Validating Satellite-based shoreline mapping

Background

Coastal environments around the world are under significant threat from various anthropogenic influences, including deforestation, overdevelopment, and anthropogenic climate change. These factors are causing substantial damage to our beaches, leading to erosion, rising sea levels, and more frequent floods. Consequently, communities and terrestrial habitats are vulnerable to these hazards, highlighting the urgent need for action (Eriksen & Kelly, 2007; Füssel & Klein, 2006; Ahmed, Creedon & Gharbia, 2023).

Traditionally, assessing the vulnerability of coastal environments has relied on labor-intensive field surveys (Feenstra et al., 1998). While this method is generally accurate, it is expensive and impractical for long-term monitoring. In contrast, remote-sensing methods, such as satellite imagery, offer several advantages. Firstly, they provide large-scale spatial coverage, allowing us to monitor vast coastal areas simultaneously. Secondly, these methods require limited resources and labor, making them cost-effective for long-term monitoring efforts. Lastly, advancements in satellite remote sensing technology have significantly improved both temporal and spatial resolution (Teodoro, 2016).

Satellite-based methods for shoreline mapping involve using the spectral signatures of water and non-water objects, where shorelines can be interpreted as the boundary separating water and non-water pixels in satellite images. By analyzing these spectral signatures, we can identify and monitor changes in the coastline over time. This approach provides a valuable tool for understanding coastal dynamics and assessing the impact of anthropogenic activities on shoreline erosion.

Moreover, the open-access availability of satellite images, such as those from Sentinel-2, Landsat, and MODIS, through platforms like Google Earth Engine, has democratized the process of monitoring environmental changes. This accessibility empowers anyone with a computer and internet access to produce maps that aid in tracking and analyzing environmental changes. This democratization of science is particularly crucial for Small Island Developing States (SIDS), where limited access to resources, labor, and data can impede scientific progress (Zitoun et al., 2020).

Although satellite imagery, such as Sentinel-2 (10 m resolution) and Landsat (30 m resolution), is widely available for open-access, it is important to consider the limitations of spatial resolution when using these images to track shoreline changes on local scales, such as small beaches on islands. To ensure the accuracy of these methods, it is necessary to conduct testing and validation. In this study, we aimed to validate satellite-based shoreline maps using in-situ survey techniques at Surfside Bay, Aruba.

Our validation approach involved GPS tracking through handheld GPS devices during in-situ/ground surveys. By utilizing the dedicated Garmin GPS 64st device to document shoreline positions, our aim was to establish a reliable basis for comparing them with shoreline positions derived from satellite imagery. Through this in-situ approach, our goal was to evaluate the local-scale accuracy and dependability of the satellite-based shoreline maps.

Furthermore, as technology rapidly advances, integrated GPS devices, such as mobile phones, have become increasingly accessible. However, before considering these devices for shoreline monitoring and validation purposes, it is crucial to acknowledge that the literature has documented inconsistencies in GPS accuracy performances (Merry & Bettinger, 2019). To address this concern and evaluate their relative accuracy in comparison to Garmin devices, we conducted a comparison between the performance of these two types of devices. This assessment allows us to gain valuable insights into the reliability of integrated GPS devices for shoreline monitoring and validation.

By conducting these validation exercises and comparing different GPS devices, we can improve our understanding of the accuracy and limitations of satellite-based shoreline mapping methods. This knowledge is crucial for effectively monitoring and managing shoreline changes, particularly on smaller beaches and islands where local-scale accuracy is essential.

Methods

The satellite remote sensing validation method builds upon the methods described by Kelly and Gontz (2018), along with the shoreline survey protocols developed by Psuty and Silveira (2010), which utilize GPS technology.

Study area

The study area encompasses the shorelines of Surfside and the reef islands directly offshore (refer to Figure 1). Surfside is a small bay on the leeward coast of Aruba, Dutch Caribbean, exposed to microtides (mean range of 10 cm according to Kjerfve, 1981). This study area serves as the pilot site for the Surfside Science project, which aims to validate various low-cost methods for long-term monitoring. The shoreline of Surfside Bay stretches for approximately 1.4 km and features a white sandy beach extending from the airport fence up to Oranjestad Lagoon. The surveyed reef islands include the northern end of Renaissance Island, located directly in front of Surfside Bay, as well as two small reef islets. The shoreline of these islands spans approximately 0.5 km and is primarily composed of coral rubble, with a sandy center resting atop the rubble.

The northern end of Surfside Beach is characterized by small patches of beach grass, particularly the whorled dropseed, and a narrow strip of woody beach vegetation, including mangroves, buttonwood, and mesquite trees. Similarly, the northern end of Renaissance Island also features beach vegetation consisting of mangroves, buttonwood, and beachgrass. The other two reef islets only have a few shrubs of buttonwood present and sparsely covered beachgrass.

The reef islands play role as a protective "barrier," mitigating the impact of waves and currents within the bay from open sea conditions. However, signs of erosion are evident, as seen for instance by the steep raised edges (berms) that expose the root systems of the grass patches and beach vegetation on Surfside Beach. Unfortunately, the protective function of these two small islets has been significantly reduced over the past few decades, as their coverage area has noticeably decreased according to observations made by the Metabolic Foundation using Google Earth data between 2002-2022. On the islands themselves, erosion is indicated by the accumulation of reef rubble and reduced sandy area cover, especially after storm events. The rubble consequently forms steep berm crests, approximately 1 meter above sea level.

Visible human-induced impacts on the shoreline of Surfside Beach include urbanization, with the presence of several establishments, a children's playground, a marina, paved and unpaved parking areas, as well as a docking area for loading and unloading boats. Moreover, Surfside Beach experiences heavy use by both local residents and tourists. In contrast, the surveyed shoreline of the reef islands remains unurbanized and poorly visited due to its inaccessibility. At the reef islands, visible human impacts include: i) the exposure of the reef islands to frequent wake production caused by motorized watersports and watertaxi's that go from and to the Renaissance Island (note: privately-owned part of the island is outside of the survey area), and ii) channeling resulting from dredging activities between the reef islands and Surfside Bay, as well as between the reef islands and the Harbor. The impacts from all these erosive activities are additionally indicated by high levels of turbidity inside the bay.

