DETECTING ANTHROPOGENIC VOLUME CHANGES IN CROSS SECTIONS OF A SANDY BEACH WITH PERMANENT LASER SCANNING

M. Kuschnerus[1,*], R. Lindenbergh[1], Q. Lodder[2], E. Brand[2], S. Vos[3]

[1] Department of Geoscience and Remote Sensing, Delft University of Technology, Stevinweg 1, 2628CN Delft, The Netherlands
{m.kuschnerus, r.c.lindenbergh}@tudelft.nl
[2] Rijkswaterstaat, Ministry of Infrastructure and Water Management, Griffioenlaan 2, 3526LA Utrecht, The Netherlands
{quirijn.lodder, evelien.brand}@rws.nl
[3] Coastal Engineering Department, Delft University of Technology, Stevinweg 1, 2628CN Delft, The Netherlands
s.e.vos@tudelft.nl

Commission II, WG II/10

KEY WORDS: Permanent Laser Scanning, Change Detection, Time Series, Volume Change, Coastal Remote Sensing.

ABSTRACT:

Coastal areas world wide are highly dynamic areas, subject to continuous deformation processes. Both natural and anthropogenic processes constantly cause changes at various spatial scales. Sandy beaches in the Netherlands fall under a regulation, according to which moving sand is permitted, if the volume change remains below a certain threshold. The threshold holds for volume changes within a cross section of 1 m width of the beach. The enforcement of this rule is currently labor intensive, because monitoring generally happens only on a yearly basis, or incidental and non-quantitative. Improved observation capabilities with remote sensing are advancing the supporting technology for this kind of regulations. Permanent laser scanning is a potential tool for monitoring and quantifying volume changes of a section of the beach. We develop and implement methodology to extract time series of volume change with respect to a reference date of 01-01-2020 covering January 2020 until the end of April 2020. The method is applied on point cloud data from a permanent laser scanner on the coast of Noordwijk, The Netherlands. We analyse the time series for incidents, where the threshold in volume change is passed, and find all shortest intervals during which the threshold is passed. Then we analyse potential underlying cause in order to support not only enforcement, but also evaluation of the current regulation. This will ultimately help to work towards a better understanding of the influence of small scale human activities on coastal development.

1. INTRODUCTION

Sandy coastal areas are underlying constant morphological changes due to various processes, as for example tides and waves, wind and human activities. Monitoring these changes is of great importance considering increased frequency of extreme weather events due to climate change. Methods for detection and quantification of coastal deformations are benefiting of the increased availability of remote sensing data. Permanent laser scanning is one of the new techniques to increase spatial resolution and observation frequency of coastal areas. The resulting data sets, provide a three dimensional representation of the beach and its evolution over long time periods (several months, up to years). For coastal management, as well as for scientific research, the differentiation between natural processes and anthropogenic changes is highly important. As explained by (Lazarus and Goldstein, 2019) there are very few beaches worldwide that are not subject to human influences, and human activities often coincide with severe impact of natural forces, such as storms. To detect and separate morphological changes caused by human activities such as bulldozer works, clearing of access paths or life guards patrolling by car, the 3D data from permanent laser scanning opens new opportunities.

1.1 Research Questions

Current Dutch rules state that moving sand below a certain volume threshold is permitted for people with a relevant licence (for example owners of beach cafes). The underlying assumption is that this does not influence the natural processes of the coast significantly. The goal of this research is, first to derive a method to automatically detect volume changes above a specified threshold on a sandy beach, and second to determine the nature and cause of the detected changes. This will help to develop ways to improve maintenance of this policy as, now, only yearly measurements are available, with occasional in-situ and non-quantitative inspections. Additionally, these results will enable the evaluation of this policy, by analysing the effect of different threshold values and comparing the magnitude of commonly occurring changes through natural processes with those caused by human activity. To accomplish this, we answer the following research questions:

1. When does the accumulated change in volume per cross section with respect to a fixed start date pass the threshold?
2. How can we find all intervals, during which the volume change is larger than the threshold?
3. How can we derive the cause of detected volume changes?

