Comparative study of airborne, mobile and static LiDAR in a coastal environment

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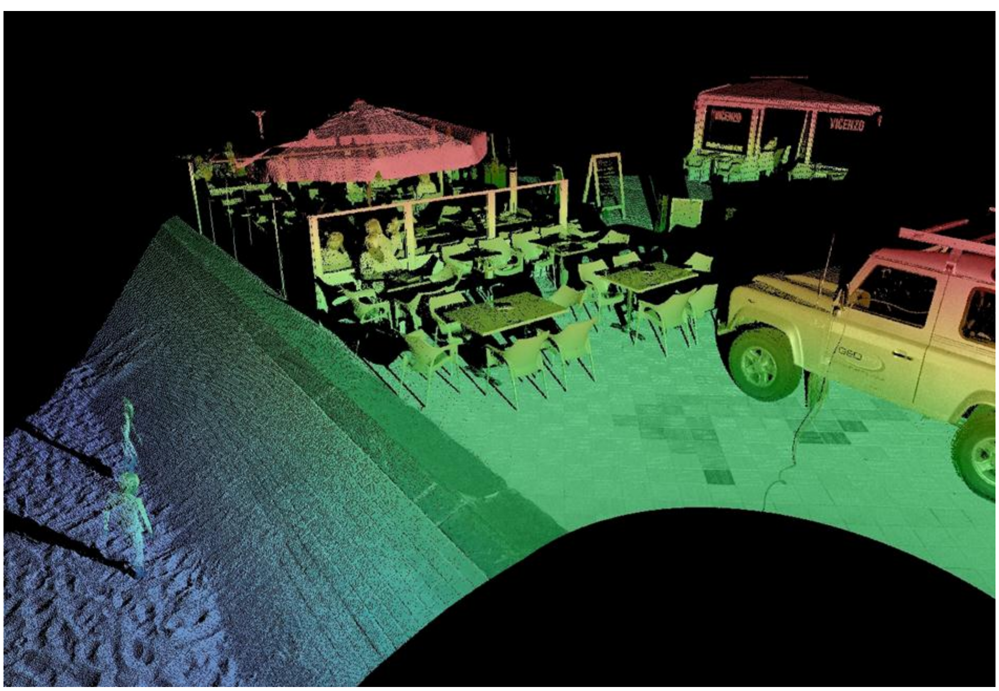

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Approval of report

Name	Organisation	Signature	Date

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Draft 2					
Draft 3					
Draft 3.2					
Draft 3.3					
Draft 3.4					

CONTENTS

1 INTRODUCTION

A comparative coastal survey study of different LiDAR techniques and platforms will be presented in this deliverable. This survey is done in the framework of WP3.6 – land and sea model - where one of the objectives is: extensive testing of new (airborne) laser techniques in coastal zone. The study is conducted by the Agency of Maritime and Coastal Services (Belgium) in cooperation with the Flemish Geographical Information Agency (AGIV).

Two test sites on sandy beaches along the Belgian coast - Wenduine and Ostend – were surveyed in 2011. For each site, three LIDAR techniques on different platforms - airborne, mobile and static LIDAR - were applied on the intertidal zone. Employability, accuracy issues, point density, cost-benefit analysis (in this study indicated as the co(a)st effectiveness) as well as more general benefits and drawbacks are evaluated for the different LiDAR platforms. The results of this study must be set in a broader context and is not intended as a review of LiDAR hardware and software or a recommendation of certain service providers.

A general outcome is that each platform has its advantages related to the area size and co(a)st effectiveness. As a result, different kinds of coastal applications with the LIDAR technique will be addressed for the best suited platform.

2 CONTEXT

The study was conducted at the Belgian coast on the intertidal zone. The focus is on the beach and not on bathymetry or monitoring of dunes. The Belgian coast consists of sandy beaches and is 67 km long. Every year an airborne LiDAR campaign is conducted during the period of 15 March till 15 May with the purpose to monitor sand levels of the beach in order to produce difference maps from consecutive years. These maps are used for local supplementation works to maintain the level of sandy beaches, which is not only important for coastal sustainability, but also for touristic purposes due to the very dense populated Belgian coastal area.

Because the mobile LiDAR technique and its industry is rapidly gaining importance in Western Europe, it is a valuable alternative to the airborne LiDAR technology. To compare these LiDAR methods on different platforms, within the BLAST project, we launched a tender for 2 sites at the Belgian coast to conduct as well as mobile (on a driving platform) as static (on a tripod) LiDAR.

This comparative study is very dependent on hardware equipment and hardware configuration and on the experience of the service provider. We tried to minimize these factors in our judgments and put the attention more at the broader context in our conclusions and not only on the raw results coming from this study.

A second point to make is that the study is made from a user's point of view and the users are in this case governmental agencies. In other words, this study is conducted taking in mind for setting up tender requirements for beach monitoring.

3 COMPARATIVE STUDY

3.1 Project conditions

Airborne LiDAR

The airborne LiDAR for the entire Belgian beach is executed every year at spring (15/03 – 15/05) and is part of a tender contract for 3 years with additional LiDAR measurements of the dunes. The tender requirements are the following:

- Point density of 1 pts/m^2 and homogeneous distributed (points must be evenly separated by 1 meter or less with a 10% tolerance)
- Vertical accuracy:
  - Total error (RMSE) and systematic error (Mean Error) < 6 cm
  - 95% confidence interval = 1.96 * RMSE for individual LiDAR points
  - Counts on every part of the covered area (errors are not averaged)
- Horizontal accuracy:
  - Total error (RMSE) and systematic error (Mean Error) < 15 cm
  - 95% confidence interval = 1.96 * RMSE for individual LiDAR points
  - Counts on every part of the covered area (errors are not averaged)
- The low water line at 0.5 m TAW(zero – level for Belgian) must be covered for 90%
- Classification in ground, non- ground, and points on water
- Delivery in LAS format (flight strips) + XYZ data divided in coastal section in CRS Lambert 72 and ETRS89

