Roinn Cumarsáide, Gníomhaithe ar son na hAeráide & Comhshaoil
Department of Communications, Climate Action & Environment

Geological Survey
Suirbhéireacht Gheolaíochta
Ireland | Éireann

Research Programme
- Short Call 2020, Final Report -

Lead Applicant Name	Donal Lennon
Host Organisation name	iGeospatial Modelling Ltd
Project Title	Real time monitoring of landslides using remote sensing approaches
Contract Number	2020-sc-o44

This report covers the period 1st December 2020 to project end date 31st May 2022

2. (a) Project information:

Final project report (*max 2500 words, excluding figures and headings*):

Executive summary (lay abstract, approx. 250 words):

Soft clay cliff coasts are dynamic environments that can retreat very quickly. Whether in response to wave energy, coastal slope, beach width and height or the intensity, duration and frequency storm activity. Sea level rise due to melting ice caps is a further contributing factor in coastal erosion. In this investigation, using remote sensing technologies, short-term changes are observed and quantified along a section of shore front at Ballyconnigar Co. Wexford. Terrestrial LiDAR scanning in conjunction with UAV and terrestrial photogrammetry were used to monitor shorefront retreat over the course of the study. Figure (1) below shows the extent of shoreline retreat based on UAV and GPS data and historic photographic data since 1971.

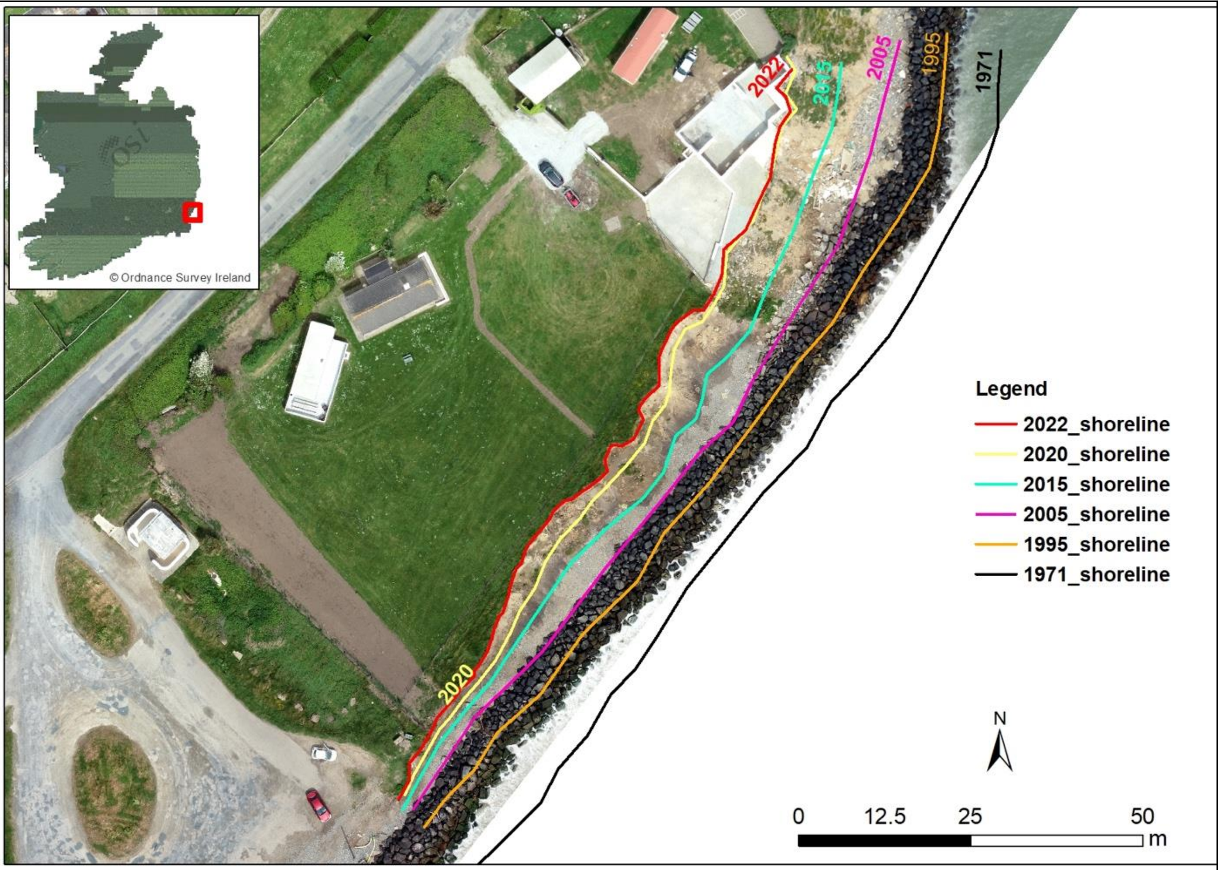


Fig.(1). Shoreline retreat since 1971

(i) Results, scientific/engineering targets reached beyond the state of the art and conclusions

- The project team set out to develop a methodology to collect 3D topographic information of ground surfaces at Ballyconnigar Co. Wexford shore line, by using photogrammetry and laser scanning. Raw image and LiDAR data collected is available on the project webpage; Ballyconnigar.eu
- Movements of the cliff were reported after a period of data collection, as described in table 3 below.
- The solution can be extended to near-real time monitoring, when cameras can be set up on site to record the surface continuously. Unfortunately, due to restrictions of privacy under GDPR current use of recording cameras on site could not be executed.

In preparation to carry out our program of work at Ballyconnigar near Blackwater Co

Wexford (Lat. 52.430975 Long. -6.326903);

- iGeospatial Modelling contacted Wexford Co. Co. coastal engineer Mr. George Colfer (contact details can provide upon request), in December 2020.
- Having met at our proposed sites, we identified two possible areas of interest depending on land owner permission and ease of access. An area adjacent to the carpark at Ballyconnigar, see Fig.1 above, was selected as a suitable candidate site due to its recent history of regular retreat events.
- Mr. George Colfer discussed how we proposed to carry out the surveys and over what time frame.
- Mr. George Colfer agreed the County Council would facilitate us as best they could should we need to move heavy equipment into place or erect poles for our cameras etc.
- The project leader called on local land owners to appraise them of the project, to agree access where necessary and set up contact procedures so they could keep an eye on the project and the project team would not cause any issues as work proceeded.
- The land adjacent to the cliff face of interest to this project, shown in Figure (2) below, was in the process of changing hands, however the project team was able to establish a good working arrangement with the new owner.
- The project team placed an order on Jan 20th 2021 with CamDo Solutions (https://cam-do.com/) for the hire of 6 GoPro camera systems expecting an early delivery date with a view to getting started on data collection.
- Our intention to deploy the cameras on the coast for a 1-year period required that each camera system would consist of a 'GoPro Hero7 Black' camera, a time lapse camera controller and a V50 power pack, all to be housed in a weather proof case as shown in Figure (3) below.
- We received confirmation of the order on Feb. 2nd. 2021.
- CamDo Solutions ran into supply problems resulting in a delayed delivery until March 2021 by which time Covid19 restrictions were in full play.
- The project team contacted Dr. Aoife Braiden GSI by phone to ask how we should proceed as a result of the restrictions and were advised to follow the government guidelines.

- During Covid19 lockdown while we could not access the site we made up survey accessories such as reference target mounting brackets. Three black and white targets were used in conjunction with TLS surveys to facilitate point cloud registration. To facilitate GPS surveys, we prepared a base station mounting bracket shown in Figure (4) below. These were fixed on-site for the duration of the study.
- We also made up a number of camera mounting configurations to test possible onsite configurations to cover as large an area as possible with 6 cameras.

Fig. 2 Land adjacent to the survey area.

Fig. 3 Weather proof camera box with camera, battery and time lapse controller

Fig. 4 Reference target and base station brackets

(ii) Implementation (milestones, deliverables, project management)

The initial plan was to install a number of cameras setup to record time lapse images of the shorefront in the study area through daylight hours over the course of one year. The photogrammetry data would be supplemented with terrestrial LiDAR 3-D, GPS and UAV surveys from time to time over the course of the study period. Weather and geophone data would be recorded to try to develop a full picture of local conditions before any recorded slump of cliff face.

Issues and changes to our proposed work flow were due mainly to Covid19 restrictions, both the early full lockdown and subsequent partial lockdowns late delivery of the camera equipment and data protection concerns under the General Data Protection Regulations expressed by Wexford Co. Co. With regard to GDPR issues we contacted Ronan O'Tool of GSI and James Barry of DECC to ask if the project might be covered under the GSI GDPR risk assessment policy. However, GSI and DECC were then also transitioning to the new EU regulations.

- On a number of occasions during the project opportunities to survey the site were restricted. As a result, we applied for and received an extension to our final report deadline to allow for the collection of a full year of data.
- Due to early restrictions a decision was taken to use local Met Eireann date rather than install our own weather station requiring multiply site visits which would have been restricted due to Covid19.
- Also, we had hoped to work with TCD to install geophones, however again due to Covid19 concerns this could not happen.
- In hind sight it may have been possible to request assistance from GSI however as GSI were funding the project we did not believe it proper to come looking for further help. As a result, the project suffers from a lack of supporting data which might explain why the measured retreat of the cliff occurred. Even so we believe the work we carried out has been very worthwhile and brings a better understanding of the systems and issues involved in monitoring coastal erosion.
- Once Covid19 restrictions were eased we were ready to install a set of stakes to

mount the cameras and contacted Wexford Co. to assist on site as previously agreed. However, Wexford Co. reported that they could not allow cameras to record continuously on the beach due to concerns they now had with data protection issues.

