Ease of Use, Applicability, and Automation of Crowd-sourced Imagery for Shoreline Change Maps

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Abstract

Shoreline change information is critical for effective management of the coastal zone. CoastSnap is a global citizen science project, developed by researchers at the University of New South Wales (UNSW), which aims to measure and quantify shoreline change using crowd-sourced cell phone imagery. CoastSnap has been shown to be an effective qualitative and quantitative coastal monitoring tool and has the potential to provide a low-cost and frequent data source for United States Army Corps of Engineers (USACE) districts. The Jennette's Pier CoastSnap station, located in Nags Head, North Carolina, was used as a pilot study to evaluate and improve the ease of use, accuracy and applicability for different USACE districts. This pilot was also used as an opportunity to engage with the local community as an educational public outreach platform, both online via social media and in the classroom. Daily CoastSnap image submissions were processed and shorelines generated using CoastSnap were used to determine the sensitivity of shoreline position to changes in water elevation due to varying tide and wave runup parameters. In addition, improvements to the efficiency of the CoastSnap workflow were implemented and will continue to be developed. The contents of this project represent a portion of a greater overall USACE effort that successfully demonstrated that CoastSnap has the potential to be utilized as an accurate quantitative tool to measure changes in shoreline position, while serving as an effective means to engage the community.

This manuscript has been prepared in a style and format consistent with The Journal of Coastal Research.

Introduction

For most stretches of coast, observational data is limited and the sparse observational record introduces uncertainty into coastal management practices that require a data-driven understanding of shoreline stability and dynamics (Harley, 2019). Frequent and long-term beach monitoring records are necessary to quantify a variety of physical processes, ranging from event-based shoreline response due to extreme storms to seasonal and inter-decadal shoreline trends at individual beaches and regional coastlines (Barnard et al. 2015; Kuriyama et al. 2012; Splinter et al. 2013; Stockdon et al. 2002; Turner et al. 2016; Walker et al. 2017). In spite of the need for regular observational data, the costs and logistics of regular and long-term coastal monitoring efforts using conventional *in situ* survey and established remote sensing techniques can be prohibitive.

Technological advances in survey and analysis methods have resulted in the evolution of coastal monitoring from *in situ* measurements to remote sensing techniques (Splinter et al. 2018; White and Wang 2003). In particular, the development of Argus and related coastal imaging systems that utilize fixed camera stations and sophisticated image processing methods have led to this shift (Holman and Stanley, 2007). Advancements in coastal imaging have ultimately resulted in the establishment of observation stations that measure nearshore processes and collect routine shoreline data that would be otherwise difficult to sample (Allen, Oertel and Gares, 2012). However, coastal imaging stations require access to electricity and communications, protection from the elements in harsh coastal environments, and require significant setup and maintenance costs. Collectively, these factors can make the use of fixed coastal imaging stations impractical in some locations (Harley, 2019.)

Recent advances in shoreline change mapping initiatives that utilize crowd-sourced imagery have demonstrated comparable accuracies to that of established coastal imaging systems and offer a low cost alternative. CoastSnap is a global citizen science project, developed by researchers at the University of New South Wales (UNSW), which aims to measure and quantify shoreline change using crowd-sourced cellphone imagery (Harley et al., 2019). CoastSnap relies on repeat imagery taken at the same location to track shoreline change resulting from processes such as storms, rising sea levels, and human activities. The crowd-sourced imagery provides a frequent and low cost data source that has the potential to aid coastal managers, planners, and engineers in better understanding shoreline dynamics and drivers of change on both a local and regional scale.

CoastSnap utilizes a simple and low-cost stainless steel camera mount that is installed at overlooking a coastal region of interest and used to constrain camera extrinsic parameters (Harley et al., 2019). The cellphone camera cradle is accompanied by signage detailing instructions for sharing participant's images to a central database. At a CoastSnap station, citizen scientists are prompted to scan a QR code, which opens an ArcGIS Online webpage. They are then instructed to place their cell phone in the metal bracket and take a snapshot image that is automatically submitted via Survey123 for image processing. When the CoastSnap station is installed, permanent ground control points (GCPs) within the field of view are measured and used to solve for the focal length of the smart phone lens and determine camera extrinsic parameters (Harley 2019). Since the images submitted by citizen scientists are roughly the same frame, the Ground Control Points (GCPs) enable rectification of the oblique cell phone image into map coordinates. The shoreline position is then mapped on rectified images using an edge detection technique that uses the red (sand) and blue (water) color channels (Harley 2019).

At this time, there are CoastSnap stations operating in the United States of America, Australia, New Zealand, Belgium, Spain, France, Portugal, the UK, Brazil, and Fiji (www.coastsnap.com). In particular, a growing regional network of CoastSnap Stations is managed by the United States Army Corps of Engineers (USACE) across the Southeastern portion of the United States. There are now five CoastSnap stations in North Carolina and Virginia, with plans to continue regional expansion. CoastSnap incorporates community involvement, serves as an outreach platform and provides a frequent and free data source that has the potential to aid Army Corps Districts, planners and engineers.