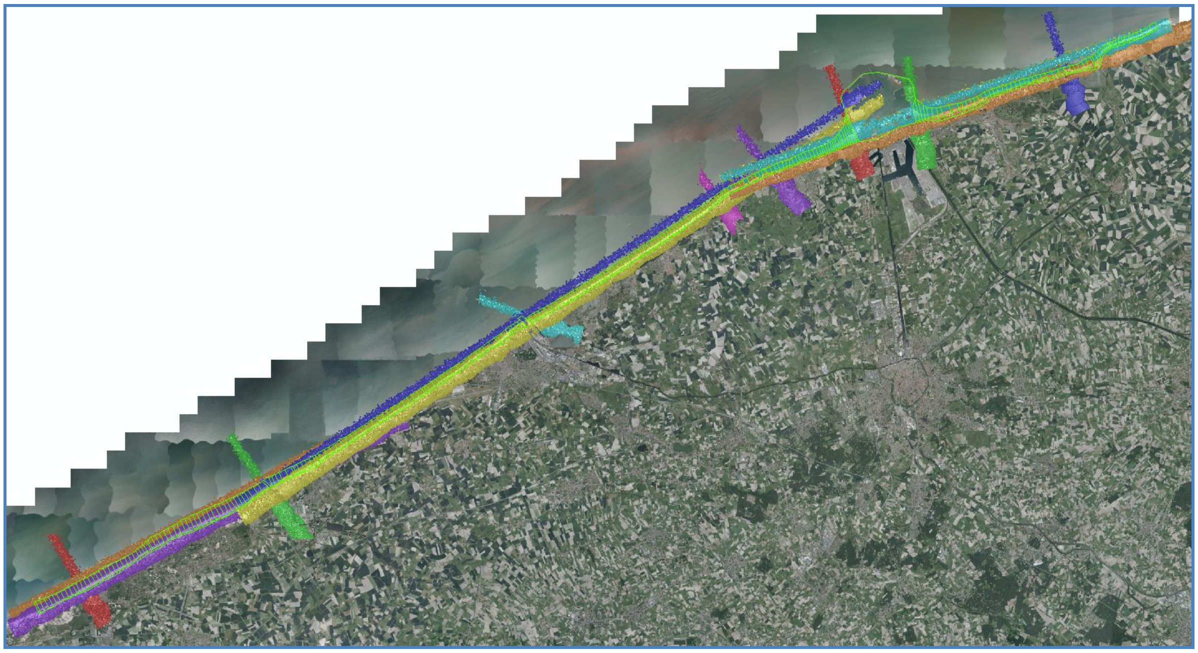


Figure 1: overview of the airborne LiDAR strips covering the 67 km long Belgian coast; flightstrips have a width of circa 0.5 km and the total beach area covered is 34.2 km²

Mobile and static LiDAR

A tender for mobile and static LiDAR on 2 test sites of the Belgian coast was issued within the BLAST project in 2011. The test sites are located in Ostend and Wenduine. The tender requirements are the following:

- Minimal point density of 5 pts/m^2
- Maximal range of 200 m for driveline separation mobile LIDAR
- Cross line every coastal section (circa 400 meter between groynes)
- Minimal range of 100 m over 360° for static LIDAR (=> pulse based laserscanner)
- 1 meter TAW for low water level
- Vertical accuracy:
    - Total error (RMSE) and systematic error (Mean Error) < 6 cm
    - 95% confidence interval = 1.96 * RMSE for individual LiDAR points
    - Counts on every part of the covered area (errors are not averaged)
- Horizontal accuracy:
    - Total error (RMSE) and systematic error (Mean Error) < 15 cm
    - 95% confidence interval = 1.96 * RMSE for individual LiDAR points
    - Counts on every part of the covered area (errors are not averaged)
- Classification in ground, non-ground and water points
- Delivery raw data in LAS format (drivelines) and thinned XYZ data at 5 pts/m^2 in Lambert72 and ETRS89-LAEA

- Mobile and static LIDAR must be independently registered and processed
- 5 to 10 static registrations per project area

The 2 selected test sites are located around Wenduine and Ostend and were selected because some infrastructure works were foreseen to be carried out that time on the beach. The Wenduine site is 4 km long and 0.3 km in width covering circa 1.2 km² of beach. The project area around Ostend is 7.2 km long separated by the harbor channel and is covering 2.5 km². The results of this study are especially based on the Wenduine area, because the data of Ostend did not fully pass the quality control.