- The iGSM data protection policy did not satisfy the Wexford Co. requirements, we checked with GSI personnel as mentioned above to ask whether the organization had a suitable policy statement that we could operate under. At the time GSI were in the process of updating their policy and could not immediately provide one. In the interest of progressing the project, already under pressure of time due to Covid19, a decision was taken to operate our cameras only when on site and in place to deal with any concerns the public might have. This approach would not provide the real time monitoring as we had intended, however by coming on site at regular intervals it would provide a time relevant data set to pinpoint cliff slump within a short time period.
- Our work produced a best practice methodology using current technologies for monitoring cliff face retreat taking account of data protection concerns. As indicated in our report the major retreat occurred during the late winter / early spring 2022. See below; *Interestingly, during a summer season (from May 2021 to Sept. 2021), the magnitude of the change of the cliff is smaller than that during winter and spring seasons (Sept. 2021 to May 2022).*
- During the project we found we could get reasonable photogrammetry results by using an iPhone7 as a video camera to record the cliff face. With a robust data management system in place this could allow for crowd sourcing photogrammetry data which would reduce the cost of on-site data collection and involve the public in any future project.

Photogrammetry:

Photogrammetry surveys require adequate photo overlap to facilitate the generation of a 3-D model. For best and consistent results, it is advised to collect images in sequence with at least 60% overlap both vertical and horizontal and in the case of photogrammetry more is better.

To carry out a hand-held camera survey great care is required to ensure high quality output. During our initial set-up we found that adequate overlap with restricted stand-off distance quite only a short length of cliff face could be covered with 6 cameras. The greater the stand-off from camera to subject the wider the field of view and the wider and higher the area that can be covered. Having tried a number of configurations, such as setting the cameras on a tripod and moving it from location to location to cover the full length of shore front. We found ***the best approach was to record a video rather than still images***. By walking slowly along the study area, holding the GoPro camera vertically at approximately a 30 degrees angle to the cliff face, we generated good quality video which captured the full cliff face and beach in one pass. Shadows, due to outcrops, can be eliminated by making the same pass with a back facing camera. Image extraction software was used to extract a still image at one second intervals for best overlap with ample image redundancy. Agisoft Metashape the image processing and model generating software used in this study is very capable of processing large data sets.

Camera quality is very important, the GoPro Hero 7 Black cameras is designed to cope with recording action videos, with their advanced stabilisation feature they are capable of record high quality video in most conditions. While the GoPro are ideally suited to the task we noted that one can also get reasonable results even with a smartphone camera. This fact may open the possibility to crowd sourced image data in the future if a suitable web based system is implemented. A typical Agisoft Metashape 3-D model, is shown in Figure (5) below. Agisoft MetaShape output can be saved in multiply file formats including as a DEM (.TIFF) and point cloud (.E57).

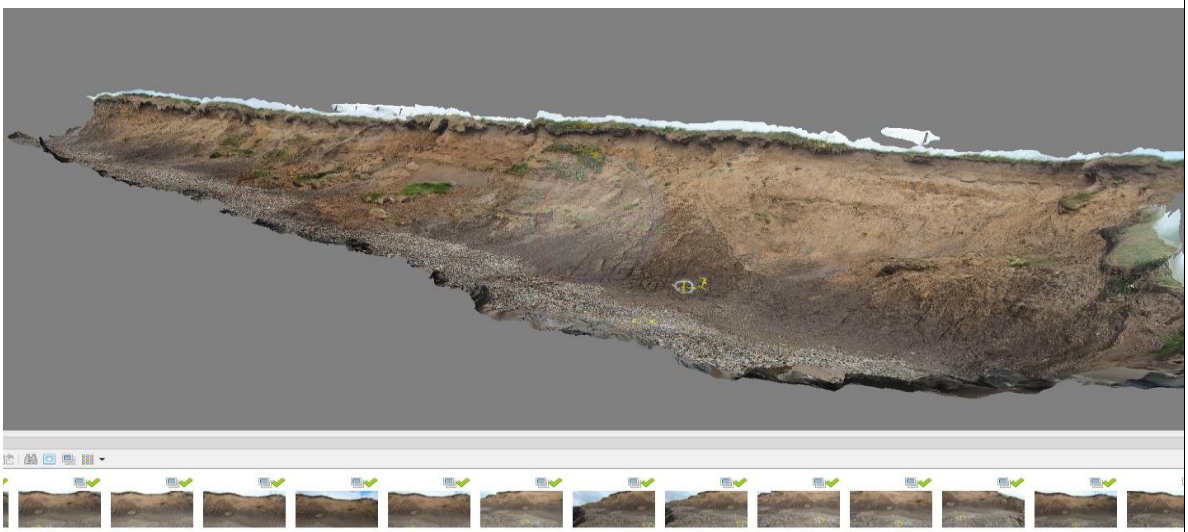


Fig. (5) Typical Agisoft MetaShape generated model

(iii) Outputs to date

3. Outputs to date (this should include the location of datasets generated, as per GSI and NORF requirements)

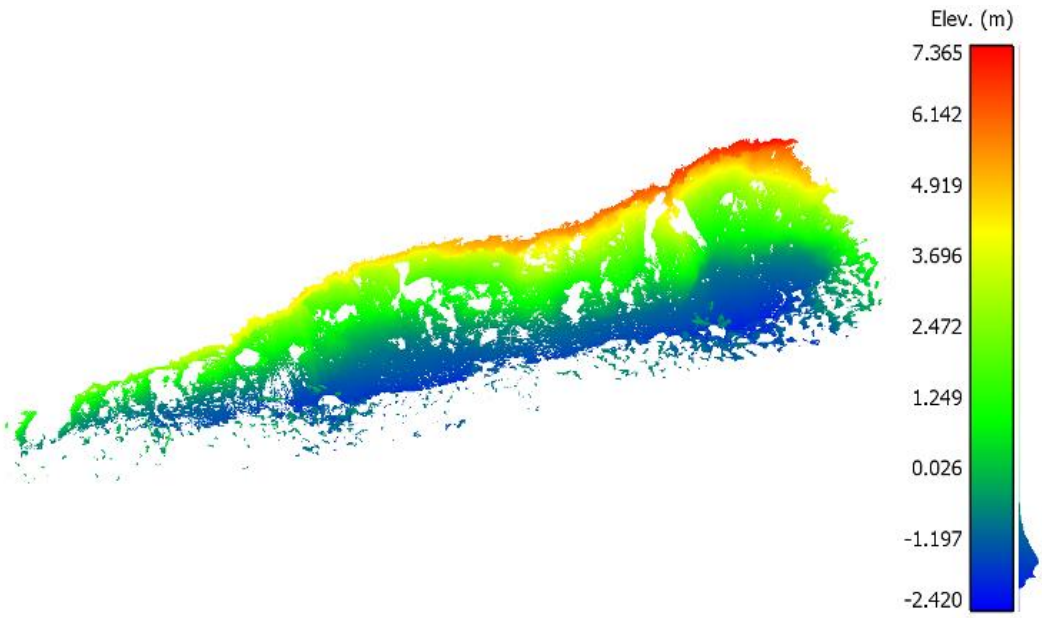
As the project monitors movement of a cliff face at Ballyconnigar Co. Wexford [52°25'49.91"N, 6°19'37.77"W] by using terrestrial laser scanning and photogrammetry. Three dimensional (3D) topographic information of the cliff was collected at different times shown in Table 1 and Figure (6) below using Leica Scan Station P20 to record terrestrial LiDAR scans, (TLS). A GoPro Hero 7 Black version 01.90 was used to record photogrammetric data. The scanner was set up in sequence at three stations along the front of the cliff face while reference targets were mounted in fixed positions so as to be in line of sight of each station position. One of the target mounting points was washed away during a winter storm, we replaced it with a tripod mounted target for subsequent scanning operations. The scanner was configured to collect data points at 3.1 mm resolution at 10meters. The point clouds from the three stations were registered in the same coordinates using Leica Cyclone software.

As mentioned above, after several tests it was decided to record videos to collect photogrammetry data. Post-processing was carried out using Agisoft MetaShape software. In order to monitor movement of the cliff, the point cloud captured on 15 May 2021 is considered as the reference data of the cliff, which means the data represents an initial stage, no movement. In addition, other data sets called sampling datasets were registered to the reference data by using mutual objects as reference, such as sections of the building visible in all scans of the site. Notably, due to difficulty in establishing permanent ground controls, and relatively low accuracy of GPS coordinates, such methods were not used to align the point clouds from different time periods to the reference data.

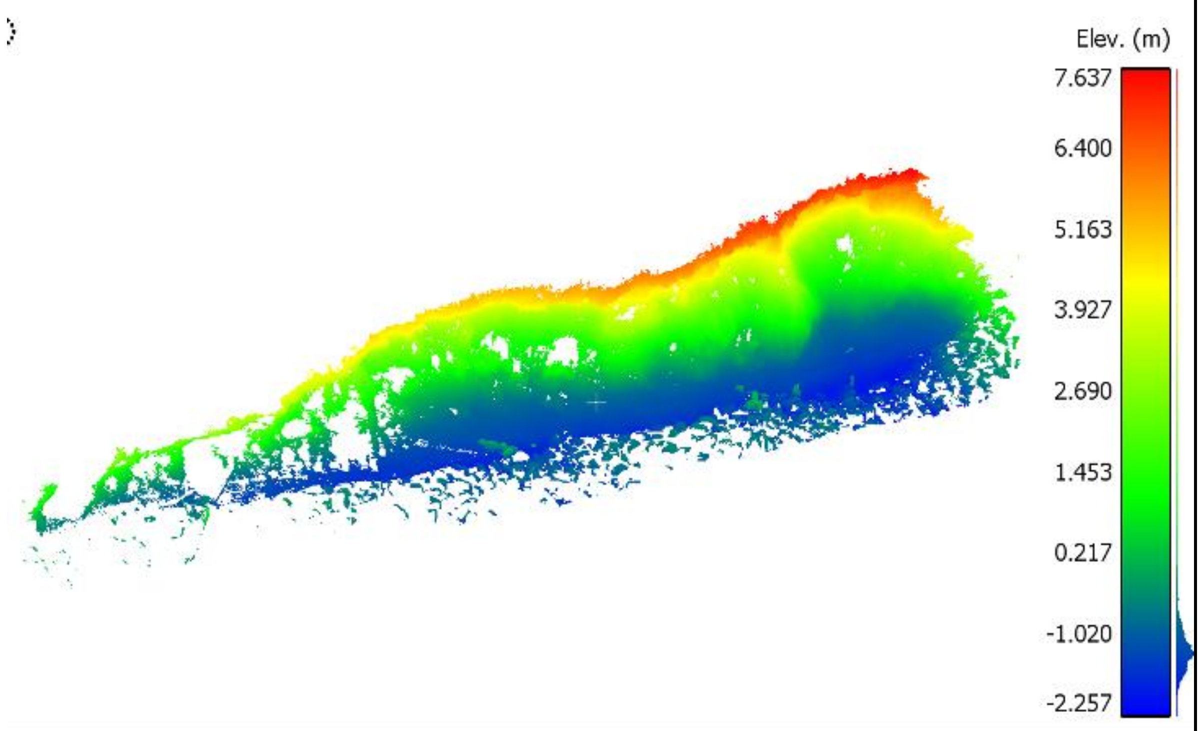
LiDAR and Photogrammetry data sets with processed models are available on the project website; ballyconnigarsurvey.eu