By focusing on this specific study area, we aimed to capture the variability in shoreline dynamics, allowing us to comprehensively evaluate the accuracy and reliability of the satellite-derived shoreline data across different coastal landforms and conditions.

Figure: 1 Study area containing the shorelines surveyed colored in yellow for Surfside Beach and blue for the reef islets. The red dots are averaged Georeference Points (GRPs) consisting of fixed structures.

Data collection

In-situ GPS measurements were recorded while walking along the shoreline with our dedicated GPS device, Garmin GPSMap 64st, and Android smart phones. The shoreline is defined as the "high-water line or wet/dry sediment line" (Figure 2) and encompasses the intertidal zone, which refers to the area above and below the maximum low and high tide (Figure 3).

Figure 2: The wet/dry sediment line used as an indicator of the shoreline for GPS mapping (left image indicated by arrow, right image indicated by dotted line) (Suanez et al., 2015).

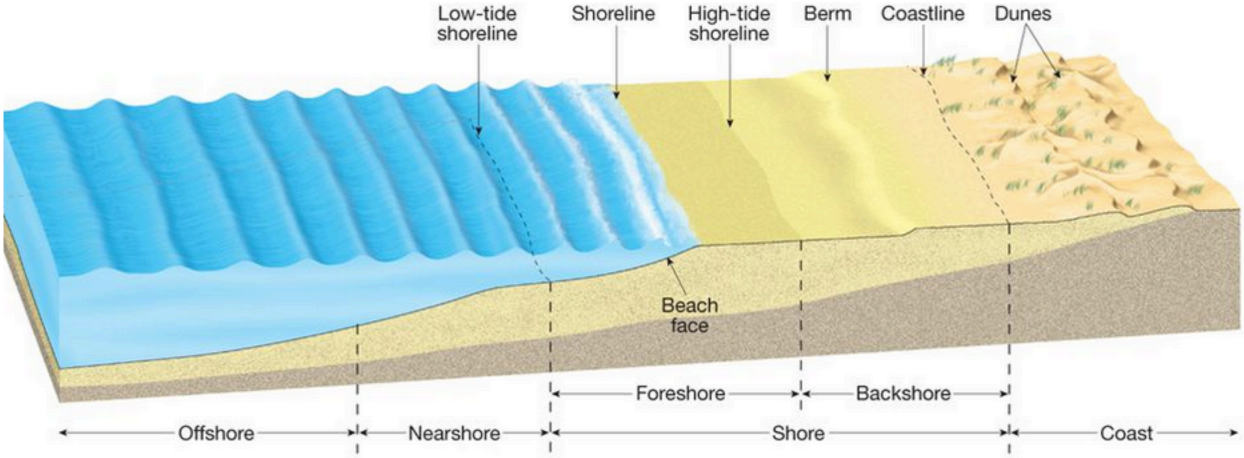


Figure 3: Coastal zonation in relation to tides (Trujillo, 2013).

- To ensure accurate measurements, we scheduled the in-situ GPS data collection to align with the satellite flyover dates and times, with a preference for recording during neap tides (7 days after spring tide or 1st/3rd quarter moon) for rigorous accuracy assessment (Figure 3). During neap tides, we initiated the survey approximately 15 minutes prior to the highest and lowest tide for Surfside beach, and about 45 minutes prior to the maximum high and low tide for reef islands. Additional measures that were taken to solve GPS accuracy issues include:
- Tracking under non-overcast conditions to mitigate cloud effects
- Utilizing the visible high-tide swash line under wet conditions
- Maintaining a minimum distance of 2 meters between GPS devices to minimize potential interference.
- Enabling WAAS (Wide Area Augmentation System) on the Garmin GPS device.

For detailed data collection techniques, please refer the Field Standard Operation Procedure (SOP). Besides shoreline tracking, we collected 30 GPS-points in fixed locations (urban structures) using two Garmin GPSMap 64st devices at two different times of the day. With the aid of these GRPs, we could apply georeferencing to the GPS tracks in order to undertake an evaluation of the accuracy of the Sentinel-2 shorelines.

Data Analysis

Considering there were doubts regarding the accuracy of the in-situ surveys, data analysis consisted of three accuracy assessments: 1) Garmin GPS performance, 2) Smartphone GPS performance, 3) Accuracy assessment of Sentinel-2 shorelines comparing short-term temporal variability and comparing against GPS-shoreline tracks. All mapping exercises were conducted using QGIS (version: 3.16.5-Hannover).

Handheld-GPS performance:

The performance of the Garmin and the Smartphone GPS were indicated by illustrating the variation in the shoreline tracks for different dates and times of day with respect to the GRPs. Georeference point (GRP) mean is calculated averaging the 120 GPS positions. and their potential use as Georeference Points (GRPs). The locations for the averaged GRPs are shown in Figure 1. to determine the maximum distance between GPS points.

Accuracy Assessment Sentinel-2 shoreline:

Five survey dates between February and March were available for the comparative analysis of the satellite-based imagery: 14th of February 2023 and 11th, 16th, 26th and 31st of March 2023. The GPX files from the GPS devices corresponding to these survey dates were imported into QGIS and converted to shapefiles. Off-track points (outliers) were removed.

The satellite-based shoreline was derived from Sentinel-2 imagery in Google Earth Engine, using the NDWI (Normalized Difference Water Index) index. For detailed information on the codes used to obtain this map data, please refer to this code. Raster data was produced for all survey dates, except the 16th of March, which was covered for the most by clouds. Cloud formation on the other dates were only limited to parts of the shoreline, therefore only a portion of the shoreline at Surfside Beach was represented (Lagoen Oranjestad to just before the pier of Pinchos Bar & Grill). The raster data distinguishing water and non-water pixels was then converted into a polygon shapefile that contain pixel-shaped edges. Both the raster and polygon files for the different dates were exported for further analysis in QGIS.