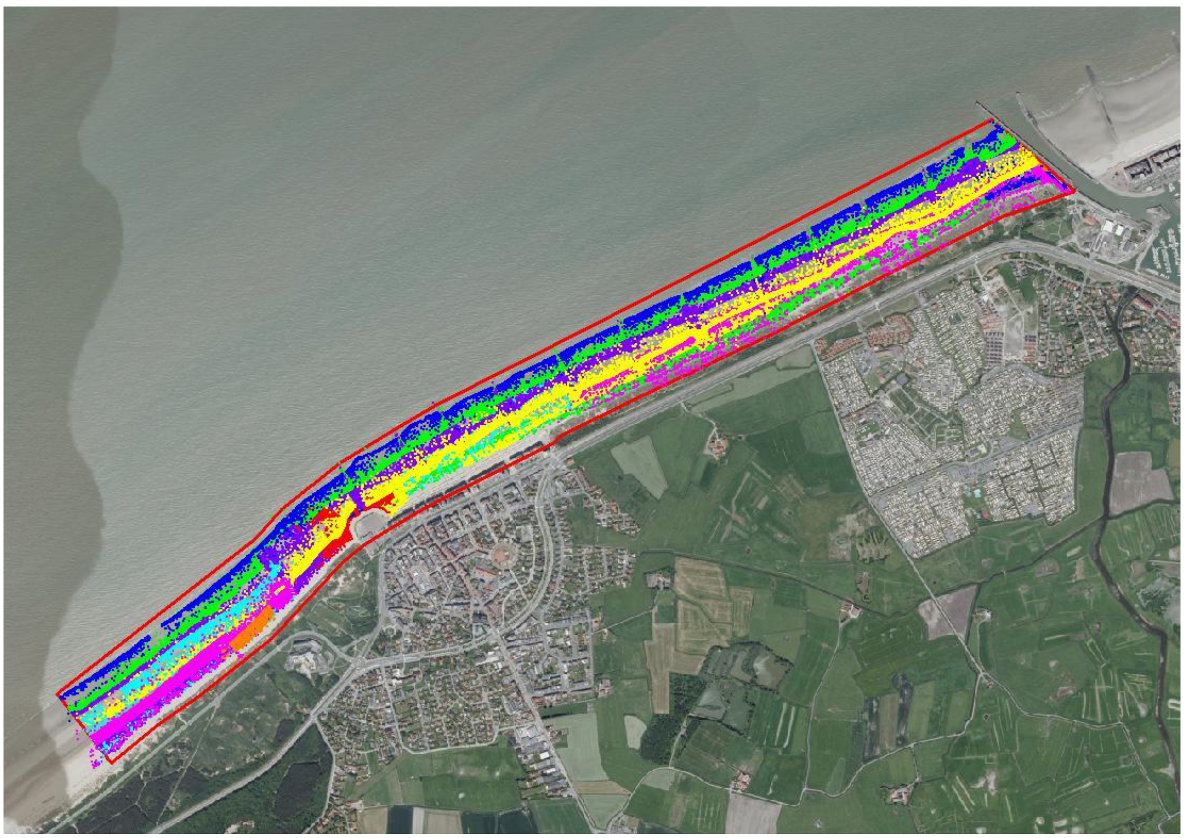


Figure 2: overview of the mobile LiDAR strips covering the 4 km long Belgian project site at Wenduine

Differences

The major difference in tender requirements between airborne and mobile/static LiDAR is the fact that the requested point density for the mobile LiDAR is at 5 pts/m² because of the inherent capability of mobile/static LiDAR of producing very dense point clouds (target distance is much closer) + the requirement to have a thinned out dataset at 5 pts/m². In the conclusions further in the document, we will discuss these tender requirements and some new recommendations will be done for tender requirements of mobile LiDAR

3.2 Hardware

The differences in hardware and specifications of the settings are summarized in Table 1. It is evident that airborne LiDAR has a much higher propagation speed and a broader scan width so that the covered area is much greater within a certain timeframe. On the downside is the fact that it is not possible to obtain point densities > 10 pts/m² in one flight strip.

The mobile and static LiDAR uses the same LiDAR scanner. On the mobile platform, the LiDAR scanner was fixed on the roof of a Land Rover pointing 90° in a horizontal plane (270° azimuth) from the driving direction and sweeping from 50° to 150° in the vertical plane. There was only 1 fixed LiDAR scanner on the vehicle having a range of 80 meters at one direction orthogonal on the driveline. With such laserscanner configuration, many drivelines must be taken into account for full coverage the whole project area of the beach. Also the time frame for the measurement is heavily constrained by the tides. A better configuration would be having 2 or more laserscanners pointing at both sides slightly towards the rear of the vehicle covering the whole 360° area when driving. In this way a more homogeneous scan pattern can be obtained with less drivelines and within a smaller timeframe.

Table 1 : comparison of hardware and specifications of the settings

	Airborne	Mobile	Static
Carrier	Twin engine aircraft (Piper Navajo Chieftain)	Land Rover Defender	Tripod
Carrier speed (m/s)	62 m/s	3 m/s	0 m/s
Carrier Height (m)	900	2.85	1.75
LIDAR scanner	IGI Litemapper 6800	Riegl VZ-400	Riegl VZ-400
LIDAR orientation Hor /Ver (FOV)	90° or 270° H -30° - 30° (60°)	270° H 50° - 150° V (100°)	0° – 360° H 50° – 150° V (100°)

Max Range (m) / Eff. Swath Width (m)	3000 / 1039	350 – 600 80 (150 max)	350 – 600 80 (350 max)
Eff. Meas. Rate (Hz)	200 000	42000 - 122 000	122 000
# strips to cover the width of the beach	2 strips	4 - 8 strips	1 measurement covers 0.03 km^2 with range of 90 meter
Theoretic Point Density	1.7	Variable > 5 pts/m^2	Variable >5 pts/m^2

Figure 2: impressions of the mobile LiDAR campaign

3.3 Point density

The resulting point density for the different platforms is one of the most remarkable outcomes of this study. Take into account that all LiDAR systems on the different platforms have an effective pulse rate in the same order of 100000- 200000 Hz. Although the results are in the line of expectations, the amount of LiDAR points of the raw data of mobile LiDAR is very high. The general results are the following:

Airborne LiDAR

- Average of 1.6 pts/m² per flight strip
- Average of 4 pts/m² in study area of Wenduine (including flight strip overlap)

Mobile LiDAR

- Average of 400 pts/m² in study area (including driveline strip overlap)
- Factor 100!

Static LiDAR

- Average of 200 pts/m² per measurement point

These big differences in point density are caused by the low carrier speed, the small target distance (swath width) and the oblique incidence angle of the mobile platform. A lot of LiDAR pulses are reflected very close to the vehicle with a very heterogeneous spaced point cloud as a result (e.g. see the red colored drivelines in the point density plots of figure 4 of the mobile LiDAR). Point density just near the car can reach up till 10 000 points. Figure 3 shows an empirical exponential curve of the point density with distance of the mobile platform coming from this study. Another theoretic relationship between target distance (considering a flat surface) and incidence angle follows a tangential curve.