Table 1. Summary laser san data collected through the project

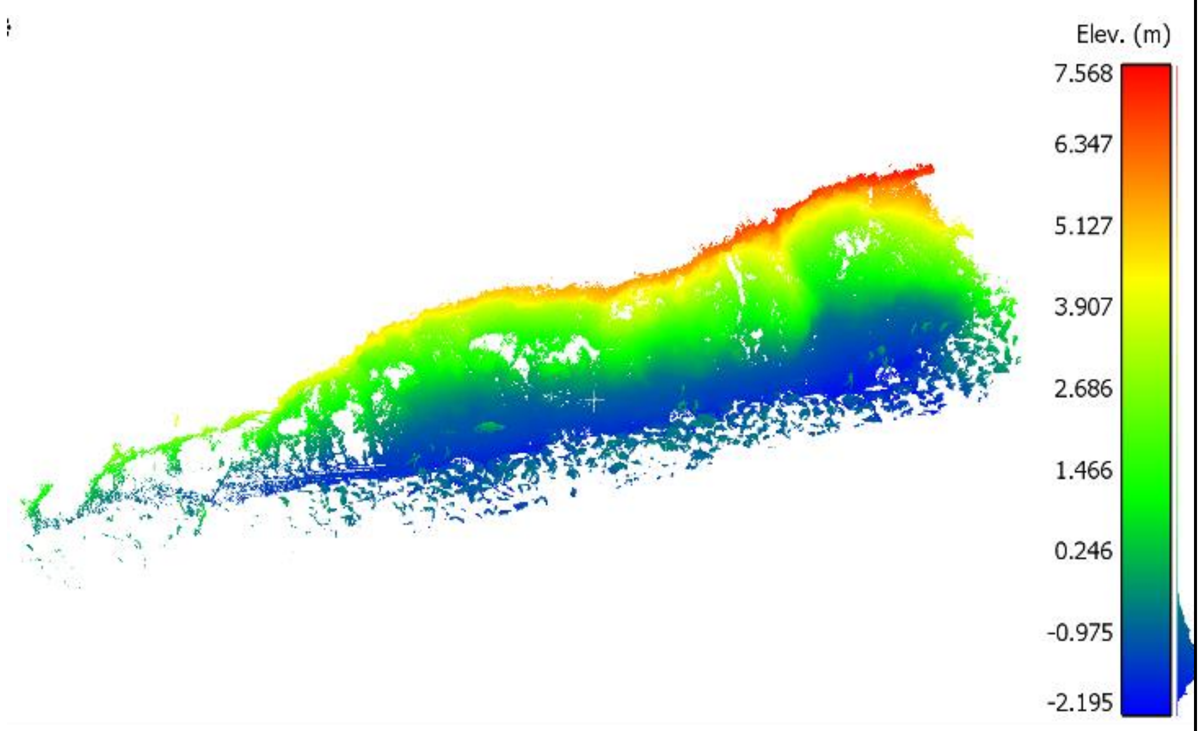
Date	Number of scanning stations	Number of points
16 May 2021	3 Scan Stations	43,498,477
05 Aug. 2021	3 Scan Stations	70,259,743
25 Sept. 2021	3 Scan Stations	200,446,690
21 May 2022	3 Scan Stations	198,734,514



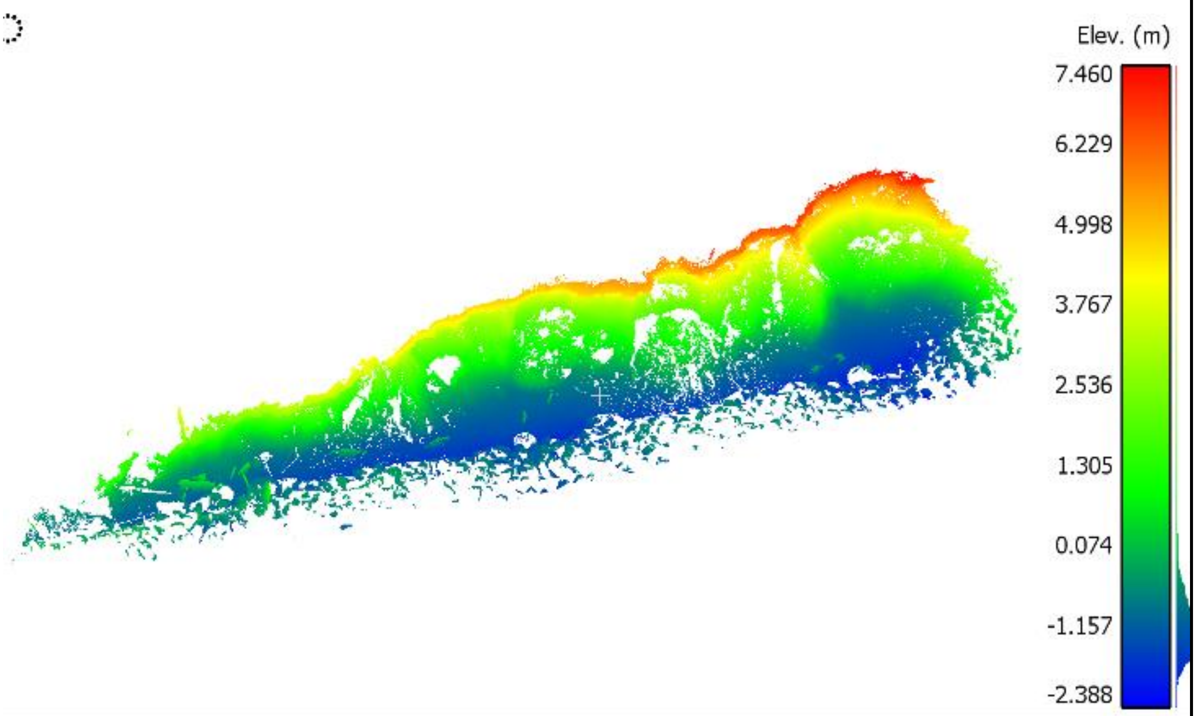
a) 16 May 2021


Elev. (m)
7.637
6.400
5.163
3.927
2.690
1.453
0.217
-1.020
-2.257

b) 05 Aug. 2021


Elev. (m)
7.568
6.347
5.127
3.907
2.686
1.466
0.246
-0.975
-2.195

c) 25 Sept. 2021



d) 21 May 2022

Fig. 6. Point clouds of the cliff collected from different times

The cell to cell (C2C) method (Truong-Hong and Lindenbergh, 2019) is used to identify movement of the cliff over a period of time.

First, measured points, appearing as regular grid points, were created from the reference point cloud of the area of interest, in which distances between grids in the x and y directions are 0.05m (Figure 7). Second, to measure difference between two data sets (t_0 and t_1), at each measured points, local planes of the reference and sampling data were determined from neighbour points of the measured point derived from the reference and sampling data, respectively. To extract the neighbour points, a hybrid neighbour searching was used to search the neighbour points, which control by the number of nearest points and the upper bound searching radius (Figure 8). In this project, the number of 20 nearest neighbour points and the searching radius of 0.05m were used. Moreover, from the local plane derived from the reference data at the measured point was used to build the cylinder search to extract neighbour points from the sample data to estimate the local plane of the sample data at the measured points (Figure 8). By using this method, the change of the cliff is measured at 245,635 different points (Figure 7). Finally, the height of the cylinder at the center determined by the local planes from the reference and sample data was the change of the cliff at the measured point. More details about the proposed method can refer to Appendix A.

