuals from the north and west coasts of the island relying on more

²⁹ Cook and Furneaux. 1777

³⁰ Arana, "Ancient Fishing Activities Developed in Easter Island." 2014

temporary rainwater drinking sources while south coast individuals had more diversified sources.³¹ My paper examines the relationship between *ahu* and coastal access in an attempt to shed further light on this relationship and support the idea of coastal water table discharge as an important resource for those Rapanui living on the south coast of the island.

Topography

If *ahu* are to be considered costly signals related to fresh water access within the ancient Rapanui culture, topography could play an important factor as to why these structures were placed in certain locations. There are a couple reasons for this. One, as partially explained in the prior section on costly signaling and water, has to do with access to the water table. If a structure is placed at a lower elevation it is placed close to the water table. Additionally, a steep decline would not only bring people closer to the water-table, but these downhill areas, specifically if there is an abrupt drop in elevation, would remain slightly damper. This is because as water percolates through the ground, gravity still acts upon it, pulling it in a downhill direction in addition to simply down into the ground. If the land falls sharply, it is possible for this percolating water to emerge in these locations, perhaps not in large quantities, but more so than in areas where the land is flat or uphill.

Ahu location and distance to resources could also result in a spatial relationship.

It is generally expected that features related to one-another would be located closer

31 Dudgeon and Tromp. "Diet, Geography and Drinking Water in Polynesia: Microfossil Research from Archaeological Human Dental Calculus, Rapa Nui (Easter Island)." 2012

together rather than being placed far apart. This is especially true when the resource being marked is an environmental one, such as land, food, or water. Thus, if *ahu* were markers of some locational based resource they should be placed near that resource.

Topography can relate to a number of other factors relevant to *ahu* placement as well, particularly slope and visibility.

Effect of Slope on Walking

Creatures use energy every day, to breath, to grow, to move; life requires energy. The more energy a creature uses, the more energy it needs to put in. Thus, to be efficient, many creatures will avoid doing unnecessary work. As animals move through a landscape they lose energy but how much they lose depends upon the terrain; the more incline, the more energy spent in trying to ascend.³² This is illustrated by Naismith's Rule, a rule of thumb proposed in the 1800s as a way to calculate walking/hiking times. In its initial form it suggested to allow 20 minutes for every mile and 30 minutes for every 1000 feet of rise. Overtime, it has been modified and expanded to take into account various terrain and slope gradation since steeper, rougher trails are harder, requiring more time and energy to ascend than the work needed for walking along flat ground.³³

Observed animal behavior in the wild supports the idea that slope dictates movement, especially for larger animals. This makes sense since, while it may take the same amount of energy to lift 1kg of body weight for all animals, a larger body means more energy expenditure. Thus, the fight against gravity is much more taxing on

32 Hausken. 2014

33 Norman. 2004

animals of larger size. This is why the smaller mouse can more easily run uphill and at greater inclines than the larger chimpanzee.³⁴ This behavior is also seen in elephants who avoid steep slopes since their large body sizes make going up even minor hills a large energy cost.³⁵ Cattle too seem to generally prefer grazing on land with less slope, and only venture to hillier locals when food is scarce.³⁶ With humans, in order to compensate for steepness, we ascend in a zigzagging manner as a way to reduce steepness (even though it increases distance). This phenomena is made permanent in the switchbacks of roads and trails.³⁷ We, like many animals of decent size, rarely scale straight up a slope; rather we traverse it.

Given this understanding, if people were regularly accessing the coastline, it would be advantageous to position one's self so as to avoid steep coastal terrain that would require excessive work. When access is desired, a lesser slope is preferred because it would make the work less strenuous and more efficient. Thus, it would make sense for *ahu* structures related to coastal/resource access to be situated near areas where there is a gentler coastal slope. Even without taking into account possible fresh water resources at the tideline, the ocean also had a number of other resources that the ancient Rapanui utilized like fish and other forms of sustenance. Since *ahu*, particularly image *ahu*, seem to be tied to community gathering areas it seems reasonable that they would be placed in areas where that limited the amount of work required; rather than

34 Taylor, et. al. "Running Up and Down Hills: Some Consequences of Size." 1972

35 Wall, et. al. "Elephants Avoid Costly Mountaineering." 2006

36 Harris, et. Al. "The Effect of Topography, Vegetation, and Weather on Cattle Distribution at the San Joaquin Experimental Range, California." 2002

37 Llobera and Sluckin. "Zigzagging: Theoretical Insights on Climbing Strategies." 2007; Gilks and Hague. "Mountain Trail Formation and The Active Walker Model." 2009

locate their communities near areas where steep cliffs would impede access to the ocean's resources and require more energy expenditure, areas with less steep coastal slopes seem more ideal. There were no beasts of burden on the island prehistorically, so the Rapanui walked everywhere; it makes sense that they would be efficient about it.

Visibility in Archeology

Visibility and elevation go hand in hand. Everyone knows that generally, the higher you are, the further you can see. Usually, for an observer standing on the ground, the true horizon (the horizon resulting due to the curvature of the earth) is about three miles in the distance, but as they ascend in elevation, that distance increases. In reality, though, an observer cannot always see to the horizon, if features are in the way, be it a building, a mountain, or something else, an observer's visibility is blocked as sight beyond the object is restricted. Conversely, if there are features of greater elevation far away their tops can be seen by an observer if they rise above the horizon line even if their bases below the horizon are not visible. This is why visibility is closely tied to topography, not only does the elevation of the observer matter, but the elevation of the landscape around them as well. Standing on a lone hill surrounded by plane has a different visibility result than standing on a hill surrounded by mountains.

Viewsheds are a way of analyzing how much area is visible from a single location. This term to describe calculating areas of visibility was first introduced by Tandy in 1967 who compared the idea to that of a watershed.³⁸ The concept grew in popularity when a computer program was developed that could quantifying visible areas

38 Tandy. "The Isovist Method of Landscape Survey." 1967

across a plane in 1968.³⁹ The modern versions of this program are now used in a wide variety of fields from architecture to the military.

In archeology, visibility and intervisibility (seeing between features) have long been considered important factors in the initial construction of archeological landscapes, especially in regards to settlements. While there are many elements that factor into the location of settlements, visibility is often analyzed as a means of assessing defensiveness. Before the advent of computers, this was hard to quantify and generally noted qualitatively through words such as ‘hidden’ and ‘prominent’ but with GIS, quantitative analysis allows for a more thorough study of this phenomena.⁴⁰ In their 1996 paper, Lock and Harris examined settlements in prehistoric southern England and used the amount of visible land from each location as a measure of defensibility, with the assumption that the greater the visible area from a settlement location, the easier it would be to defend.⁴¹ Jones also used visibility as a way to examine the placement of Onondaga Iroquois settlements and found that while settlements were not placed for a maximum field-of-view, they were generally within line-of-sight from one another making communication and mutual defense easier.⁴²

Though a large focus has been on settlements, there have also been a number of viewshed analyses of other archeological features. One very extensive study was conducted by Fraser on the Neolithic stone cairns of Orkney where visibility was

39 Amidon et. Al. “Delineating landscape view areas...a computer approach.” 1969

40 Wheatly and Gillings. “Spatial Technology and Archeology.” 2002

41 Lock, Gary R., and Trevor M. Harris “Danebury Revisited: An English Iron Age Hillfort in a Digital Landscape.” 1996

42 Jones. “Using Viewshed Analysis to Explore Settlement Choice: A Case Study of the Onondaga Iroquois.” 2006

studied as a significant factor for the position of the territory delineating cairns.⁴³

Another study by Paliou used a visibility analysis to show how Bronze Age Aegean wall paintings would appear to the public outside looking in through windows as a way to show status.⁴⁴ All these studies show how the informative light visibility sheds on the relationship between features and their surrounding topography allows for a better archeological understanding of civilizations.

This idea is especially important if these ancient structures are meant to be a form of costly signaling. Costly signals are a way of communicating, they are meant to be seen, which means that visibility should have been an important factor considered by those constructing the *ahu*, particularly the image ahu.

43 Fraser. *Land and Society in Neolithic Orkney*. 1983

44 Paliou. "The Communicative Potential of Thera Murals in Late Bronze Age Akrotiri." 2011

Part 3: Field Work and Data Analysis Methods

Data Collection

For the first two and a half weeks in January of 2015, I traveled to Rapa Nui with Drs. Lipo and Lee from California State University Long Beach (CSULB) in order to help them collect data on the island. Their main goal for the trip was to collect visual imagery for the south coast of the island using drones and I assisted them in this endeavor. We flew a Trimble UX5 Aerial Imaging Rover to collect our data (fig. 8) that was generally able to capture areas of about 1km^2 per flight. Over the course of a week and a half we flew about 26 flights, capturing the whole of the southern coast as well as some more inland areas (fig. 9).

Inside the body of the drone was a camera that took pictures at regular intervals during the plane's flight path; Dr. Lee would adjust the settings to account for the sun brightness of each individual flight. The unmanned aircraft was controlled via a touch-screen Yuma tablet computer onto which a map of the current location was loaded beforehand. With this map and our location locked on thanks to satellites, I would then indicate the wind direction (important for take-off, flight planning, and landing), decide the coverage location and area for the flight, and confirm and adjust the take-off and landing approaches for the drone by establishing boxes, points, and vectors in relation to map seen on the handheld computer screen. Before launch, we would go through a pre-flight checklist to ensure readiness and that everything was set (fig. 10). To launch, the UAV was placed upon a slingshot-like launch rail and at takeoff, a loaded bungee would fling the plane into the air. This speed and increase in altitude would start the

motor and the plane would begin to fly along its directed path. If the flight area was far away, Dr. Lipo and I would follow the drone in a car with the Yuma computer to ensure a signal between the devices was maintained. When the drone reached the area designated for imaging, it would begin to travel along designated flight paths that transected the square area. In general we would try to have the flight lines perpendicular to the wind so as to reduce velocity change as the plane traversed across the set coverage area taking pictures. When the plane reached the end of each flight line, it would continue for a little bit not taking photos before banking into a turn and coming back to align itself for its next flight path. When it was done flying all the flight paths for the assigned area, the drone would return to a set rally point near its landing location, circle to lose altitude and await confirmation to land. We would position ourselves to observe the area and descent approach before I gave the OK to land and watch then watch for any danger that would have me abort the landing (horses, cars, a bad angle, etc.).

There was a variable range as to the exact landing spot due to satellite inaccuracy and the wind could also seriously affect the landing location. Since the UX5 has no wheels and instead lands on its belly, its last few moment of flight are glide with one sharp reverse from the propeller. This means that a large, clear, rock-free area is needed for landing and given the rocky nature of Rapa Nui that is an uncommon thing, but we were able to find three decent locations for landings from which we launched most of our flights to cover the south coast. We had brought along extra bodies for the drone in case of accidents and had several very close calls with rocks but only ended up crashing once on a landing bad enough to warrant a body change.

Each flight produced several hundred overlapping photos along with data from the flight path, which, among other things, included GPS coordinates for each picture. After each flight we would download the pictures from the camera's memory card onto a laptop as well as extract the flight log from the drone's body onto the Yuma computer. This data we would then bring back to the house we were staying at for further saving and processing.

In general, we flew about two to three flights per day and towards the end when we were most efficient, we had a day where we flew four flights, and a day we flew five. Ideally we could have gotten more flights off but we were limited by only having 4 lithium batteries (1 needed per flight) and the fact that we were not allowed to fly from around 11am until 1pm because we weren't allowed to fly when the airport was busy and that's when the flight from Chile arrived and departed. It also took us a while to achieve the necessary local permission to start flying so despite arriving on January 2nd, we didn't start drone flights until January 9th. Despite that, we were still able to get imagery for the whole south coast as well as some other flights people requested.

The data from each flight was taken and processed using the laptops set up back at the house we were renting. First, the pictures from the camera had to be matched with their flightlog metadata that was recorded by the drone as the pictures were being taken. Then, we input the photos into a structure from motion program called Agisoft PhotoScan which would analyze the images and composites them together. The result of this process is an Orthophoto with approximately 3cm resolution, a Digital Elevation Model (DEM), and a three-dimensional point-cloud model of the area.



Figure 8. The UX5 Drone

Photo taken by author

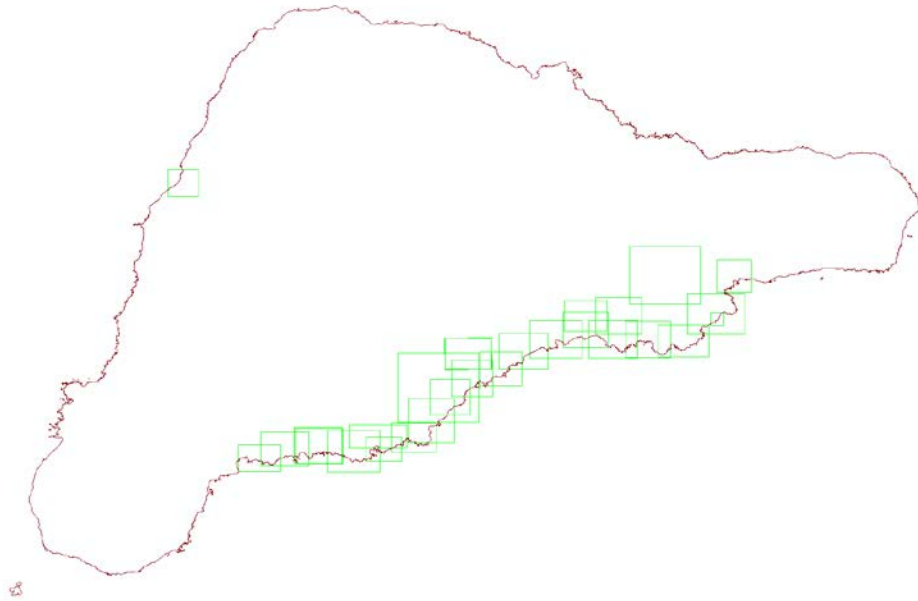


Figure 9. UX5 Flight Areas

Each green square represents the area flown for one flight. While the flight area was a rectangle, the resulting orthophotos have jagged edges resulting from the corners and edges of the actual camera pictures taken and that the drone often flew at an angle to account for the crosswind. Generally these flights covered about 1km but the two flown at a higher altitude (225m) covered more.



Figure 10. Final Checks of the Drone before a Launch

Photo taken by Dr. Lipo

Structure from Motion and Topography

Structure from motion (SfM) is a form of photogrammetry, the science of getting ground measurements by measuring angles and lengths in photographs.⁴⁵ While the concept of photogrammetry is about as old as the technology of photography itself, a more modern subset of the field is structure from motion. SfM, like traditional photogrammetry, uses location triangulation between matching features to create the geometry of the scene and estimate three-dimensional features from two-dimensional images. To do this, SfM needs three or more overlapping images of an area or object taken from slightly different angles, unlike traditional photogrammetry's two. Those

⁴⁵ Slama. *Manual of Photogrammetry*. 1980

points that are similar align and match up, their slightly different angles and the images are then composited together. This allows for the creation of perceived depth and three-dimensional effects just like how human, and many animal, eyes work (Fig. 11). With SfM, however, feature recognition algorithms incorporated into the programs allow for larger camera angle and photograph scale changes than the traditional methods and the processing power of the computer means that many images can be used to achieve more accurate results.⁴⁶ The end result of this is a composite three-dimensional model. The shape arises from the angle and points that allow a structure to be made and the texture and color detail come from the combined photo imagery which is “draped” over the shape.

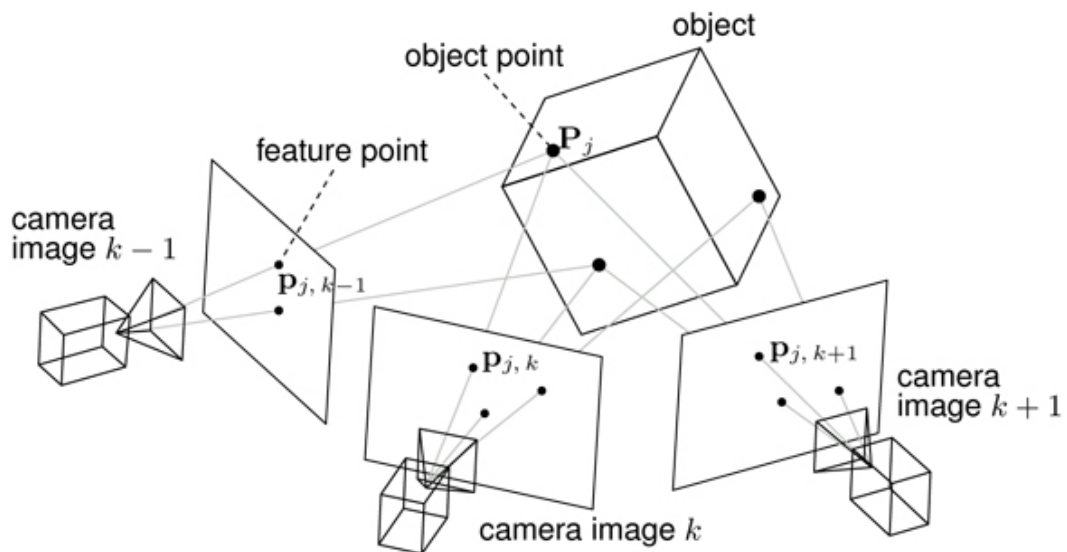


Figure 11: Structure from Motion Diagram

How structure from motion uses various different camera angles to recreate 3D features. Source: <https://www.jvrb.org/past-issues/8.2011/2822>

46 Johnson et. al. "Rapid Mapping of Ultrafine Fault Zone Topography with Structure from Motion." 2014

Topography

While SfM can be used to create 3D images of objects or buildings, if a large number of images are taken from above looking straight down at the ground, it can also be used to make 3D models of the landscape topography. For creating a topographic model, the more points of data there are, the more accurate the resulting image. If done by hand, acquiring topographic data requires a large number of man-hours to conduct in-the-field surveys and does not result in a very dense data set of points. With SfM software, however, the matching and creation of points between photos can be done more quickly and with a much greater density than before.

This is not to say that collecting data by hand is the only way to amass topographic data. One other way is the use of Light Detection and Ranging (LiDAR). LiDAR works via active remote sensing. With LiDAR, a laser beam is sent down to the earth's surface from a platform (usually a plane for high resolution data) and the reflected light is analyzed upon its return; the varying elevations create different return times which can be used to determine elevation given the known location GPS location of the platform. A DEM can then be derived from the data via triangulation.⁴⁷

LiDAR and SfM both have their pros and cons in when it comes to mapping topographic data. One advantage of LiDAR is that it can collect topographic data of the ground even if there is tree or other vegetation cover in an area. This is because the laser beam can have different returns (ie. One for the tree canopy, one for a smaller plant in the understory, and one for the ground) each of which is analyzed. Unlike LiDAR, SfM

⁴⁷ Johnson et. al. 2014

uses just a simple camera and passive remote sensing (ie. the sunlight that is bouncing off the earth's surface) to collect data. Thus, it is only useful in collecting topographic data if there is minimal to no vegetation. Luckily this is the case on Rapa Nui.