1.2 Related Work

Several methods have been explored to detect and localise changes in permanent laser scanning data, mostly focused on analysing elevation changes (see for example (Anders et al., 2021), (Kuschnerus et al., 2021a), (Brand et al., 2019)). General analysis of time series from remote sensing data for sudden

* Corresponding author: m.kuschnerus@tudelft.nl

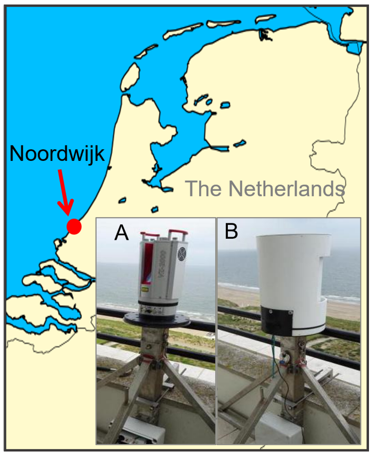

Figure 1. Location of study area on the Dutch coast in Noordwijk, The Netherlands and two photographs of the laser scanner, without, (A), and with protective cover, (B).

changes has been presented for example by (Verbesselt et al., 2010) and (Kuenzer et al., 2015).

Analysis of volume changes in a beach dune system of the Southern Texan Gulf Coast using LiDAR data has been presented by (Caudle et al., 2019), while wind-driven sand transport has been analysed using laser scanning in (Lindenbergh et al., 2011). Specifically erosion of a beach during a stormy period and the recovery has been analyzed by (Dodet et al., 2019) and (Phillips et al., 2019). Typical human activities influencing coastal areas world wide varies a lot per region and their impact has been less frequently studied. The effect of anthropogenic influences on landscapes in general has been analyzed by (Hooke et al., 2012), and on the Dutch coast in particular, by (de Haas et al., 2018). The studies of (Poppema et al., 2019) and (Hapke et al., 2013) cover mainly the influence of human infrastructure on coastal areas. However, the effects of short-term and small scale maintenance activities on sandy coastal beaches are poorly studied (i.e. bulldozer works to clear paths, forming plateaus to accommodate sun beds, clean up after storms etc.), even though they are increasingly frequent and few areas worldwide remain unaffected.

By providing a method to detect volume changes of a specific magnitude on a sandy beach and by identifying if they are caused by human activities, we contribute to the quantification of anthropogenic effects on the coast. Ultimately, this does not only help with regulation of these activities, but also lead to a better understanding of their consequences.

1.3 Data Set

The data for this research is selected out of a data set of hourly 3D point clouds, acquired over a period of two years from a permanently installed laser scanner, (Vos et al., 2017). The observed area includes dunes, sandy beach and the intertidal zone in front of Grand Hotel Huis ter Duin in Noordwijk, the Netherlands, where a Riegl VZ-2000 laser scanner is mounted on a balcony of the top floor at about 55 m height, compare Figure 1. The range on the sandy beach within the point cloud varies between 150 and 500 m. Point spacing varies between 1 and 40 points per m^2. The incidence angle is rather unfavourable due to a surface slope of about 1 degree (on average) towards the sea and the position of the laser scanner. It ranges between $\sim 70^\circ$ and $\sim 80^\circ$ in the area relevant for our research.

The consecutive point clouds are aligned with the help of inclination data from an internal sensor of the laser scanner. The scan closest to the lowest low tide per day is selected for further analysis in this research. From the selection of daily scans, two cross sections of 1 m width are extracted (see Figure 2). One cross section (cs1) is close to the entrance of a beach cafe and on a location frequently undergoing bulldozer works. The second cross section (cs2), is located on a relatively quiet part of the beach, and we assume that natural processes dominate the deformations occurring in this location.

We chose the observation period from the beginning of January 2020 until end of April 2020. The period includes three major storms within a two weeks period, on 9/10 February 2020, 17/18 February and 22/23 February 2020. A few days are missing form the data set (three days in January and seven days in April) because of instrument failure and maintenance activities. We use January 1st as the reference date for a zero change measurement.