Short-term variability of Sentinel 2 shorelines

The following steps were taken for comparing the short-term variability of Sentinel-2 shorelines

1. By overlaying the polygon files from different dates on top of eachother, select polygon files from dates which contained the longest stretches of the shoreline uncovered by clouds:
    a. This resulted in selecting the polygon files from the 11th-, 26st- and 31st- of March.
2. For each polygon shapefile, remove the section of polygons where cloudyness masks the shorelines on any of the selected dates.
    a. This resulted in focusing only on the shorelines from just North of the Pinchos Bar, all the way to Lagoen Oranjestad/Rooi Manonchi.
3. Using the tool “Symmetrical Difference”, create a polygon layer which consists of extracted portions of the shorelines where the Sentinel 2 imagery does not overlap between two different dates.

    a. This resulten in a polygon layer containing the non-overlapping pixels between two layers.

4. Repeat step 3 to cover the differences between all dates
    a. This resulted in three polygon layers showing the non-overlapping pixels (i.e. differences over time):
        i. between 11th and 26st of March
        ii. between 26st and 30th of March
        iii. between 11th and 30th of March

Comparison of Sentinel 2-shorelines against GPS-shorelines

The following procedure was followed to conduct a comparative analysis between Sentinel-2 shorelines and GPS-shoreline tracks, which is partly based on Kelly and Gontz (2018).

1. Manually digitize a boundary layer from the Sentinel-2 data:
    1. Create a sub-pixel raster by exporting raster file in QGIS and saving at a higher resolution.
    2. Convert sub-pixel raster to polygon shapefile with "Pixels to Polygon"tool, which creates a sub-pixel grid to be used as reference for smoothing the shoreline edges.
    3. Create a new line vector layer which smoothes the shoreline, where a balance in splitting pixels between land and sea is kept consistent by snapping the line between the middle of each pixel or block of pixels.
2. Split the boundary layer where it intersects the intertidal zone boundary (between the lowest and highest tide measured with the GPS devices):
    1. Create intersection points with "Line intersection" tool using digitized boundary layer as input layer and separately for both Garmin tracks (low and high tide) as an intersecting layer. Georeferencing of Garmins tracks were required:
        1. Garmin tracks were georeferenced based on Georeference points
    2. Create a new line vector layer creating segments between intersection points for within the Garmin tracks and between intersection points for outside the Garmin tracks, respectively categorizing each segment as in or out.
    3. Create a new field calculating the length of each segment
3. Sum up the shoreline segments that fall within and outside the intertidal zone to obtain the total Sentinel-2 shoreline distance and the percentage within the intertidal zone.
4. Measure the true shoreline distance with the GPS during high tides and compare it to the distance measured for the Sentinel-2 shoreline, using both Garmin GPS devices. Note the following edits were required:
    1. GPS-based shorelines were cut to represent the same portion of shoreline available for satellite imagery
    2. "Wandering"- points from the GPS-based shorelines were removed to avoid overestimating the actual length of the GPS-tracks.

Results

The following results demonstrate the performance of the handheld GPS devices, the short-term variability of Sentinel-2 shorelines and an attempted accuracy assesment of the Sentinel-2 shorelines.

Garmin GPS performance

Figure 4, illustrated for one of the GRPs along Surfside Beach how differences of up to 5 meters between GPS measurements were recorded with Garmin 64st at fixed structures.

Figure 4: Variation in GPS positions recorded at a fixed structure (in this case: southern corner between the pier of Pinchos bar & grill and boardwalk of Aruba Surfside Marina hotel).

Figure 5 shows how the GPS measurements from Garmin exhibit displacement (estimated maximum 16 m) during low and high tide. Furthermore, the GRP's representing fixed structures that occur along the shoreline, are demonstrating how the Garmin GPS tracks are clearly displaced from the GRP's.

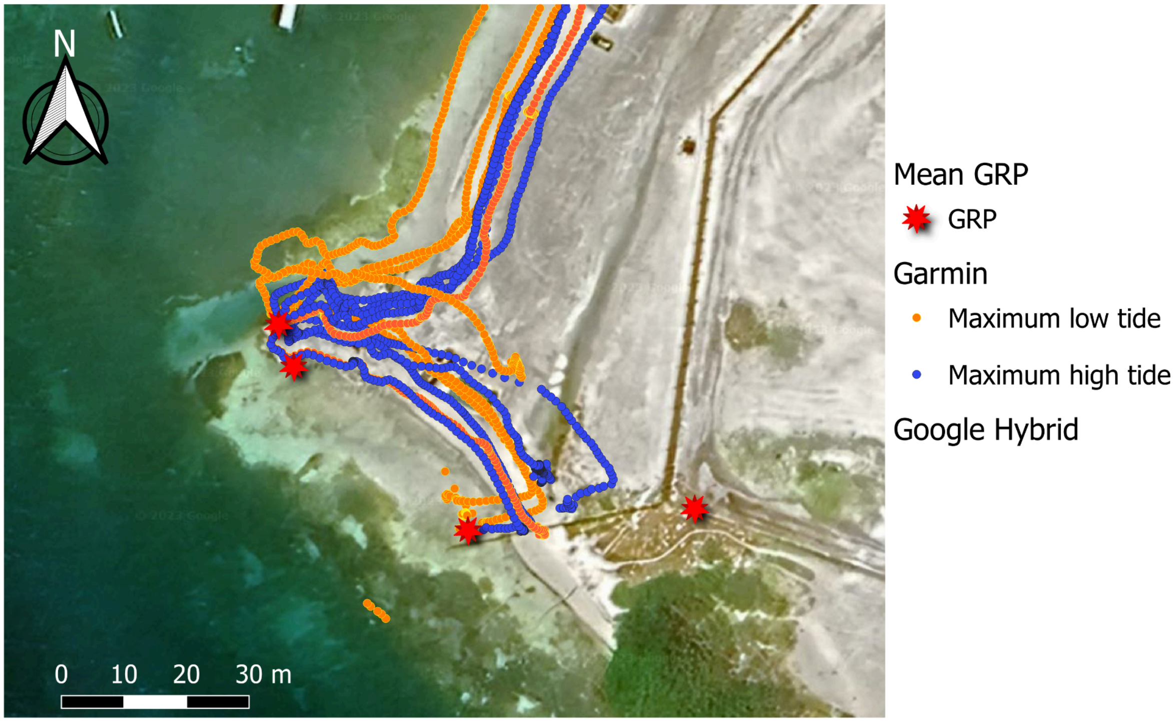


Figure 5: In-situ GPS surveys illustrating differences between tidal times and dates for Garmin 64 st. Note: adaptations in the SOP did not improve accuracy of GPS tracks over time.