Given that a plane is required to fly the LiDAR equipment, data can be collected for large areas, this can also be a good thing, but in some instances it can be a disadvantage. For one, a pilot and plane are needed which are expensive, especially when only a small area is needed to be surveyed. While we used a fixed wing drone to collect our SfM imagery data, it required little skill to use and if we did not have that option, we could have used a balloon to elevate the camera.⁴⁸ Additionally, because SfM data collection generally takes place closer to the ground, it generally has a better resolution than LiDAR data. Studies have shown that SfM data results in a higher cloud density of data points and is generally quite accurate (when there is little to no vegetation) and that it results in a higher cloud density of data points than conventional airborne LiDAR.⁴⁹

Another advantage to SfM is that of the orthophoto. Since SfM uses regular photographs to get its elevation data, it has visible-light imagery for the area as well. During processing, the images are matched and meshed together so that all the images are incorporated into one, large area image that has been geometrically rectified, an orthophoto. The result is that features can be visually looked at and analyzed whereas with LiDAR datasets, there is only the density data with which to base ones

48 Johnson et. al. 2014

49 Harwin and Lucieer, 2012; Fonstad et. al. 2013

understanding of the area. This easy visual accompaniment to the topographic data is a big advantage when trying to determine features on a landscape.

When collecting areal imagery for topographic analysis using SfM, there are a few key concepts that factor into the collection method and process. The major one is that it all depends on the quality of photos being used. While the computer does most of the processing work and can create 3D models rich in information and detail as outputs, it is still the job of the individual to acquire the photos needed for the reconstruction. Given the essential nature of having overlap between the images it is important to be methodical when taking pictures of the subject. Just as important, however, is to ensure that the subject and its varying aspects are captured from different angles. The easiest way to ensure this is to move while taking photos of the feature, hence the name structure from motion.

With the drone, we were able to get regular pictures of the ground with systematic overlap and height (fig. 12) and as it moved across the landscape, it captured the ground features at different angles. This made it easier to get quality reconstructions of the landscapes.

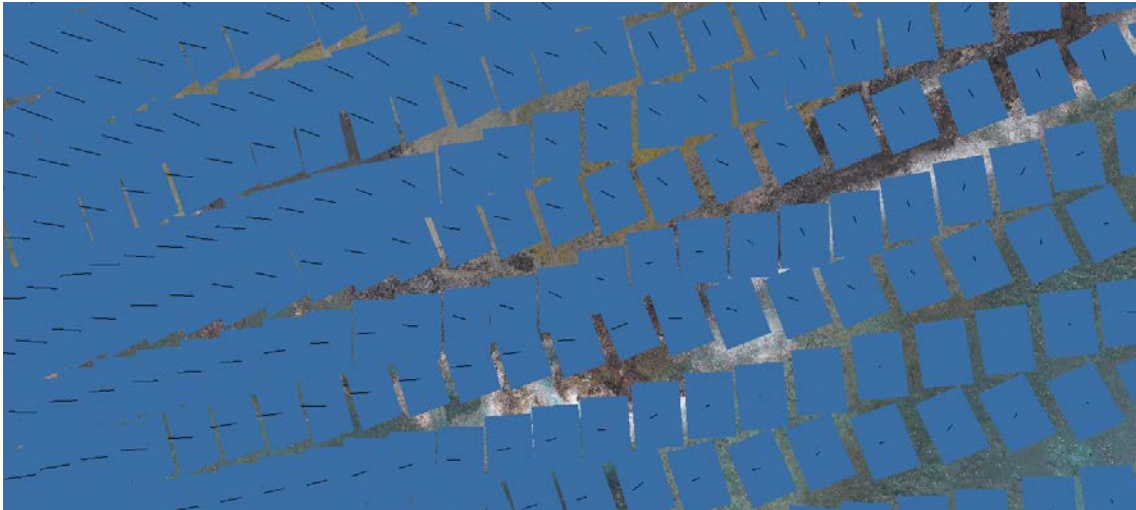


Figure 12: Camera Angles and Overlap in Photoscan

An image showing the camera location (black line and blue rectangle) for each photo taken and used in the reconstruction with the created ground topography beneath

Ground Calibration

An important aspect of SfM is the ground calibration. This is what gives the orthophotos, DEMs, and other outputs location in the real world. Just as the object of study was located in the world, so must the SfM outputs be able to align with that location. The outputs must be able to exist in a correct relationship to those areas around it as well as to the other points within the model. One way to ensure this is to collect GPS data at certain identifiable site. These locations or Ground Control Points (GCPs) can then be marked in the model and, by having certain points with known locations, the model becomes, in a sense, anchored. Thus, the more known points, the more precise and accurate the model. In more technical terms, GCPs register a model to a coordinate system.

While having specific GPS points is one way to register a model, there are also others. One, is that if you have the GPS locations for where the individual pictures were taken, they can be used to help provide a location for the whole emerged image. Another way to ensure a correct data output is, if a DEM of the location at a different resolution exists, the same area of the two can be compared and used to correct each other. These various methods are not mutually exclusive and can be used in conjunction with one another in order to ensure the greatest accuracy for the data.

For this project, we did not collect GCP data, rather, we used the GPS data associated with the various camera positions to provide locations for the images. As the drone was flying, it oriented itself based on its triangulation from several satellites. Since the drone knew its position, every time it took a picture, the drone's position at that time was recorded. This data could then be used to help Photoscan align the photos as well as provide locational grounding for the output model, Orthophoto, and DEM. Unfortunately, this consumer-grade GPS on the UAV has error associated with it that can translate into registration error for the model. This is discussed in further detail in the sub-section "Errors" (page 45).

Processing

While there are a few free, open source SfM software options available, we used program Agisoft Photoscan to process the data and goes through the several steps to create the final products. There are several advantages to using Photoscan, the first being that the software can incorporate GPS camera positions into its calculations. This helps to reduce processing time as well as georeference the final files without relying on ground control points. Another perk to the Photoscan software is that it allows for batch

processing. This means that all of the processing steps can be set up before-hand and left to run rather than having to manually initiate each step. With an average of 853 pictures taken per flight area (table 1), it could easily take 12 hours or more to process one flight, so the batch processing was key.

To process a new flight's worth of photos, first, the photos from the camera were matched up with their associated metadata (ie. GPS data) that was collected by the drone as it flew and extracted onto the handheld Yuma computer at the end of each flight. Once back at a computer, Agisoft Photoscan is opened and the photos are imported into a new project. A batch process is then set up to process the photos in the following order. First, the photos are then aligned with each other and since they have associated GIS data, this can be used to help speed up the alignment process. Next the geometry is constructed; first a sparse point cloud (fig. 13), and then a dense point cloud (fig. 14) that illustrates the points of overlap. It is during the construction of the point cloud that the various qualities (from low to very high) can be selected for the final product. This affects both processing time and the output because while a lower quality takes less time to construct, the end result is not as accurate as one constructed at a higher quality. While we were in the field we processed the data at a medium setting and the results were fairly good. Once we got back in the US however, Drs. Lipo and Lee used their resources at CSULB to reprocess the images at a high resolution. To do this processing myself would have been lengthy and redundant so I used the outputs of these re-runs as my data.

After creating the dense point cloud, the next step is for Photoscan to create a wire frame (fig. 15) and then a solid surface (fig. 16) using these points. This helps to

create a dynamic, continuous, 3D surface and fill in any gaps that may occur in the data. Shading and texture (more imagery coloration) are then overlaid on top of the solid surface (fig. 17 and 18). The result of these steps is the final 3D model. During the model construction process, the images are processed in a way that creates a composite image of the photos as well as a topographic landscape this means that an orthophoto (fig. 19) and DEM (fig. 20) for the area can easily be exported and saved as their own files. This process was repeated for the data from all 26 flights.

One of the trade-offs that must be considered when performing SfM is resolution and time. The closer to the ground an image is taken, the higher the resolution will be but conversely, the picture will be smaller and much more time must be taken to get imagery of the whole desired area. The opposite is also true, pictures that are taken farther away from the earth's surface cover more area and less of them are needed but the resolution is not as good.⁵⁰ For our flights we flew at a 100 meters off the ground and the resulting resolution was about 3cm².