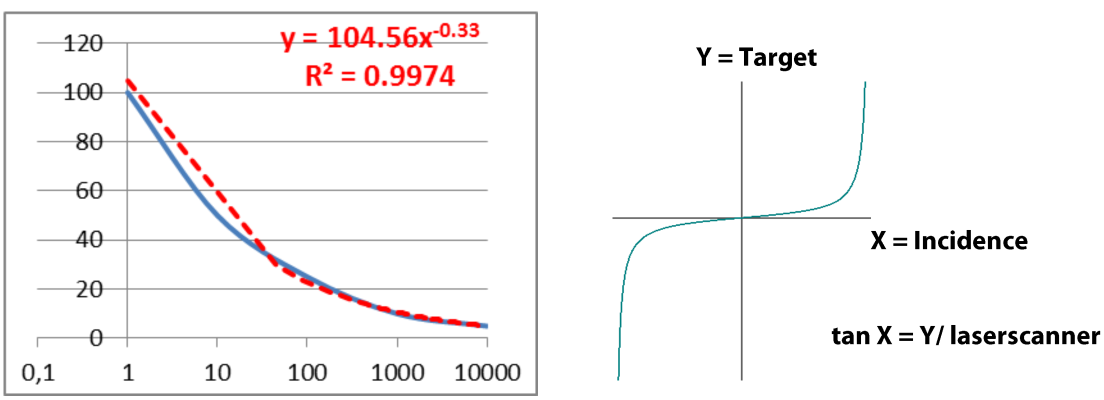
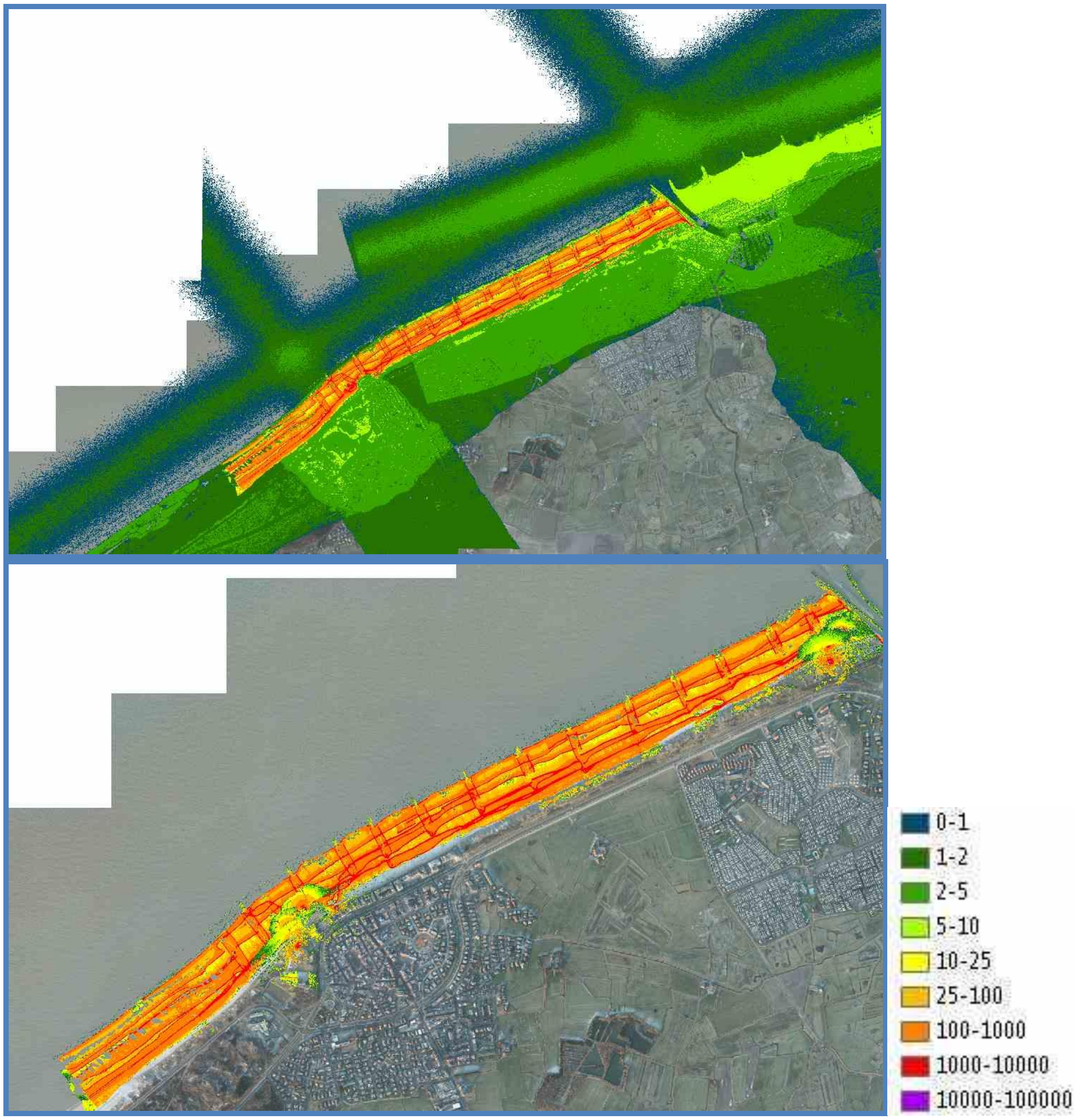


Figure 3: relationship between point density and target distance (left) and between incidence angle and target distance (right)