Android GPS performance

Figure 6 shows show the GPS measurements from Android exhibit c (estimated maximum 10 m) during low and high tide and therefore less compared to Garmin. Again, the GRP's representing fixed structures that occur along the shoreline are demonstrating how the Android GPS tracks are clearly displaced from the GRP's.

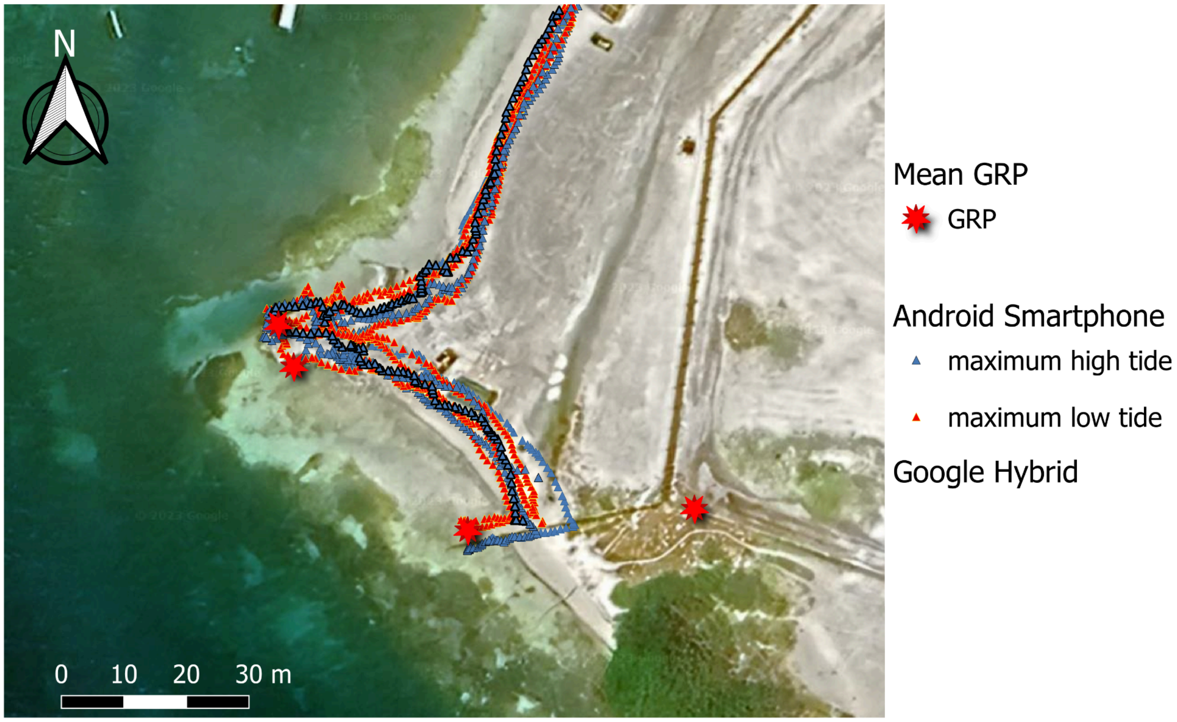


Figure 6: In-situ GPS surveys illustrating differences between tidal times and dates for Android. Note: adaptations in the protocol did not improve accuracy of GPS tracks over time.

Garmin vs Android

As shown in Figure 7, when comparing GPS measurements between different devices, both horizontal and vertical displacements are noticeable. Overall, the GPS measurements used to verify the accuracy of the Surfside Bay shorelines, exhibited significant variations that were both time- and device- dependent. android a bit less crazy then garmin

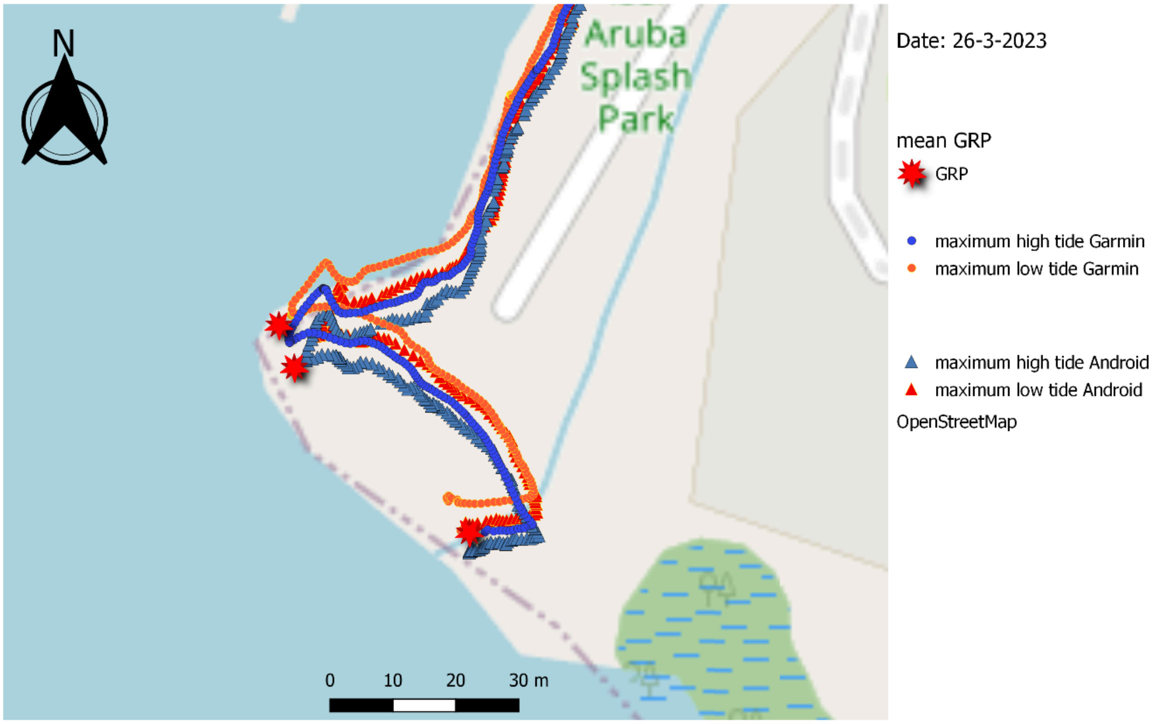


Figure 7: In-situ surveys illustrating differences between times of day and between devices.