⁵⁰ Johnson et. al. 2014

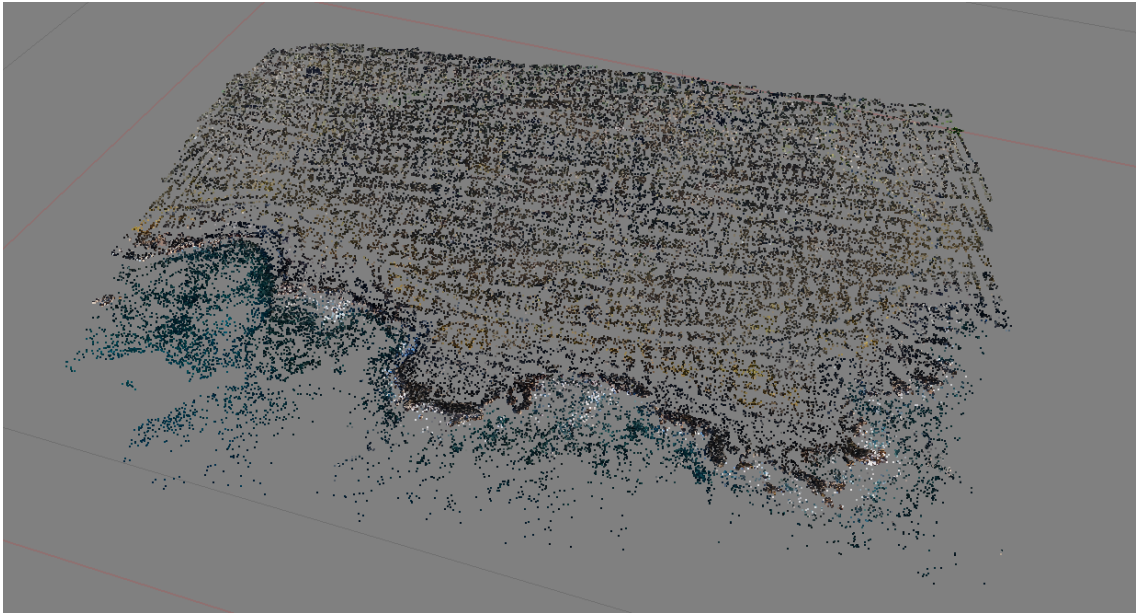


Figure 13. Photoscan Processing: Sparse Point Cloud

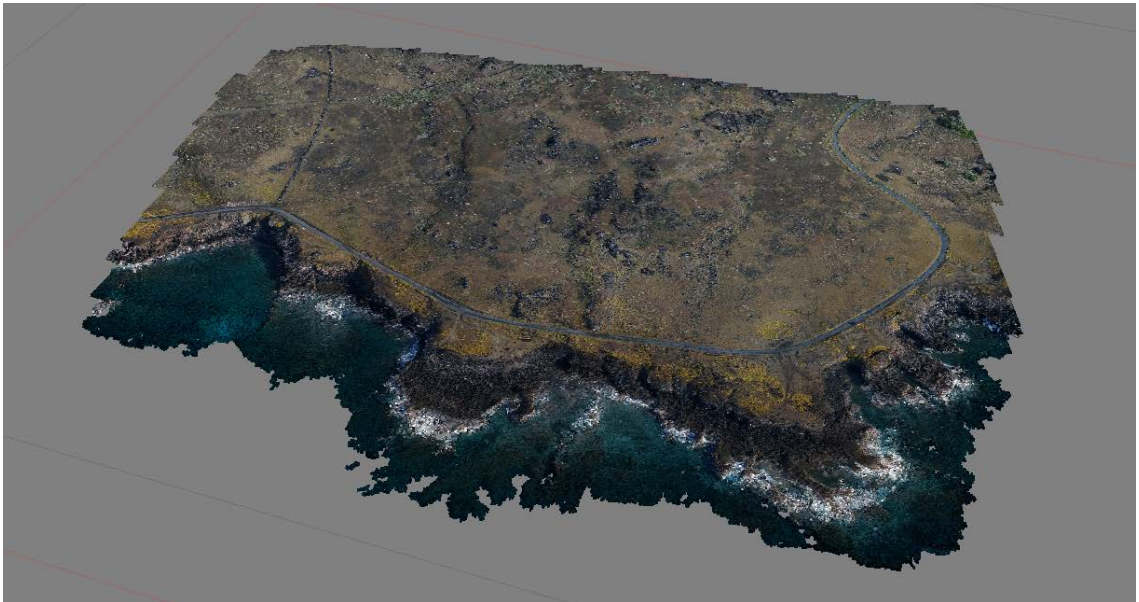


Figure 14. Photoscan Processing: Dense Point Cloud

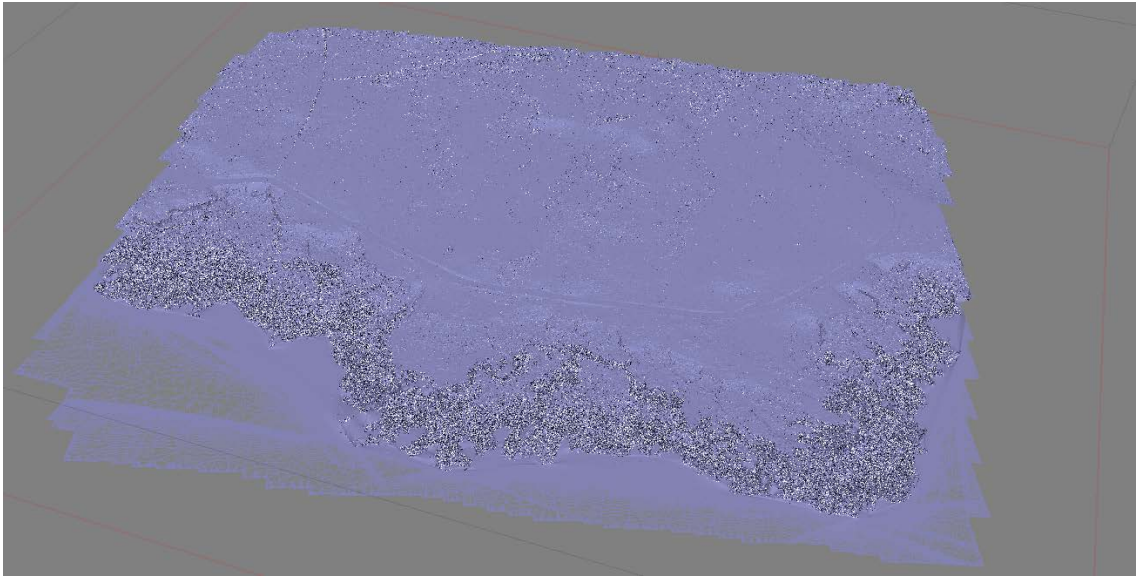


Figure 15. Photoscan Processing: Wireframe

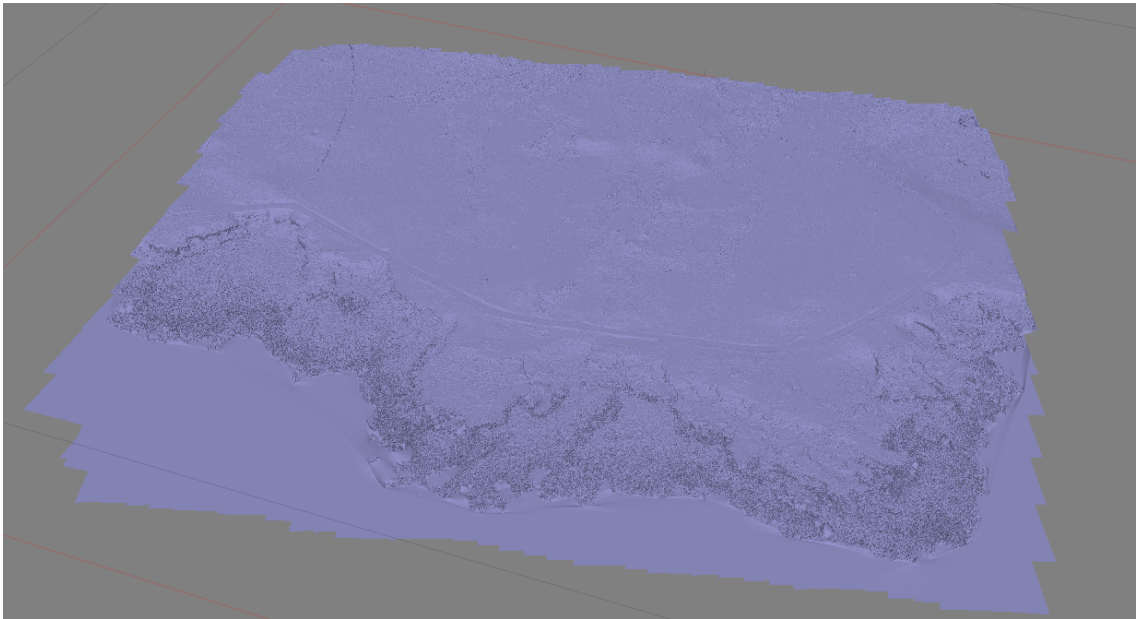


Figure 16. Photoscan Processing: Solid

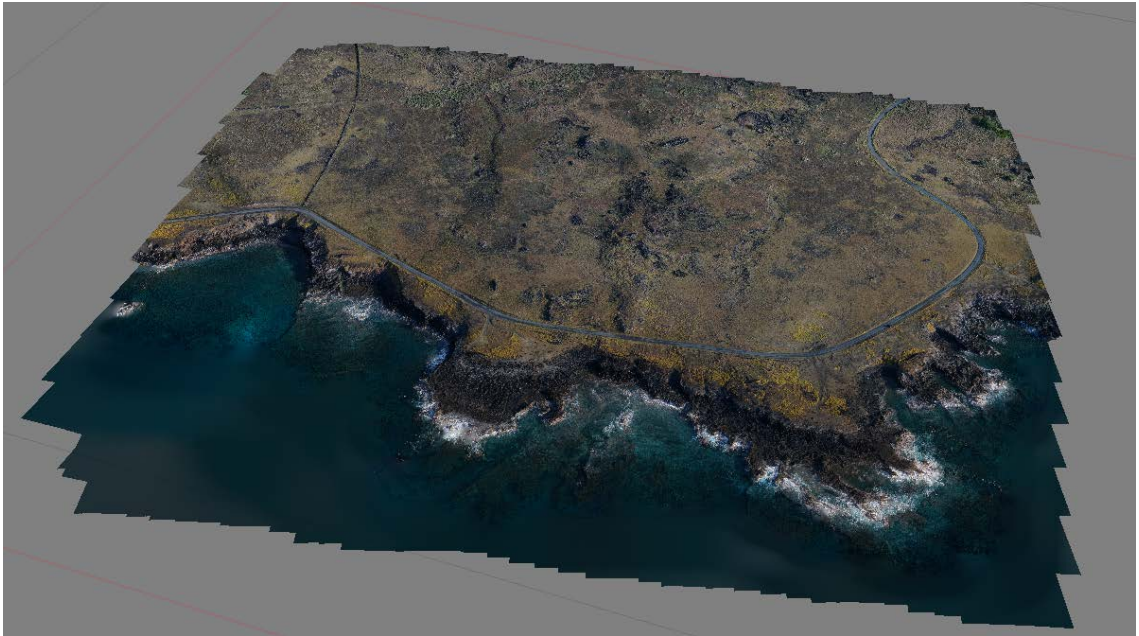


Figure 17. Photoscan Processing: Shaded

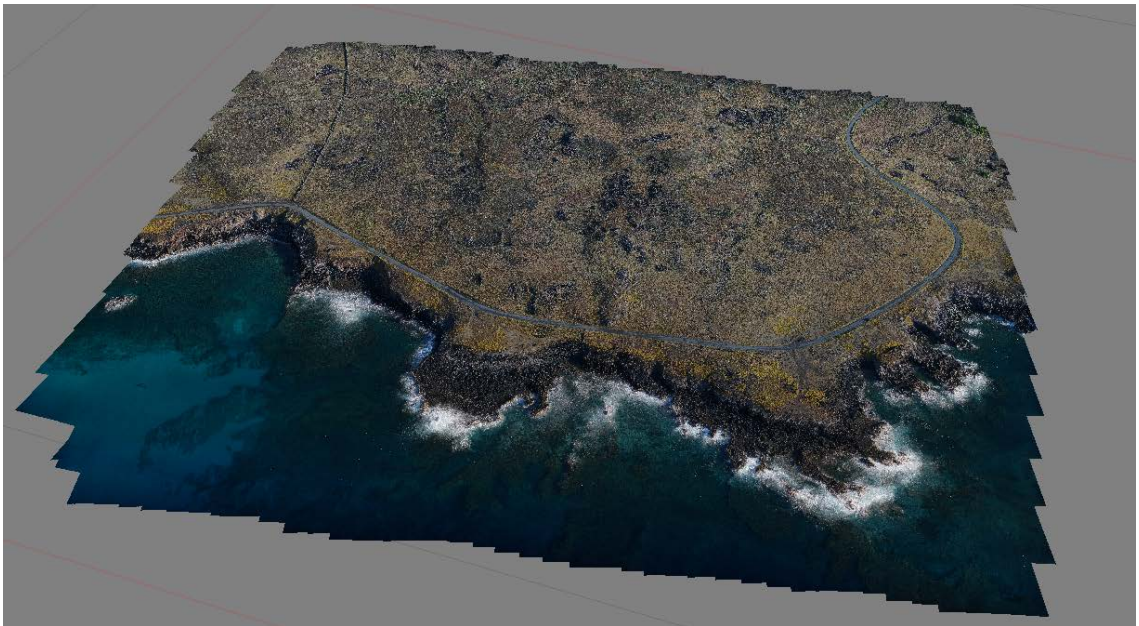


Figure 18. Photoscan Processing: Texture

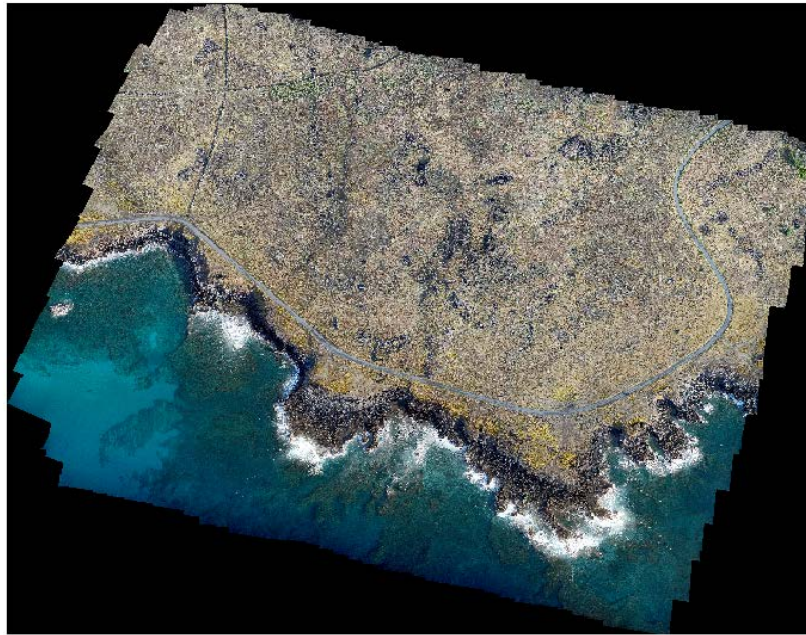


Figure 19. Photoscan Processing: Orthophoto Output

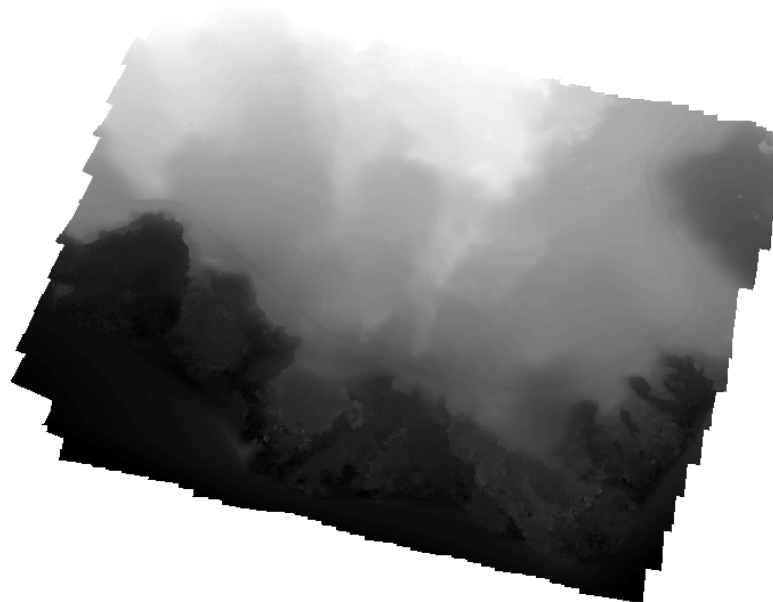


Figure 20. Photoscan Processing: DEM Output

In this DEM the lighter color corresponds to higher elevation. If desired, this coloring can be changed.

Errors

While SfM is a highly useful tool to process data, the process is not without its share of room for possible errors. The major possibility for error in the output features is tied to the errors in the drone's GPS location. This arises because GPS, especially consumer-grade GPS, has a margin of error; it's only accurate up to a certain point. This margin of error is due to the way the system works. GPS devices receive signals from different satellites and use the transmitted information to carry out trilateration calculations in order to pinpoint their location on earth. The error results from the fact that most GPS devices are only accurate to ten nanoseconds which is important since knowing when and where a satellite transmitted its data from is important critical to the calculation. Additionally, the transmitting microwave signals travel at the speed of light and this in conjunction with the limited timing accuracy equates to about a three meter error (in x, y, and z directions) for all GPS locations.⁵¹

As we collected our data over a number of different days, different satellites in different positions were used for trilateration and locating purposes. While the resulting position trilateration is still accurate for GPS, it may be slightly different than information provided by the satellites being used a day prior. Another possibility for error is due to the atmosphere. As the microwave signals are transmitted between the satellites and earth, molecules and particulates in the atmosphere distort the signals being sent. Though mathematical equations can correct most of this error, certain varying locational atmospheric disturbances cannot be accounted for.

⁵¹ "GPS Accuracy and Error Sources." Mio Technology Corporation

As errors in GPS location can affect the data, the result can come in the form of the output topographic data being shifted or tilted, it can also include bending, shrinking, stretching.⁵² This data warping can also result from the picture itself. When a 2D image is taken of a 3D, curving landscape, distortion occurs. If an aerial picture is taken looking vertically straight down at the ground, some distortion occurs, especially around the edges whose light has the farthest distance to travel to be captured by the camera. Most of this error can be corrected for by algorithms and is in fact the definition of an orthophoto, a photograph that has been geometrically corrected so that it can be used like a map. Since the images used for this project were taken relatively close to the ground compared to using satellite imagery or photos taken from a manned plane, this should help to limit the distortion. Additionally, combining all the photos together with Photoscan should help to decrease error as there are a number of visual references for every location; the randomness of the error associated with each individual photo should help to counteract the random error in other photos when meshed together so the final composite datasets have less than 3m of error in all directions.

Recently, studies have found that a doming effect occurs in the final resulting composite images of topographic SfM DEMs. In essence, this means that the middle of the DEM bulges up slightly. This is thought to be a result of combining near-parallel imaging directions in tandem with radial lens distortion. This error can be

⁵² Johnson et. al. 2014

reduced by the inclusion of oblique images into the mix of analyzed photos.⁵³ I did not test for, nor correct for this doming affect however, so it could be influencing the data.

ArcGIS Processing

ArcGIS is a Geographic Information System (GIS) developed by ESRI (Environmental Systems Research Institute). ArcMap is the main program of the ArcGIS software suite and allows the user to view and edit geospatial information in order to create maps from datasets. While there are open-source GIS options available, I chose to use ArcGIS because the University of Oregon has the software licensed and available to use on most of its PCs and it also has the extensions I needed to process the data. I have also taken some classes that have used it and so am familiar with the program.

There are two main types of data that can be used in/processed by ArcGIS. One is vector data, vectored polygons and points that generally come in the form of shapefiles. These various shapes can be visualized and modified and also have associated data in attribute tables. The other form of data is raster data. Rasters are a grid of cells/pixels where each cell has value that represents some form of information. Digital imagery falls under this category and thus so do the orthophotos and DEMs created as outputs from Photoscan.

While we flew a total of 26 flights while on Rapa Nui, for my analysis I only used the 23 that took place along the south cost (the images from two flights had been

⁵³ James and Robinson, 2014.

combined on island to provide a composite output for a local so I actually used only 22 files). We flew our flights on the island in a rather patchwork manner so there was no correlation between the flight numbers and the images' position along the coast. Thus, the first thing I did was order and rename the files providing each with a number (N) so that there was a general sense of moving from west to east along the south coast as N increased (table 1).

With some organization established, I then imported the orthophotos and DEMs into ArcMap. While these files had geographic extents (longitude and latitude points) associated with them due to the camera GPS data for each image, the coordinate system they were associated with was a Geographic Coordinate System (GCS). This places points based on a global/spherical surface which can be a problem when viewing data on a flat surface. When there is no consistency amongst the coordinate systems used problems arise when comparing and joining data features. Thus, I re-projected these files into a Projected Coordinate System (PCS). A PCS is created through the mathematical conversion, or projection, of our three-dimensional world onto a flat two-dimensional plane. As a result there are constant areas, lengths and angles across the surface. One side effect from the 3D to 2D transformation is that there is some distortion, especially in areas that are closer to the edges. In order to minimize this, a projection is generally chosen that places the desired area at or near the center. There are many different projections, but I chose to transform my files so they were in the ESRI designated PCS, "WGS 1984 UTM Zone 12S." UTM zones are based on the Universal Transverse Mercator projection and encircle the globe with each zone being about six degrees of longitude wide. UTM zone 12S is the one associated with the area

where Rapa Nui is located. Since the earth's curved surface is transformed into a flat plane, a coordinate system is superimposed onto the surface. Except for the polar regions, the UTM coordinate system is used to "flatten" all the zones using the Transverse Mercator projection. The "WGS 1984" refers the World Geodetic System of 1984 which is the datum the projection is based on.⁵⁴ Datums reference specifications of a measurement system and are important factors in a projection because the projected coordinates are based on geographic coordinates which in-turn reference a datum.⁵⁵

Ahu and Coastline Identification

Once the files were projected, I opened up all the orthophotos and used them to identify and mark all the *ahu* along the south coast. While the major *ahu* along the coast have been noted by many, I felt that it was necessary to go through myself because the aerial view and resolution of our orthophotos gave me a unique perspective to identify the long low shapes of the *ahu*. Additionally, this would ensure consistency throughout the data. To mark the *ahu*, I created a new shapefile in ArcCatalog and then used the Editor tool in ArcMap to added features to it. Wherever I saw an *ahu*, I placed a point on it and added information about in in the attribute table (fig. 21) (table 2). I recognized *ahu* as low, long stone structures, generally with a fatter, denser, or taller center and thinner, less dense, or lower "wings." This recognition resulted from a number of factors. One was that I used an already established dataset of *moai* and *ahu* locations (though the *ahu* in this dataset were not categorized). I checked out these markers and ensured they corresponded with my orthophoto locations in my newly

54 "UTM - Universal Transverse Mercator." UTM: Projection

55 "Support." Datum. ESRI

created vector file. From these already established *ahu* locations, I extrapolated out to include further similar features that seemed to follow these established shapes and guidelines. I also used the knowledge I had gained on Rapa Nui about how to recognize *ahu* (the strong retaining wall in the back, etc.) to help identify these features for the data set.

As I was going through, I classified each *ahu* as one of four categories. These categories were “image ahu,” “ahu,” “ahu?,” and “image ahu?” Those classified as an “image ahu” had *moai* clearly associated with them, this generally meant there were fallen statues (or parts) near the platform (fig. 22). To be classified as “ahu” there had to be a clear *ahu* shape and no nearby *moai* (fig. 23). There were a number of features, however, that seemed close to an *ahu* shape but I had some doubt about whether it truly was an *ahu* or was actually just a bit of wall or extended lithic-mulching area so I classified these as “ahu?” (fig. 24). This is the only way I categorized the *ahu* and I did not attempt to include notation or distinction to *ahu* in regards to construction chronology or other features that may differentiate them. As a result, my spatial analyses are pure ones, as they assume time is not a factor.

Another initial step I took was to modify the shapefile of the Rapa Nui coastline. The initial file I downloaded was a series of vector lines indicating the shoreline for all of Rapa Nui. As I only needed to look at the south coast, I edited out the northerly sections as well as the small islands and bits of rock off the coast. In addition, I went along and, using the orthophotos as a guide, edited the coastline to match what the images were showing me. The initial outline was a bit courser than what I could see with my imagery and sometimes the features indicated didn’t quite match. Thus, going

through and manually adjusting helped to improve the resolution and accuracy of the coastline. This was important as I would use the vector file later for processing data.

It should be noted, however, that in reality a shoreline, is an area, not a line; as tides move in and out the shore changes. Thus, while better, my modified coastline still has some error in it. I tried to get the line to match up with what the tideline according to the orthophotos but in many cases it is still a general match. If there was water right up against a cliff, I would leave room to ensure I wasn't cutting off any data associated with the cliff and if there were low rock formations jutting out into the ocean I generally included them.

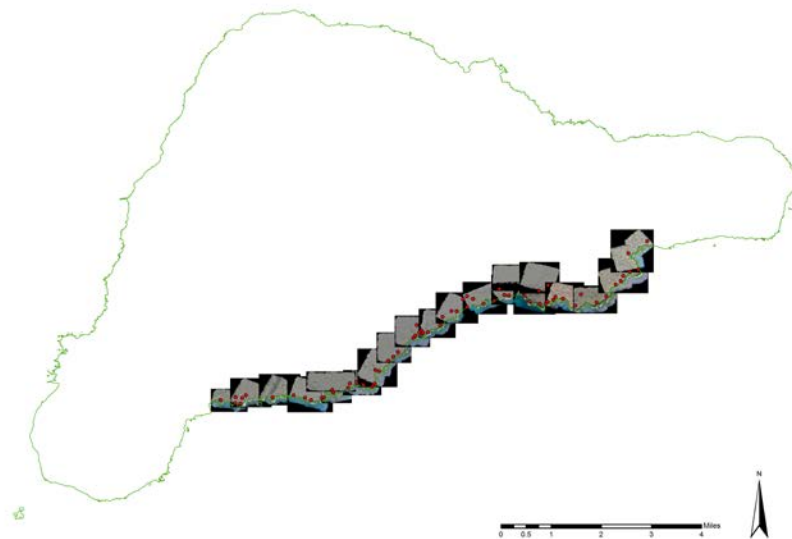


Figure 21. South Coast Orthophotos and Ahu Points

All 22 orthophotos placed along the south coast of Rapa Nui. The red dots indicate *ahu*.



Figure 22. Identifying “Image Ahu”

The large grey stone in the middle of the platform are identifiable as the body of fallen *moai*



Figure 23. Identifying “Ahu”

This ahu has the very clear oblong shape and no nearby *moai*



Figure 24. Identifying “Ahu?”

A series of images of *ahu* that I considered to be questionable. I was unsure if these were actual *ahu* or historic walls with rocks piled around. The enclosed areas in the bottom right picture are clearly *manavai*.

Batch and Model Data Processing

Processing this data was time-consuming. This was mainly due to the fact that I was dealing with large raster files that require a long time to analyze due to their size and the amount of information they hold. In addition, though I was examining features along the continuous coast, the data I had for the coast was broken up into twenty-two pieces. Though I tried to join the raster features together to create one raster, the files were too big to make this reasonable so each step needed to be repeated around twenty-two times in order to get data for the whole coastline (if it involved the coastline, this

number was nineteen because three flights were more inland and contained no actual coastal data).

To make this process easier I used the ModelBuilder feature in ArcMap to help automate the process. ModelBuilder allows you to build a visual flow-chart of your process rather than running each tool by hand. The major advantage to this is that it allows the user to iterate through datasets, applying the same processing to all the files indicated (fig. 25). This made it much easier for me because certain processes I could set to run and then just wait until the computer finished processing all the files.

Unfortunately, I was not always able to use models in helping me process data due to the limits on iterators. In ModelBuilder, iterators allow the same tool/function to be run on multiple files within a database but the program only allows for one iterator at a time. This was fine when I was using a shapefile that contained data for the entire coastline (ie. vector data associated with *ahu* or the coastline) because I would simply extract the data within the set parameters associated with that area from each raster. Some situations, however, called for two iterators. This was when data was processed using information previously extracted from the individual rasters and thus existed as its own file rather than as one continuous one. In these instances it was possible to use batch processing. This was not quite as convenient because each file must have all its information entered manually into a table (input file, output file, extents, etc.) rather than have a computer automate the process. Once it is done though, all the files can be completed in one run rather than having to repeat the process after each one finishes running.

Additionally, as each of the flight files were processed separately, they also had separate outputs. This is not as important when the outputs are shapefiles or rasters because they can be viewed in ArcMap at one time and any future processing can occur in the same manner as before. When this becomes a problem is when the outputs are data tables. With each flight area being processed separately, the data associated with one tool can end up spread amongst 19-22 different data tables. In order to fix this, I would merge all of the data table files together in order to create one big table. The problem is that while the resulting table would have all of the combined output data, it wouldn't have the *ahu* category information I had assigned to each point. It was important that the tables have this material so that I could use it to separate out the data associated with each type of *ahu* (*ahu*, *image ahu*, etc.). In order to attach a category column to each data table, I would perform a join. In ArcMap, a join allows data to be added to an attribute table based off of a common field. This means that additional information is not just tacked onto a table, but systematically matched so that the correct associations remain.⁵⁶ For these tables, as the general identification information remained with the output datasets, I was able to use that as a shared column to bring all of the information into one table. The table would then be paired down as some of the information was redundant and unnecessary. The final tables are the ones that can be seen in Appendix B. This process was followed for most of the output data tables.