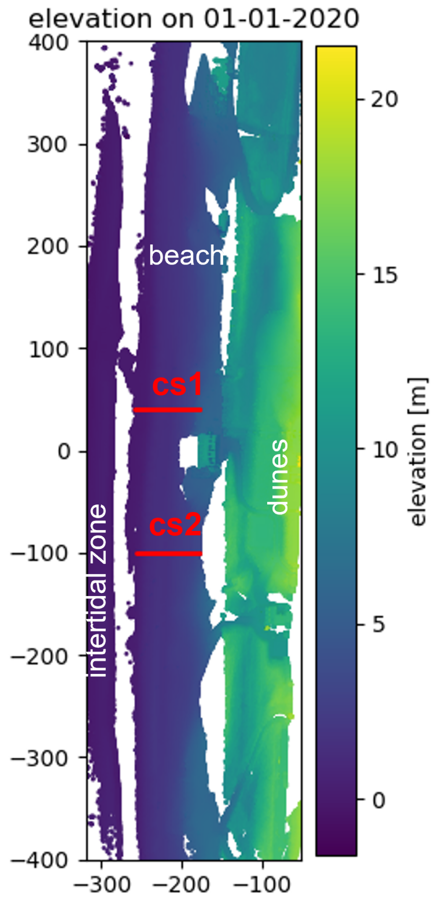

Figure 2. Location of cross section cs1 and cs2 marked in a point cloud of the observed area, covering the sandy beach, a part of the dunes and the intertidal zone in Noordwijk, The Netherlands.

Next to the laser scanner data, we use data from a Davis VantagePro weather station, mounted next to the laser scanner for a period of two months (February/March 2020), as well as from a nearby weather station of the KNMI, (KNMI (Koninklijk Nederlands Meteorologisch Instituut), n.d.). From both sources we use hourly maximal wind speed and wind direction to verify the occurrence of storm events.

2. METHODS

The methods are presented in three steps. We first explain the extraction of the cross sections from the point cloud data set. Then we show how to obtain a relative volume change estimation per cross section and how to detect intervals with volume changes above the threshold, which we refer to as significant volume change. Finally we explain, how we determine a likely cause for the most prominent detected changes.

2.1 Extracting Cross Sections

After preparing and selecting the relevant point clouds, the two cross sections are cut out of each point cloud. A digital elevation model with a grid size of 1 m^2 is generated for the beach area of each point cloud. Each grid cell contains the mean elevation of all points laying in the grid cell. Then, all grid cells at location y = 41 (cs1) and y = -100 (cs2) are selected to represent the two cross sections, which are about 81 m and 78 m long, respectively. The cross sections do not include the intertidal area, as the available data in this area is limited. As an example we show three cross sections for each of the two locations in Figure 3. We chose cross sections at day 1 of the time series, after some bulldozer work and after tents were set up on the beach at location y = 41 (cs1). For location y = -100 (cs2) we show a cross section before, during and after a heavy storm in the beginning of February. It can be seen, that during the storm nearly half of the cross section is cut off, because of water and high waves covering the sand in that area.

Due to changes in elevation (and volume) on the beach, not all points in each cross section are visible at all times. The scanner uses a rather unfavorable incidence angle (70° around 80° on average). Therefore, a low pile of sand of a few decimeters height already leads to a gap in the cross section directly behind the sand pile (see Figure 3 for an example cross section and Figure 7 for the matching point clouds). We use all available data on 01-01-2020 as a starting point. No gaps are found in either of the cross sections on this day. For all consecutive days we loop through each cross section to identify gaps. Wherever there is a gap, we have no new information, that the elevation has changed in that specific location. Therefore, we assume that the last known elevation in that location is still valid and unchanged. In this way we obtain a continuous cross section of elevation data for each day with an available point cloud.

2.2 Estimating accumulated Volume Change

Since the cross sections are 1 m wide, the volume calculation is directly derived from the elevation data as volume above a plane at elevation zero. By comparing the volume in each grid cell of the cross section with the first cross section on January 1st, we derive the volume change over time per grid cell of the cross section. As an example this data is shown in Figure 4. Every vertical line represents the accumulated volume change of the same cross section at that time stamp. It can clearly be seen that most of the variability at this location occurs close to the intertidal zone and not in the vicinity of the dunes.

The accumulated volume changes, per cross section are then summed up to derive one time series of total volume change for each of the two cross sections. This volume change time series can then be analyzed to answer the first research questions. We define a threshold and loop through the time series to find all events, where the volume change with respect to the first day passes the threshold.