Currently, the Jennette's Pier CoastSnap station, located in Nags Head, North Carolina, is being used as a pilot for the USACE. Jennette's Pier is a state-of-the-art concrete pier extending 1000 feet (304 meters) into the Atlantic Ocean in Nags Head, North Carolina. The pier was originally constructed in 1939 and rebuilt after Hurricane Isabel in 2003. Jennette's pier is open year round and is visited by thousands every year. Views from the pier provide long, unobstructed views of the shoreline, making it an ideal location for a CoastSnap station. The pier also hosts educational programs and camps based on fishing, surfing, coastal studies, and more.

The Jennette's CoastSnap station has averaged over 7 submissions per day, since May 17th, 2021 and consistent monitoring of image submissions has already led to improvements in the CoastSnap submission process for other stations in the southeastern United States (Figure 1). Prior to May 17th, CoastSnap images were submitted via social media hashtags or email. It was determined that participants were not immediately submitting their shoreline images, or would fail to submit their images at all. Recreating the sign and submission process and creating a QR code, that would allow for images to be submitted automatically via Survey123 and ArcGIS Online resolved this issue and led to a significant increase in image submissions. The utilization of Survey123 and ArcGIS infrastructure have also made it possible to begin streamlining the current, user intensive CoastSnap workflow, and provide a platform to post public CoastSnap related data products and maps.

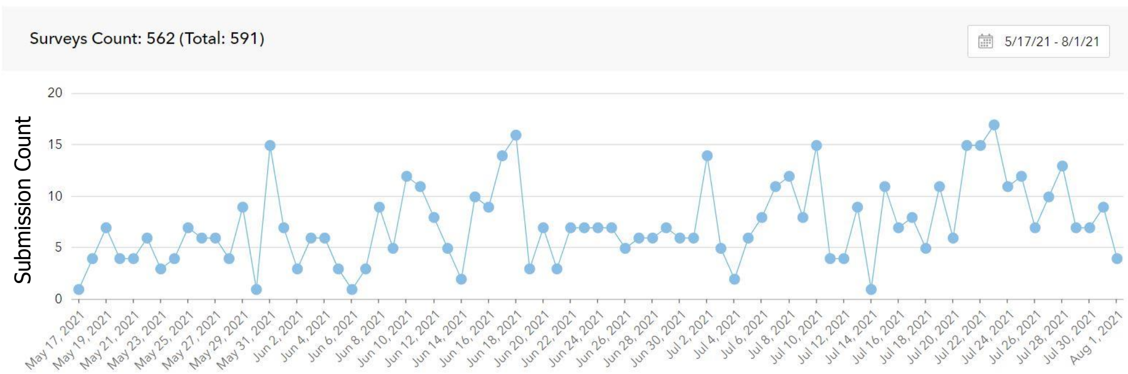

Figure 1. Graph depicting CoastSnap submissions by citizen scientists between 5/17/21 and 8/1/21. Daily submissions counts are logged in Survey123 and graphed by date through time.

Despite overcoming problems with image submission, image processing for CoastSnap requires significant user input (Figure 2). As the regional CoastSnap network grows and photo submissions increase, the need for an automated file management system and automated image processing procedure will become a necessity. Currently, a user is required to manually download and name individual CoastSnap images, one at a time. Each of the files must then be moved to a specific folder that the CoastSnap code, which is written in Matlab, accesses. The code makes use of an Excel database, which also requires significant user input to populate (Figure 3). Once the information in the database has been entered, the images are manually rectified using four preselected GCPs in the camera field of view using the Matlab-based CoastSnap graphical user interface (GUI) (Figure 4). Once the image has been rectified, the shoreline is mapped and saved.

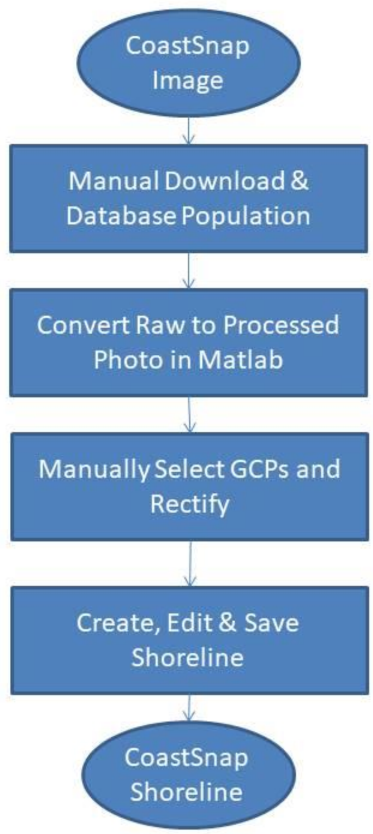

Figure 2. Flowchart depicting the current CoastSnap workflow. The workflow requires significant user input, including manually downloading each image and naming each file, populating an Excel Database and processing the CoastSnap image in Matlab.