Another problem that arose from processing what should be a contiguous area artificially broken up into flight areas is repetition. The flight areas overlapped each

⁵⁶ "ArcGIS Help 10.1." ArcGIS Resources. ESRI

other in order to ensure data was collected for the whole coast but the side effect was that some *ahu* were captured multiple times. When it came time to process the data, these features would then receive associated information from each flight area they fell within. Thus some features had more than one set of associated data. This caused problems because some datasets were cutoff if they were close to the edge of the flight area making them incomplete, while when overlap occurred data was repeated within the two outputs.

A singular feature should only have one set of associated data so I processed the data to achieve this. How I went about doing this depended on the data in question as well as how the overlap affected each data set. For some, it was easy because a feature that lay on the edge of one flight might not be on the edge of the other, this meant that the data associated with the area not cut off by an edge was used while the incomplete data was rejected. Other times, the complete data set was not contained in any one flight area. To make sure all the appropriate data was associated with each feature, I would clip down the resulting data so that it didn't include the overlapped area (this data remained in the unclipped section of data) and then would add this data together to get a single complete data value associated with each figure.

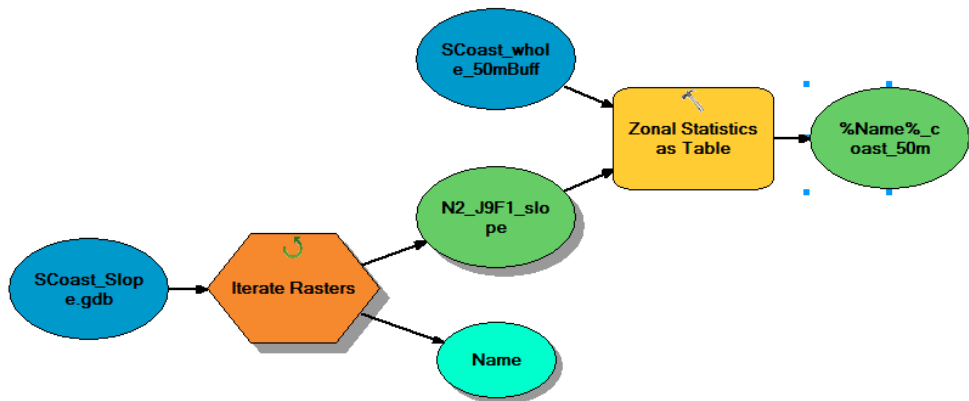


Figure 25. ModelBuilder Example

This model is set up to run the tool “Zonal Statistics as Table.” The data being analyzing comes from the rasters being iterated through within the “SCoast_Slope” geodatabase. The data provided by these rasters is examined within the area parameters dictated by the file “SCoat_whole_50mBuff” and this information is processed and results in a saved output file “%Name%_coast_50m.” the %Name% means that the first part of the saved file name is the individual file name from the extracted raster. I created other models like this one to run other tools and iterate through other datasets.

Removing Extraneous Data

In order to get more accurate data regarding the topography, it was necessary to remove the data associated with the ocean. In order to capture the coastline, and given its rectangular flight paths, the drone flew over a good deal of water. This data was encompassed in the original orthophoto and DEM outputs but if it was left included in the data, the elevations associated with the varying wave height would add inaccuracies to the terrain (fig. 26). I went through several steps in order to remove this part of the data.

First I used the Feature to Polygon tool on all of the DEMs. This created a polygon of the area encompassed by each flight area raster (I used the DEM data to ensure that the outline was that of the images and did not include the black areas around the orthophotos as a result of trying to make them a rectangle). Then I used the merge tool to combine each new polygon with the coastline vector. When this was done, the newly created output files contained a polygon outline of the flight area that was split into two pieces along the path of the shoreline. This allowed me to go in and edit out the area associated with the ocean. The result was a set of polygons that matched the flight areas on their land side, but their southern side conformed to the coastline (fig. 27). These polygons were then used in conjunction with the Clip Raster tool to extract a reduced raster area so that each raster only contained terrestrial data. With ocean associated data gone, when analysis tools were run, no irrelevant ocean data would be included in the results.

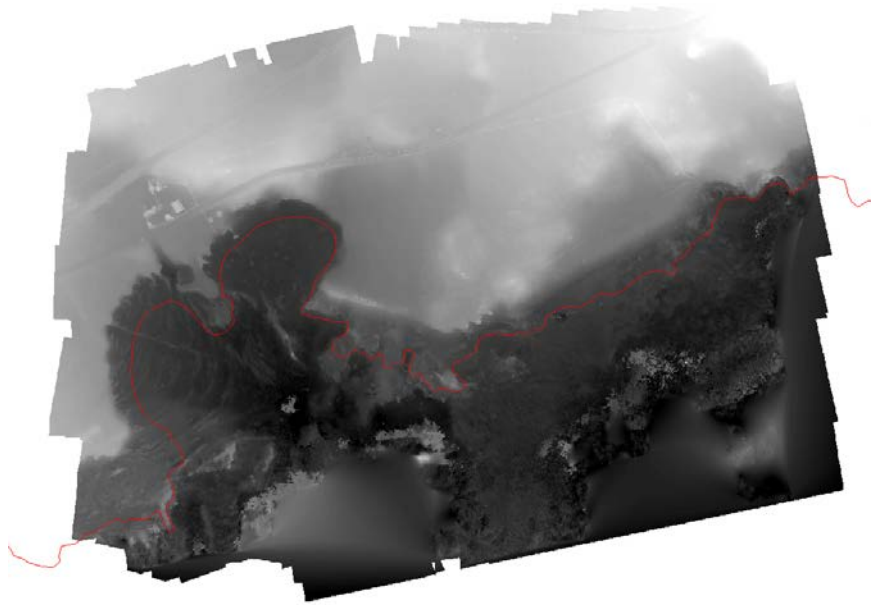


Figure 26. Removing Extraneous Data Before

This image of a flight's DEM shows how much of the data is water. The red line is the coastline and everything below it is data resulting from the ocean and thus not useful in assessing topography.



Figure 27. Removing Extraneous Data After

This is the same DEM as the one above in fig. 26 but the undesired ocean data has been removed at the coastline.

Elevation and Viewshed Analysis

I started to analyze the *ahu*-topography relationship by looking at the elevation of each *ahu*. While I had points marked where each *ahu* was located, I decided not to use a single point to collect elevation data as it would be giving a lot of weight to one single point in the raster. In reality the *ahu* are large and the resolution of my data is very high so I used a uniform area to get a more representative measure of the local elevation rather than a rock I may or may not have placed the marker on. I created a five-meter buffer around each *ahu* point which I used as the polygon input when I ran the Zonal Statistics as Table tool (fig. 28). Having the buffer polygon was essential in order to extract the raster data for the area because extracting data from a raster is messy due to the large amount of it. In an attempt to minimize the processing work and time, the Zonal Statistics as Table tool requires a pre-defined area as determined by a shapefile and the tool then summarizes the raster data found within that space. This data is then outputted as a tables which I merged together.

In addition to looking at general elevation relationships, I also wanted to analyze how each *ahu* was located in relationship to its surrounding topography in general. The tool I used to help me look at this was the Visibility spatial analysis tool. This tool is essentially a combination of two other tools, Viewshed and Observer Points, that analyze topography in relation to points in order to determine lines of sight/areas of visibility. When it runs, if there is a large structure or hill that can block visibility the tool will indicate in the output raster that the areas behind it are unable to see the indicated point. In order to run, all of these tools require a DEM (or elevation

equivalent) as well as a set of points to analyze the visibility of, in this case these points refer to the *ahu* locations.

The Visibility tool allows you to collect data in one of two ways, one is by frequency (essentially the Viewshed tool) and the other is by observers (the Observer Points tool). The input data is the same for both and visually the outputs look the same (fig. 29) but the main difference lies in how the visibility data is recorded. With frequency, the number of observers who can see a specific location is calculated but no indication is given as to who those observers are. As a result, the attribute table for the created visibility raster is fairly small and only has a couple columns. With observer points, however, the output attribute table indicates exactly which observers can see which areas. For this sort of analysis, the table looks like a matrix. Each observer point is a column and the rows represent various groups of locations within the DEM. If an observation point can see a certain group of locations, a “1” is placed in that row for the observer. Thus, the areas that can only be seen by Observer 1 only have a “1” in the Observer 1 column. If there is a “1” placed in the columns of both Observers 1 and 2 though, this means that both those points can see those associated areas.

For my purposes, I preformed my visibility analysis using the observer points because I wanted to get a precise area of observation for each *ahu* point and the matrix data table was much more conducive to that. First, though, I had to set up my parameters. Visibility is affected by a number of factors and the ArcGIS tool allows for these to be factored in. Parameters can constrict the vertical angle and direction of sight as well as how far the visibility extends (earth curvature can be automatically factored in) but I left these at their default settings; the two that I adjusted were the offset A and

offset B. The amount of these offsets, indicate a vertical addition to the surface elevations (z value) with offset A referring to the observation point and offset B referring to the observed areas (the rest of the topography). These are important parameters to include in order to take into account the height associated with the people doing the observing. In order to incorporate it, two new columns must be created in the attribute table of the observation points. For me this was my shapefile of *ahu* points and for both offset columns I instructed an offset of 1.75, about the height of a person (the DEM is in meters).

While the Observer Points tool preforms the same sort of analysis as the Visibility tool, I chose to use the visibility tool because it allows for the non-visible areas to be ignored which made the resulting matrixes simpler. One aspect of the tool, however, is that it can only analyze up to 16 observer points at a time so I split up the points into 6 smaller groups that conformed to the edges of the flight areas and made them their own shapefiles which I used to run the visibility tests. I then used these attribute tables to ensure that each observation point was correctly matched up with its associated *ahu* ID (the output tables had columns numbered OBS1-16). In order to get the total observable area for each of the *ahu*, I selected out all the areas associated with each *ahu* point (rows with “1”) and then summed this area together. This ensured that the area associated with an *ahu* was not just the area it alone could see but also the area that could be seen by multiple *ahu*.

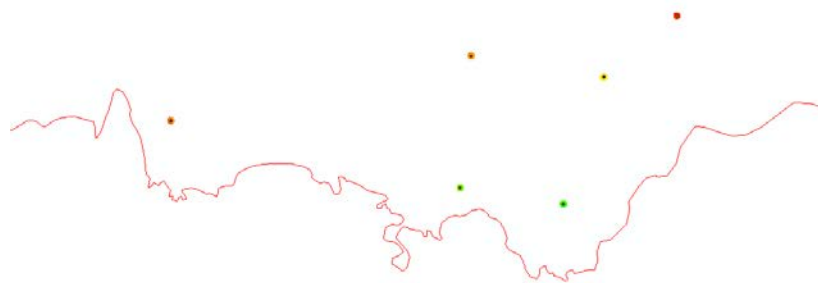


Figure 28. Elevation within 5m of *Ahu*

The relative elevation around each point is indicated by the color of the 5m circle with green indicating lower elevation and orange/red higher. The red dots are ahu, the yellow image ahu, and the grey unsure (ahu?).

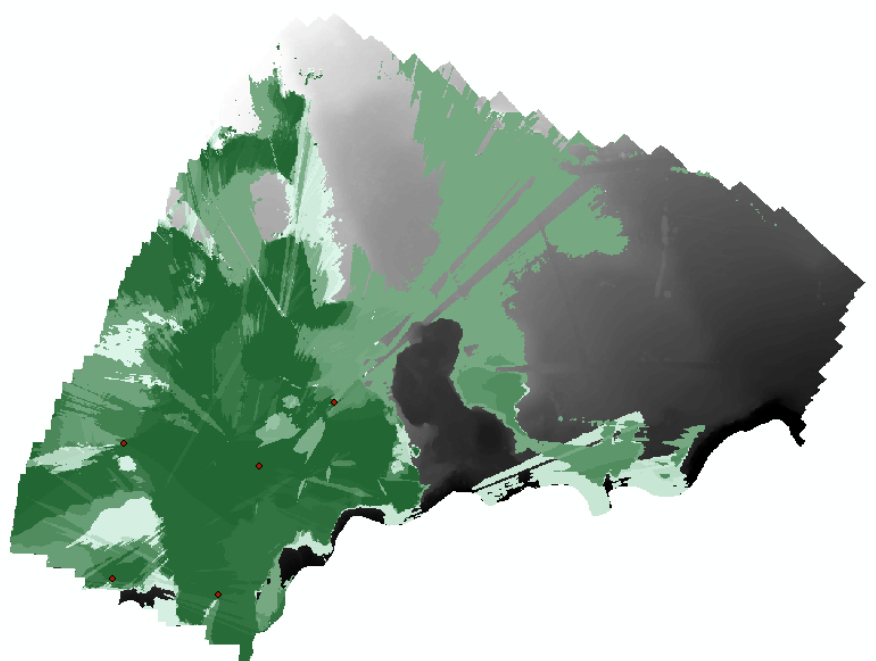


Figure 29. Visual Raster Output of Observation Points

The colored areas represent the areas visible to the five *ahu* points located within the DEM. The dark green represents areas that are visible by many locations while the light green areas are areas of low visibility. The area that are not green cannot be seen by, or see any of the *ahu*. The gray-back background is the flight area DEM underneath the Observation Point raster layer.

Extracting Slope Data

The first step I took towards collecting data about the slope along the South Coast was create slope rasters for all the flight areas. This was done using the DEM and the slope spatial analysis tool which looks at the elevation data associated with a single raster cell and then compares that to the data from the cells surrounding it in order to determine a slope gradient. The resulting files showed the slope for their respective areas in decimal degrees.

I established a set area of 50 meters within which the slope data would be analyzed. I did this because I was interested in getting a general feel for slope in an area and at my high data resolution the slope data for a single point generally had little meaning. Fifty meters was a decision I made as it seemed to allow for the cliff area to always be included in the coastline buffer and gave some room on either side of the *ahu* for slope variation. Establishing a set area also helped to keep size consistency throughout the data which was important for later statistical analysis. I realized that comparing slope data from around *ahu* and the coast would not necessarily be that useful since a number of *ahu* are not right along the coast, so for each *ahu* I calculated its closest point along the coastline vector (table 3). The resulting table had X,Y coordinates for each of the resulting locations and I used those to create a new shapefile of vector points along the coast. I then created a 50 meter buffer around these points as well as a 50m buffer along my coastline. I also made 50 meter buffers around all of the *ahu* points as well.

Once I had these polygon areas, I used them to cut and extract slope data from the larger slope raster files. To visualize the data I used the Raster Clip tool to clip the slope rasters using the 50 meter buffer created around the closest coast points and I also clipped them with the 50 meter coast buffer. The fact that I could now look at the slope in these areas in isolation was more for my own personal viewing to see the area and data collected rather than for data collection but I found it helpful in understanding exactly what data was being analyzed (fig. 30, 31, 32). To actually collect the slope data for these modified area, I used the Zonal Statistics as Table tool in combination with the already created buffers to act as the constraining boundary for the statistical summary. I collected this data for the 50 meter buffered stretch of coastline (table 7), the 50 meters around each *ahu* (table 8) and its associated closest coast point (table 6) and processed the resulting sets of data tables.

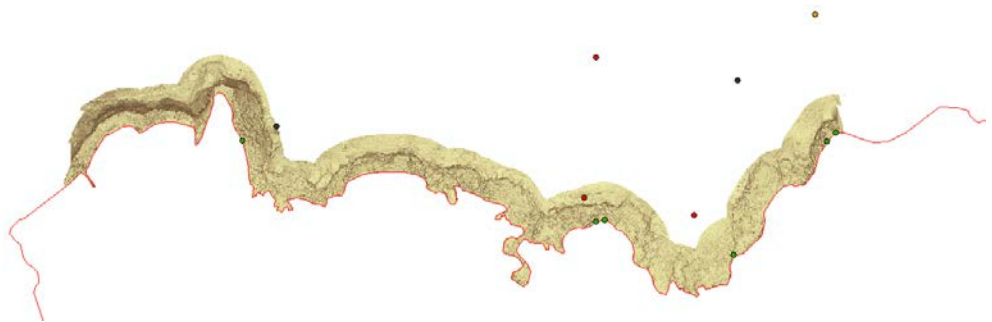


Figure 30. 50m Coast Buffer Isolating Slope Data

This image shows one section of coast slope data. The darker brown areas indicate a steeper slope while the lighter areas show gentle to no incline. The red line is the coastline and the ocean data below that line has been removed so only the land data is analyzed. The green dots represent the closest coast points, the red dots ahu, the yellow dots image ahu, and the grey dots unsure ahu (ahu?).

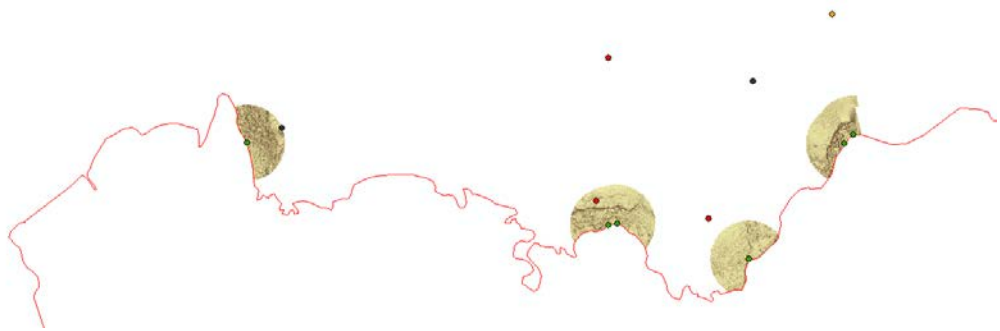


Figure 31. 50m Closest Coast Points Buffer Isolating Slope Data

This image shows the slope data surrounding 50m of the closest coast points for *ahu*. The darker brown areas indicate a steeper slope while the lighter areas show gentle to no incline. The red line is the coastline and the ocean data below that line has been removed so only the land data is analyzed despite that the buffers used to extract this data were circular. The green dots represent the closest coast points, the red dots *ahu*, the yellow dots image *ahu*, and the grey dots unsure *ahu* (*ahu?*).