2.3 Finding all intervals with significant Volume Change

To find all intervals, during which volume change is larger than the threshold, we derive the time series of the accumulated absolute volume, without comparison to any reference date. Then, for each point in time we calculate the difference with all following points in time and check on which occasions the threshold is passed. This results in a list of pairs of time stamps (t_i, t_j), between which the total volume change in the cross section has passed the threshold. From all indices $j_1, \ldots, j_k$ appearing as the second time stamp of the pair (t_i, t_j), we then choose the smallest one, to find the shortest interval over which the volume change has occurred, starting from t_i.

2.4 Deriving Cause

To derive a plausible cause for a deformation process, which leads the volume change to pass a fixed threshold, we consult weather data, collected with the weather station next to our laser scanner and from nearby weather stations (KNMI (Koninklijk Nederlands Meteorologisch Instituut), n.d.) as well as the entire data set of hourly point clouds. Using wind speed and wind direction we can localise the time periods of heavy storms. In most cases, suspected natural causes can be confirmed by the coinciding weather conditions and suspected human activities become apparent when visually inspecting the respective point clouds.

3. RESULTS

In this section we discuss the results of our analysis. For our exemplary data set covering January to April 2020 we chose the threshold to be 10 m^3 and completed our analysis using the methods described in section 2. The following three subsections answer the three research questions posed at the beginning of this article.

3.1 Accumulated Volume Change

The time series of the total accumulated volume change for each of the cross sections is shown in Figure 5. Cross section cs1 notably experiences volume increase, while cs2 is affected by volume loss. We can see, that on numerous occasions, the threshold of 10 m^3 was passed. Especially prominent is the steep rise of cross section cs1 in the beginning of January. A positive volume change by more than 20 m^3 within two days (double our threshold) points to a clear human influence. The same holds for another steep rise a few days later, which turned out not be an actual deformation of the beach, but a much higher elevation caused by the placements of large tents in the area next to the beach cafe, compare Figure 7.

Both time series, cs1 and cs2, are subject to several heavy storms, which can be seen clearly in Figure 5. Interestingly, at the location of cs1, the erosion caused by the storms is much worse, following the human interventions. About 23.5 m^3 of sand is lost during the stormy period of two weeks. The overall loss of sand in the same time at the location of cross section cs2 was only 8.7 m^3, with several peaks, apparent short recoveries, in between. Over the entire observation period, at the location of cross section cs1, about 14.3 m^3 of sand are accumulated, with a daily average of 0.015 m^3.

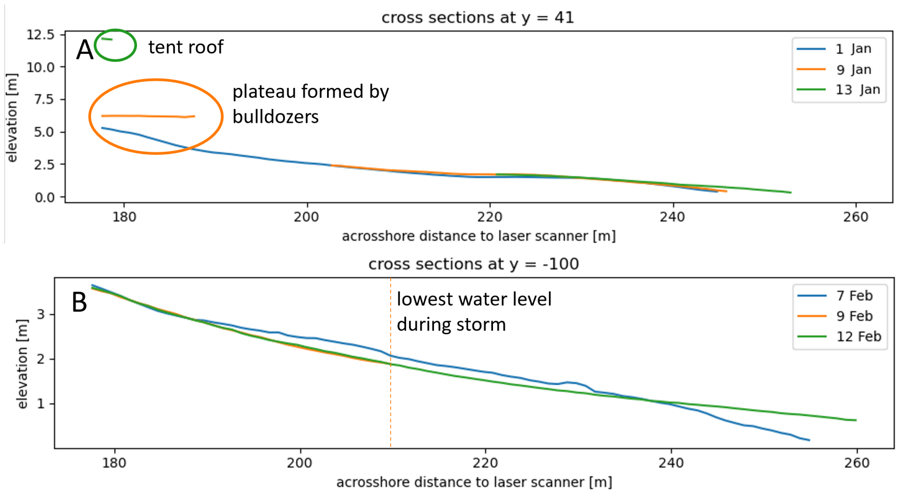

Figure 3. Cross sections at location cs1 (A) and cs2 (B). A: For cs1, the first cross section of the time series is shown together with the first cross section after a plateau was formed, Jan. 9, and after tents were set up, Jan. 13. The gaps in the cross sections appear due to the plateau/tents blocking the view of the scanner. B: For cs2, the cross section just before a major storm on 9/10 February 2020 is shown, Feb 7, together with one short cross section during the storm, Feb. 9, where a large part of the beach was covered with water, and the first complete cross section right after the storm, Feb. 12.