0-1
1-2
2-5
5-10
10-25
25-100
100-1000
1000-10000
10000-100000

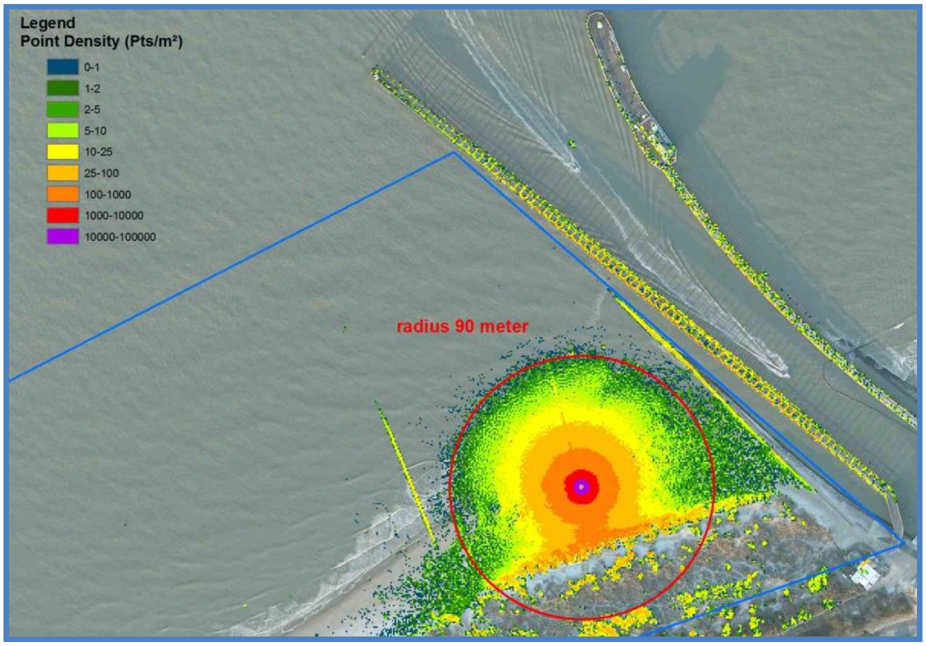
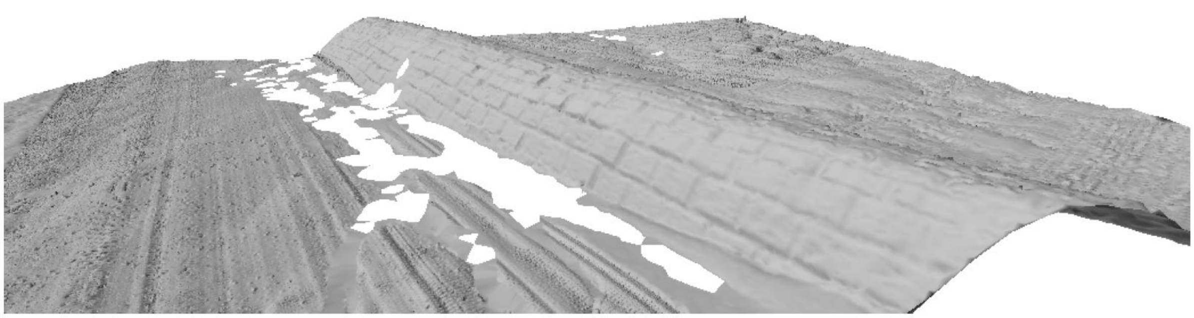


Figure 4: visual comparison of the point density for the Wenduine area with the same color legend (above: airborne with superposition of mobile LiDAR; middle: mobile LiDAR with superposition of static LiDAR; under: static LiDAR

The high point density of the mobile platform makes it possible to have very high resolution point clouds (almost 3D images) of some structures near the car. This is an interesting site effect for monitoring groynes and dikes . A disadvantage of the mobile platform is the low position (circa 2 to 3 m above ground) of the laserscanner which makes it not as suitable for monitoring undulating terrain like dunes or rocky beaches. The low laserscanner position together with the target on the horizontal plane will often cause gaps in the dataset because of shadow effects and occlusion of higher terrain and objects. Another aspect of the mobile laserscanning technique is that the laser range indicated on the product sheets will never be realistic for covering the whole "laser range area" on ground level, because of the very low incidence angle and bad reflectance. Drivelines must be separated by at least 4 times less than the laser range distance set on the product sheets to obtain a point density of 1 pts/m^2.



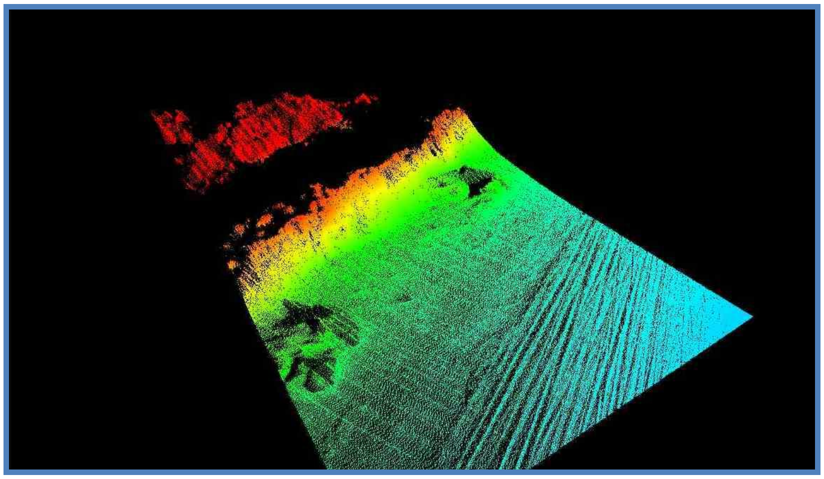


Figure 5: examples of mobile LiDAR data where (above) a groyne structure is registered in very high detail with some gaps caused by water bodies, (under) gaps are visible at the undulating terrain of the front dunes.

3.4 Data volume

Data volume is an important factor for archiving, managing and hosting the LiDAR data for internal use distribution to third parties. Data volumes can have a serious weight on yearly budget of servers and IT operations. The data volumes in this study were the following:

- Airborne LiDAR 7.3 GB (LAS files) for 34 km^2
- Mobile LiDAR 8.9 GB for 1.25 km^2
- Static LiDAR circa 150 MB per 360° measurement

While the point density of the mobile LiDAR is 100 times greater with respect to the airborne LiDAR, the data volume only covers an area that is 30 times smaller than the area covered by the airborne LIDAR.. In reality, this factor will be higher - close to the factor of 100 -, considering that the flightstrips of airborne LiDAR cover more area (factor 2) than the requested 34 km^2. Moreover, the completed LAS files of the airborne data contain more data per LIDAR point (intensity values, GPS time,…) than the LAS files delivered by the service provider of the mobile laserscanning (only XYZ data).