	A	B	C	D	E	F	G	H	I
489	jennettes	anonymous	04/07/2021 19:59	EST	20210704_1959.jpg	Email	Snap	1	1.65
490	jennettes	anonymous	05/07/2021 07:15	EST	20210705_0715.jpg	Email	Snap	1	1.41
491	jennettes	anonymous	05/07/2021 14:41	EST	20210705_1441.jpg	Email	Snap	1	0.74
492	jennettes	anonymous	05/07/2021 18:08	EST	20210705_1808.jpg	Email	Snap	1	0.71
493	jennettes	anonymous	06/07/2021 06:52	EST	20210706_0652.jpg	Email	Snap	1	0.62
494	jennettes	anonymous	06/07/2021 14:04	EST	20210706_1404.jpg	Email	Snap	1	0.44
495	jennettes	anonymous	06/07/2021 18:56	EST	20210706_1856.jpg	Email	Snap	1	0.43
496	jennettes	anonymous	07/07/2021 06:24	EST	20210707_0624.jpg	Email	Snap	1	0.66
497	jennettes	anonymous	07/07/2021 14:52	EST	20210707_1452.jpg	Email	Snap	1	0.91
498	jennettes	anonymous	07/07/2021 20:13	EST	20210707_2013.jpg	Email	Snap	1	1.18
499	jennettes	anonymous	08/07/2021 09:08	EST	20210708_0908.jpg	Email	Snap	1	0.9
500	jennettes	anonymous	08/07/2021 13:12	EST	20210708_1312.jpg	Email	Snap	1	0.57
501	jennettes	anonymous	08/07/2021 17:42	EST	20210708_1742.jpg	Email	Snap	1	0.82
502	jennettes	anonymous	09/07/2021 06:35	EST	20210709_0635.jpg	Email	Snap	1	0.77
503	jennettes	anonymous	09/07/2021 13:42	EST	20210709_1342.jpg	Email	Snap	1	0.52
504	jennettes	anonymous	09/07/2021 18:43	EST	20210709_1843.jpg	Email	Snap	1	1.27
505	jennettes	anonymous	10/07/2021 08:58	EST	20210710_0858.jpg	Email	Snap	1	0.84
506	jennettes	anonymous	10/07/2021 13:53	EST	20210710_1353.jpg	Email	Snap	1	0.27
507	jennettes	anonymous	10/07/2021 19:28	EST	20210710_1928.jpg	Email	Snap	1	0.68
508	jennettes	anonymous	11/07/2021 11:13	EST	20210711_1113.jpg	Email	Snap	1	0.97
509	jennettes	anonymous	11/07/2021 13:51	EST	20210711_1351.jpg	Email	Snap	1	0.54
510	jennettes	anonymous	11/07/2021 20:20	EST	20210711_2020.jpg	Email	Snap	1	0.67
511	jennettes	anonymous	12/07/2021 11:24	EST	20210712_1124.jpg	Email	Snap	1	1.39
512	jennettes	anonymous	12/07/2021 18:43	EST	20210712_1843.jpg	Email	Snap	1	0.85
513	jennettes	anonymous	13/07/2021 07:24	EST	20210713_0724.jpg	Email	Snap	1	0.96
514	jennettes	anonymous	13/07/2021 14:46	EST	20210713_1446.jpg	Email	Snap	1	1.05
515	jennettes	anonymous	13/07/2021 19:15	EST	20210713_1915.jpg	Email	Snap	1	1.15
516	jennettes	anonymous	14/07/2021 10:57	EST	20210714_1057.jpg	Email	Snap	1	0.84
517	jennettes	anonymous	15/07/2021 06:36	EST	20210715_0636.jpg	Email	Snap	1	1.12
518	jennettes	anonymous	15/07/2021 12:19	EST	20210715_1219.jpg	Email	Snap	1	0.77
519	jennettes	anonymous	15/07/2021 17:42	EST	20210715_1742.jpg	Email	Snap	1	0.67
520	jennettes	anonymous	16/07/2021 10:30	EST	20210716_1030.jpg	Email	Snap	1	0.93
521	jennettes	anonymous	16/07/2021 15:42	EST	20210716_1542.jpg	Email	Snap	1	0.82

database | manly | nthnarra | insert_newsitename_here | tidal offset calculation | jennettes | avalon | oceanview pier

Figure 3. Example image of the CoastSnap Database. Each of the fields shown requires manual user input.