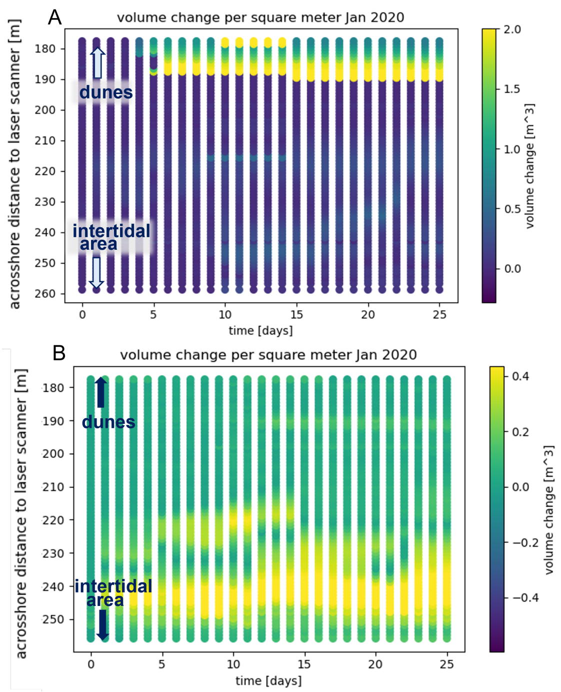

Figure 4. Volume change per square meter compared to 01-01-2020 in January 2020 for cross section cs1 (A) and cross section cs2 (B). For the cross section cs1 it can be seen that the formation of a plateau close to the dune foot dominates all other changes in the cross section, whereas in cross section cs2 most changes appear close to the intertidal zone.

The overall more gradual variation in volume change of the time series at cs2 points to more natural influences in this area. Looking at the entire observation area, more sand is lost at the location of cross section cs2 (about -10 m^3, with daily average of -0.007 m^3) than at the location of cross section cs1.

3.2 Deriving Cause

Within the time series for cross section cs1, we derive two main events of human activity clearly surpassing the exemplary threshold of 10 m^3. First, a higher elevated flat surface is formed by substantial bulldozer works at the beginning of January, which is followed by a several day event held in tents on the beach at the location of our cross section (see Figure 5 A, red circles and Figure 7). Subsequently a period of heavy storms leads to the deconstruction of the higher flat area and a return to the natural state of the beach, within a three weeks period.

At the location of our second cross section, the deformation appears to be of natural cause, dominated by the stormy period (see Figure 5 B), with recorded wind speeds of up to 20 m/s. When inspecting the point clouds during this period, we can see that almost half of the beach, that is usually always dry is submerged under the high waves during the storm (see cross sections in Figure 3 B).

3.3 Intervals with Passed Threshold

The time series of total volume per cross section is shown in Figure 6. With lines in different colours we indicated each smallest interval, starting from a given date, during which the volume passed the threshold of 10 m^3. For cross section c1 we obtain 15 such intervals and for cross section c2, there are 11 intervals, starting at different dates. We analyse the events corresponding to the changes occurring in these intervals by, (i), consulting weather data, and, by (ii), considering the corresponding point clouds. From this analysis we conclude that for cross section c1, three interval events at the beginning of the time series are caused by human activities, while six include the effects of the stormy period. For c2 these conclusions are