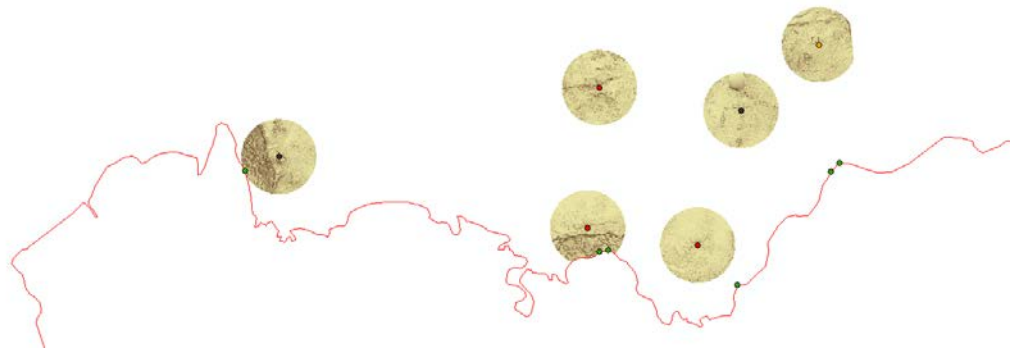


Figure 32. 50m Ahu Buffer Isolating Slope Data

This image shows the slope data surrounding *ahu* for 50 meters. The darker brown areas indicate a steeper slope while the lighter areas show gentle to no incline. The red line is the coastline and the ocean data below that line has been removed so only the land data is analyzed meaning that some buffers are not analyzing a complete circle of data. This is also the result of the edge of the flight area. The green dots represent the closest coast points, the red dots *ahu*, the yellow dots image *ahu*, and the grey dots unsure *ahu* (*ahu?*)

Part 4: Data Analysis and Discussion

I organized my data into several questions around which I ran a series of statistical tests. For the most part, these questions revolve around seeing if there is a topographic difference between regular ahu and image ahu through the various ways I used to measure the landscape (ie. elevation, slope, visibility) but there are some questions that are about comparing *ahu* associated features with the overall topography of the South Coast.

1. Are image ahu at higher elevations than ahu? (Table 3, Appendix B)
2. Do image ahu have a larger viewshed than ahu? (Table 4, Appendix B)
3. Are image ahu closer to the coast than ahu? (Table 5, Appendix B)
4. Is the coastal slope near image ahu less steep than the coastal slope near ahu? (Table 6, Appendix B)
5. Is the coastal slope near image ahu less steep than the general slope of the coast? (Tables 6 & 7, Appendix B)
6. Is the coastal slope near ahu less steep than the general slope of the coast? (Tables 6 & 7, Appendix B)
7. Is the ground slope around image ahu steeper than the ground slope around ahu? (Table 8, Appendix B)

Is the ground slope around image ahu steeper than the ground slope around ahu?

In order to help answer these questions, I made use of the open source statistics computer software R. R is a programming language and software environment specifically tailored for dealing with statistical computing and graphics. The software provides a platform that makes analyzing data and computing statistics much easier. My use of the program mainly focused around running one type of test because, though the

questions and data varied, a t-test could be used to answer all of the topographic relationship questions I'd asked.

A t-test is a statistical hypothesis test which uses the average of a group or population in relation to the variation in the data to determine significance. There are a couple different types of t-tests that can be used in different situations but I used a two-sample t-test that compares the mean of two independent samples to each other. Like most statistical tests, a t-test operates on the assumption of a null hypothesis (H_0). Often this is a general statement that assumes no effect or difference between groups.

Opposite the null hypothesis is the alternative hypothesis (H_A) which is the statement hoped to be proved true. It is important to have null and alternate hypotheses because it clarifies the goals of the statistics and helps to ensure that the statistics have purpose.

The null and alternative hypotheses for my seven questions are:

1. "Image ahu **are not at** significantly higher elevations than ahu" (null) and "image ahu are at higher elevations than ahu" (alternative). This alternative hypothesis is founded on the concept that image ahu are costly signals so higher elevation is preferred as discussed in the sections "Costly Signaling and Water" (p. 18), "Topography" (p. 22), and "Visibility in Archeology" (p. 25).
2. "Image ahu **do not have** significantly larger viewsheds than ahu" (null) and "image ahu have larger viewsheds than ahu" (alternative). This alternative hypothesis centers on the concept that image ahu are costly signals so locations with greater visibility are preferred as discussed in the sections "Costly Signaling and Water" (p. 18) and "Visibility in Archeology" (p. 25).
3. "Image ahu **are not** significantly closer to the coast than ahu" (null) and "image ahu **are** closer to the coast than ahu" (alternative). This alternative hypothesis is based on the concept that image ahu are markers related to coastal water resources so distance to these resources would be a concern as discussed in the sections "Costly Signaling and Water" (p. 18) and "Topography" (p. 22).
4. "The coastal slope near image ahu **is not** significantly less steep than the coastal slope near ahu" (null) and "the coastal slope near image ahu **is** less steep than the coastal slope near ahu" (alternative). This alternative hypothesis

is founded on the concept that image ahu are placed in relation to coastal access to water and that less steep slopes provide easier coastal access, as discussed in the sections “Costly Signaling and Water” (p. 18) and “Effect of Slope on Walking” (p. 23).

5. “The coastal slope near image ahu **is not** significantly less steep than the general slope of the coast” (null) and “the coastal slope near image ahu **is** less steep than the general slope of the coast” (alternative). This alternative hypothesis is also based on the concept that image ahu are placed in relation to coastal access to water and that less steep slopes provide easier coastal access as discussed in the sections “Costly Signaling and Water” (p. 18) and “Effect of Slope on Walking” (p. 23).
6. “The coastal slope near ahu **is not** significantly less steep than the general slope of the coast” (null) and “the coastal slope near ahu **is** less steep than the general slope of the coast” (alternative). This alternative hypothesis centers on the idea that ahu are placed in relation to coastal access to water and that less steep slopes provide easier coastal access as discussed in the sections “Costly Signaling and Water” (p. 18) and “Effect of Slope on Walking” (p. 23).
7. “The ground slope around image ahu **is not** significantly steeper than the ground slope around ahu” (null) and “the ground slope around image ahu **is** steeper than the ground slope around ahu” (alternative). This alternative hypothesis is grounded in the ideas that ahu are markers of fresh water and that steeper slopes on land indicate better access to this water as discussed in the sections “Costly Signaling and Water” (p. 18) and “Topography” (p. 22).

In statistics, in order for the null hypothesis to be rejected and the alternative accepted, statistical significance needs to be proven. This means showing that the difference in the results did not occur by random chance, which comes in the outputs of a t-test

Normalizing Data

Before running a t-test, one concern is whether the data being used in the test is normally distributed. Normally distributed data clusters around the mean of the data set and then symmetrically moves out away from the center in decreasing concentrations. The resulting graphic has a peaked middle and flaring sides which is where it gets the colloquial name “Bell Curve.” Having data that conforms to these general parameters of

normality is generally required for most statistical assessments because it is an underlying assumption for most parametric tests.⁵⁷ Unfortunately, raw data often does not conform to a normal distribution. Rather, data can often be concentrated on one side of the graph rather than being evenly distributed in the middle. This is skewed data. If the concentration is more the left on the graph the data is positively skewed and if it's more clustered on the right the data is negatively skewed.

Skewness is important to consider when doing t-tests because t-tests are parametric tests. This means that one of the underlying assumptions of the test is that the data being compared is normally distributed. Thus, if the data is actually skewed, the results can be false and misleading. There are, however, a number of ways to assess the skewness of a dataset.

One way is that there is an actual equation that can calculate skewness. There are also histograms which are a type of bar chart used to show statistical information. For these graphs, the dependent variable is graphed along the x-axis in numerical intervals of equal size or "bins" and the bars represent the frequency of data associated with each group. The resulting graph can provide a visual for the data's distribution so that a person can assess for themselves. There are a number of other ways to help gauge skewness and luckily in the statistical computer software IBM SPSS (Statistical Package for the Social Sciences), they provide a number of them. Their descriptive statistics option made it easy to get such information for various different data sets. When assessing skewness, there are a couple things to go by. One is simply visually, by

⁵⁷ Laerd Statistics. "Testing for normality."

looking at histograms and other graphic representations as seeing if the data looks off. There are also rules of thumb like normalized data should have a skew value between -1 and 1.

If data are very skewed, this does not necessarily preclude it from being a part of t-test or other parametric test because there are ways of transforming data so that it takes on a more normalized shape. There are two main methods for a normalization transformation, one is through the use of \log_{10} and the other via square-root. By applying these functions to a data set, they help to change its distribution while still maintaining the essence and relationships of its original state. If it is desired to revert, these transformation functions can be inverted. Transformation is also different if the skew is positive or negative. With a positive skew the function can just be applied to the data set but if the skew is negative a reflected transformation needs to occur.

This does not mean, though, that data must be perfectly normalized in order for a t-test to work. T-tests are fairly robust and there are a number of other factors involved like sample size that can affect the shape of the data. Additionally, assessing skewness in smaller sample sizes can be difficult depending on the data. This is what I found with my data. I looked at histograms and q-q plots as visuals but I sometimes found the patterns in the histograms hard to see so I generally went for a more quantitative rather than qualitative approach, using the rule of thumb that skew should be between -1 and 1 and the Shapiro-Wilk significance test should be greater than .05 to indicate normality.⁵⁸

58 Shapiro and Wilk. "An analysis of variance test for normality (complete samples)" 1965

As you can see in the table on skew indicators, it can be hard to get a transformation that works for both of the data sets involved. Even if one data set is normally distributed, if the other data set isn't the same transformation needs to be applied to all the variables. This is because though the relative differences stay the same, the unit of measurement changes which affects the differences between the variables.⁵⁹ From the data, only two sets seemed to already be normally distributed (both the *ahu* groups associated with Observable Data and Slope Around *Ahu*). No transformation adequately worked to help normalize the *ahu* data for Slope Around Closest Coast Points and there were also problems with transformations in conjunction with the Whole Coast Slope data. After having gone through the data and also looked at the accompanying graphics I decided to just leave the data as it was and not transform any of it.

59 Francis and Field. *Discovering Statistics Using SPSS*. 2011.

Table: Skew Indicators

Type of data and type of <i>ahu</i>	<i>Ahu</i> Type	Normal		Log10		SquareRoot	
		Skew	Shapiro-Wilk	skew	Shapiro-Wilk	skew	Shapiro-Wilk
Elevation	Ahu	0.043	0.217	-1.072	0.01	-0.478	0.13
	Image Ahu	1.846	0.004	-0.787	0.25	0.615	0.411
Observable Area	Ahu	0.059	0.462				
	Image Ahu	0.373	0.278				
Distance to Coast	Ahu	0.894	0.075	-0.174	0.45	0.439	0.326
	Image Ahu	1.096	0.003	0.624	0.051	0.879	0.012
Slope Around Closest Coast Point	Ahu	-1.666	0.011	-1.185	0.001	-2.042	0.002
	Image Ahu	-0.884	0.218	-1.476	0.012	-1.185	0.058
Whole Coast Slope		-1.016	0.09	-1.666	0.009	-0.201	0.178
Slope Around <i>ahu</i>	Ahu	0.701	0.148				
	Image Ahu	-0.443	0.179				

This table shows the different values for two tests of normalcy, skew and Shapiro-Wilk as they applied to different data sets under different conditions. Each row “block” is its own set of data and the subset rows indicate the subset divisions of data by *ahu* type. “Normal,” “Log10,” and “SquareRoot” refer to when that transformation was applied to the data. Normalcy for Skew is a value between -1 – 1 and for Shapiro-Wilk it’s any number above 0.05. The two areas are blanked out because their initial data values meet the normalcy requirement.

The T-Test

A t-test is a hypothesis test using the average of one or two data sets. There are a couple different types but I used a two-sample t-test because it tests whether or not there is a significant difference between the averages of two independent groups, which applies exactly to all of my research questions. Additionally, the t-test is fairly good with smaller sample sizes and even if a dataset is not normally distributed, a t-test is generally still valid unless the data is extremely skewed.

T-tests compare the mean of the two data sets in an attempt to show if there is a significant difference between the two, the likelihood of any difference occurring by chance. In equations, statistical significance is generally represented by “p” which stands for probability. Another common symbol when determining significance is alpha (α) which refers to random chance. The α value commonly referenced in significance statistics is 0.05. Often this number is used as a cut-off for significance if a result is less than this, it means that the chance of such a result occurring randomly is less than 1 in 20 and this is considered to be unlikely enough to conclude that the result is not random.

When performing a t-test, or any test of significance, there are two ways to look at the results. One way is called a one-tailed test and the other is a two-tailed test. With a two-tailed test, significance and difference are being looked for at both extreme ends of the data. And the alpha is split between the two extremes. With a one-tailed test, though, significance is only being looked for one side of the data. This means that the whole alpha does not have to be split up. The main deciding factor in whether a one or two-tailed test is run lies in the wording of the research and study question. If the question mentions “greater,” “less than,” or other ranking indicator, a one-tailed test is used but if the question simply refers to there being a difference, then the test is two-tailed. All of my questions have words such as “higher,” “larger,” “closer,” and “steeper” so I ran one-tailed tests.

Performing a t-test within R is fairly simple. First the data needs to be organized into separate columns in a CSV (Comma-Separated Values) or a Tab-delineated file. This information is then brought in, or “read in,” to R via certain commands and given a

variable name. The columns of data within the table can then be accessed through the use of the files variable name, followed by a “\$” and then the header of the column. To run a t-test, the command “t.test” is used in conjunction with the variables being compared, but this automatically runs a two-tailed t-test. In order to run a one-tailed test, alt=“greater” or alt=“less” is also typed as part of the t.test command. Whether “greater” or “less” is used depends on the alternative hypothesis being studied and is in relation from the first variable to the second variable. For example, (assuming a fake dataset named “Trial”):

```
t.test(Trial$X, Trial$Y, alt=“greater”)
```

In this instance, the one-tailed test being run is comparing the mean variable “X” of the dataset “Trial” to variable “Y” and with the alternative hypothesis guessing that the mean of variable “X” is greater than that of “Y.”

In order to answer my seven questions I ran one-tailed t-tests on my data and these were my results:

1. Are image ahu at higher elevations than ahu?

```
> t.test(Elevation$image.ahu, Elevation$ahu, alt="greater")

Welch Two Sample t-test

data:  Elevation$image.ahu and Elevation$ahu
t = -0.50275, df = 28.005, p-value = 0.6905
alternative hypothesis: true difference in means is greater than 0
95 percent confidence interval:
 -7.723042      Inf
sample estimates:
mean of x mean of y
  9.41345  11.17524
```

Figure 33. Elevation t-Test Results

The t-test p-value is 0.6905 which means that I must accept my null hypothesis that image ahu are not higher than ahu.

2. Do image ahu have a larger viewshed than ahu?

```
> t.test(Visibility$image.ahu, Visibility$ahu, alt="greater")

Welch Two Sample t-test

data:  Visibility$image.ahu and Visibility$ahu
t = -1.1345, df = 34.63, p-value = 0.8678
alternative hypothesis: true difference in means is greater than 0
95 percent confidence interval:
 -33632582      Inf
sample estimates:
mean of x mean of y
 53676827  67185809
```

Figure 34. Area Visible by *Ahu* t-Test Results

A p-value of 0.8678 means that I cannot reject my null hypothesis and thus image ahu do not have a significantly greater viewshed than ahu. The image ahu mean (13,676,827) is actually smaller than that of ahu (67,185,809) rather than greater so insignificance is expected.

3. Are image ahu closer to the coast than ahu?

```
> t.test(Distance$image.ahu, Distance$ahu, alt="less")

Welch Two Sample t-test

data:  Distance$image.ahu and Distance$ahu
t = -0.22829, df = 34.574, p-value = 0.4104
alternative hypothesis: true difference in means is less than 0
95 percent confidence interval:
 -Inf 30.52737
sample estimates:
mean of x mean of y
 77.96459  82.73198
```

Figure 35. Distance to Closest Coast Point t-Test Results

A p-value of 0.4104 indicates that image ahu are not significantly closer to the coast than ahu.

4. Is the coastal slope near image ahu less steep than the coastal slope near ahu?

```
> t.test(CoastSlope$image.ahu, CoastSlope$ahu, alt="less")

Welch Two Sample t-test

data:  CoastSlope$image.ahu and CoastSlope$ahu
t = 0.088412, df = 26.892, p-value = 0.5349
alternative hypothesis: true difference in means is less than 0
95 percent confidence interval:
 -Inf 2.254186
sample estimates:
mean of x mean of y
 17.57271  17.46150
```

Figure 36. Slope Surrounding Closest Coast Points t-Test Results

A p-value of 0.5349 shows that the coastal slope close to image ahu is not less steep than that associated with ahu. Though the difference is not large, the image ahu mean (17.57) is actually greater than that of ahu (17.46) rather than less so insignificance is expected.

5. Is the coastal slope near image ahu less steep than the general slope of the coast?

```
> t.test(CoastSlope$image.ahu, CoastSlope$general.coast, alt="less")

Welch Two Sample t-test

data: CoastSlope$image.ahu and CoastSlope$general.coast
t = -0.088041, df = 22.212, p-value = 0.4653
alternative hypothesis: true difference in means is less than 0
95 percent confidence interval:
 -Inf 1.914702
sample estimates:
mean of x mean of y
 17.57271  17.67624
```

Figure 37. Slope Comparison between Image Ahu and Coastline t-Test Results

The p-value is 0.4653 which means that the null hypothesis is accepted. This means that the coastal slope close to image ahu is not less steep than that associated with the general coastline.

6. Is the coastal slope near ahu less steep than the general slope of the coast?

```
> t.test(CoastSlope$ahu, CoastSlope$general.coast, alt="less")

Welch Two Sample t-test

data: CoastSlope$ahu and CoastSlope$general.coast
t = -0.24819, df = 36.326, p-value = 0.4027
alternative hypothesis: true difference in means is less than 0
95 percent confidence interval:
 -Inf 1.245671
sample estimates:
mean of x mean of y
 17.46150  17.67624
```

Figure 38. Slope Comparison between Ahu and Coastline t-Test Results

The p-value of 0.4027 is well above the 0.05 alpha value which means that the null hypothesis must be accepted which says that the coastal slope close to ahu is not less steep than that associated with the general coastline.

7. Is the ground slope around image ahu steeper than the ground slope around ahu?

```
> t.test(AhuSlope$image.ahu, AhuSlope$ahu, alt="greater")

Welch Two Sample t-test

data: AhuSlope$image.ahu and AhuSlope$ahu
t = -0.10334, df = 30.69, p-value = 0.5408
alternative hypothesis: true difference in means is greater than 0
95 percent confidence interval:
 -2.021939      Inf
sample estimates:
mean of x mean of y
 10.71170  10.82782
```

Figure 39. Slope around *Ahu* t-Test Results

The p-value of 0.5408 signifies that the slope surrounding image ahu is not steeper than the coast surrounding ahu.

Overall, my p-values were: 0.6905, 0.8678, 0.4104, 0.5349, 0.4653, 0.4027, and 0.5408. All of these are well above the 0.05 alpha value so I accepted all of my null hypotheses. This means that none of my predictions about the relationship between ahu, image ahu, and topography are true.

Discussion

While the questions I was asking over the course of this research had to do with topography in regards to analysis, beneath it all were underlying questions about costly signaling and water resources; could topographic analysis reveal or prove something about *ahu* in relation to these concepts, concepts that could provide great insight into the ancient Rapanui culture. Thus, the questions about visibility and elevation were actually about costly signaling and the other questions about slopes and distance to coast were actually questions about proximity to water resources, whether image ahu

indicated locations with access to water. I had originally thought that image ahu, given their associated *maoi* and likely existence as costly signals would be placed in areas of higher elevation where they would be the most visible, where they would be able to signal the most. I had also believed that image ahu would be in areas closer to coastal resources as well as near areas where these resources would be the most accessible.