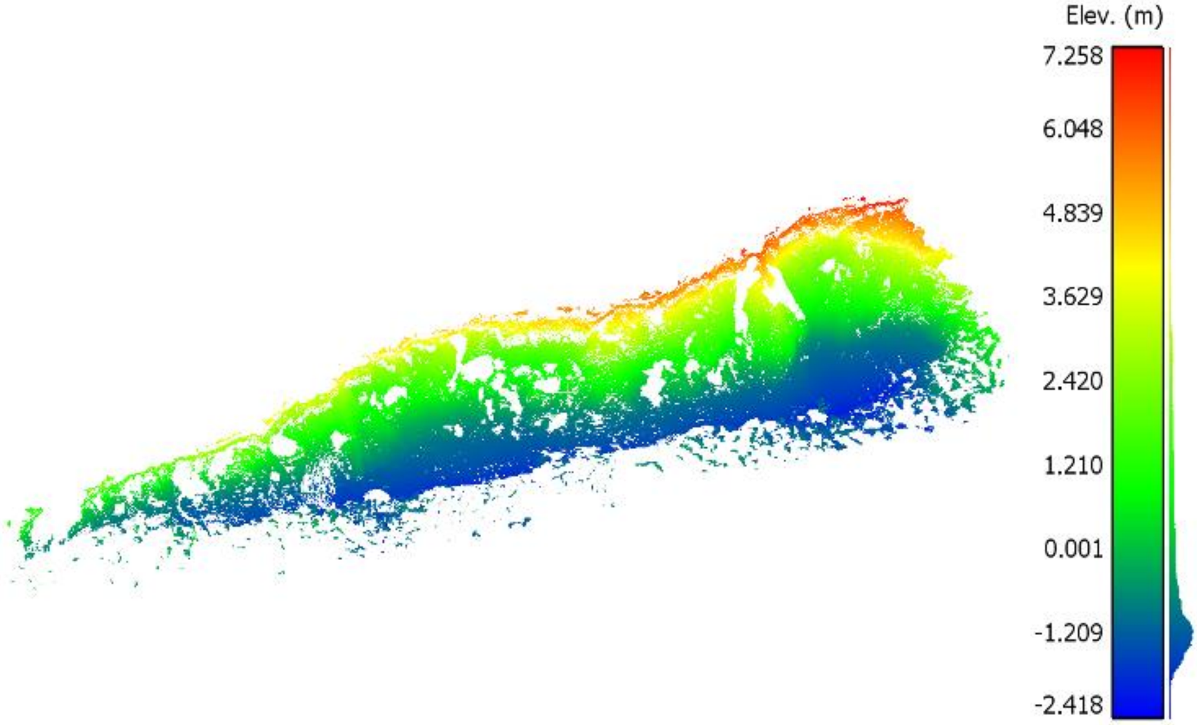
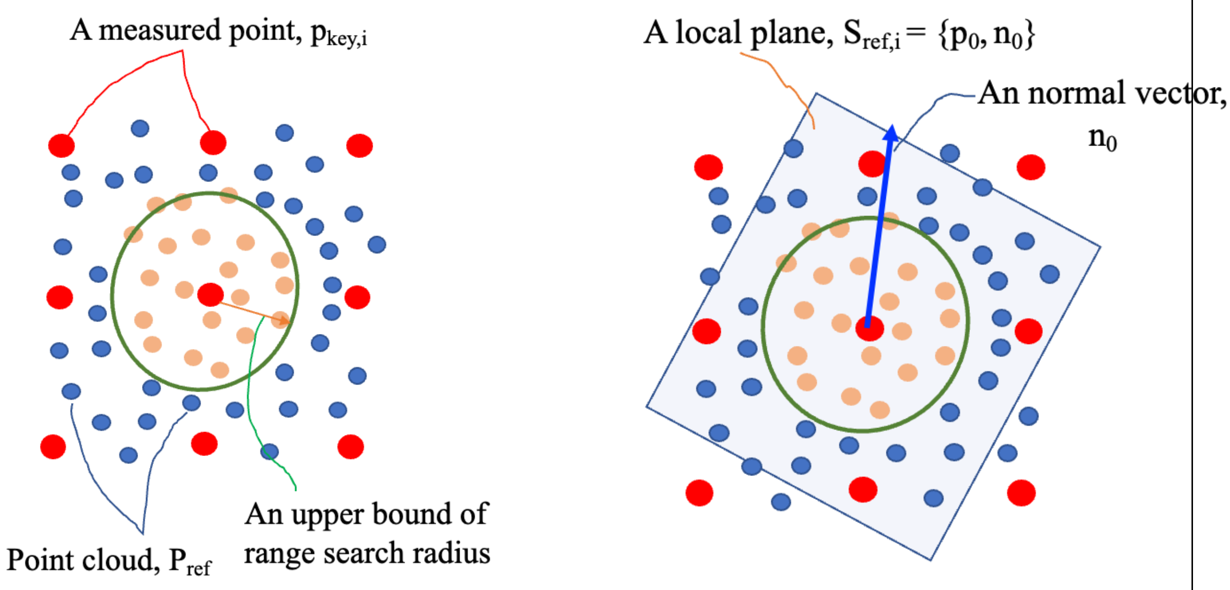
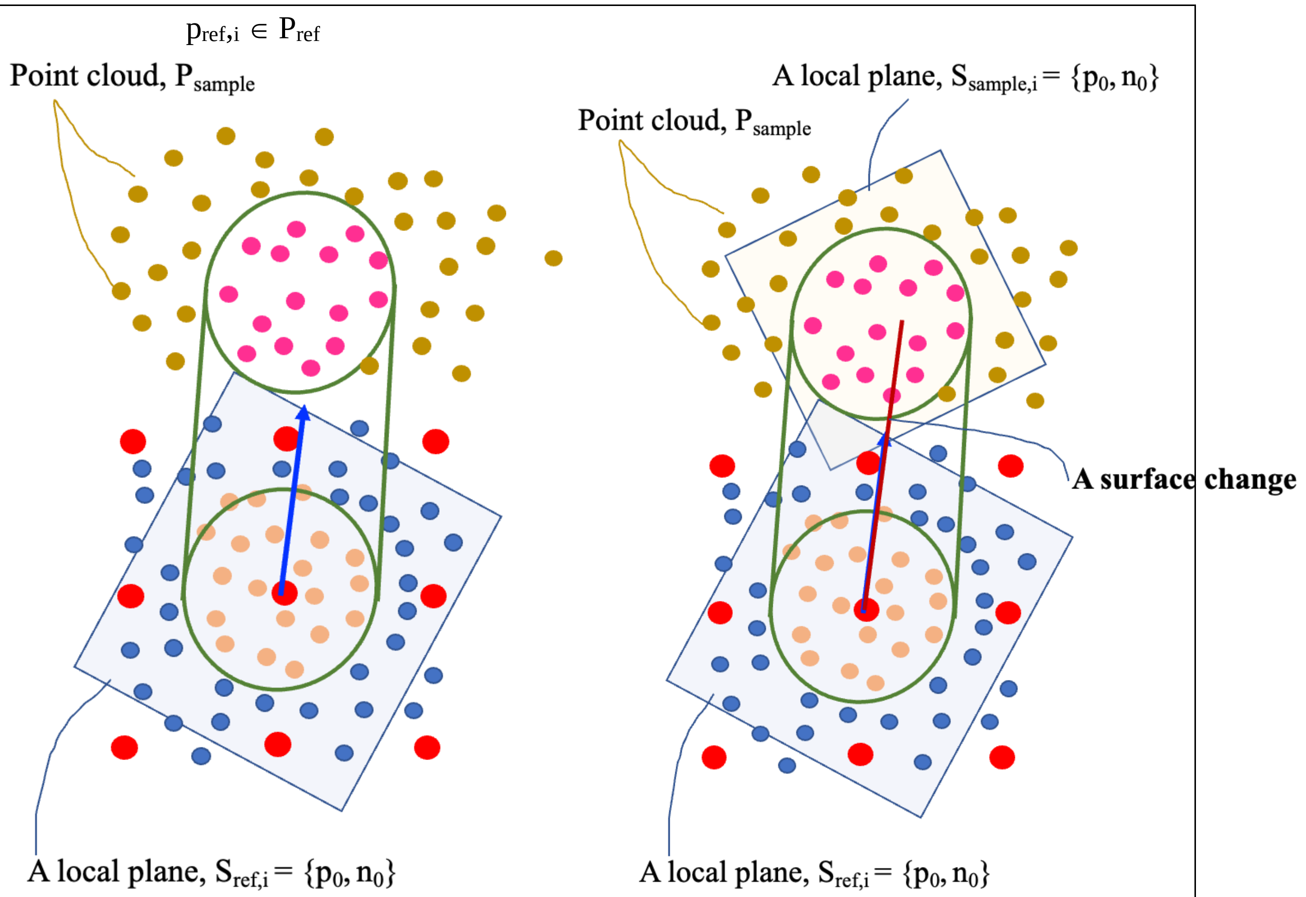


Fig. 7 Measured points used to compute changes of the cliff



a) Measured points and neighbor points, b) A local plane of the reference dataset P

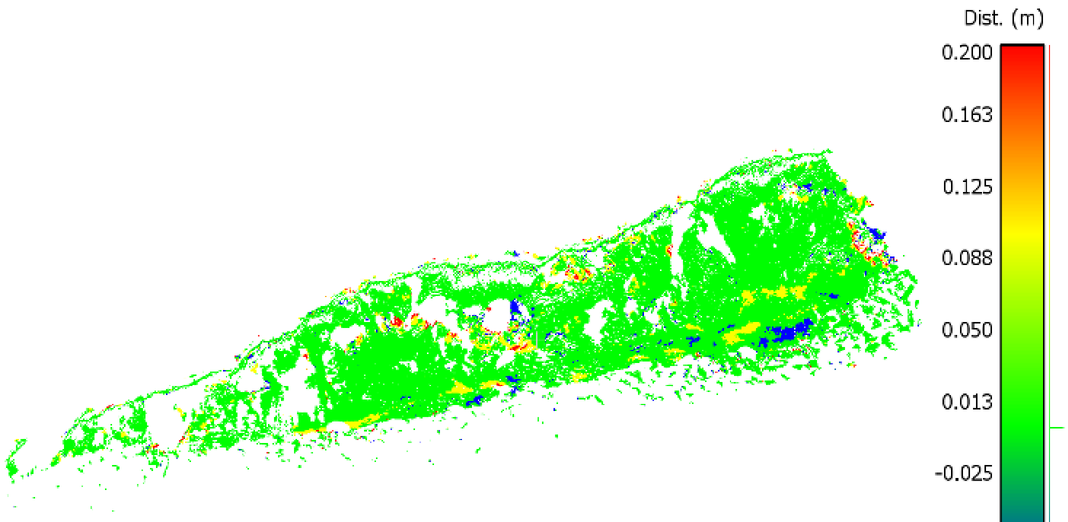


c) Select neighbor points $p_{sample,i} \in P_{sample}$ by a cylinder neighbor searching