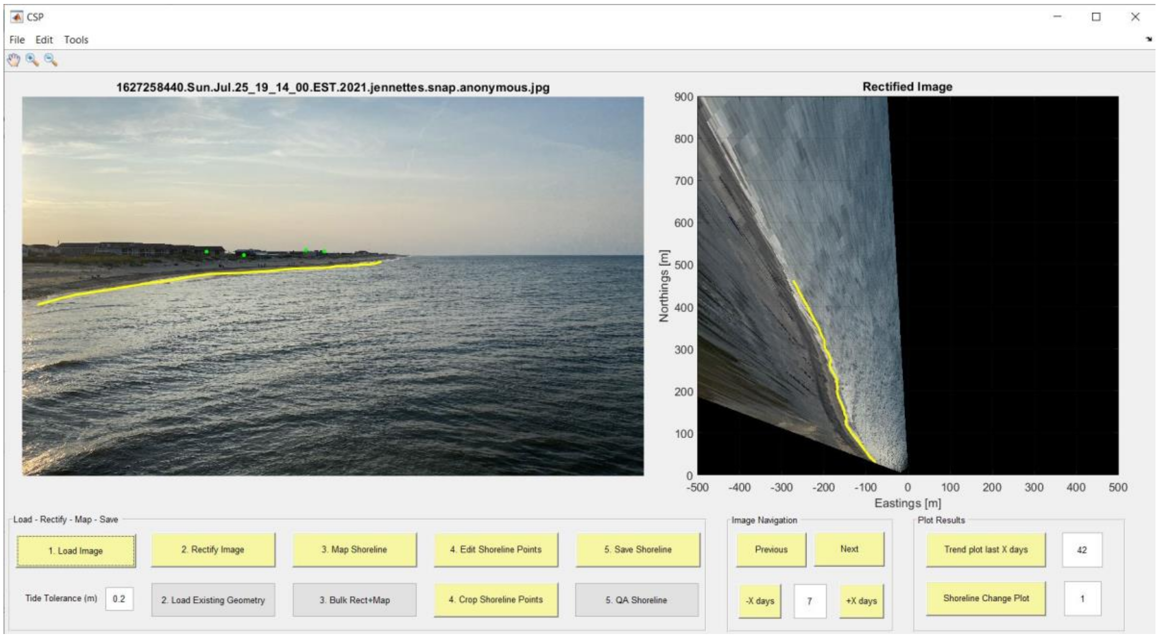

Figure 4. Example image of the Matlab-based CoastSnap graphical user interface (GUI). The window to the left depicts an example of a rectified CoastSnap image. Manually selected ground control points, shown in lime green, and a final shoreline, shown in yellow. The window to the left shows a planar map view of the CoastSnap image and shoreline. The toolbar below represents the basic CoastSnap workflow that is utilized within the GUI.

Project Objectives

The CoastSnap Jennette's location will be used to evaluate and improve the ease of use, accuracy and applicability for different Army Corps Districts, while utilizing CoastSnap as a public outreach platform. The major objectives of this Project were:

1. Process daily CoastSnap image submissions.
2. Determine the sensitivity of CoastSnap derived shorelines to changes in water elevation due to varying tide and wave runup parameters.

3. Generate relevant imagery using CoastSnap data for public outreach via in person presentations and social media.
4. Improve the data management and image processing system that is currently in place for CoastSnap.

Data Processing in the CoastSnap GUI

I downloaded three raw CoastSnap images from Survey123 per day and saved them to a data folder. I also entered corresponding information for each image, including file name, station name, date time, image name, submission method and image quality, into the excel database. I then ran a script to rename files for all unprocessed oblique images, and move them to a processed folder. Next, I would open the CoastSnap GUI and select “Load Image” to select an image for rectification. Once the image was loaded, I would select “Rectify Image” which opens a cursor for GCP selection within the viewer. I then selected each of the four GCPs within the frame manually using the cursor.

To finish processing the image, I would then click “Map Shoreline” to initiate the CoastSnap algorithm that automatically digitizes the shoreline at specific cross-shore transects and creates a georectified shoreline, camera calibrations and water level estimates. If any editing was required, I would then select “Edit Shoreline Points” to enable the dragging/deleting of shoreline vertices as needed. To complete the process, I would save the shorelines as a .mat file for each image by selecting “Save Shoreline”.

Shoreline Data Collection

Between June and August 2021, I visited the CoastSnap station at Jennette's Pier four times and performed walking surveys using a backpack equipped with a RTK-GPS. At the beginning of each survey, I would take and submit a photo from the CoastSnap Station. Immediately after submitting the image, I would walk the upper swash envelope captured within the CoastSnap frame and measure the X, Y, and Z coordinates of the average shoreline position using the GPS backpack. I conducted this survey four times, for four different combinations of wave and tide conditions. The four conditions were: 6/23/21 with high tide and large wave height; 7/02/21 low tide with moderate wave height; 7/21/21 high tide with low wave height, and 8/05/21 mid tide with high wave heights. After conducting the four surveys, I exported the walked shorelines as CSV files, and converted them to .txt files using Microsoft Excel. I also logged relevant wave and tide data for when each survey was taken. Tidal predictions and measurements were taken from NOAA station 8651370, and wave data was taken from NBDC station 44086.

Assistance with Study: Shoreline Sensitivity to Wave Runup and Tidal Elevations

After collecting shoreline data for the four wave and tide scenarios, I assisted researchers at the FRF with a shoreline sensitivity analysis that compares RTK-GPS walking surveys of the average shoreline position to CoastSnap derived shorelines. The goal of this portion of the project was to assess the accuracy sensitivity to tidal and runup elevation error for a given image. The original CoastSnap shoreline is estimated and plotted with a preprogrammed tidal timer series and constant estimate of wave runup using the Stockdon equation (Stockdon et al. 2006). This original shoreline was compared to:

1. The walked shoreline, which was considered truth
2. A CoastSnap shoreline that used only the NOAA predicted tidal elevation
3. A CoastSnap shoreline that used only the NOAA measured tidal elevation
4. A CoastSnap shoreline that used the NOAA measured tidal elevation in combination with an estimate of wave runup at the time the image was taken.