Sentinel-2 Temporal Variability

Figure 8 shows the differences between shorelines mapped from Sentinel-2 imagery data with regards to the different in-situ survey dates. For the most part, the difference between the different dates covers 1 pixels, i.e. 10 meters. However, at the mouth of the outlet of Rooi Manonchi/Lagoen Oranjestad a difference of up to 3 pixels could be observed.

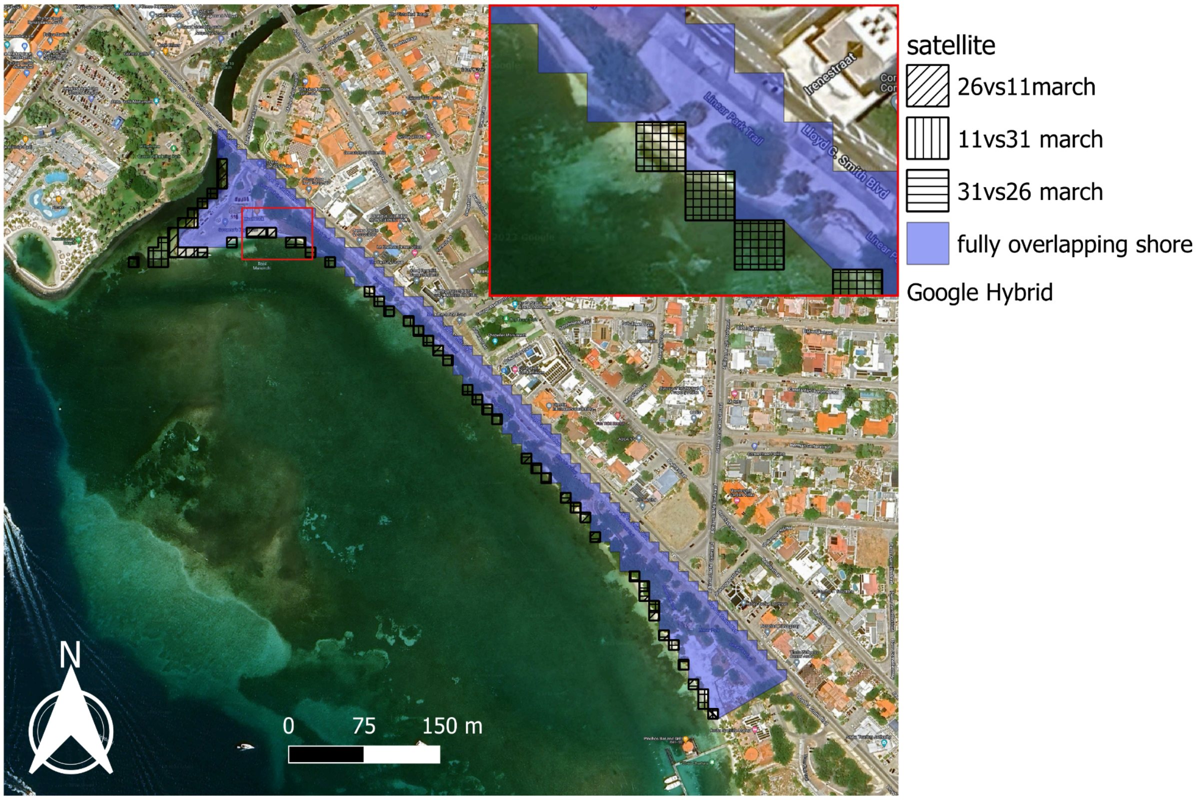
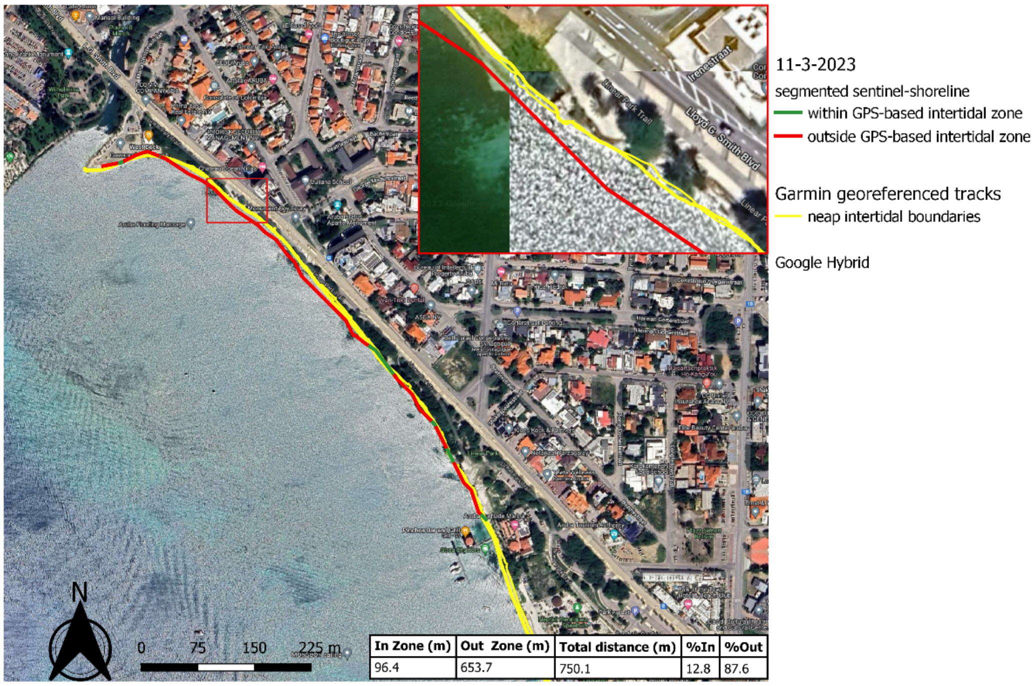


Figure 8: Satellite-based shoreline map illustrating differences in shorelines between survey dates.