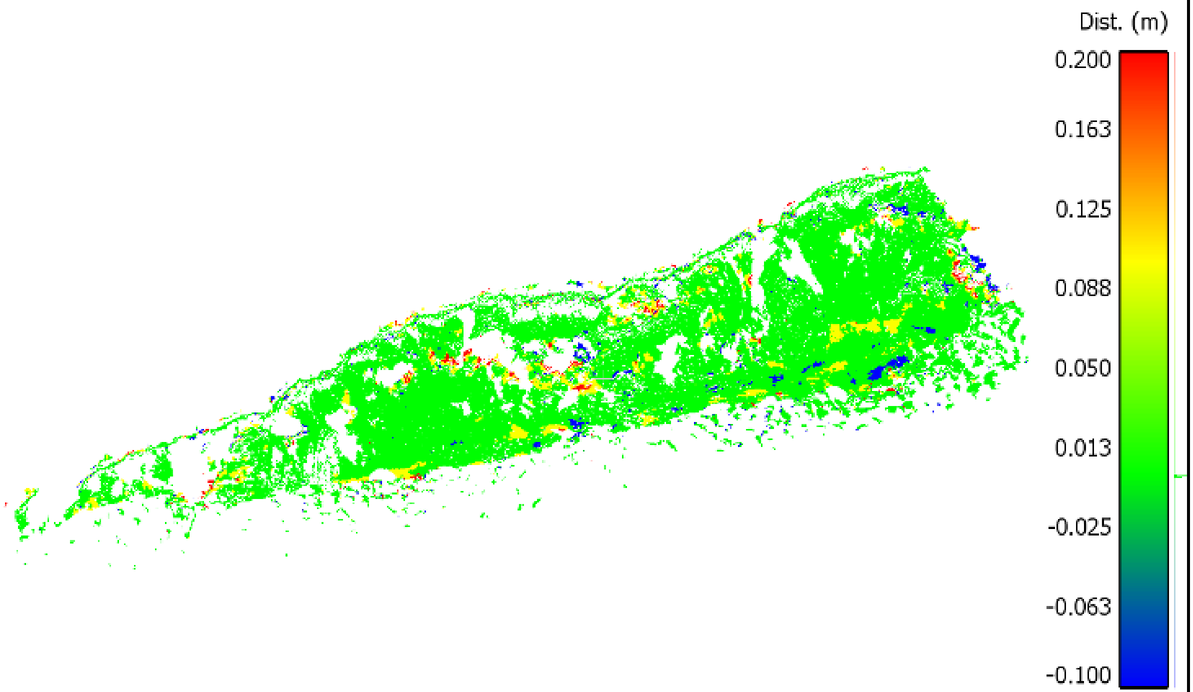
d) Determine a local plane $S_{sample,i}$ and a surface change at the measured point $p_{key,i}$

Fig. 8. A procedure to determine the surface change at the measure point

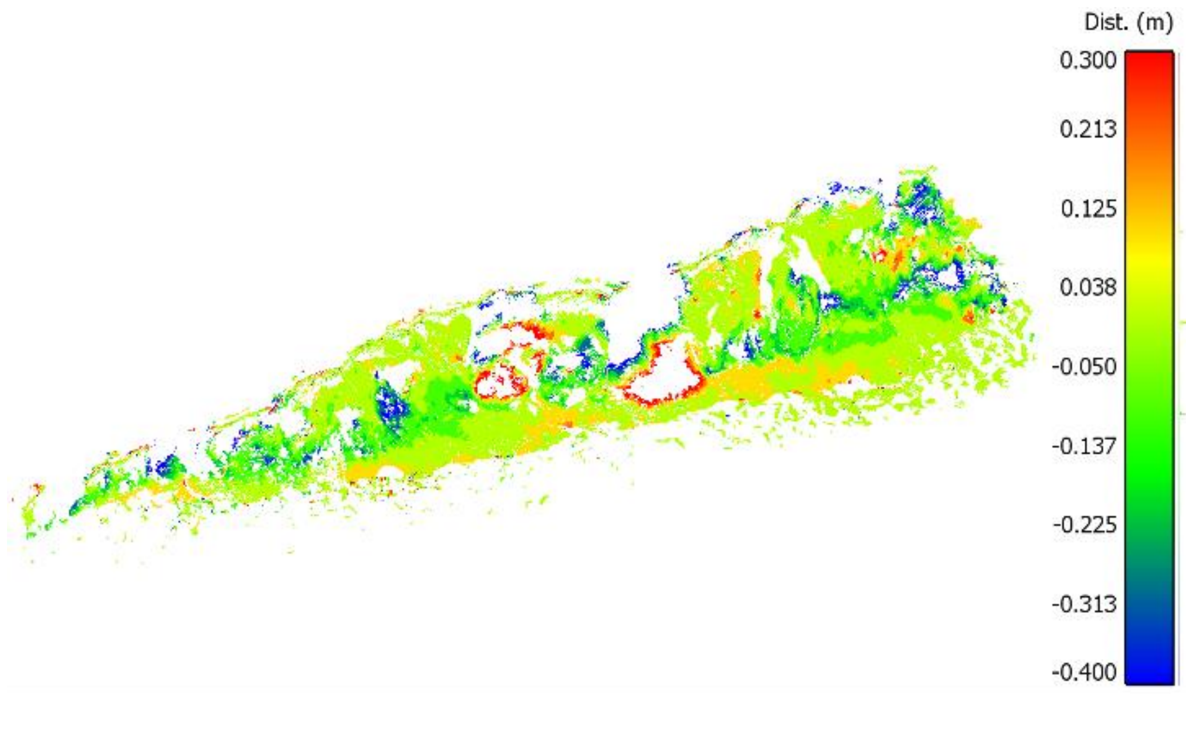
Results of changes between the reference data (16 May 2021) and the sampling data (05 Aug. 2021, 25 Sept. 2021, and 21 May 2022) were shown in Fig. 9. Moreover, Table 2 gives a summary of recorded change or retreat of the cliff face. The analysis showed that there are movements of the cliff, from 16 May 2021 to 25 Sept. 2021, the absolute average of the movement was around 0.012m, while from 16 May 2021 to 21 May 2022, the absolute average of the movement was around 0.073m. Resulting change detection is also shown after 1 year monitoring, local areas of the cliff moved up to 0.4m (a minimum movement recorded at 21 May 2022). Interestingly, during a summer season (from May 2021 to Sept. 2021), the magnitude of the change of the cliff is smaller than that during winter and spring seasons (Sept. 2021 to May 2022).



a) At 05 Aug. 2021



b) At 25 Sept. 2021



c) At 21 May 2022

Fig.9. Illustrates changes of the cliff regarding to the cliff status on 16 may 2021

Table 3. Summary of cliff retreat Aug. 2021 to May 2022

Data sets	Min. (m)	Abs. mean (m)	Standard deviation (m)	Max. (m)
At 05 Aug. 2021	-0.100	0.011	0.035	0.200
At 25 Sept. 2021	-0.100	0.012	0.036	0.200
At 21 May 2022	-0.400	0.073	0.119	0.300

In order to predict the change of the cliff face, the machine learning model was developed. In this model, for each measured points, a set of features including the statistical quantities of the surface change (an average, minimum and maximum values of the surface change), point elevation regarding to the sea level, the number of drain day and the total of rainfall of the area were used to build the prediction tool. For example, when using an average surface change shown in Table 3 and accumulative precipitation amount, it shows that there is a relationship between them (Fig. 10), in which the R-square equals to 0.79. That observation can be fundamental support to build the predict tool if the data is sufficient. However, due to COVID-19, the topographic information of the cliff face were captured only at intervals throughout the study period instead of in real-time as in the initial plan of the project. As such, these limited data sets were not adaquate to build an accurate, reliable tool to predict the change of the cliff face. The project team will acquire more information from other sources for this task.

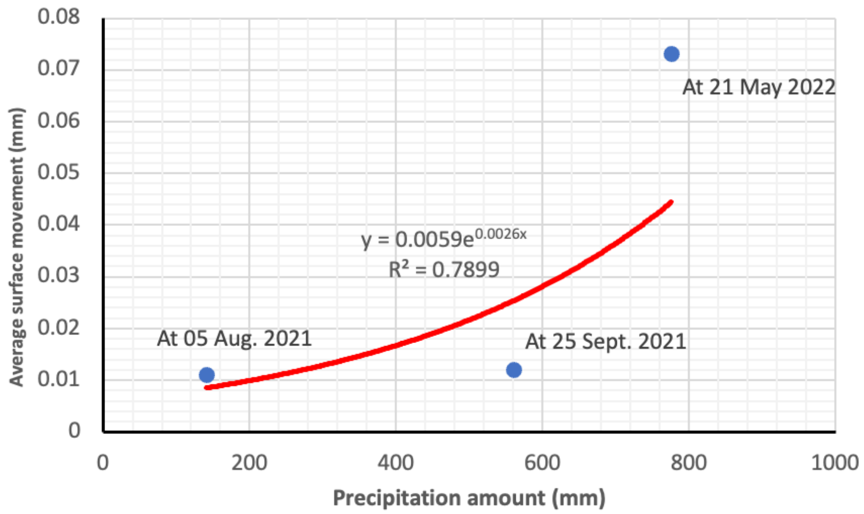


Fig. 10. A relationship between the precipitation amount and surface change (Note: The precipitation amount is accumulative precipitation with the reference time is May 2020).