Though my statistical results do not indicate that these topographic differences exist between the *ahu* features, this does not mean that the underlying theories about *ahu* signaling and demarcation of water resources is false. My results simply show that other factors could be more important in regards to why *ahu* were placed where they were on the landscape. One of these features could actually be the water data itself. My analysis of slopes and coastal distance was merely an attempt to see if any resource relationship manifested itself in a spatial one as well. In reality the hydrology and geography of Rapa Nui might result in coastal water outflows in locations that do not necessarily correspond with areas of easy coastal access. This question is currently the thesis subject of another student (Sadie Trush) in the Clark Honors College (currently set to defend in 2016) and I am interested to hear about the results of her analysis.

Another aspect that could be a factor as to why these architectural structures are located in certain places is time. My analysis was a pure spatial analysis because I assumed that time played no factor. In reality, however, chronology could be important, with *ahu* built at different times having different purposes that resulted in different spatial relationships. It is known that some *ahu* were rebuilt during the time of the ancient Rapanui and there are also some structures that could have been built

historically. This data thus shows that perhaps factors other than topography are more important in terms of understanding *ahu* placement.

Errors

Unfortunately, there was some error in my analysis and data. Some of this error lies in the SfM data processing. As stated in the “Error” section in Part 3, no ground calibration points were used to help correct for error in the consumer-grade GPS and no testing or correction was done for any doming affect. All of this could have an impact on the data. There were other error sources, however, that were not just SfM.

One large source of analysis error lies in how the viewshed data was processed. A continuous elevation surface is key to this analysis but my analysis was hampered by the restricting flight areas. Though the detail was fantastic, my rasters were too big to merge together which meant that the viewshed for each point was only calculated for within that limited area. This is problematic as key amounts of area may be excluded simply because they are located outside of the arbitrarily located flight zone. Those *ahu* that were located in the overlap between two flight zones had two different viewsheds that were combined together (with the redundant data due to the overlap removed) but not all *ahu* got this. A complete viewshed was not collected for every *ahu* point, even for those with a combined viewshed area due to overlap, so it is hard to accurately understand assess the results of this analysis (question #2).

Another cause for analysis concern in in the size of the slope buffer area. For all of my slope analyses I used a buffer area with a radius of 50m from the feature in question. The reason for this was because in some places, the coastline was further away from the cliffs. Thus, in order to ensure that the cliff areas (ie. Where the livable

land began) were always included, I chose a 50m buffer area. Unfortunately, slope is a concept that is very sensitive to scale and the 50 meter buffer I used in my data collection could easily be too big to accurately show the topographic nuances of Rapa Nui's south coast. There might be topographic differences there but my analysis simply aggregated too much data together to reflect it.

Future Research

As a result of these areas of error, there are a couple things I would do if I was to further this research. One of the first and easiest things would be to try analyzing the slope with different buffer areas to see if there are any different results. If ground calibration points could be collected during another trip to Rapa Nui, they could be applied to the SfM results in order to lessen any error in the data. In order to correct for the visibility analysis error, performing a viewshed analysis with a more complete DEM could produce more reliable results. Unfortunately, such a publically accessible dataset does not yet exist. From my understanding there is a 30m DEM from satellites but just as my 3cm SfM resolution was too small, this is too big. It won't be able to get the nuances of the topographic data that distinguishes the *ahu*. Ideally this analysis would use a 1m LiDAR DEM but to my knowledge, such a dataset does not yet exist.

Another analysis test that could be run is a least-coast path. This tool can take into account elevation and the work associated with it in order to calculate the path between points that will require the least amount of work and energy expenditure. This would be a particularly strong analysis tool to use because the 3cm resolution of the dataset is at a human, walking-scale level. If this analysis is performed with a DEM of a

few meters, the results are still useful, but for short distances and more realistic results, having the finer detail is a great advantage and could produce some interesting results.

In addition to these topics, one major area for further study is the testing of random points in comparison to the *ahu* locations. This would be a true null hypothesis as it would see if there is any topographic relationship as to how the *ahu* are placed or if they are equivalent to points picked at random along the coast. Though no statistical difference was shown between the two types of *ahu*, I believe that performing this true null hypothesis test would show that *ahu* locations are not just random points in regards to topography. I think this would be particularly obvious when comparing the distance to the coast. While there are a few *ahu* further inland than others, the majority are very near the coastline and this is true throughout the island, not just on the south coast (fig. 1). This is one obvious spatial relationship and I think it would be reflected through the running of the true null hypothesis.

Part 5: Conclusion

The main reason for conducting this study and topographic analysis was to further the research and understanding into the lives and society of the ancient Rapanui. It is obvious given the amount of effort put into the construction of the *moai* and *ahu* that they played an important part in Rapanui culture and by better understanding the purpose of these features, we better understand the lives of those who built them. My examination into the relationship between topography and *ahu* is just one attempt to understand this purpose.

Given the possible errors and incomplete topographic data analysis as talked about in the previous Discussion section, I am hesitant to definitively say that there is absolutely no relationship between *ahu* and topography. That being said, however, none of the results of my tests were all that close to being significant. To me this means that if any topographic relationship exists for *ahu*, it exists on a smaller scale than I was able to capture with my slope areas, in the incomplete visibility areas, or in some manner that I did not think of. Rather, I think that this is simply an indication that other factors play a larger role in the purpose of these structures, factors that do not have a topographic manifestation.

This study was just one in a number of studies, tests, and projects meant to contribute towards the research being conducted by Drs. Hunt and Lipo on Rapa Nui on relation to the prehistoric and current water resources there. Since this study was solely focused on the southern coast of the island, I hope that my work and methods can lay a groundwork for others and encourage the continued study of topographic relationships both on Rapa Nui and off it. There is undoubtedly much research still to be done in this

regard and much still to be discovered and learned from Rapa Nui. My study on topography has added to this growing knowledge and understanding about *ahu*, their purpose, and the people who built them.

Appendix A: Terms

Ahu- long, low platforms built by the ancient Rapanui that are generally found near the coast. Generally “*ahu*” (in italics) refers to all such long low platforms. When I conducted my analysis, I classified those *ahu* without *moai* associated with them as “*ahu*” while those with *moai* became “image *ahu*”

Alpha (α)- in statistics, it refers to the probability level of rejecting the null hypothesis when it is in fact true. To keep this from happening, a probability level of 95% or 0.05 is generally used to determine significance. If a p-value is less than .05 than the null hypothesis is rejected, but if the p-value is greater, the null hypothesis is accepted.

Attribute Table- the information table that accompanies each GIS shapefile. Each row is associated with a vector feature within the shapefile. Columns contain information about various fields for each feature.

DEM (Digital Elevation Model)- a graphical output/file that depicts the topography of the region in question

Geographic Coordinate System (GCS)- a geographic locating system associated with a 3D spherical surface. This is how places are located on a globe. A grid is created over the surface with lines of latitude running parallel around the sphere and longitude lines being meridians. Longitude and latitude refer to angles measured from the center of the earth to the surface and are generally described in degrees. With this grid, every point on the surface can be referenced by a longitude and latitude value.

Ground Control Points (GCPs)- Points on the ground with a known GPS location that are used to calibrate the output structure from motion features. They help ensure data accuracy as they ground the constructed models.

Image *ahu*- long low platforms built by the ancient Rapanui that have *moai* associated with them (historically they stood on top of the platform)

Kurtosis- A measure in statistics used to indicate the peakedness or flatness of a data set.

LiDAR- Light Detection and Ranging. A form of active remote sensing where a laser beam is emitted from an aerial platform and the differing return times are analyzed to determine the surface. The use of a laser allows for multiple returns which makes it possible for ground topography to be recorded even in the presence of vegetation.

Lithic Mulching- a form of agriculture that places small to medium sized rocks in the desired growing area in order to put nutrients back into the ground and help retain water moisture in the soil.

Manavai- a small enclosure created by a low stone wall. These features were constructed by the ancient Rapanui as a strategy for growing crops. The enclosed area is more protected from the wind and the soil has more nutrients.

Moai- the large stone statues built on ancient Rapa Nui

Orthophoto- an aerial photograph that is geometrically corrected to have a uniform scale

P-value- in statistics, the p-value is a function of the observed sample results used for testing a statistical hypothesis. It represents the probability of the occurrence of a single event.

Projected Coordinate System (PCS)- a geographic coordinate system that has been projected onto a flat surface. The process of changing 3D features to 2D creates distortions within the projection. There are a wide variety of projections and different projections have different advantages, fidelity of shape, area, and direction cannot exist all at once so projections are chosen based off of the desired purpose of the map. There is more accuracy towards the center of a projection so a singly type of projection may have multiple versions where the center is placed in different locations.

Puna- A structure created by the ancient Rapa Nui considered to be a well. Though there is also some confusion about whether some were boat ramps.

Ranu Raraku- the quarry where the *moai* statues were carved out of the hillside by the pre-historic Rapanui

Rapa Nui- the local name for Easter Island

Skew- In statistics, if one side of a dataset is more heavily favored. It is a measure of symmetry and often used in determining whether a data set fits a normal distribution.

Structure from Motion (SfM)- A way to process images in order to create a 3D model of the observed area. The process uses a computer program and many overlapping images taken from different angles to composite the final model together

T-test- a statistical examination of the of the two different population means.

Taheta- rocks carved into basins. Thought to have been for holding water.

Trilateration- The calculation of a point in 3Demensional space. This is similar to triangulation but triangulation refers to working with angles whereas trilateration refers to working with working with distances. This is how GPS calculates position because it uses speed and time to determine distance.

Trimble- name of the company that made the drone we used

UAV-Unmanned Aerial Vehicle

Yuma- name of the hand-held tablet computer used to program and communicate with the drone

Appendix B: Tables

Table 1: Basic Flight Data

Number (N)	Flight Date	Date Flight #	Overall Flight #	# of Pictures	Description
1	13-Jan	2	10	367	Furthest west (left) of S coast
2	9-Jan	1	1	861	Quarry
3	9-Jan	2	2	869	right of quarry
4	13-Jan	1	9	938	
5	13-Jan	3	11	391	Hanga Te'e
6	15-Jan	1	16	621	
7	17-Jan	3	25	821	long, mainly non-coastal over the top of and overlapping N4-6
8	15-Jan	2	17	931	
9	16-Jan	2	19	935	
10	16-Jan	3	20	981	West side of Akahanga
11	10-Jan	1	2!	874	East side of Akahanga.#2! b/c accidently pressed reflly flight for CIR of N3 and can't jump straight to flight 4
12	16-Jan	4	21	1028	Top. Inland flight overlapping N10-11
13	10-Jan	2	4	894	Launched and flew near Akahanga. Crashed during landing b/c small landing zone and too windy. Came up ~30m short of landing zone
14	11-Jan	1	5	853	Flew in the morning. Light wind & sunny
15	11-Jan	2	6	627	Hanga Tetenga. Landed shorter than expected b/c more headwind than 1st flight
16	12-Jan	1	7	925	Little wind. Launch ~9am from Hanga Tetenga.
17	17-Jan	2	24	934	Top. Inland flight on top of N15
18	17-Jan	1	23	878	Top. Inland flight on top of N16
19	12-Jan	2	8	831	Wind slightly stronger than flight7. Cracked the lense flighter cover for camera on landing
20	14-Jan	1	12	1053	

Number (N)	Flight Date	Date Flight #	Overall Flight #	# of Pictures	Description
21	14-Jan	2	13	1124	
223	14-Jan 3&4		14&15	14=665, 15=374	Tongariki combined flights. Far east (right) of South coast
101	9-Jan	3	3/2b	873	Same area as flight 2 (N3) but with thermal (CIR)
102	16-Jan	1	18	576	Large overlapping flight. Accidentally flown at 225m not 100m
103	16-Jan	5	22	436	Ranu Raraku. Flight Height @225m
104	17-Jan	4	26	266	Tepeu out on NW coast (last flight of stay)

This table shows some of the basic data about the various drone flights flown on Rapa Nui. The order in which the flights were flown were not linear in relation to the coast, this is the Overall Flight #. For organizational purposes, I re-numbered the flight images into a general order moving from west to east along the south coast and this is the Number (N). Numbers 1-223 (a combo of 22 and 23) are images of the south coast and the ones that I used for my data. Numbers 101-104 were other flights we flew at different heights and of different places for research purposes but are not related to the research I am conducting. The Date Flight # refers to the flight's order in the day's launches since more than one flight was flown per day. The # of Pictures refers to how many images were taken by the drone while flying over the area. For N1-223, the average number of pictures taken per flight was approximately 853.

Table 2: Basic Ahu Data

Ahu_ID	Pic_Order (N)	PointPicID	Category	Notes
1	2	2.1	ahu	Also in Pic #1
2	2	2.2	ahu	Close to coast/cliff. Ramp to right
3	2	2.3	ahu	Small. Depressed area behind it/on ocean side. CIR showed water?
4	2	2.4	ahu?	Part wall? Maybe all wall? Near dirt road
5	2	2.5	image ahu	covered moai b/c close to quarry. Close to road where it bends
6	1	1.1	ahu?	Could easily just be rocks/old wall bits. Close to cliff
7	4	4.1	ahu?	Questionable ahu. Right on coast/cliff
8	4	4.2	ahu?	Questionable ahu. small
9	4	4.3	ahu?	Questionable ahu. near cliff. tarp over part of it
10	4	4.4	image ahu	Large. w/ fallen moai. wall include ahu as one part of enclosure.
11	4	4.5	ahu	Maybe small one behind? smaller and off to the SE side of the big image ahu (4.3)
12	5	5.1	ahu	smaller. Toward back of bay. Main identifier placed stones/"porch"
13	5	5.2	image ahu	big. Fallen moai. Scattered hats. Near bay/inlet and ocean.
14	5	5.3	ahu?	Maybe. grass behind, close to cliff and dirt road going down
15	6	6.1	ahu	long. Midway btw road and coast
16	6	6.2	ahu	x2? Large back wall stones. At back of bay/inlet. 2nd ahu at diagonal, different ages?
17	6	6.3	ahu?	small. back and west of 6.4. In grassy, rocky area a back from water. curved? no wings
18	6	6.4	ahu	large. maybe image? Near rocky, flat coast
19	6	6.5	ahu	long right along coast. not cliffy. paninsula w/ grassy flight field
20	6	6.6	ahu	long. close to shore. near 6.5. paninsula w/ grassy flight field
21	6	6.7	ahu?	Maybe? or maybe wall. very faint outline
22	3	3.1	image ahu	Image ahu. On "point" of land. Not cliffy, especially back of nearby, inlet. Fallen moai and hats

Ahu_ID	Pic_Order (N)	PointPicID	Category	Notes
23	8	8.1	ahu?	long, wall built over part, makes it slightly uncertain. Near back of inlet. gentle coastal slope
24	8	8.2	ahu	small. on other side of road, but near back of inlet. back wall stones clear/inline
25	8	8.3	ahu	long, maybe 2in1/built on top of each other. Near coast and road. gentle slope. no moai?
26	9	9.1	ahu?	small. Maybe ahu. Near road and coast. not too steep access to water? Rocky
27	9	9.2	ahu?	maybe. on other side of road but still close to water. near wall. not too big
28	10	10.1	image ahu	2in1 ahu. Maybe more. can see diff angles. fallen moai and hats. near sloping water access
29	10	10.2	image ahu	1 fallen moai. not much left. Directly behind = easy slope to water. Puna? back of inlet
30	10	10.3	image ahu	Fallen moai and hats. large. near 10.2 but more out on point of land
31	10	10.4	ahu?	smaller. Maybe ahu. to right of 10.3. more cliffy
32	10	10.5	ahu	larger. away from coast, other side of road. Big back stones.
33	10	10.6	ahu?	Maybe ahu. has the long shape, but maybe a chicken house reconstruction thing?
34	10	10.7	ahu?	maybe ahu? Main aspect is the long form of rocks w/ squared ends. no big stones
35	10	10.8	ahu?	maybe. 1 side of back continues as wall. one end squared. Seems wide at places
36	11	11.1	ahu	long, intact w/ tapered ends and bulge in middle. no big wall stones. Near easy shore access, left
37	11	11.2	image ahu	squarish. side walls/edges most distinct. fallen moai. On other side of road but near back of inlet

Ahu_ID	Pic_Order (N)	PointPicID	Category	Notes
38	13	13.1	image ahu	Cpt. Cook's ahu. Other side of road but nearish water. Fallen moai
39	13	13.2	ahu	part of large back rocks clear, faint outling of squarish form stretching out from it. Clifty
40	13	13.3	ahu	2in1? rectangular outline pretty clear. bigger one "ontop" of smaller?
41	13	13.4	ahu?	ahu? Far from coast. 1 fallen moai near. faint straight lines of stones. rounded "porch" stones?
42	14	14.1	ahu?	maybe? just rectangular outline. not raised 1layer of stones? far from sea, close to other features
43	14	14.2	ahu?	maybe? long center wall? w/ manavi surrounding. Wall w/ 2 sides and center. far from ocean
44	14	14.3	image ahu	fallen moai. 2parts? back and front. 1 wall right along cliff/edge going down to the sea. near puna?
46	14	14.5	ahu	stubby/squarish. 1 bigger, 1 smaller. far from ocean. don't really see hint of "wings"
47	15	15.1	image ahu	long. 2 parts? bulge in back. fallen moai. Right along coast w/ gentle slope
48	15	15.2	ahu?	Maybe if more over-grown? has has right shape but rocks not very clear. near easy slope to sea
49	16	16.1	image ahu	small to have fallen moai (1?). structure not well defined. bit of back wall. along coast but clifty
50	16	16.2	ahu?	maybe? small. has wings but in odd osition w/ bed rock running under. Not quite perp to coast
51	16	16.3	ahu	long. tapered ends. near sloping ocean access on left, right, front(?)
52	16	16.4	ahu	long, more squared. right by/behind/front of slope/ramp to the ocean
53	16	16.5	ahu?	Maybe? definitely manavai built around center wall(?) maybe manavai on side of ahu?