I modified existing Matlab code to compare each walking shoreline to four georectified shoreline elevation estimates. Using camera calibration parameters calculated in CoastSnap, I projected coordinates (easting, northing and elevation) of the walking surveys onto each CoastSnap image. In order to plot the modified CoastSnap shorelines onto the image, I obtained camera intrinsic and extrinsic values from CoastSnap Shoreline files in Matlab and tabulated them in excel to create an 11 variable array. These values were then fed into a photogrammatic function and used to plot each shoreline. I then used the tidal elevation and wave data to adjust the z-values of the modified CoastSnap shorelines plotted on the CoastSnap image. I created four images that correspond with each of the four wave and tide scenarios (Figure 5).

These four images and the shorelines they contain were used in an error analysis by researchers at the FRF that highlights when CoastSnap will over/under predict shoreline position and under which scenarios errors estimates are the largest. It was determined that error estimates are the largest during large wave events, where there is significant runup. They determined that the use of measured tidal elevations was most effective at reducing error under small wave conditions and that the use of measured tidal elevations, along with runup estimates under large scale wave events would yield the most accurate CoastSnap shorelines.

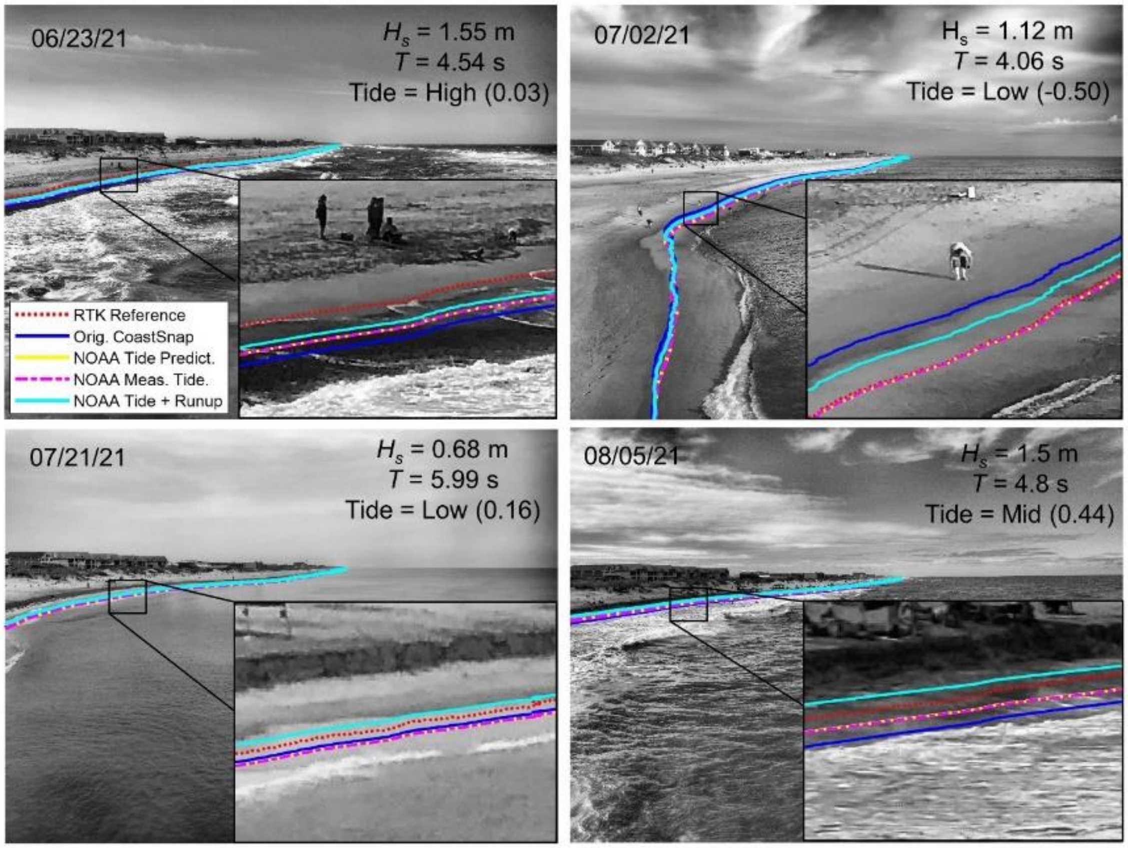

Figure 5. Example of CoastSnap imagery taken during four different wave and tide conditions at Jennette’s Pier, with RTK-GPS walking survey shoreline position shown in dotted red, the original CoastSnap shoreline shown in blue, the CoastSnap shoreline using only the NOAA predicted tide in yellow, the CoastSnap shoreline using only the NOAA measured tide shown in fuschia, and the CoastSnap shoreline using NOAA measured tide and runup shown in cyan.