Short Term cliff erosion using real time kinematic GPS surveys

Digital shoreline analysis system (DSAS v5) was used within the ArcGIS program to calculate the cliff erosion rates along the study area. As part of this investigation, highly accurate and spatially dense cliff line location was mapped using a real time kinematic (RTK) global navigation satellite system (GNSS). Field surveys were conducted on 15/05/2021, 05/08/2021, 25/09/2021, 10/01/2022, 21/05/2022. See Figure 9

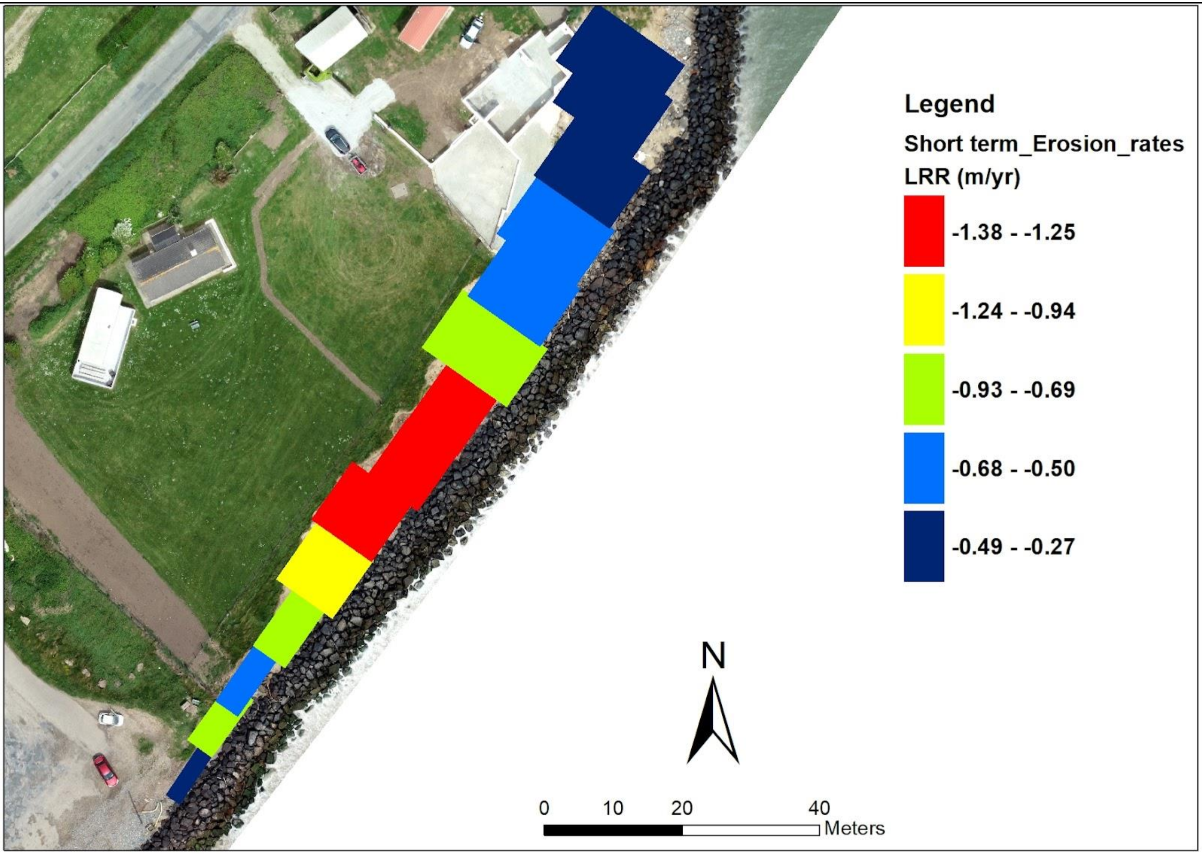


Fig.9 showing maximum erosion at the mid-section of the cliff

(iv) Impact

- Relevance/application to GSI programmes, where applicable

Real time data collected using a combination of remote sensing approaches will help meet goals of the Coastal Management Program initiatives within GSI. OPW, County Councils, parks and wildlife organisations. Preserving, restoring, and preventing loss of shore front features and coastal natural resource areas are directly addressed through mapping and analysis of chronically eroding coastal sections. Real time data will address GSI goals by providing accurate scientific data to improve policy making. Approaches developed in this investigation can be used to collect, process, analyse and quantify as well as share data obtained to the public, to meet the goals of educating the public and making coastal management processes visible.

- Other impacts

- Estimate long / short term volumetric changes in beach dune sediment budget
- Development of coastal vulnerability maps

Publications:

Publications:

See appendix B

Lennon, D., Truong-Hong, L. Mathew, S. 2022. Real time monitoring of landslides using remote sensing approaches: A case study - Ballyconnigar, Co. Wexford. Irish Geological Research Meeting, Queen's University, Belfast, February 22, 2022.

Lennon, D., Truong-Hong, L. Mathew, S. 2022. Real time monitoring of landslides using remote sensing approaches: A CASE STUDY BALLYCONNIGAR CO WEXFORD. Kildare County Public Participation Event, Climate Action Weekend, September 9-11, 2022.

Lennon, D., Truong-Hong, L. Mathew, S. 2022. Real time monitoring of landslides using remote sensing approaches: A CASE STUDY BALLYCONNIGAR CO WEXFORD Wexford Co. Co.

4. Supplemental information/datasets

3-D Data collection;

- With regard to TLS, the technology is robust and well tested. Even so and in general, sea shore terrain presents a number of difficulties that need careful attention.
- For example, TLS equipment must be level during the scanning process. Setting and maintaining a tripod on the shore front with sand and gravel underfoot where tidal action changes the nature of the ground (whether wet and unstable, or dry enough to support the tripod) requires careful attention.
- Depending on weather conditions, the equipment must be protected from sea over spray and rain.
- To increase the accuracy of our data sets we used a resolution of 3.1mm @ 10m, meaning that at a 10m stand-off from the scanner points on an object will be approximately 3.1mm apart although this varies with angle of incidence.
- It is possible to apply different resolutions according to project requirements, the main consideration besides data quality is the time required to record a full scan. At 3.1mm resolution @ 10m scanning time is approximately 10mins per scan. Station set-up and relocation can add significant time required to carry out a complete cliff face survey.
- With regard to photogrammetry, the technology is a little less obvious. In general image overlap, crisp focus, camera quality and adequate lighting are the main issues to be consider. Overcast conditions with good lighting levels are ideal. The images are up loaded to processing software to generate a 3-D model in a series of steps that require operator inputs to ensure model quality in terms of resolution and accuracy.
- When carrying out a survey of a cliff face with 6 fixed cameras requires careful set-up taking account of field of view, stand-off distance, and image overlap to inform camera position and spacing.
- At Ballyconnigar, due to the limited stand-off distance and fixed field of view we could record a limited area of cliff face even with a 6-camera set-up.
- Having tried a number of approaches it was found that by using just 1 camera in video mode and walking along in front of the cliff face with the camera oriented vertically such that it is at approximately at 30degrees to the face of the cliff in the horizontal and at a height of approximately 1.7m above the ground we could record the full

length and profile of the cliff and beach front. This became our preferred method for recording the photogrammetry data.

- Camera settings included; resolution / FPS 2.7 / 60, FOV (field of view) Linear, Low light control set to Auto, stabilisation set to Auto.
- As the GoPro camera is quite small it is a good idea to mount it on a uni-pod which helps to keep the camera as steady as possible while walking, however with the stabilisation feature and as the video is converted to JPEG stills at 1 second intervals a little shake is not a major problem.
- Walking slowly delivers best results, for example a 3minute 47second clip of video delivers 227 stills providing good level of overlap and a high-resolution model. The more stills with high degrees of overlap will generate a point cloud of high point count, shown in Figure (5) above.
- In photogrammetry, besides excellent image quality, point cloud density is a function of user settings *low*, *medium*, *high* that need to be selected at the various stages of the Agisoft Metashape data processing. The *high* setting requires longer processing time to generate high resolution models.
- When considering costs involved in data collection and processing; Terrestrial Laser Scanning machines are expensive, onsite work can require extended time to setup and record multiple scan stations and reference targets. A good weather window is critical. Initial data processing software is generally propriety to the scanner manufacturer requiring the appropriate license, the process of registering the scans is quite fast depending on the size and complexity of the scan project.
- Once the scans are registered in Cyclone it is possible to export the model in a wide selection of file formats including xxx.E57 which can be viewed and edited by more readily available 3-D processing software such as CloudCompare.
- On the other hand and in comparison, cameras are quite cheap, terrestrial video recording is far more straight forward and generally can be completed quite quickly in comparison to TLS, again survey complexity impacts the time required. While a shorter time and therefore a shorter weather window is required, ambient light levels must be good.
- In the case of coastal erosion monitoring it would be cheaper to use photogrammetry surveys. However, this will require some system of permanent known ground control

points (GCP's) to better facilitate point cloud referencing. With such a system in place it may be possible to invite beach walkers to upload videos recorded while leisure walking using a dedicated crowd sourcing app.

Appendix A:

Proposed method to identify the change of the surface of the cliff

The project proposes the method called cell-to-cell (C2C) to process point clouds of the cliff to identify a surface change consists of three main steps (Fig 1). First, Step 1 is to create the regular grid for the area of interest. Second, based on the grid, measured points, which were used to identify the change of the surface, were generated. Third, the change of the cliff surface at the measured points is determined based on the different between two different point clouds of the surface, which represent to the status of the cliff at time t_0 and t_i, respectively. In this method, the dataset at time t_0 was considered as the reference data (P_{ref}) referring that no movement of the cliff face (or a ground surface), while the dataset at time t_1 was referred to the sampling data (P_{sample}). The difference of the ground surface between P_{ref} and P_{sample} was known as the movement or change of the cliff from time t_0 to t_1.