Ahu_ID	Pic_Order (N)	PointPicID	Category	Notes
54	16	16.6	ahu?	maybe? near coast (cliffish). not very clear shape, more blobbish w/ tail.
55	18	18.1	ahu?	very ahu in shape w/ tapered ends but far from sea and w/ manavai on either side
56	19	19.1	image ahu	long pile of rocks w/ tapered ends & surrounding square outline. near coast
57	19	19.2	ahu?	maybe? Could be wall w/ surrounding rocks? Does have bit of taper. Close to coast
58	19	19.3	image ahu?	maybe ahu? 1 moai. right position & shape but odd wall? intersects perpendicular
59	19	19.4	ahu?	maybe ahu or just wall w/ stones piled on 1 side. near less cliffy coast access
60	19	19.5	ahu?	Pretty sure not ahu but maybe? more inland w/ manavai & 1 fallen moai
61	20	20.1	ahu	tapered ends. near coast easy access to ocean?
62	20	20.2	image ahu	2in1. can see overlapping ahu stuctures. several fallen moai. easy ocean access
63	21	21.1	ahu?	maybe? small, could be wall w/ rocks on 1 side. near coast
64	21	21.2	ahu?	maybe? small, sort of tapered ends? maybe just wall (splits w/ taper). coast access
65	21	21.3	image ahu?	big ahu. more sure ahu but still. back wall some near fallen moai
66	21	21.4	ahu?	ahu? maybe 2in1. ends seemed squared off, couple manavai. not quite right angle to coast

Ahu_ID	Pic_Order (N)	PointPicID	Category	Notes
67	21	21.5	ahu?	maybe? working off natural rock features? just one end. near coast access (behind&to side)
68	22	22.1	image ahu	Tongariki. Numerous re-erected ahu. easy ocean access. at back of inlet
69	23	23.1	image ahu	small ahu w/ fallen moai. can see one squared end. Bit far from water but easy coast access

This table shows the data associated with the ahu I identified on the surface. Ahu_ID refers an individual ID number given to each ahu and is used in other tables to connect data to their associated ahu. Pic_Order (N) refers to the general placement of the ahu's source image's position along the south coast in relation to the other images (see table 1) and the PointPicID gives reference to the source image while also identifying it in relation to the other ahu associated with that image. I placed each point/location in one of 4 categories: "Ahu" means that I am sure that the feature is an ahu but it has no *moai*, "Image ahu" means that the feature is an ahu and that there are *moai* on/near it, "Ahu?" means that I am not sure if the structure is an *ahu* (ie. it could be some other be an old wall or just rubble) and "Image ahu" refers to structures with nearby/associated *moai* but I can't be sure if this is accidental of the structure really is an *ahu*. This is the smallest category.

Table 3: Ahu Elevation Data

Ahu_ID	Category	Ahu and Buffer			Elevation (m)				
		COUNT (pixels)	AREA	MIN	MAX	RANGE	MEAN	STD	
1	ahu	5258	78.17052985	35.77054596	38.97062302	3.200077057	37.44282974	0.750844709	
2	ahu	5257	78.15566288	20.21980667	21.80511475	1.585308075	20.90596939	0.391522837	
3	ahu	5259	78.18539682	15.37493896	17.17373276	1.798793793	16.46717508	0.367214494	
4	ahu?	5250	78.05159408	29.43226624	30.58823967	1.155973434	30.16313582	0.23955855	
5	image ahu	5263	78.2448647	40.9881897	43.95716095	2.968971252	42.79300643	0.91400665	
6	ahu?	10874	78.15337235	22.32330132	26.71371651	4.390415192	25.00321591	1.257770847	
7	ahu?	14573	78.11763711	14.06881905	15.72385597	1.655036926	14.92161981	0.387286827	
8	ahu?	14566	78.08011405	9.114654541	10.46166801	1.347013474	9.547680665	0.255213843	
9	ahu?	14580	78.15516016	3.131350517	3.847153187	0.71580267	3.432646997	0.159351965	
10	image ahu	14589	78.20340409	2.767888546	4.83490324	2.067014694	3.631177232	0.5145006547	
11	ahu	14579	78.14979972	0.80136013	2.677035809	1.875675678	1.799051096	0.25177592	
12	ahu	17659	78.15827909	-1.576896667	1.174106598	2.751003265	0.526074197	0.548469785	
13	image ahu	11685	78.12952953	-4.204084396	-1.411496997	2.792587399	-2.86066489	0.733201911	
14	ahu?	17649	78.11401935	5.524364471	7.093770981	1.569406509	6.184684635	0.362483912	
15	ahu	17659	78.15827909	15.19166946	17.51583099	2.32416153	16.24842639	0.502146447	
16	ahu	16437	78.16679441	3.787125349	6.288125992	2.501000643	5.249379122	0.467910793	
17	ahu?	16427	78.11923902	0.112529993	1.076705217	0.964175224	0.507591373	0.211464418	
18	ahu	16443	78.19532764	-0.293637991	2.075410366	2.369048357	0.755978393	0.604513494	
19	ahu	16427	78.11923902	0.304261923	2.033238411	1.728976488	1.2943043	0.32097155	
20	ahu	16425	78.10972794	2.025630951	4.005832672	1.980201721	2.921742529	0.541035149	
21	ahu?	18549	78.16278035	5.76669693	7.706986427	1.940289497	6.479044049	0.474087426	
22	image ahu	15168	78.11195432	10.26497841	12.33226776	2.067289352	11.24330811	0.469134663	
23	ahu?	18547	78.15435264	8.949839592	12.50040531	3.55056572	10.27094318	0.788274246	
24	ahu	18543	78.13749723	8.601445198	10.36573696	1.764291763	9.34618184	0.311050543	
25	ahu	19624	78.11984435	10.02213669	13.37867928	3.356542587	11.78043277	1.150816137	
26	ahu?	19635	78.1636335	4.794815063	6.566035271	1.771220207	5.788479132	0.357415533	
27	ahu?	19627	78.13178685	7.892707348	9.313272476	1.420565128	8.530046856	0.282289441	
28	image ahu	21249	78.159444336	2.352689743	4.607476711	2.254786968	3.608067121	0.42410477	

Ahu and Buffer		Elevation (m)						
Ahu_ID	Category	COUNT (pixels)	AREA	MIN	MAX	RANGE	MEAN	STD
29	image ahu	4684	78.23780392	-1.947060943	0.03496033	1.982021272	-1.10364924	0.462557153
30	image ahu	4678	78.1375847	3.864570379	7.281821251	3.417250872	5.396367391	0.842249916
31	ahu?	4679	78.1542879	6.852833271	8.423128128	1.570294857	7.856178488	0.442494983
32	ahu	21243	78.13737377	23.4456749	27.99999619	4.554321289	25.94676597	1.437717227
33	ahu?	4679	78.1542879	9.460072517	11.10894775	1.648875237	10.21609396	0.374269712
34	ahu?	4677	78.1208815	5.275479317	5.809027672	0.533548355	5.571741895	0.136202442
35	ahu?	21242	78.13369551	-0.833846092	1.298415661	2.132261753	0.396886331	0.601997672
36	ahu	4679	78.1542879	8.530769348	9.895947456	1.365178108	9.138055875	0.365581586
37	image ahu	4677	78.1208815	21.22824669	23.52791595	2.299669266	22.35133288	0.512311614
38	image ahu	5182	78.16345831	20.9667511	23.18281174	2.216060638	21.84412381	0.403166924
39	ahu	5188	78.25396019	16.00992012	17.76012421	1.750204086	17.08240119	0.384259015
40	ahu	5178	78.10312372	11.91665649	13.77226448	1.855607986	12.89151498	0.422373723
41	ahu?	5173	78.02770549	27.00385857	27.85616302	0.852304459	27.28661498	0.180738245
42	ahu?	4815	78.20872694	33.90341187	34.09913635	0.195724487	34.01877025	0.046741405
43	ahu?	4805	78.04629968	25.89300919	28.54395294	2.650943756	27.03142863	0.575630944
44	image ahu	4810	78.12751331	10.15695	12.30537987	2.148429871	11.25339158	0.558499378
45	ahu	4813	78.17624149	11.78697014	13.46378613	1.676815987	12.59634131	0.334369351
46	ahu	19513	78.14217837	9.436817169	11.25318718	1.81637001	10.371244635	0.476947202
47	image ahu	19502	78.09812753	1.304790497	3.791117668	2.486327171	2.560397601	0.651973325
48	ahu?	19508	78.12215526	-1.388778687	4.111877441	5.500656128	2.034032132	1.438038752
49	image ahu	19509	78.12615988	4.625286102	7.074736595	2.449450493	5.584055971	0.586035523
50	ahu?	19385	78.14219406	7.597230911	9.005449295	1.408218384	8.277996634	0.296570446
51	ahu	19385	78.14219406	7.18862772	9.385305405	2.196677685	8.150353672	0.485339449
52	ahu	18320	77.24689766	8.255261421	9.867665291	1.61240387	9.093831172	0.247912105
53	ahu?	19391	78.16638045	34.14980698	36.45748138	2.307674408	35.34035635	0.562006252
54	ahu?	19385	78.14219406	4.53157568	6.541506767	2.009931087	5.55059201	0.392926823
55	ahu?	32286	78.11810503	23.99713898	26.0338974	2.036758423	25.04406288	0.569439142
56	image ahu	18533	78.14501934	9.510854721	11.7730093	2.262154579	10.874444894	0.558395379
57	ahu?	18534	78.14923588	-0.273830414	1.758551598	2.032382011	0.759569471	0.446915147

Ahu and Buffer		Elevation (m)						
Ahu_ID	Category	COUNT (pixels)	AREA	MIN	MAX	RANGE	MEAN	STD
58	image ahu?	18535	78.15345241	0.466711044	2.834900856	2.368189812	1.576006969	0.702391363
59	ahu?	16121	78.09130284	9.41672802	11.54556274	2.128834724	10.19061797	0.525857568
60	ahu?	16132	78.14458765	18.85496521	21.64041901	2.785453796	19.66182602	0.583737191
61	ahu	16143	78.19787245	3.653702736	5.763171196	2.10946846	4.655940417	0.550395289
62	image ahu	16126	78.11552321	9.304086685	13.03999519	3.735908508	10.27177079	0.804785464
63	ahu?	16784	78.13211141	6.442501068	7.833558559	1.391057491	7.028641689	0.295850092
64	ahu?	16783	78.12745626	7.316351414	9.425189972	2.108838558	8.237234116	0.569310422
65	image ahu?	16780	78.1134908	8.923236847	11.6310091	2.707772255	10.4750103	0.514747284
66	ahu?	16786	78.14142172	11.063591	12.95788383	1.894292831	11.55218533	0.313566774
67	ahu?	16794	78.17866296	1.014877319	6.912035465	5.897158146	4.648100508	1.470521723
68	image ahu	4136	78.18996521	-1.678109646	-0.966703296	0.71140635	-1.37865741	0.191636427
69	image ahu	4139	78.2466794	3.873942137	5.4145298	1.540587664	4.546718179	0.317781661

This table shows the data summary for the elevation surrounding each *ahu*. This table is a result of running the Zonal Statistics as Table tool with a 5m buffer around each of the *ahu*. The raster being used to extract the data is the DEM. The elevation data is a summary of the elevation raster data found within the 5m buffer. For those *ahu* that had more than one set of associated elevation data due to overlapping flight areas, those repetitions were removed from the table with no additional work because the 5m buffer area was small enough that each could be fully covered by at least one of the overlapping flights.

Table 4: Total Observation Area per Ahu

Ahu_ID	Category	Total area
1	ahu	27270207
2	ahu	41267371
3	ahu	6416704
4	ahu?	32789215
5	image ahu	38590412
6	ahu?	28978536
7	ahu?	126231516
8	ahu?	78724656
9	ahu?	61513165
10	image ahu	87982982
11	ahu	96667308
12	ahu	55351865
13	image ahu	28039359
14	ahu?	86308918
15	ahu	152277219
16	ahu	62193056
17	ahu?	49362420
18	ahu	56283049
19	ahu	62274463
20	ahu	62997228
21	ahu?	160892525
22	image ahu	72199192
23	ahu?	91371303
24	ahu	68968654
25	ahu	164217474
26	ahu?	123914565
27	ahu?	104118609
28	image ahu	65125910
29	image ahu	15094927
30	image ahu	66526067
31	ahu?	105714152
32	ahu	105382698
33	ahu?	63155748
34	ahu?	57577396
35	ahu?	41362115
36	ahu	16059996
37	image ahu	46694941
38	image ahu	27849872
39	ahu	30543048
40	ahu	27190978
41	ahu?	24913031
42	ahu?	17032999
43	ahu?	23966681
44	image ahu	21335856

Ahu_ID	Category	Total area
46	ahu	66748032
47	image ahu	46700787
48	ahu?	25951425
49	image ahu	81685118
50	ahu?	80862453
51	ahu	57357014
52	ahu	123892964
53	ahu?	114549902
54	ahu?	70756356
55	ahu?	74438721
56	image ahu	104562093
57	ahu?	54411863
58	image ahu?	49872018
59	ahu?	138399675
60	ahu?	153886299
61	ahu	101919250
62	image ahu	98893844
63	ahu?	67521589
64	ahu?	82310538
65	image ahu?	101766741
66	ahu?	111177724
67	ahu?	45927297
68	image ahu	19201560
69	image ahu	38346306

A summary table showing the total amount of area from which each ahu can be seen. These numbers were acquired from the point data observations. For each ahu point, the area from all the rows that had a 1 in it (indicating visibility) were added together and then associated with the basic ahu information from table 3. For those *ahu* located in more than one flight rea, they had two different viewsheds. One of these viewsheds was clipped by the other in order to eliminate overlap and redundant data. The two viewsheds were then added together to get a more complete assessment of land that was not a part of the previous flight area, and thus makes the overall area for these ahu more accurate. Unfortunately, not all the ahu have this position, and most ahu probably indicate having less observable area than they do in reality because they are only being analyzed wthin their specific flight area and not the whole coast.

Table 5: Closest Coast Points to Ahu

Associated Ahu Data		Closest Coast Point		
Ahu_ID	Category	NEAR_DIST (m)	NEAR_X	NEAR_Y
1	ahu	217.2275975600	659494.542301	6993805.84591
2	ahu	35.6039123486	659483.429778	6993803.30591
3	ahu	74.8716587650	659667.262646	6993759.01457
4	ahu?	145.7052238760	659792.552462	6993910.04158
5	image ahu	159.7561154090	659803.931983	6993922.54071
6	ahu?	49.5485065790	659009.802026	6993910.94393
7	ahu?	48.5971014531	661167.722098	6994020.17422
8	ahu?	60.0561808506	661445.124572	6993922.45018
9	ahu?	59.1630980914	661658.849100	6993842.50013
10	image ahu	83.7072109411	662030.149142	6994009.44967
11	ahu	36.3323681853	662034.774878	6994001.24360
12	ahu	16.1397631470	662239.121522	6994207.14176
13	image ahu	33.6507134615	662258.982838	6994101.75168
14	ahu?	33.2078723512	662725.679458	6994254.37529
15	ahu	115.4937263430	662855.652218	6994351.00132
16	ahu	31.4781502604	662958.887363	6994410.72593
17	ahu?	52.0368184976	663100.415723	6994337.87101
18	ahu	31.8053701825	663130.186245	6994327.18084
19	ahu	48.6100742748	663406.043135	6994257.20690
20	ahu	55.5172763245	663468.284945	6994313.45846
21	ahu?	53.7486735677	663524.780867	6994377.26015
22	image ahu	59.1449327589	660502.665871	6993957.78562
23	ahu?	51.0607194931	663591.841036	6994749.19759
24	ahu	90.1874834291	663517.086635	6994753.34493
25	ahu	93.7450148079	663944.970040	6995072.38428
26	ahu?	51.0566937832	664049.112876	6995220.36852
27	ahu?	123.4481060930	664182.020355	6995290.43646
28	image ahu	44.8810859066	664586.513995	6995810.90176
29	image ahu	35.5910981939	664763.789925	6995984.96916
30	image ahu	42.6636718265	664838.516820	6995932.66733
31	ahu?	41.6711975387	665052.444241	6996011.01616
32	ahu	281.1863909640	664760.922767	6995984.39619
33	ahu?	119.1496077010	664769.601619	6995983.33286
34	ahu?	85.4942758100	664847.513656	6995930.88607
35	ahu?	51.7313752519	664692.440731	6995891.48609
36	ahu	46.6483533891	665397.522160	6996201.04867
37	image ahu	137.4171584260	665501.834890	6996392.26597
38	image ahu	183.6820164540	665868.345652	6996620.68169
39	ahu	60.2796169566	665893.313946	6996653.53237
40	ahu	35.6362636393	666165.376364	6996788.07144
41	ahu?	303.2488911810	666235.395650	6996844.65230
42	ahu?	312.3470079380	666288.173304	6996884.61438
43	ahu?	183.7133399190	666329.133711	6996893.37530

Associated Ahu Data		Closest Coast Point		
Ahu_ID	Category	NEAR_DIST (m)	NEAR_X	NEAR_Y
44	image ahu	31.8517616434	666631.909768	6996887.76435
45	ahu	36.3399356277	666927.298177	6996977.32036
46	ahu	256.1859019310	667172.850592	6997148.74032
47	image ahu	43.7039928550	667235.332898	6997154.00352
48	ahu?	27.7703706420	667326.431511	6997151.71344
49	image ahu	44.0301275507	667753.798914	6997153.42072
50	ahu?	72.5546343842	668209.128493	6996820.13463
51	ahu	30.8559034373	668431.259745	6996878.83157
52	ahu	51.5795743990	668470.532582	6996914.22597
53	ahu?	413.7235394280	668104.536855	6996915.17842
54	ahu?	37.1403624253	667909.466572	6996986.14110
55	ahu?	506.2277938750	668693.468820	6997028.07596
56	image ahu	50.4988756399	668646.266140	6996977.74866
57	ahu?	83.8409202663	668697.966829	6997029.53889
58	image ahu?	37.1446319874	668906.918763	6997016.32622
59	ahu?	132.0229110560	669225.040314	6996692.37845
60	ahu?	282.9764710180	669523.913768	6996920.41297
61	ahu	91.6472449230	669889.170376	6996834.21607
62	image ahu	60.6691312905	670185.848395	6997070.72083
63	ahu?	53.1627908877	670441.450314	6997439.84993
64	ahu?	62.5352616575	670613.256435	6997563.53451
65	image ahu?	107.6961487150	670729.660894	6997712.34357
66	ahu?	78.3144750139	670830.555134	6997808.20049
67	ahu?	44.4738161174	671098.706639	6997979.12795
68	image ahu	82.7930983721	670849.631377	6998425.27019
69	image ahu	153.3925149840	671316.365271	6998701.88861

This table shows data about the closest point on the coast for each ahu. This data does not take into account elevation, merely distance. NEAR_DIST refers to the distance between each ahu and its associated point on the coast and the NEAR_X and Y columns relate to coordinate points. These coordinate points were used to map the points in ArcMap.