The following recommendations related to data volumes and point density can be taken into account when ordering a LiDAR campaign for coastal monitoring:

- For scientific reasons and for visualization purposes, always demand the original flight lines or drivelines in LAS format on a HDD; you are not obliged to store the data on servers,

but afterwards you have always the ability to reprocess the data or make some derivative products or distribute the data to research institutions
- Demand a second homogeneous thinned out point file especially for mobile LiDAR campaigns. 1 pts/m^2 is mostly enough for coastal monitoring; our requirement for the study of 5 pts/m^2 is not necessary and lower point density requirement can speed up the measurements
- Data storage management must be taken into account, especially when ordering a mobile LiDAR campaign (factor 30 – 100 in data volume when storing the original drivelines)
- Take into account a small tolerance for the coverage requirement (95% - 99%) so that gaps inherent by the mobile LiDAR technique may occur
- Data range specification provided by the static and mobile laserscanners product sheets are not suitable for covering flat surfaces on the ground. As a general rule for the mobile LiDAR campaigns, divide the maximum laser range by 4 to obtain the maximum swath width with a point density of circa 1 pts/m^2.

3.5 Data quality

Data quality of different LiDAR projects was controlled by the the Flemisch Geographical Information Agency (AGIV) on data accuracy and correct delivery of the LAS format. The data quality for LiDAR projects is always dependent on how much time is spent on post processing the data with use of reference measurements and thus dependent on the service provider. For this study, we want to diminish the effect of these dependencies and verify if there are data quality issues that are inherent on the platform.

AGIV uses 1) control reference fields of 25 RTK-GPS measured control points in a grid of 5 m x 5 m and 2) profiles on groynes, and 3) an internal database of reference points (FLEPOS control points). The results of these reference fields for the mobile and static LiDAR at Wenduine and the airborne LiDAR for the whole Belgian beach are listed below:

Airborne LiDAR

- Mean Error in Z = 0.02 m
- RMSEz = 0.025 m
- Method service provider:
    - boresight error calibration by overflying a building with known coordinates
    - DGPS – INS processing
    - Strip adjustments with control points

Mobile LiDAR

- Mean Error in Z = 0.01 m
- RMSEz = 0.02 m
- Method service provider:

- Calibration just before measurements
- DGPS – INS processing
- Strip/Block adjustments (not always necessary)

Static LiDAR

- Accuracies of 0.01 to 0.03 m, if:
- measurement position of laserscanner is precisely recorded with RTK GPS
- georeferencing can be done (semi-) automatic with sufficient overlapping areas or use of reference/tie points

All LiDAR platforms can provide excellent accuracy results on the vertical component. Note that the mobile LiDAR data of Ostend were rejected because of bad data quality due to problems during the measurements with GPS and IMU. On the other hand, the mobile LiDAR campaign in Wenduine has proved that it is possible to have very good accuracy results (even slightly better than the airborne campaign because of the shorter scan range) without the need of strip adjustments. On the downside for mobile LiDAR, there were some issues due to shocks during driving with some banding in the elevation data; these were all removed with post processing by the service provider, but it is not clear if this a common problem with mobile LiDAR.

In general we can conclude that data quality is not an issue in the choice of LiDAR platform if a serious effort in post processing is done. It is advisable that the concerned authority set in the tender requirements a precise description of the calibration procedure and to make it an obligation that a calibration procedure is used before, during or after the measurements.

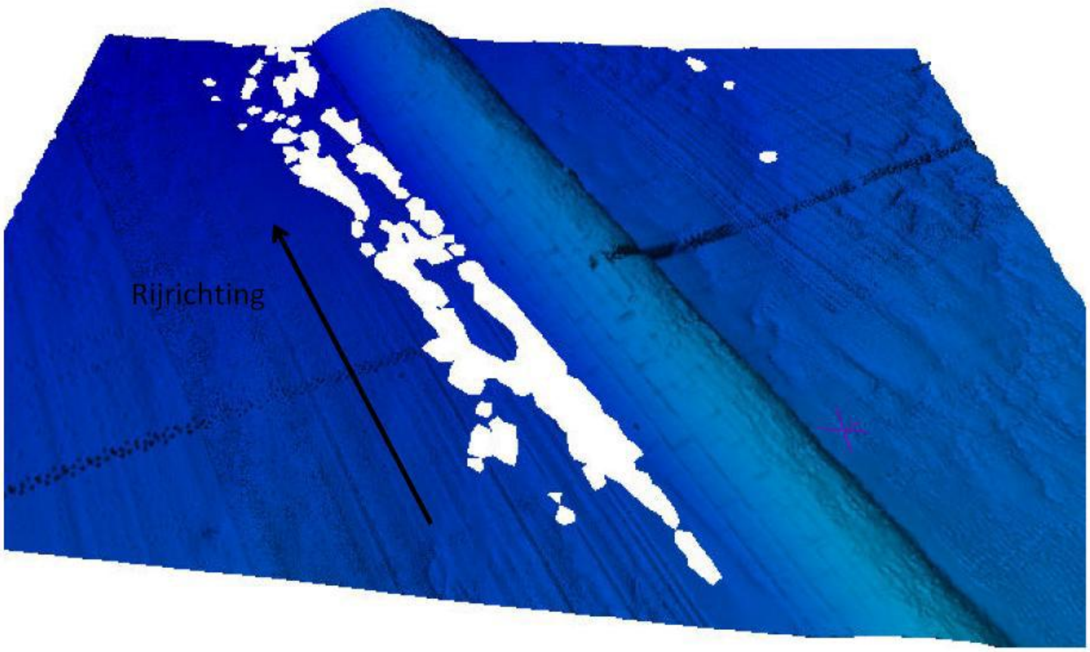


Figure 6: example of some 'raw' mobile LiDAR data where some banding in the elevation data is visible

3.6 Classification and filtering

In the tender requirements we 've demanded a classification of the LiDAR points in ground, points on water and non-ground points corresponding to LAS classes 2, 9 and 1 respectively. The purpose of this classification requirement is that we will obtain all the LiDAR data – also data points reflected on vegetation and buildings and other objects, but one can easily extract a DTM based on the points classified as ground. The classification makes it also easier for precise height models/profiles of the first dune/seawall for coastal sustainability studies. Because of the vegetation of the first (and other) dunes, a good classification is necessary to not overestimate the height of the seawall. The procedure to perform the classification by recursively filtering the data out by full waveform analysis and triangulation processes was in this study different for the different platforms.