Step 1 – Cell grid generation: The area of interest is divided into the regular grid by using 2D cell grids (Hinks et al., 2013) with the predefined grid size (cs_0). The method starts to determine an initial bounding box of the area, which is defined a pair of points (x_{min}, y_{min}) and (x_{max}, y_{max}). Next, with the predefined grid size, the number of the grids in the x and y directions can be determined based on Equation 1 & 2. A topology of each cell c_i is defined by a pair of the points called the bottom left (x_{i1}, y_{i1}) and the top right (x_{i2}, y_{i2}), in which these coordinates are derived from the grid coordinate.

$$N_x = \frac{(x_{max} - x_{min})}{\Delta x} + 1 \qquad \textit{Equation 1}$$

$$N_y = \frac{(y_{max} - y_{min})}{\Delta y} + 1 \qquad \textit{Equation 2}$$

where N_x and N_y are the number of grids along the x and y directions, while Δx and Δy are a grid size, which equal to 0.05m used in this project.

Step 2 – Determine measured (or key) points: Measuring the change of the ground surface at every point cloud is not necessary and in practice because this requires a heavy computation and results may contain large errors due to uncertainty of the point cloud (e.g., noise, outlier or bias of the point cloud). The proposed method is used the center point of each cell as a measured point (or also called a key point) to identify the change of the ground surface (Figure 2a). The center of the cell c_i, or the measured point ($p_{key,i}$) at the cell c_i, is determined according to Equation 3. Thus, the set of the points $p_{key,i}$ = (x_{i0}, y_{i0}) used as key points to measure the change of the ground surface, which is an input data for Step 1.

$$\begin{cases} x_{i0} = \frac{x_{i1} + x_{i2}}{2} \\ y_{i0} = \frac{y_{i1} + y_{i2}}{2} \end{cases} \qquad \textit{Equation 3}$$

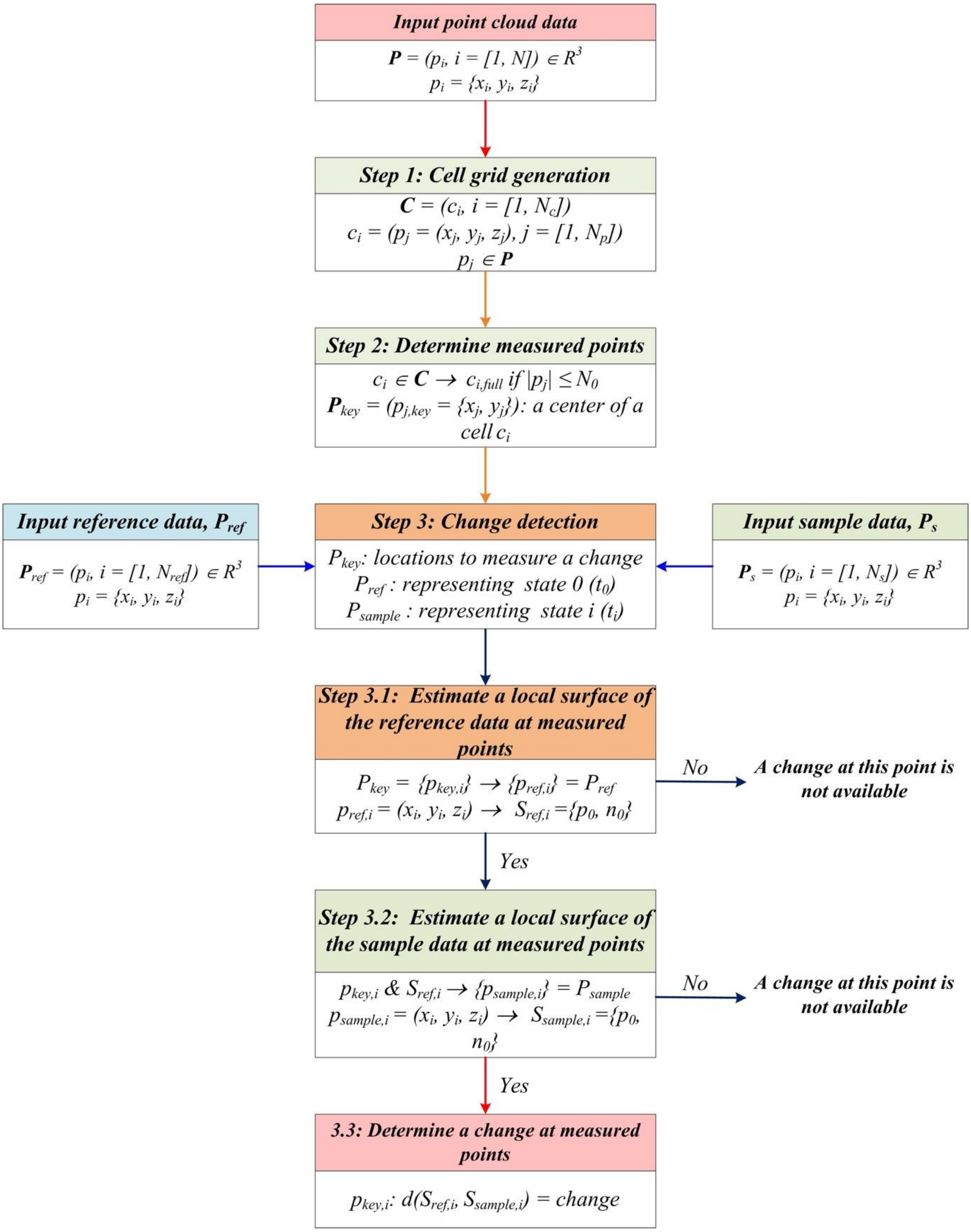
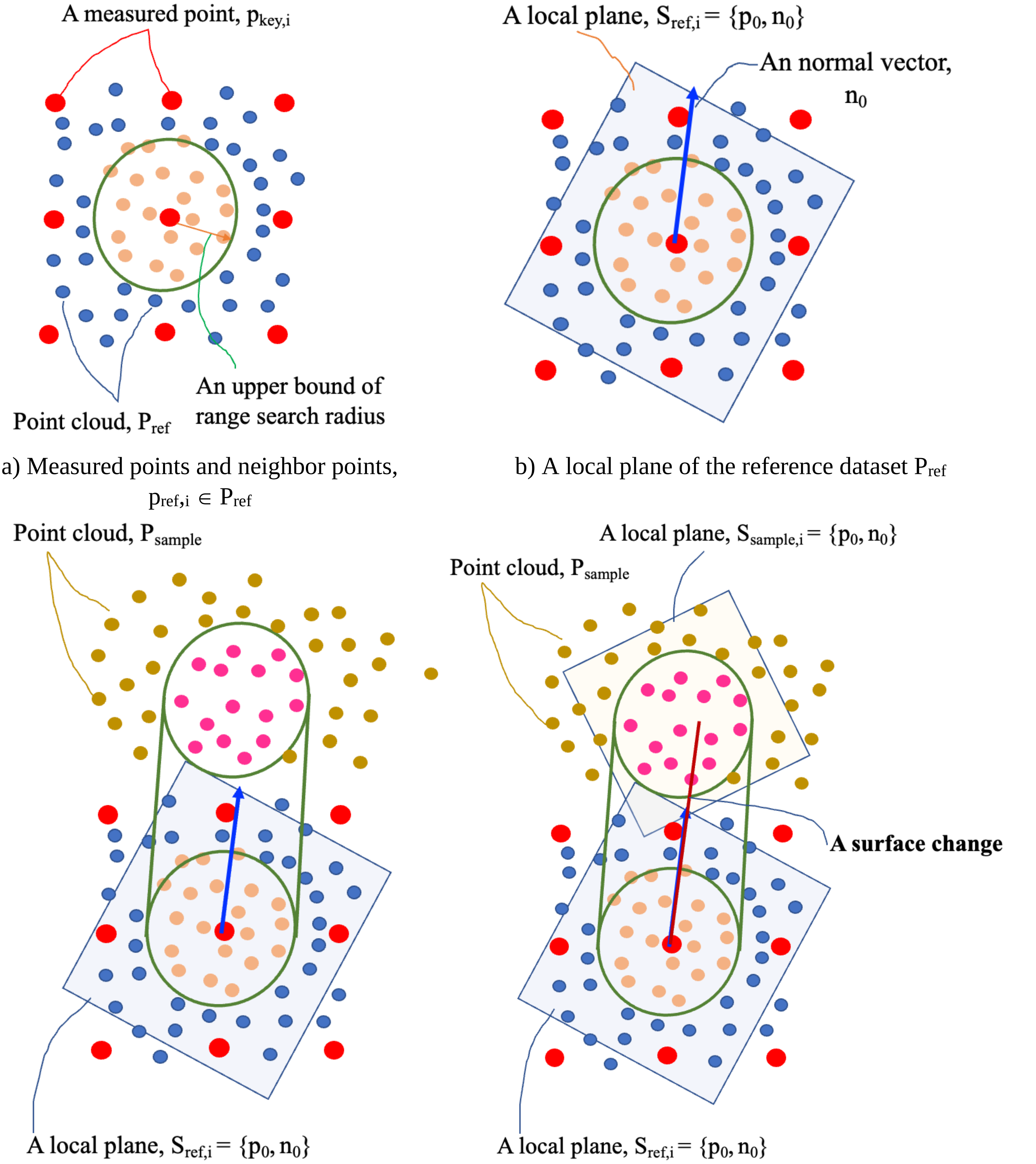


Fig. 1. Workflow of the proposed method to measure the surface change



a) Measured points and neighbor points, $p_{ref,i} \in P_{ref}$

b) A local plane of the reference dataset P_{ref}

c) Select neighbor points $p_{sample,i} \in P_{sample}$ by a cylinder neighbor searching

d) Determine a local plane $S_{sample,i}$ and a surface change at the measured point $p_{key,i}$

Fig. 2. A procedure to determine the surface change at the measure point

Step 3 - Change Detection:

The cliff face at Ballyconnigar Co. Wexford was acquired from different types of remote sensing methods, in which laser scanning (or also known as LiDAR) and photogrammetry methods were used in this project. The surface of the cliff face was captured from different time periods from May 2020 to May 2021. By using laser scanning, the topographic information of the surface is described by a massive point cloud with x-, y- and z-coordinates in the local coordinate system with the origin at the center of the laser scanner. As such, the point clouds from different period time were aligned into the same coordinate system before determining a surface change. To do this, the project (1) used GPS coordinates of the ground control points (distributed around the site) to roughly align the sampling data (P_{sample}) captured at the time t_i to the reference data (P_{ref}) captured at the time t_0, and (2) Iterative Closest Point (ICP) (Besl and McKay, 1992) based on point to point was implemented to improve an accuracy of the alignment. Thus, input data of this step consists of the measured points, the reference (P_{ref}) and the sample (P_{sample}) datasets.