almost 3 pixel difference which would be 30 meters at the point

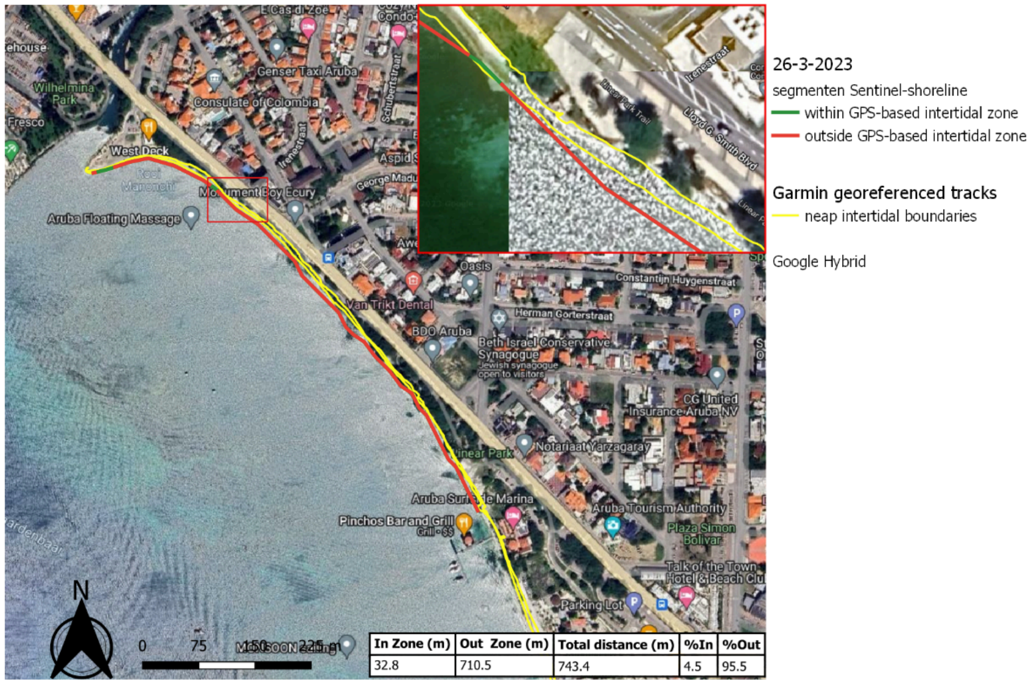
most of the coast is 1 pixel maximum 10 meters

Sentinel-2 Accuracy Assessment



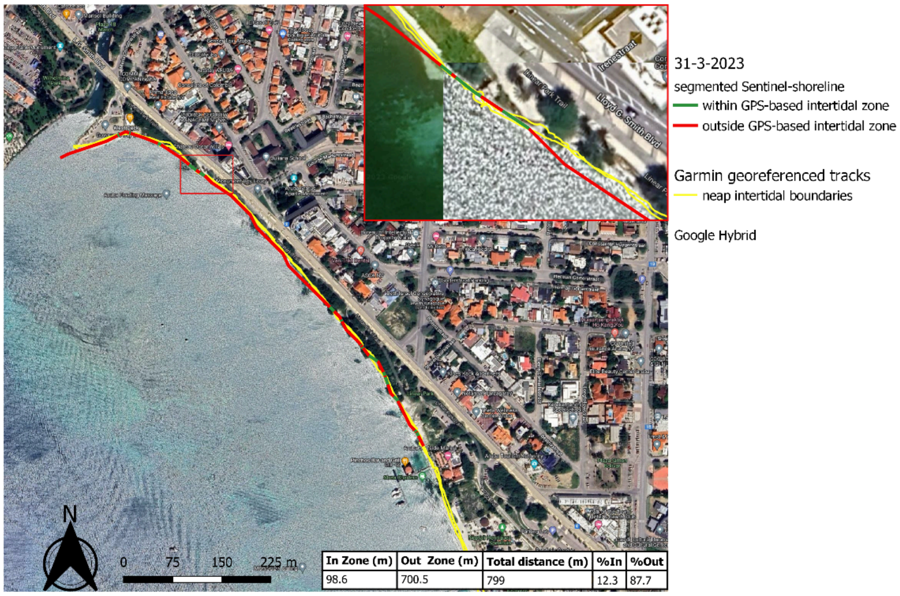
In Zone (m)	Out Zone (m)	Total distance (m)	%In	%Out
96.4	653.7	750.1	12.8	87.6

Figure ….: Accuracy Assessment Method – Calculating the accuracy of the Sentinel 2-derived shoreline for the 11th of March 2023. The shoreline vector is split where it crosses the Garmin-tracked intertidal zone boundary (yellow) and the sum of the shoreline segments that are within the zone (green) and out (red) is calculated. The red-highlighted box represents a zoomed-in section of the shoreline.



In Zone (m)	Out Zone (m)	Total distance (m)	%In	%Out
32.8	710.5	743.4	4.5	95.5

Figure ….: Accuracy Assessment Method – Calculating the accuracy of the Sentinel 2-derived shoreline for the 26th of March 2023. The shoreline vector is split where it crosses the Garmin-tracked intertidal zone boundary (yellow) and the sum of the shoreline segments that are within the zone (green) and out (red) is calculated. The red-highlighted box represents a zoomed-in section of the shoreline.



In Zone (m)	Out Zone (m)	Total distance (m)	%In	%Out
98.6	700.5	799	12.3	87.7

Figure …: Accuracy Assessment Method – Calculating the accuracy of the Sentinel 2-derived shoreline for the 31st of March 2023. The shoreline vector is split where it crosses the Garmin-tracked intertidal zone boundary (yellow) and the sum of the shoreline segments that are within the zone (green) and out (red) is calculated. The red-highlighted box represents a zoomed-in section of the shoreline.

Table …: Alongshore lengths for the Sentinel-2 shorelines and comparison to measured lengths of the surveyed high tide lines.