Shoreline Change Analysis and Plotting in the CoastSnap GUI

Using the “Shoreline Change Plot” function in the CoastSnap GUI, I created graphics highlighting the average beach width change that occurred after the passing of storms. I created graphics for Hurricane Henri and the November Nor’Easter (Figure 6).

Whenever a significant storm occurred, I would attempt to create beach width change plots. This portion of the project demonstrated that the CoastSnap GUI allows users to rapidly assess storm impacts and generate easy to read figures, but also highlighted some drawbacks.

Although the GUI can be useful in some instances, I determined that it does suffer from several drawbacks. Under most circumstances, multiple images per day were processed, but users are not able to specify images to use for shoreline change analysis and plotting. This lack of functionality led to misleading plots when the program automatically selected images taken at different tidal stages. Due to the fact that a shoreline is generated from a static image, a high tide will show a more onshore shoreline than a low tide. Wave runup will also impact where the shoreline will appear in the image. I determined that the program would be more useful if users could select preferred images and shorelines to compare.

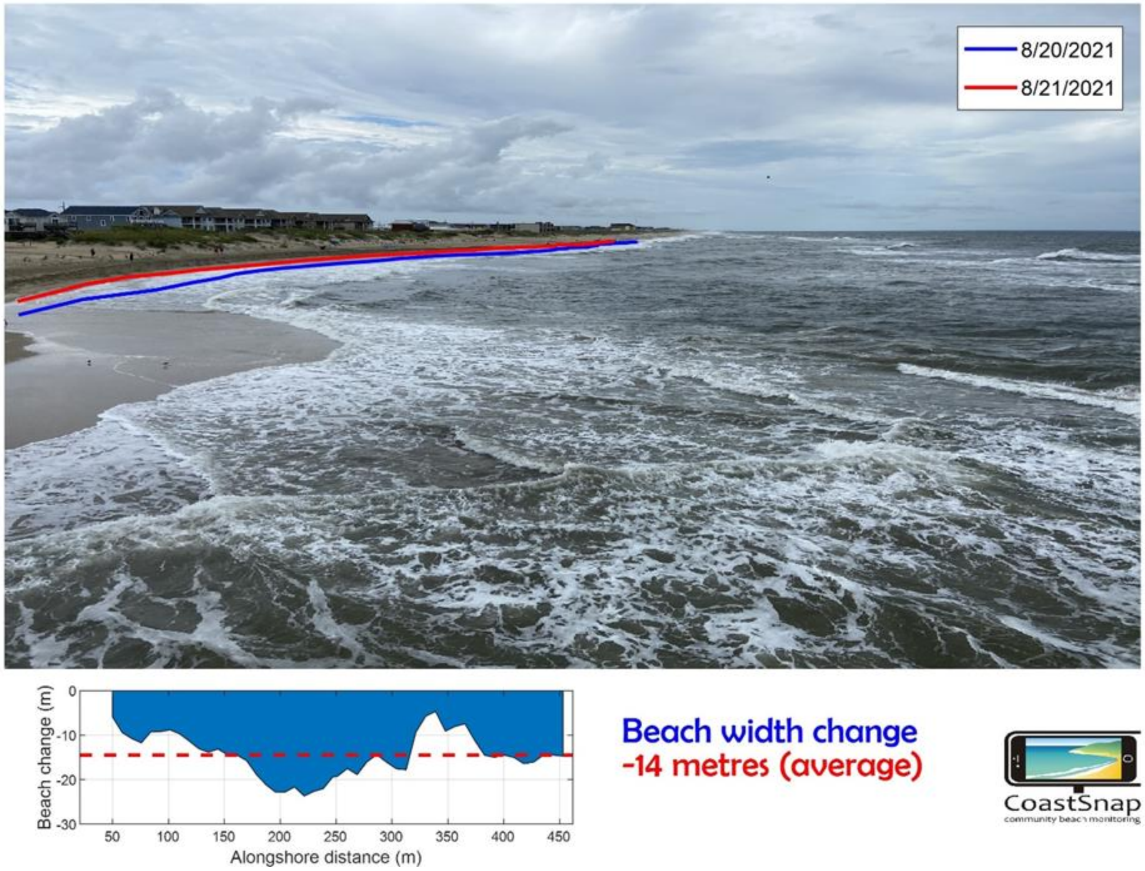

Figure 6. Storm impacts of Hurricane Henri captured by CoastSnap shorelines using the "Beach Width Change" function in the CoastSnap GUI. The pre-storm shoreline is shown in blue and the post-storm shoreline is shown in red. Bottom panel shows an alongshore beach width change plot.

Outreach

The use of CoastSnap to monitor shoreline change is dependent on consistent citizen scientist participation, and CoastSnap provides an excellent platform to engage in scientific outreach, both online and in person. Throughout my time working at the Field Research Facility in Duck, I was responsible for creating content for social media posts on the CoastSnap USA South East Facebook page. I designed graphics using the CoastSnap GUI and Matlab to illustrate shoreline change trends occurring over the span of weeks to months at Jennette's Pier, along with image stabilized time lapses in Adobe Photoshop and accompanying educational write-ups (Figure 7).