Step 3.1 – Estimate a local surface of the reference data (P_r) at the measured points: At each measured point $p_{key,i}$, a hybrid searching was employed to search the point cloud from the reference dataset (P_{ref}), in which both the number of nearest points (kNN) and an upper bound radius are used to select the neighbor points ($p_{ref,i} = \{x_i, y_i, z_i\} \in P_{ref}$) (Fig. 2a). The kNN of 20 points and the radius of 0.2m were used in this project. Next, when the neighboring points ($p_{ref,i} \in P_{ref}$) is available, the local surface ($S_{ref,i} = \{p_0, n_0\}$) of the ground at time t_0 was estimated based on the neighboring points ($p_{ref,i} \in P_r$) by using a principal component analysis (Laefer and Truong-Hong, 2017), in which the eigenvector corresponding to the smallest eigenvalue is the normal vector (n_0) of the local plane $S_{ref,i}$ while the averaged point of the neighbour points $p_{ref,i}$ is the point p_0 on the local plane $S_{ref,i}$ (Fig. 2b). Notably, the measured point $p_{key,i}$ is considered to identify the change of the ground surface if the local plane $S_{ref,i}$ of the reference data P_{ref} is available.

Step 3.2 - Estimate the local surface of the sample data P_{sample} at the measured point $p_{key,i}$: From the local plane $S_{ref,i}$ at the measured point $p_{key,i}$, the cylinder neighboring searching is established to extract the neighbor points $p_{sample,i} = \{x_i, y_i, z_i\} \in P_{sample}$ (Fig. 2c). The process started to project both the measured point $p_{key,i}$ and the neighbor points $p_{ref,i} \in P_{ref}$ at the measured point $p_{key,i}$ derived from Step 3.1 onto the local plane $S_{ref,i}$. Next, the cylinder defined by the center that is the projection of $p_{key,i}$, a radius that is the maximum distance from the projection of the neighbor points $p_{ref,i}$ to the center, and the directional vector that the normal vector of the local plane $S_{ref,i}$. Additionally, the points from the sample data P_{sample} inside the cylinder are considered the neighbor points $p_{sample,i}$ to identify the local surface ($S_{sample,i} = \{p_0, n_0\}$) (Fig. 2d). The neighbor points $p_{sample,i}$ is only considered if the number of the point is no smaller than 10 points. Following, the similar procedure using to estimate the local plane for the reference data in Step 3.1 was used to estimate the local surface ($S_{sample,i} = \{p_0, n_0\}$). Notably, if the local plane of the sample data is not available, the change of the ground surface at this measured point will not be calculated.

Step 3.3 – Determine a change at measured points: For each measured point $p_{key,\ i}$, if both local planes $S_{ref,i}$ and $S_{sample,i}$ were available, the distance between two planes was considered as the change at the measured point. This distance was a height of the cylinder limited by two local planes $S_{ref,i}$ and $S_{sample,i}$ (Fig. 2d) Notably, the height of the cylinder was herein considered as the center of the cylinder. Once the changes of the ground surface at the measured points were computed, the statical quantities were calculated.

All codes of the proposed method are available upon request.

References:

Truong-Hong, L. and Lindenbergh, R., 2019. Identifying bridge deformation using laser scanning data. In *4th Joint International Symposium on Deformation Monitoring*.

Hinks, T., Carr, H. and Truong-Hong, L., 2013. Point cloud data conversion into solid models via point-based voxelization. *Journal of Surveying Engineering*, *139*(2), pp.72-83.

Paul J. Besl and Neil D. McKay, A Method for Registration of 3D Shapes, PAMI, 1992.

Laefer, D.F. and Truong-Hong, L., 2017. Toward automatic generation of 3D steel structures for building information modelling. *Automation in Construction*, *74*, pp.66-77.

Appendix B;

Posters;

REAL TIME MONITORING OF LANDSLIDES USING REMOTE SENSING APPROACHES

A CASE STUDY: BALLYCONNIGAR CO. WEXFORD

Donal Lennon [1] Linh Truong-Hong [1] Sojan Mathew [2]

[1] iGeospatial Modelling Ltd., Ireland. [2] University College Dublin

Project funded by Geological Survey Ireland Short Call 2020

INTRODUCTION

Landslide events result in the loss of life, and substantial damage to buildings, roads and other infrastructure around the world. While Ireland is not generally considered a high-risk country for such major landslide events, there have been more than 900 events including 63 major ones. Landslide events continue to be more prevalent mainly due to climate change triggering very heavy rainfall. A monitoring and early warning scheme is crucial for forecasting and the prevention of landslides.

The project aims to develop an approach and methodology to acquire spatial and temporal information of coastal surfaces using a terrestrial laser scanner and UAV photogrammetry insitu-video camera. Subsequently, the changes of the surface are monitored.

METHODOLOGY

A coastal area near Blackwater Co. Wexford, subject to ongoing landslide is selected as a case study. The area was captured by a terrestrial laser scanner and camera for every 3 months.

Feature-based object under a hypothesis of Iterative closest point is used to register 3D point clouds from different epochs.

A cell-based method is developed to determined change of the slope.

Until relatively recent due to Covid 19 regulations data collection has been curtailed. However, we are currently engaged in extensive data collection and analyses.

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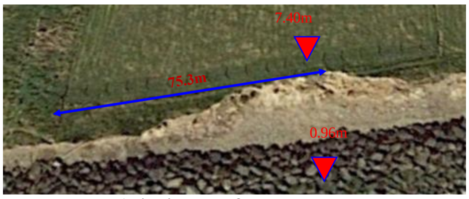
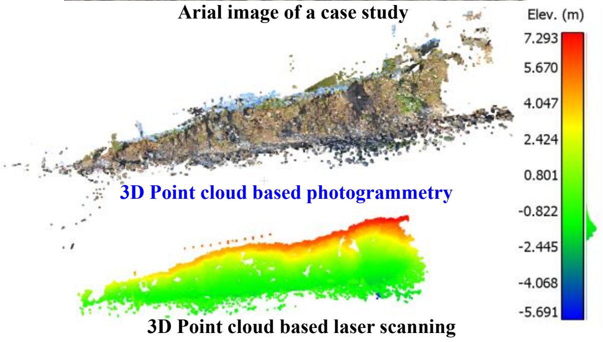


Arial image of a case study



3D Point cloud based photogrammetry

3D Point cloud based laser scanning

Roinn Cumarsáide, Gníomhaithe ar son na hAeráide & Comhshaoil
Department of Communications, Climate Action & Environment

Geological Survey
Suirbhéireacht Gheolaíochta
Ireland | Éireann

REAL TIME MONITORING OF LANDSLIDES USING REMOTE SENSING APPROACHES

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Project funded by GSI Short Call 2020

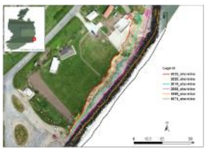
INTRODUCTION

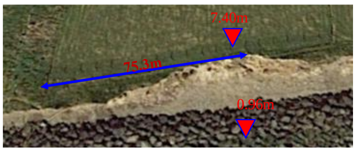
Landslide events can result in the loss of life and substantial damage to buildings, roads and other infrastructure. While Ireland is not generally considered a high-risk country for such major landslide events, such events continue to be more prevalent mainly due to climate change triggering extreme rainfall. A monitoring and early warning scheme is crucial for forecasting and the mitigation of landslides.

This project acquires spatial and temporal information of coastal topology using a terrestrial laser scanner and UAV photogrammetry insitu-video camera to monitor changes by comparing 3-D point clouds of ground surfaces captured in different period times.

METHODOLOGY

An area of coast line near Blackwater Co. Wexford, subject to ongoing landslide, was selected as a case study. Topology was captured as described above every 3 months. 3D point clouds from different epochs (capturing times) were mapped into the same frame to compute changes of the cliff face.





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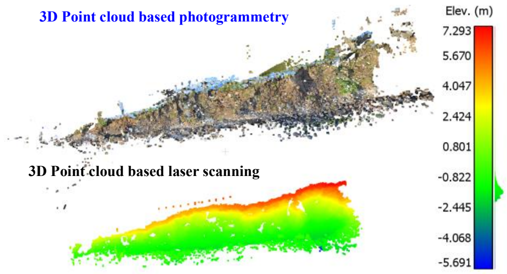
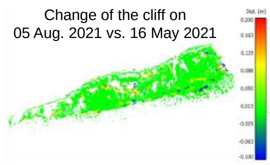
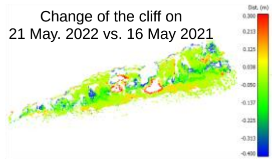


RESULTS





- After 1 year monitoring, local areas of the cliff moved up to 0.4m
- During a summer season (from May 2021 to Sept. 2021), the magnitude of the change of the cliff is smaller than that during winter and spring seasons (Sept. 2021 to May 2022).