For the airborne LiDAR, the classification is performed generally very well; only in very dense vegetation, problems arise when to little points reflect on the surface. An overestimation of the ground surface level is the consequence. Another problem is sometimes visible at the waterline where different flightstrips represent different water levels due to the tide. In this case, the classification of ground points and points of water at the waterline is incorrect if only one waterline is detected. To prevent these problems, classification algorithms at the waterline must be done flight strip by flight strip separately.

For the mobile LiDAR, the results of classification were not as good as the airborne LiDAR classification because the final classification step was done manually to filter out objects and vegetation. The lack of experience of the service provider in this matter had also an influence. But from a theoretical point of view, we expect also that classification algorithms on mobile LiDAR are much more difficult to implement because of the heterogeneous point distribution and the fact that larger gaps can occur by the oblique incidence angle on a horizontal scale.

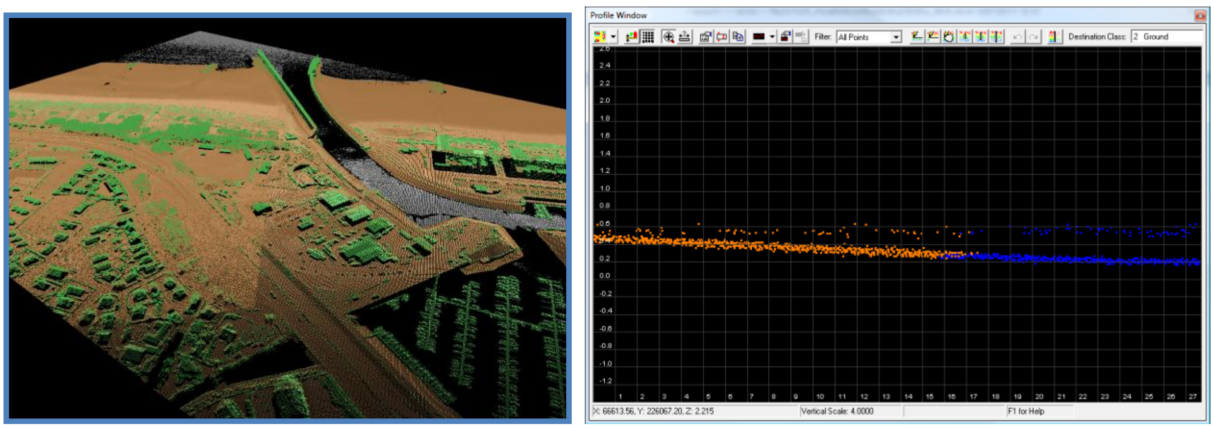


Figure 7: (left) example of the classification of the airborne LiDAR dataset with 1) ground points (brown), points on water (grey) and non-ground points (green); (right) example of a wrong classification at the level of the waterline with a local overestimation of the ground points

3.7 Covered area at 1 low tide event

The covered area at 1 low tide event is an important factor to know how much time will be spent for completion of a whole project. If project completion cannot be done in one or several days, it is important to know that project completion time is mostly limited by the few days in a month that the tide is favorable for capturing the low waterline. Because of the dynamic nature of the beaches and sand transports during the tides, LiDAR campaigns are preferable done in one tide frame.

In order to compare the covered area at 1 low tide event for the different platforms, we have made some premises:

- Time span of 1 low tide = maximum 4 hours
- Point density is at least 1 pts/m^2
- As much as possible homogeneous distributed
- No concessions on data quality

- 0.5 – 1 meter for the low water level

The empirical results from this study are not optimal to compare with each other even after extrapolation with some of the premises. Therefore we did some assumptions to have the most reasonable covered area at 1 tide frame. This is also only applicable on sandy beached where the accessibility is good enough for mobile LiDAR.

Airborne LiDAR

- Current situation: 34 km^2 in 2 h over 67 km beach
- Extrapolation: 75 km^2 in 4 h over 150 km beach
- Facts:
    - Long flight strips can cause drifting (maximum of 25 km)
    - Cross strips necessary
    - Only 2 hours for registration of low waterline

⇨ ***Reasonable*: 50 km² (100 km beach) at one tide frame**

Mobile LiDAR

- Current situation: 1.25 km^2 at 10 km/h over 8 drivelines in 4 h over 4 km beach and groynes
- Extrapolation:
    - 20 km/h and no groynes or other cross lines
    - 2 LiDAR scanners with 4 drivelines for beach swath of 300 - 400 meter

⇨ **5 km² in 4 h over 20 km beach**

- Facts:
    - multiple LiDAR scanners configuration for mobile platform is a preferable requirement for future tenders
    - no obligation for cross strips around groynes
    - speed can be set higher by lack of groynes or other obstacles(15 - 20 km/h)

⇨ **Reasonable: 3 km² (12 km beach) at one tide frame with 2 laserscanners and with obstacles (groynes)**

Static LiDAR

- Current situation: 0.3 km^2 in 1 tide frame
- Facts:
    - 25 - 30 minutes per locations
    - 10 locations at 1 tide

⇨ **Little margin for time win because of extra RTK–GPS measurements for georeferencing**

⇨ ***Not intended for large-scale projects***

From the above summed up facts, it is clear that for large scale projects that must be done in a tight tide frame, the airborne LiDAR is the only option. The mobile LiDAR platform will always have difficulties with the tide frame and with obstacles on the beach. There can be circumstances that mobile LiDAR measurements can be seriously facilitated (no groynes, small beach width and/or new hardware specs needing less drivelines) and can be applied for large scale projects, but it is better to be conservative when considering mobile LiDAR in large-scale projects.