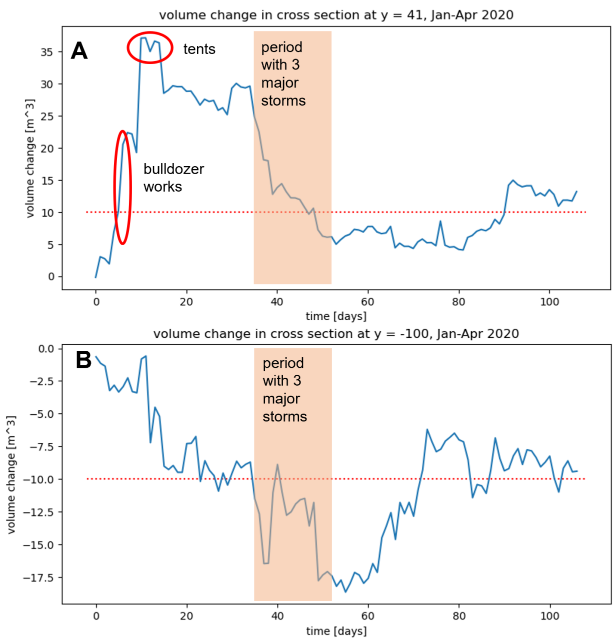

Figure 5. Time series of total volume change, w.r.t. January 1, from January 2020 to April 2020, for cross section cs1 (A) and cs2 (B). The threshold of volume change, red dotted line, is set at absolute values greater than 10 m^3. A period of heavy storms is marked in orange and parts of the time series affected by human activities are circled in red.

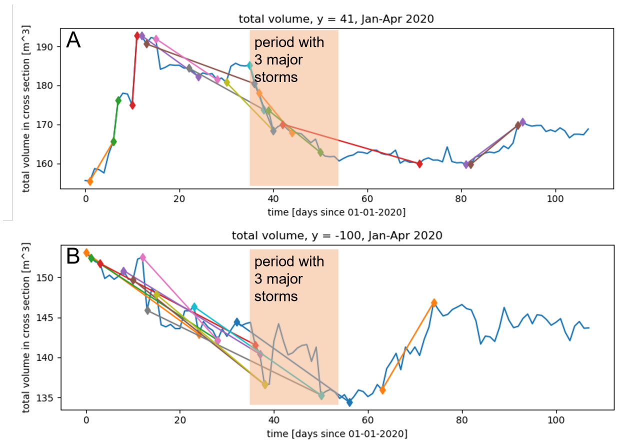

Figure 6. Time series of total volume in cross section cs1 (A) and cs2 (B) for January to April 2020. The threshold of volume change is set at absolute values greater than 10 m^3 and all pairs of time stamps, between which the threshold is passed are marked with different colours.

less obvious. We assume that the six intervals overlapping with the stormy period represent changes in volume caused by the storms. The last interval shown in orange in Figure 6 B could be the natural recovery period after the storm, but this has not been independently verified.

4. DISCUSSION

The presented methods allow to find volume changes of a predefined quantity. By looking at characteristics of the time interval over which the change happened, as well as the slope of the change curve, an indication on the cause can be derived. To confirm what caused the specific change, we now consult next to weather data, the entire point clouds. This is not a practical solution, when it comes to analyzing large amount of data. Extending the method to cover not only single cross sections, but all neighboring cross sections of the entire beach, would allow to provide more information on the nature of the change. A regular and sudden volume change is more likely to be caused by bulldozer works, than a spread out gradual change. This would also allow to derive the origin of the sand that was added in case of a steep positive volume change. Additionally the choice of the location of the cross section(s) and the time period are critical for the detection of specific changes. Especially without prior knowledge of the processes (natural or anthropogenic) that will be analyzed, the data selection can play a huge role in the results. For further analysis, we plan to analyze the entire observation area and cover an extended time period, for example analysis of two consecutive winter periods.

Filling the gaps in the cross sections with previous elevation gives in many cases a rather conservative estimate of volume changes. When a plateau or a pile of sand on the beach is formed, it causes the area right behind (from the point of view of the laser scanner) to be hidden. As sand mostly does not form very steep cliffs, the sand accumulated in this hidden area is missed with our current method. A simple assumption on the slope of sand piles could provide an alternative volume estimate in these areas. Another alternative is a spatial interpolation using data surrounding the cross sections.

Another issue is, that some changes in the cross sections do not actually represent volume changes of the beach itself. The set up of tents in January 2020 at the location of cross section cs1 is one such example. The roof of the tent was scanned by the laser scanner, but there was probably little actual volume change underneath the tents. A ground filter, to remove all temporary objects from the beach, before extracting the cross sections would prevent these false positives in volume change.

For this research we did not consider the decreased data quality especially on stormy days (Kuschnerus et al., 2021b). Just a slight deviation in the alignment of the point clouds can lead to changes in the volume estimation. An estimation of the statistical confidence in the estimated volume changes would improve the quality of the derived conclusions.