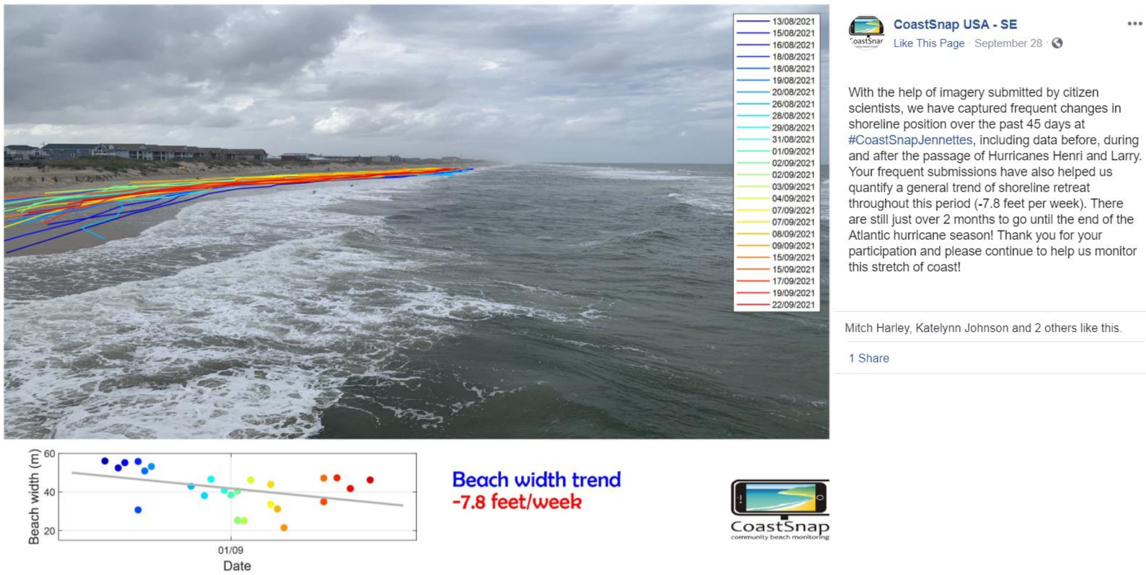

Figure 7: Example social media post, highlighting beach width trend changes occurring at Jennette's pier in August and September of 2021, and created using the "Beach Width Trend" function in the CoastSnap GUI.

I also had the opportunity to present slides with Dr. Ian Connery to summer camp groups and science educators at Jennette's Pier. Dr. Connery and I shared slides about coastal imaging and photogrammetry, CoastSnap, the work done at the Field Research Facility, basic surf science, and how shifting sand impacts the quality of surf breaks in the Outer Banks of North Carolina and other surf spots around the world (Figure 8).

Figure 8. Author presenting on CoastSnap, Coastal Imaging, and Surf Science at the Jennette's Pier summer camps.

Current and Future Works

As the regional CoastSnap network grows and photo submissions increase, so will the need for an automated file management system and automated image processing procedures. The final objective of this project is to streamline the current workflow for data management and image processing, thus reducing user input. I have downloaded and incorporated a previously existing Python script, which was created using the ArcGIS API for Python, into the data management workflow (Figure 9). Currently, the script is setup to run multiple times per day, and downloads new CoastSnap imagery from the hosted ArcGIS Online web layer to a local database. The script names each of the downloaded images using the images Object ID.

I am modifying the code, to download new image submissions and name each submission using the date and time the image was downloaded to remove a step in the file management process. Ultimately, our goal is to automate the transfer of images from ArcGIS Online to a server, run automated image processing scripts to extract a shoreline and return the imagery and corresponding shoreline to the ESRI platform. The team intends to make a web mapping application that will serve as an interactive outreach platform that will allow the public to view shoreline data and track shoreline change through time at each CoastSnap station.