Table 6: Data for Slope within 50m of Closest Coast Points of Ahu

Ahu_ID	Ahu and Buffer			Slope (degrees)				
	Category	COUNT	AREA (m)	MIN	MAX	RANGE	MEAN	STD
1	ahu	709209	5097.210206	0.02479816	87.83206177	87.80726361	19.06085039	14.88378769
2	ahu	91076	654.5792801	0.006356403	86.61362457	86.60726817	19.77460163	15.31373583
3	ahu	680864	4893.48969	0.003279554	84.83907318	84.83579363	15.02754326	10.83065903
4	ahu?	325411	4837.875673	0.199958712	87.46607971	87.266121	17.49459308	16.2659421
5	image ahu	102101	1517.932535	0.539770186	87.40715027	86.86738008	15.00621585	14.30683171
6	ahu?	573870	4124.504935	0.033286132	88.77558899	88.74230286	30.594475	16.90152916
7	ahu?	904684	4849.500886	0.013763064	87.99647522	87.98271216	24.30001271	17.56036123
8	ahu?	764652	4098.86828	0.007388444	88.99255371	88.98516527	18.68379489	17.14191324
9	ahu?	995111	5334.229052	0.013287202	87.84417725	87.83089004	16.71453643	12.47047077
10	image ahu	838350	4493.921709	0.007376655	84.38886261	84.38148595	14.59769239	13.17481908
11	ahu	90049	602.0955075	0.023384731	81.74728394	81.7238992	19.17156568	14.76695757
12	ahu	779092	5209.250443	0.00497158	86.18468475	86.17971317	8.596762515	9.744851263
13	image ahu	830822	5555.133246	0.012617367	84.75100708	84.73838971	16.43828625	12.72511878
14	ahu?	1024584	4534.78239	0.011525417	88.4438858	88.43236039	17.69727902	16.2149032
15	ahu	1181972	5620.913933	0.025323501	87.94454193	87.91921843	22.93103343	16.42916911
16	ahu	1090271	5184.826252	0.011213547	88.51112366	88.49991011	18.68672535	14.19216883
17	ahu?	1000889	4759.766666	0.007600136	86.38388824	86.37628811	17.09855154	11.88155967
18	ahu	451269	2146.027325	0.016022649	86.68530273	86.66928009	16.90016892	14.25076499
19	ahu	1152664	5481.538596	0.006202784	88.48069763	88.47449485	17.16694183	16.81382844
20	ahu	861276	4095.831601	0.006026874	88.32978821	88.32376133	15.44060108	14.34953907
21	ahu?	862947	4103.778106	0.015388933	88.63426971	88.61888078	19.29127891	16.58115338
22	image ahu	891109	4589.020669	0.003931223	87.86357117	87.85963994	21.14132069	16.66343303
23	ahu?	1057613	4456.626913	0.002862258	88.42752838	88.42466612	24.44648609	16.34225932
24	ahu	1148130	4838.052348	0.019038264	85.14723206	85.12819379	16.3905182	10.9927908
25	ahu	1013736	4271.735635	0.009910981	87.28845978	87.2785488	19.87905224	15.43693353
26	ahu?	1211013	4820.839129	0.019301662	88.08272552	88.06342386	22.56429648	15.39600415
27	ahu?	1087267	4328.22711	0.013152015	86.39406586	86.38091384	20.25332501	13.67171979
28	image ahu	1293559	4758.052209	0.008918962	88.55721283	88.54829387	21.02002451	16.6662712

Ahu and Buffer				Slope (degrees)				
Ahu_ID	Category	COUNT	AREA (m)	MIN	MAX	RANGE	MEAN	STD
29	image ahu	1569048	5771.373631	0.013393601	88.25222778	88.23883418	17.74096645	13.66524753
30	image ahu	454780	7596.282764	0.010895002	89.6089325	89.59803749	24.02771891	18.64555348
31	ahu?	294017	4911.025704	0.034572221	86.89238739	86.85781517	18.79410263	15.00905608
32	ahu	57529	211.6068811	0.023971824	72.70927429	72.68530247	18.52403304	12.63860812
33	ahu?	19891	332.2434154	0.75510931	74.88694763	74.13183832	10.08230328	12.34973079
34	ahu?	54788	915.1350985	0.113508373	69.88656616	69.77305779	11.29432074	10.90940488
35	ahu?	1102550	4055.470576	0.014756956	85.35734558	85.34258862	18.25662083	13.00288429
36	ahu	269125	4495.249569	0.073442087	88.38409424	88.31065215	20.47164886	14.68796891
37	image ahu	326205	5448.668409	0.04178717	88.76180267	88.7200155	21.22939754	15.50308675
38	image ahu	299854	4522.180095	0.067586184	85.89655304	85.82896686	19.08201314	13.10027719
39	ahu	174231	2627.625312	0.054960754	85.73416901	85.67920825	15.41214711	14.74977858
40	ahu	252079	3801.672268	0.009804519	85.06694794	85.05714342	14.12725228	13.60521569
41	ahu?	269043	4369.899792	0.105997883	87.50665283	87.40065495	18.02169157	14.53592449
42	ahu?	239182	3607.169088	0.019640561	87.82590485	87.80626429	16.15137629	16.94832768
43	ahu?	177270	2879.28746	0.042544022	87.67431641	87.63177238	15.07242018	14.65748836
44	image ahu	239745	3894.030418	0.024556693	86.3550415	86.33048481	15.57305378	16.37839365
45	ahu	258632	4200.80033	0.014046267	88.57723999	88.56319372	16.8711572	15.2455355
46	ahu	299311	4861.52428	0.018994343	83.53678131	83.51778697	16.03049615	11.59755282
47	image ahu	633471	2536.702109	0.008777293	86.76561737	86.75684008	19.13851451	12.9849413
48	ahu?	1240486	4967.462525	0.018544413	88.47890472	88.46036031	19.6885975	13.45981044
49	image ahu	1025527	4133.78815	0.005759308	89.23705292	89.23129361	20.13819784	14.99853821
50	ahu?	1412192	5692.392843	0.008298002	87.01522827	87.00693027	15.24223171	12.04865852
51	ahu	1666056	6715.691104	0.012189744	88.19931793	88.18712819	18.78300839	13.63528819
52	ahu	971187	3914.749502	0.026245711	88.6516037	88.62535799	22.47210284	16.15973082
53	ahu?	1193971	4812.767652	0.007218701	86.65522766	86.64800896	15.65783296	12.09750008
54	ahu?	1212473	4887.347208	0.008595416	86.99263763	86.98404222	15.92833699	13.06447584
55	ahu?	1177861	4966.47398	0.004909046	87.86862183	87.86371278	18.50945772	13.44016372
56	image ahu	1051632	4434.226928	0.006478092	89.0898056	89.08332751	17.58953436	14.55293413
57	ahu?	52424	221.0468229	0.042734116	74.89872742	74.85559933	14.65391266	10.65026823

Ahu and Buffer				Slope (degrees)				
Ahu_ID	Category	COUNT	AREA (m)	MIN	MAX	RANGE	MEAN	STD
58	image ahu?	1160524	4893.37218	0.010710596	87.33125305	87.32054246	20.71011742	15.07350405
59	ahu?	1362266	5744.021274	0.009702253	86.45975494	86.45005269	16.14834867	11.98377584
60	ahu?	1039764	5036.329453	0.033999287	89.18469238	89.1506931	20.78637942	15.53708897
61	ahu	1003941	4862.812742	0.003710685	78.67411041	78.67039973	14.97318804	10.95062338
62	image ahu	1042661	5050.36172	0.018047499	88.69371033	88.67566283	20.3639827	16.3447975
63	ahu?	940996	4380.377408	0.010812469	86.70051575	86.68970328	17.47829287	13.43738049
64	ahu?	1215948	5660.290957	0.004941953	87.14710999	87.14216803	20.32580168	15.25103728
65	image ahu?	839833	3909.459233	0.004917049	83.02371216	83.01879511	18.1325362	12.3378501
66	ahu?	1244904	5795.082399	0.01918116	88.26079559	88.24161443	20.84604179	16.2141321
67	ahu?	1009949	4701.35663	0.00585656	88.25434113	88.24848457	16.17606232	13.52083285
68	image ahu	337433	6378.399686	0.003992422	72.50704956	72.50305714	9.66428812	9.369442555
69	image ahu	225875	4269.650654	0.025796553	88.15641785	88.13062129	8.412211847	7.568528765

This table shows slope data (in degrees) from within 50m of each categorized ahu's closest coast point. The slope from the flight images (minus the ocean areas) were used to calculate this information. Since the flights overlap in places, some points had associated data from more than one flight area. Fortunately, every 50m buffer zone was always completely covered by at least one of the overlapping flights so the associated data from the incomplete sections were removed from the table.

Table 7: Slope data for the Whole Coast Within 50m

Coast Area				Slope (degrees)			
Picture (N)	COUNT (pixels)	AREA (m)	MIN	MAX	RANGE	MEAN	STD
1	10213144	73403.66779	0.003002785	89.59512329	89.59212051	22.19675991	16.78463958
2	4051241	60229.67963	0.00724162	89.6339035	89.62666188	17.05909297	14.83268349
3	13784233	70985.85038	0.002678186	88.92612457	88.92344639	18.68870046	15.8056167
4	17995646	96464.51271	0.003511513	89.04361725	89.04010574	18.03211576	15.48290414
5	10903901	72906.85967	0.002166135	88.01211548	88.00994934	14.60443084	12.64811992
6	17125459	81440.78803	0.004463901	88.63426971	88.62980581	17.56639977	14.7180999
7	8085755	35787.34333	0.005261089	88.6603775	88.65511641	17.40310185	14.3915717
8	16848831	70998.51618	0.002862258	88.67095947	88.66809721	19.68455267	14.64146545
9	13894419	55311.34578	0.004836777	88.46727753	88.46244075	18.36475352	14.71122008
10	14912041	54850.43174	0.003098811	89.24559021	89.2424914	18.93047609	15.12779689
11	5121990	85553.6399	0.00887517	89.65000916	89.64113399	17.66693952	14.63101314
13	4476403	67509.85661	0.009804519	89.52443695	89.51463243	16.22453192	14.57552222
14	4633315	75256.0827	0.005919636	88.57723999	88.57132035	15.20411729	13.74946146
15	11887828	47604.19714	0.001774575	89.24838257	89.24660799	19.53718309	15.20290634
16	20995221	84629.45957	0.003194968	89.23705292	89.23385795	17.24720604	13.80881859
19	19388655	81752.64361	0.003550106	89.0898056	89.0862555	18.95018087	14.22220431
20	23285630	112789.1562	0.000812178	89.50908661	89.50827443	18.88073006	14.40190052
21	21970143	102271.9736	0.003007423	88.47764587	88.47463845	18.32636534	13.91545019
223	4502044	85100.85272	0.003992422	88.4995575	88.49556507	11.28082969	10.23792344
Averages	12846099.95	74465.62407	0.004213372	88.98434609	88.98013272	17.67623514	14.41522727

This is slope data (in degrees) for the areas that are within 50m of the coast line. The 50m slope data does not include ocean data, only terrestrial. The data was collected by flight so there is some repetition in the data where the edges of the flight images overlap but this is minimal.

Table 8: Data for Slope within 50m of Ahu

Ahu_ID	Category	Ahu and Buffer			Slope (degrees)				
		COUNT	AREA	MIN	MAX	RANGE	MEAN	STD	
1	ahu	1089890	7833.232	0.00338762	85.04649353	85.04310591	12.2695277	9.698196248	
2	ahu	1009649	7256.53	0.006356403	87.83206177	87.82570536	14.22372098	14.8306929	
3	ahu	1089964	7833.76	0.003279554	69.31267548	69.30939592	8.304434674	6.127700979	
4	ahu?	1089958	7833.72	0.00455752	85.26071167	85.25615415	11.31924652	9.025879205	
5	image ahu	526866	7832.90	0.011203443	81.75337219	81.74216875	9.884723381	8.209144444	
6	ahu?	1089509	7830.49	0.021009127	88.77558899	88.75457986	21.50198974	16.38038355	
7	ahu?	1460477	7828.79	0.007261015	87.94948578	87.942222476	16.42461398	15.36850128	
8	ahu?	1461303	7833.22	0.003079966	77.56052399	77.55744402	8.721335047	7.750283146	
9	ahu?	1461307	7833.24	0.003777936	87.29682922	87.29305129	9.221415006	9.34907435	
10	image ahu	1461313	7833.28	0.004100627	87.05348969	87.04938906	9.079385294	11.05734055	
11	ahu	672688	4497.80	0.00638167	84.02983856	84.02345689	17.49910292	13.87334368	
12	ahu	942908	6304.57	0.00497158	85.73413849	85.72916691	7.222907622	8.745549869	
13	image ahu	1123928	7514.93	0.008088565	84.75100708	84.74291852	10.9080709	11.14153921	
14	ahu?	1609037	7121.56	0.001057015	88.4438858	88.44282879	13.34398318	13.89693408	
15	ahu	1769837	7833.25	0.000821331	81.34458923	81.3437679	10.48098522	8.205411292	
16	ahu	1470358	6992.34	0.00555006	88.50134277	88.49579271	13.28590431	13.10088179	
17	ahu?	1647178	7833.22	0.002445308	83.4563446	83.4538993	10.56202798	9.519090602	
18	ahu	702900	3342.67	0.017384335	86.68530273	86.6679184	15.39193819	12.30670501	
19	ahu	1646107	7828.13	0.005326983	87.62743378	87.62210679	9.53242947	10.70563033	
20	ahu	1236450	5879.99	0.00162446	83.04147339	83.03984893	7.013531657	9.06991566	
21	ahu?	1160031	5516.57	0.001832334	87.68520355	87.68337122	10.98163468	12.82063274	
22	image ahu	1521122	7833.45	0.003931223	87.72168732	87.71775609	13.05011263	13.3049359	
23	ahu?	1859004	7833.57	0.002088532	88.42752838	88.42543985	15.47079498	14.41501112	
24	ahu	1858902	7833.14	0.001840576	83.61711884	83.61527826	7.437977819	7.978549755	
25	ahu	1859003	7833.57	0.002948002	83.58790588	83.58495788	7.62640414	8.245480119	
26	ahu?	1967782	7833.41	0.004253726	86.98892212	86.98466839	15.19645133	13.60876208	
27	ahu?	1967776	7833.39	0.005158016	82.22937012	82.2242121	9.326604866	8.832421229	

Ahu and Buffer							Slope (degrees)				
Ahu_ID	Category	COUNT	AREA	MIN	MAX	RANGE	MEAN	STD			
28	image ahu	2099341	7721.93	0.005333816	87.65337372	87.6480399	15.35862984	15.01800236			
29	image ahu	2054526	7557.09	0.001815925	88.25222778	88.25041186	14.54146174	11.2035512			
30	image ahu	448626	7493.49	0.033194676	89.65000916	89.61681448	12.90306988	14.24189411			
31	ahu?	456917	7631.98	0.020360883	86.89238739	86.87202651	14.36118971	13.68812687			
32	ahu	2129662	7833.46	0.000955603	84.79904175	84.79808615	10.0164364	10.76209275			
33	ahu?	2063515	7590.15	0.003635341	77.38443756	77.38080222	8.121886774	5.879765641			
34	ahu?	1177537	4331.29	0.005910078	60.9873085	60.98139842	7.409598676	5.617162151			
35	ahu?	2041708	7509.94	0.002356687	85.35734558	85.35498889	12.61745557	11.22076653			
36	ahu	466206	7787.13	0.079452671	88.35865784	88.27920517	12.56012468	12.6259744			
37	image ahu	519423	7833.56	0.008306252	68.66130829	68.65300204	5.552167217	6.114869421			
38	image ahu	519423	7833.56	0.009961641	82.52391052	82.51394888	6.026220514	8.643724996			
39	ahu	519421	7833.53	0.028984925	85.74331665	85.71433173	7.758150253	9.261805663			
40	ahu	469021	7073.43	0.009804519	85.06694794	85.05714342	10.02440936	11.84157828			
41	ahu?	518453	7818.93	0.006370605	89.62355042	89.61717981	11.1655658	18.80626872			
42	ahu?	482270	7833.21	0.002572463	70.1722641	70.16969164	2.289131569	2.884526034			
43	ahu?	482269	7833.20	0.09358988	74.17396545	74.08037557	4.2355687	4.305699911			
44	image ahu	424224	6890.41	0.008698586	86.3550415	86.34634292	11.6413578	14.51053669			
45	ahu	448919	7291.51	0.014046267	88.57723999	88.56319372	11.91391483	13.38692003			
46	ahu	1956130	7833.22	0.000965398	82.01065826	82.00969287	7.407701318	6.314458846			
47	image ahu	1904130	7624.99	0.002135231	87.2954483	87.29331307	13.24739368	12.64329663			
48	ahu?	1776146	7112.49	0.004056538	88.05539703	88.0513405	15.29960423	12.48475057			
49	image ahu	1909250	7695.98	0.005759308	89.06407166	89.05831235	15.40608921	13.0763205			
50	ahu?	1943331	7833.36	0.004918778	86.41790009	86.41298131	10.77663538	8.356855164			
51	ahu	1907044	7687.09	0.010328256	88.19931793	88.18898968	15.9629344	12.76625468			
52	ahu	1540552	6209.80	0.002996836	88.6516037	88.64860686	12.87741234	11.84850101			
53	ahu?	1943339	7833.39	0.004303206	84.68468475	84.68038155	10.20884391	8.383857243			
54	ahu?	1837254	7405.77	0.007101105	86.99263763	86.98553653	12.66761115	10.46454202			
55	ahu?	3237502	7833.35	0.000878201	86.26481628	86.26393808	9.036765405	9.599555954			
56	image ahu	1857775	7833.34	0.004462641	89.0898056	89.08534296	11.12683949	11.03154974			

Ahu and Buffer				Slope (degrees)				
Ahu_ID	Category	COUNT	AREA	MIN	MAX	RANGE	MEAN	STD
57	ahu?	1857777	7833.35	0.004293764	74.94041443	74.93612066	9.676798802	7.149960846
58	image ahu?	1800035	7589.88	0.003719733	87.33125305	87.32753332	14.02761071	13.55883707
59	ahu?	1857777	7833.35	0.002611693	74.47331238	74.47070068	8.56456625	6.781330456
60	ahu?	1617219	7833.36	0.004003315	83.03836823	83.03436491	10.35821655	8.611199436
61	ahu	1617212	7833.33	0.000505203	78.28594971	78.28544445	8.574263895	7.694023345
62	image ahu	1617222	7833.38	0.00323711	88.15891266	88.15567555	11.81078933	13.89390068
63	ahu?	1682780	7833.41	0.001424569	86.70051575	86.69909118	9.42249484	10.84789773
64	ahu?	1682787	7833.45	0.004941953	86.66812134	86.66317939	9.038797706	10.21759721
65	image ahu?	1682783	7833.43	0.011195377	81.51365662	81.50246124	12.67300479	10.51065243
66	ahu?	1682780	7833.41	0.003317203	83.67861176	83.67529455	7.287386674	6.599444783
67	ahu?	1659908	7726.94	0.00585656	88.25434113	88.24848457	10.5584816	10.77296052
68	image ahu	4144408	7833.44	0.017717987	83.34534454	83.32762656	6.124288661	9.271956692
69	image ahu	4144417	7833.61	0.023650032	73.32328033	73.2996303	4.726539565	4.138573959

This table shows slope data (in degrees) from within 50m of each ahu. The slope from the flight images (minus the ocean areas) were used to calculate this information. Since the flights overlap in places, some points had associated data from more than one flight area. Fortunately, every 50m buffer zone was always completely covered by at least one of the overlapping flights so the associated data from the incomplete buffer zones was removed.

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