When extracting more data over longer periods of times, and thus generating longer time series, additional time series analysis could be beneficial. Following an approach as for example presented by (Verbesselt et al., 2010) gradual changes could be found with partial linear fitting and seasonal changes in volume could be detected as well.

5. CONCLUSION

We analysed two cross sections from an exemplary four-months data set from permanent laser scanning to answer the following research questions:

1. When does the accumulated change in volume per cross section with respect to a fixed start date pass the threshold?
2. How can we find all intervals, during which the volume change is larger than the threshold?
3. How can we derive the cause of detected volume changes?

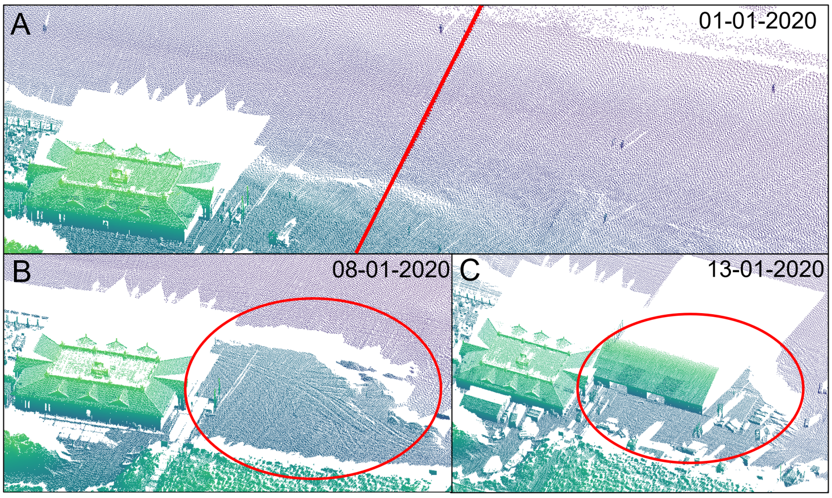

Figure 7. Point clouds at the location of cross section 1 (cs1) at the beginning of the time series, on 01-01-2020 (A), after extensive bulldozer works forming a plateau, on 09-01-2020 (B), and showing the tents put up for an event on 13-01-2020 (C). The large shadow of the tent is visible as well. The location of the time series is marked with a red line in panel A.

We found all major events, where the accumulated volume change passed the threshold of 10 m^3 compare to our first time stamp and all 15 (for cs1 and 11 for cs2) smallest intervals during which these volume changes happened. Two main human activities were identified in cross section cs1: extensive bulldozer works on 09-01-2020 and the set up of tents on 13-01-2020. Generally we find that sudden rises in volume within a cross section are indication for human activities on the beach, such as bulldozer works (in our example). On the other hand, a steep decline in volume can be caused by natural processes, such as heavy storms. In our example, in both cross sections, a two weeks period with three heavy storms caused the loss of about 23 m^3 (cs1) and 8 m^3 (cs2) of sand (over a length of 81 m and 78 m respectively). The considerably larger loss of sand in cross section cs1 can be explained by the previous bulldozer works, accumulating an unnatural height and shape of sand in the area of cross section cs1.

The presented method allows to identify and quantify volume changes on a sandy beach. Our assumption that steep, short term volume changes are caused by human activities were confirmed for our example and the effects of severe storms was clearly visible. We provide a new way to analyze the effect of small scale human activities and to maintain current regulations for moving sand on the beach. This will help with establishing future regulations and with the analysis of their effects on coastal areas.

ACKNOWLEDGEMENTS

The authors would like to thank Grand Hotel Huis ter Duin for their cooperation. This research has been supported by the Netherlands Organization for Scientific Research (NWO, grant no. 16352) as part of the Open Technology Programme and by Rijkswaterstaat (Dutch Ministry of Infrastructure and Water Management).

REFERENCES

Anders, K., Winiwarter, L., Mara, H., Lindenbergh, R. C., Vos, S. E., Höfle, B., 2021. Influence of Spatial and Temporal Resolution on Time Series-Based Coastal Surface Change Analysis Using Hourly Terrestrial Laser Scans. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, V-2-2021, 137–144.