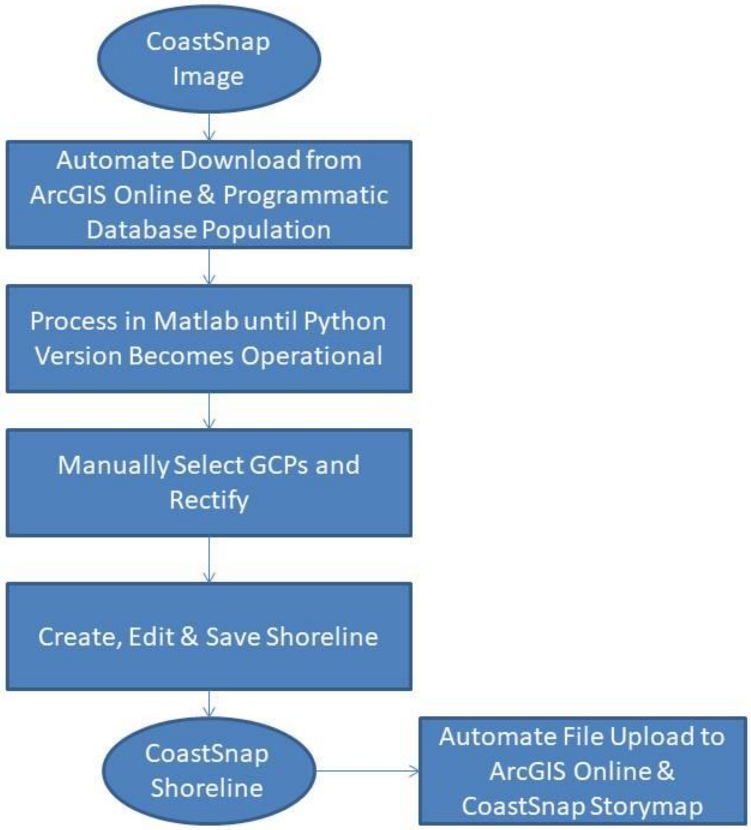

Figure 9. Updated diagram depicting the streamlined CoastSnap workflow. The proposed workflow features a programmatic element, and automated download and upload of CoastSnap data to ArcGIS Online. This proposed workflow will increase operating efficiency and expedite the amount of CoastSnap imagery that can be processed by a single user or group of users managing regional network of CoastSnap Stations.

Broader Significance and Application

My contributions to the CoastSnap research project have helped demonstrate that CoastSnap can be effectively utilized as both an accurate quantitative tool to measure changes in shoreline position over short to long term time scales, in addition to a useful and engaging public outreach platform. Data that I collected, processed and helped analyze was used to highlight the conditions CoastSnap is most effective under, when the program will over and under predict shoreline position, and when error estimates will be the largest.

The scope of this project is significant for coastal managers and planners, USACE districts, and a variety of other stakeholders in coastal communities. Many USACE beach project sites suffer from infrequent monitoring data due to high costs and personnel requirements. CoastSnap has the potential to provide a low cost monitoring solution that can be used to track the subaerial evolution of beach nourishment projects and nearshore berm placements. It can also be utilized as a cost effective tool to assess seasonal fluctuations in shoreline position, along with rapid storm impacts.

The work that I accomplished managing and creating content for the CoastSnap USA – SE Facebook page, along with the presentations I gave with Dr. Connery also demonstrate the utility of CoastSnap as a community outreach platform both online and in person. This portion of the project has shown that CoastSnap can be used to rapidly disseminate scientific information that is relevant to coastal communities. In addition to providing an opportunity to quickly and effectively communicate scientific findings with the public, CoastSnap also allows for station and network managers to answer questions posed online, thus strengthening community engagement.

Reflection on Work Experience and Professional Goals

Over the course of this project I engaged in new activities that helped me develop a variety of valuable and marketable skills. This project also gave me the opportunity to contribute to the scientific process from start to finish at a world renowned research facility and network with a variety of scientists working for the USACE, the USGS and academic institutions from around the globe. While working at the FRF, I successfully tackled new problems that I had never encountered before and demonstrated that I can learn new skills while contributing to the group effort at a high level.

Ultimately, I am interested in finding an occupation that allows me to work both in the field and in the lab, and connect with the public, as I did over the course of this project. When working in the highly dynamic coastal environment, it is of the utmost importance to develop an intimate knowledge of the day to day changes occurring along the coast, and the myriad of conditions driving that change. After working on this project, I now understand the importance of personally observing the coastal environment in the field and using that insight to develope new tools and technology to quantify the changes that impact our coast. Throughout my career, it is my goal to continue to improve upon my aptitude in the field, my quantitative and analytical skills in the lab, and my ability to share scientific information with my fellow scientists, members of the public and the youth.

While working on this project, I learned how to operate state of the art survey equipment to collect critical datasets that would be used for scientific analysis. Prior to conducting surveys, I was able to use my forecasting skills to select potential days and times that would offer the research team at the FRF the most useful datasets. While conducting surveys in the field, I also had the chance to speak with interested beachgoers who were interested in the work I was doing. This gave me the opportunity to practice communicating complex scientific concepts to members of the public, while promoting CoastSnap and the work done at the USACE FRF. I was also able to develop my communication skills while presenting in front of the classes at Jennette's pier. I am thankful to have been able to engage in community outreach, and try to inspire the youth to get involved in coastal issues and activities. In addition to developing my oral communication skills, I was also able to hone my written communication skills for a variety of audiences while generating scientific social media content and assisting with an internal technical report.

Processing CoastSnap daily image submissions from the CoastSnap Jennette's station and creating three rectified shoreline plots per day allowed me to familiarize myself with a vulnerable stretch of coast. Throughout this portion of the project, I qualitatively and quantitatively assessed how the beach north of Jennette's pier responded to daily wave conditions. Processing imagery with the CoastSnap GUI helped me begin to familiarize myself with Matlab code and data structures. Also, taking part in the shoreline analysis and sensitivity study helped me learn how to trouble shoot problems in Matlab independently. Beginning to implement an automated data management workflow has shown that I can effectively identify a problem, research and prescribe a solution, and work towards a long term goal while learning another valuable programming language. Ultimately, it is my desire to play a significant role in creating a CoastSnap web mapping application, and develop interactive web mapping tools in Python that will allow the public to learn more about processes affecting the coast.

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