Date	**Sentinel-2**	**GPS-high tide (m)**	**Difference (m)**	**% Difference**
11/3/2023	750.058	821.408	-71.35	8.686304
26/3/2023	743.348	791.8	-48.452	6.119222
31/3/2023	799.062	791.777	7.285	0.920082
mean	764.156	801.6616667	-37.5057	4.678491

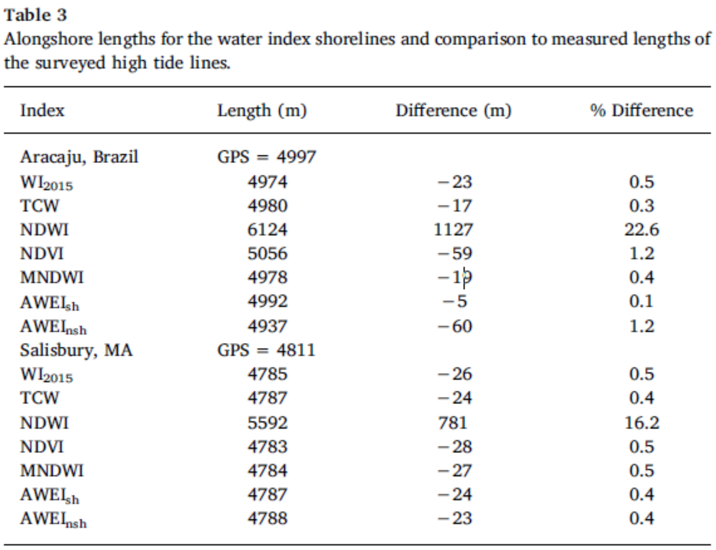


Table 3
Alongshore lengths for the water index shorelines and comparison to measured lengths of the surveyed high tide lines.

Index	Length (m)	Difference (m)	% Difference
Aracaju, Brazil	GPS = 4997		
WI_{2015}	4974	−23	0.5
TCW	4980	−17	0.3
NDWI	6124	1127	22.6
NDVI	5056	−59	1.2
MNDWI	4978	−19	0.4
AWEI_{sh}	4992	−5	0.1
AWEI_{nsh}	4937	−60	1.2
Salisbury, MA	GPS = 4811		
WI_{2015}	4785	−26	0.5
TCW	4787	−24	0.4
NDWI	5592	781	16.2
NDVI	4783	−28	0.5
MNDWI	4784	−27	0.5
AWEI_{sh}	4787	−24	0.4
AWEI_{nsh}	4788	−23	0.4

Table results from Kelly paper.

Lower % difference compared to kelly study with respect to NDWI

Discussion

The validation of satellite-based shoreline maps is crucial to ensure their accuracy and reliability, especially when monitoring coastal environments at local scales. In this study, we aimed to validate the satellite-based shoreline maps using in-situ survey techniques at Surfside Bay, Aruba. Our findings revealed that GPS devices, particularly the Garmin GPS 64st, were not appropriate for groundtruthing or establishing a basis for comparison with the shoreline positions derived from satellite imagery.

Initially, we employed handheld GPS devices to track and document shoreline positions during our in-situ/ground surveys. The intention was to evaluate the local-scale accuracy and dependability of the satellite-based shoreline maps. However, our validation exercise highlighted the limitations with using the Garmin GPS 64st for these types of accuracy assessments.

Despite the common use of Garmin 64st for field surveys and even accuracy assessments (…) we observed discrepancies of 5-6 m between GPS points measured along the same shoreline tracks and at fixed structures that did not coincide with actual shoreline changes.

We hesitate to use this data as a reference to assess the accuracy of satellite-based shorelines. In comparison, the USDA Forest Service (2023) reported an accuracy of 4.05 m for this device. Moreover, the mean error for Sentinel-2 -based shorelines of microtidal beaches is 3.06 m (±5.79 m) (Pardo-Pascual, 2018). Therefore, the Garmin device does not serve the purpose as a reference, considering its accuracy is not much better than Sentinel-2 –based mapping. Despite attempts to improve the accuracy of the GPS positions recorded with the Garmin, inconsistencies in the GPS positions from the GPS devices remained significant. This is likely attributed to the limitation in the device's spatial accuracy and unknown factors that cause signal interferences, indicated by the displacement in the tracks.

Furthermore, to assess the viability of integrated GPS devices, such as mobile phones, we conducted a comparison between the Garmin GPS 64St and these ubiquitous devices. The findings indicate that GPS capabilities in smartphones our similar to the dedicated Garmin GPS device. Considering they fare no worse than Garmin devices, a device commonly used in field surveys, and considering that integrated GPS devices are ubitiquous, suggests that these devices can serve a similar purpose to Garmin.

The limitations of low-cost GPS devices for groundtruthing shoreline changes underscore the need of developing accuracy assessment tools that are accessible to the wider scientific and public community to improve monitoring efforts in countries where financial resources for research are limited, e.g. SIDS. Nevertheless, with the current technologies available and where the resources are available future studies should explore alternative groundtruthing methods with higher spatial accuracy, such as the use of differential GPS systems or ground-based LiDAR.

Nevertheless, we attempted to assess the accuracy of the satellite imagery by: i) comparing the shoreline differences over different dates in march where no disturbances or weather changes occurred that could cause extreme shifts in coastlines.

Other data sources such as aerial imagery or high-resolution satellite imagery (Planet), could potentially be used to serve as a basis for comparison.

Even with the use of real-time differential GPS (DGPS) corrections or postprocessing, the locations collected using standard GPS receivers are still not as accurate as those of survey-grade receivers. Such receivers process dual-frequency signals, rely on a DGPS reference station close to the survey site, and also use 3 postprocessing techniques.

That said, there are no defined acceptable accuracy for monitoring shoreline changes, that we are aware off.

If we base them on the shoreline changes projected for the region in 2050, i.e. 80 m ± of shoreline retreat, then we can assume that 5 m accuracy would be acceptable.

GPS pathfinder

Satellite imagery consistency indicated lower variation than the GPS measurements, in essence a better tool for tracking shorelines than GPS devices, including dedicated GPS devices.

Post processing corrections:
https://www.fs.usda.gov/t-d/pubs/pdfpubs/pdf04712307/pdf04712307dpi300.pdf

Conclusion

In conclusion, our validation efforts demonstrated that GPS devices, including the Garmin GPS 64St and integrated GPS capabilities in smartphones, were not suitable for accurate groundtruthing and establishing a basis for comparison with satellite-derived shoreline positions. The limitations of these devices, along with the spatial resolution of satellite imagery demands further research of satellite-based shorelines using alternative methods to assess their accuracy. Understanding the accuracy and limitations of these methods is vital for effective monitoring and management of shoreline changes, particularly in smaller beach and island environments. "

In the end, however shoreline mapping using satellites when being the only source of information, i.e. where no in-situ monitoring programs exist,should be considered for monitoring purposes.”