Brand, E., De Sloover, L., De Wulf, A., Montreuil, A.-L., Vos, S., Chen, M., 2019. Cross-Shore Suspended Sediment Transport in Relation to Topographic Changes in the Intertidal Zone of a Macro-Tidal Beach (Mariakerke, Belgium). *Journal of Marine Science and Engineering*, 7(6), 172.

Caudle, T. L., Paine, J. G., Andrews, J. R., Saylam, K., 2019. Beach, Dune, and Nearshore Analysis of Southern Texas Gulf Coast Using Chiroptera LIDAR and Imaging System. *Journal of Coastal Research*, 35(2), 251–268.

de Haas, T., Pierik, H. J., van der Spek, A. J. F., Cohen, K. M., van Maanen, B., Kleinhans, M. G., 2018. Holocene evolution of tidal systems in The Netherlands: Effects of rivers, coastal boundary conditions, eco-engineering species, inherited relief and human interference. *Earth-Science Reviews*, 177, 139–163.

Dodet, G., Castelle, B., Masselink, G., Scott, T., Davidson, M., Floc'h, F., Jackson, D., Suanez, S., 2019. Beach recovery from extreme storm activity during the 2013–14 winter along the Atlantic coast of Europe. *Earth Surface Processes and Landforms*, 44(1), 393–401.

Hapke, C. J., Kratzmann, M. G., Himmelstoss, E. A., 2013. Geomorphic and human influence on large-scale coastal change. *Geomorphology*, 199, 160–170.

Hooke, R. L., Martín Duque, J. F., Pedraza Gilsanz, J. d., 2012. Land transformation by humans: a review. *GSA today*, 22(12), 4–10.

KNMI (Koninklijk Nederlands Meteorologisch Instituut), n.d. Weather Data at Valkenburg(ZH), The Netherlands. https://www.knmi.nl/nederland-nu/klimatologie/daggegevens.

Kuenzer, C., Dech, S., Wagner, W., 2015. Remote Sensing Time Series Revealing Land Surface Dynamics: Status Quo and the Pathway Ahead. C. Kuenzer, S. Dech, W. Wagner (eds), *Remote Sensing Time Series: Revealing Land Surface Dynamics*, Springer International Publishing, Cham, 1–24.

Kuschnerus, M., Lindenbergh, R., Vos, S., 2021a. Coastal change patterns from time series clustering of permanent laser scan data. *Earth Surface Dynamics*, 9(1), 89–103.

Kuschnerus, M., Schröder, D., Lindenbergh, R., 2021b. Environmental influences on the stability of a permanently installed laser scanner. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, XLIII-B2-2021, Copernicus GmbH, 745–752.

Lazarus, E. D., Goldstein, E. B., 2019. Is There a Bulldozer in your Model? *Journal of Geophysical Research: Earth Surface*, 124(3), 696–699.

Lindenbergh, R. C., Soudarissanane, S. S., De Vries, S., Gorte, B. G., De Schipper, M. A., 2011. Aeolian beach sand transport monitored by terrestrial laser scanning. *The Photogrammetric Record*, 26(136), 384–399.

Phillips, M. S., Blenkinsopp, C. E., Splinter, K. D., Harley, M. D., Turner, I. L., 2019. Modes of Berm and Beachface Recovery Following Storm Reset: Observations Using a Continuously Scanning Lidar. *Journal of Geophysical Research: Earth Surface*, 124(3), 720–736.

Poppema, D. W., Wijnberg, K. M., Mulder, J. P., Hulscher, S. J., 2019. Scale experiments on aeolian deposition and erosion patterns created by buildings on the beach. *Coastal Sediments 2019: Proceedings of the 9th International Conference*, World Scientific, 1693–1707.

Verbesselt, J., Hyndman, R., Newnham, G., Culvenor, D., 2010. Detecting trend and seasonal changes in satellite image time series. *Remote Sensing of Environment*, 114(1), 106–115.

Vos, S., Lindenbergh, R., de Vries, S., 2017. CoastScan: Continuous monitoring of coastal change using terrestrial laser scanning. *Proceedings of Coastal Dynamics 2017*, Helsingør, Denmark, 1518–1528.