Such limitations create the potential to explore low-cost solutions with performance within acceptable standards, so that such cost-effective sensors could be used to complement the existing high-cost instruments for greater spatial and temporal coverage and couldalso act as a backup when a standard instrument fails or becomes dysfunctional due to technical issues”

Recommendations

Alternative validation methods from meta-analysis:

Test grid of control points measured with DGPS, GCPs Measured using RTK-GPS, Comparison

with manually digitised shorelines, RTK-GPS, Terrestrial laser scanner, shoreline validated against tape measure

While not completely open-access, delineating shorelines with higher-resolution satellite imagery can be potentially used as well, e.g. Planet.

Obtain more spatially accurate survey-grade equipment, such as a Trimble GPS unit for comprehensive validation

real time kinematic (RTK) and post-processing kinematic (PPK), were implemented by Trimble R12.

Acquire high-resolution satellite imagery or aerial photographs to supplement the satellite-based shoreline maps. Higher resolution imagery allows for more detailed analysis and improves the accuracy of groundtruthing.

Global Positioning System (GPS) receivers are commonly used to collect accurate positional data of shoreline features. They can provide precise location information that can be used to compare against the mapped shoreline positions.

Differential GPS (DGPS): DGPS is a more precise version of GPS that uses a network of base stations to correct for atmospheric and other errors. DGPS receivers provide higher accuracy for shoreline positioning, making them useful for groundtruthing purposes.

https://www.ngs.noaa.gov/cgi-cors/corsage.prl?site=CN19

https://www.ngs.noaa.gov/cgi-cors/CorsSidebarSelect.prl?site=cn19&option=Coordinates14

Trimble NetR9 is a high-precision reference station used in the field of surveying, geodesy, and geolocation. It is manufactured by Trimble Inc., a leading provider of positioning technologies.

The Trimble NetR9 reference station is designed to provide accurate and reliable GNSS (Global Navigation Satellite System) data for use in various applications that require precise positioning. It supports multiple satellite constellations, including GPS (Global Positioning System), GLONASS (Global Navigation Satellite System), Galileo, and BeiDou, allowing it to receive signals from a wide range of satellites.

The NetR9 reference station incorporates advanced technology and features to ensure the highest level of accuracy. It utilizes multiple antennas and receivers to track signals from different satellites simultaneously, which helps mitigate errors caused by signal obstructions and multipath effects. It also includes advanced signal processing algorithms to improve the quality of the position data.

One of the key features of the NetR9 is its ability to operate as a base station in a Real-Time Kinematic (RTK) system. In an RTK setup, the NetR9 receives GNSS signals and transmits corrected data in real-time to roving receivers or other users in the field. This enables precise positioning in real-time, making it useful for applications such as land surveying, construction, precision agriculture, and machine guidance.

The Trimble NetR9 reference station is known for its robust construction, reliability, and versatility. It offers various connectivity options, including Ethernet and wireless connections, for data transfer and remote control. The station can be integrated into existing surveying networks and used with Trimble's software solutions for data processing and analysis.

Overall, the Trimble NetR9 reference station is a powerful tool for professionals who require high-precision positioning data. Its advanced features, multi-constellation support, and compatibility with RTK systems make it a popular choice in the surveying and geospatial industry.

2. Postprocessing: If the Garmin 64st handheld GPS device does not support real-time corrections or SBAS, another option is to collect raw GPS data during the field survey and then postprocess it using software capable of differential correction. Trimble offers software like Trimble Business Center and Trimble GPS Pathfinder Office that can perform postprocessing and apply differential correction techniques.

To postprocess the data, you would need to collect raw GPS data with the Garmin 64st and simultaneously collect raw data from the Trimble NetR9 reference station. The two sets of data can then be combined in postprocessing software, which analyzes the data and applies differential correction techniques to improve the accuracy of the GPS positions.

Postprocessing typically requires precise timing synchronization between the reference station and the handheld GPS device, as well as access to the reference station's raw data files. It may also require knowledge of the specific data formats and coordinate systems used by both devices.

It's important to note that the availability and compatibility of real-time correction services or the feasibility of postprocessing may depend on the specific models and capabilities of the Garmin 64st handheld GPS device and the Trimble NetR9 reference station. Consulting the user manuals, technical specifications, and support resources for both devices would provide more accurate and detailed information on the available options for achieving higher-precision positioning.

RTK stands for Real-Time Kinematic. It is a technique used in surveying, geodesy, and navigation to achieve highly accurate real-time positioning.

RTK utilizes a base station and one or more roving receivers or mobile devices. The base station, typically a reference station with known coordinates and high-precision GNSS equipment like the Trimble NetR9, continuously tracks GNSS signals from satellites and calculates highly accurate position solutions.

The roving receivers, such as handheld GPS devices or surveying instruments, receive signals from the same set of satellites as the base station and establish a communication link with the base station. The roving receivers measure the phase and timing of the satellite signals and transmit the data back to the base station.

Using this communication link, the base station compares the phase and timing measurements from the roving receivers with its own measurements. It calculates the difference between the observed and expected measurements, known as the carrier phase ambiguity, and determines the precise baseline vector between the base station and the roving receiver.

The base station then computes correction information based on the carrier phase ambiguity and sends it to the roving receivers in real-time. The roving receivers apply these corrections to their own measurements, resolving the carrier phase ambiguity and achieving highly accurate real-time positions relative to the base station.

The key advantage of RTK is its ability to provide centimeter-level positioning accuracy in real-time. This makes it invaluable for applications where precise positioning is critical, such as land surveying, construction, precision agriculture, and machine guidance.

It's important to note that RTK requires a clear line of sight between the base station and the roving receivers, as signal obstructions and multipath effects can degrade the accuracy of the measurements. Additionally, RTK systems typically operate over relatively short distances, typically up to a few kilometers, although longer baselines are possible with advanced equipment and techniques.

Overall, RTK is a powerful technique that allows for real-time, highly accurate positioning by utilizing a base station to compute and transmit correction information to roving receivers, enabling a wide range of applications that require precise positioning data

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