3.8 Co(a)st effectiveness

To have a better insight in the processes and the workload and the price of each LiDAR method on different platforms, we did an inquiry to certain service providers to estimate the workloads for the total project from flight planning till post processing and delivering the data. The inquiry was only completed by 3 service providers and is not statistical relevant, but it gives some good indications. The inquiry was subdivided in following topics:

- Actions before survey (workload)
- Actions during survey (workload)
- Post processing (workload)
- Quality assessment & control
- Employability

Table 2: partial results from the inquiry with the total amount of workload for the different LiDAR platforms for a LiDAR survey during 1 low tide

Workload (hours)	Airborne	Mobile	Static
Pre Processing	18	9	1
During Survey	15	12	5
Post processing	60	40	20
Total	**93**	**61**	**26**

The costs of the workload is expressed in the amount of time per men per hour work for processing a LiDAR campaign during 1 low tide (4 hours of measurements). By comparing the airborne workload with the mobile, we can conclude that there is a factor of 1.5 in workload, but regarding the covered area of 1 low tide, there is a factor of 15 to 20. We can conclude that for larger project areas the workload cost for airborne LiDAR is much smaller than for the mobile LiDAR.

Table 3 gives a summation of the appreciation of different aspects in LiDAR monitoring of coastal projects for the 3 different platforms. The choice of the best suited platform can be deduced from this table. A general advice would be:

- For small ad hoc measurements: Static LiDAR
- For area-wide well prepared homogeneous datasets of the whole coastline (including dunes): Airborne LiDAR
- For local datasets of several km of easily accessible beach with less preparation time: Mobile LiDAR

Table 3: appreciation of the different aspects in LiDAR monitoring of coastal projects for the 3 different platforms.

Advantages/disadvantages	Airborne	Mobile	Static
Deployment	- -	+/-	+
Ease of use / flexibility	-	+/-	+
Involved people	-	+/-	+
High point density	-	+	+
Monitoring Cliffs	+/-	+ +	+
Coverage of dunes	+	-	+/-
Speed of data acquisition	+	+/-	--
Low water level line	+	+/-	-
Homogeneous dataset	+	-	--
Obstacles, groynes, tourists	+	-	-
LiDAR reflectivity	+	-	-

The co(a)st effectiveness of the different LiDAR platforms should also be addressed to the costs for obtaining the different LiDAR platforms and executing the measurements / processing the data yourself or to get data as a service from a service provider. The fact whether it is interesting for the concerned governmental agency to own their own LiDAR equipment and platform, is discussed:

Airborne LiDAR

- Huge costs for airplane and competent employees
- For most governmental agencies this is not beneficial
- If large governmental agencies who have already airplanes/helicopter, it could be interesting. Certainly if LiDAR measurements can be for multidisciplinary use (DTM/DSM generation, vegetation mapping, asset management, aerial photography …)

Mobile LiDAR

- A complete system can range from 50 000 up to 1 000 000 €

- For governmental agencies, it could be interesting if there is a large coastline, there are competent technical employees and if it is cost effective for the organization.
- Data results are often and quickly needed for infrastructure work and/or the mobile LiDAR can be used for the yearly monitoring of the beach instead of airborne LiDAR
- Take into account that hardware and software is quickly outdated and that a service provider can provide new, faster and better techniques

Static LiDAR

- Equipment can cost from 25 000 up to 150 000 (supplementary costs for software/training)
- It can be very interesting for fast local measurements for beach supplementation and infrastructure work or as a control tool
- Cost effective to purchase for most governmental agencies

Finally the co(a)st effectiveness can also play a role in tendering. If no other special requirements than obtaining a DEM of a relatively "flat" beach are mandatory, set the tender requirements platform independent and let the market play. More competition of service providers with different LiDAR platforms will make prices lower. From our experience, it is also beneficial to make a distinction between the mobilization cost (the cost of driving/flying out for 1 measurement of a whole project area at 1 tide) and the further cost/Ha (pre and post processing cost + data registration). In this way, the demanding authority has a better control on comparing the prices (especially If the tender is set platform independent), but it has also the advantage that it is easier to extend or reacquire the project area if working with variable quantities.

Table 4: indication of prices of mobile and airborne LiDAR when mobilization cost and cost/Ha are split

Platform	MOB	Cost/Ha (1pts/m^2)	Cost/Ha (5 pts/m^2)
Airborne	3000 - 8000 €	2.5 – 12 €	8 – 20 €
Mobile	1000 – 4000 €		6 – 40 €

4 CONCLUSIONS

Airborne LiDAR is the choice if:

- Large region-wide areas (> 5 km^2)
- Full coverage with undulating terrain / dunes / vegetated areas
- Homogeneous dataset
- Good overall accuracy

Mobile LiDAR is the choice if:

- Smaller areas – municipal size (< 10 km^2)
- Faster deployment
- Not too much obstacles (no dunes, best not in touristic season if it exists)
- Monitoring cliffs
- Very dense, (but more heterogeneous) point clouds
- Visualization of infrastructure
- Very good accuracy (mm to cm)

Static LiDAR is the choice if:

- Very small areas / beach sections (< 1 km^2) and/ or for small projects (infrastructure works)
- Fast deployment and flexibility with few involved people
- Price make it a consideration for purchasing
- Often additional need of RTK-GPS equipment for precise measurement

Other additional conclusions:

- LAS format is best format for LiDAR data (approved by the ISPRS) with integration of all the metadata in one file
- If mobile LiDAR is chosen platform, always demand an extra homogeneous thinned/filtered output at the required point density (e.g. 1 pts/m^2)
- Divide the maximum laser range on the product sheet for static and mobile LiDAR by 4 to estimate the practical point cloud range reflecting on flat terrain
- The costs for data storage management must be taken into account, especially for mobile LIDAR datasets
- Importance of a good filtering/classification algorithm at the first dune belt for coastal sustainability purposes, especially for mobile LiDAR
- Classification of water and ground at the low water level must be done flight strip by flight strip
- Data quality is not an issue in choice of the LiDAR platform

- Reasonable covered area in 1 low tide frame for airborne and mobile (2 scanners) are 50 km^2 and 3 - 5 km^2 respectively
- If no other special requirements than obtaining a DEM of a relatively "flat" beach are mandatory, set the tender requirements platform independent
- Split the mobilization cost and the cost/ha for data registration and processing in the inventory of a tender

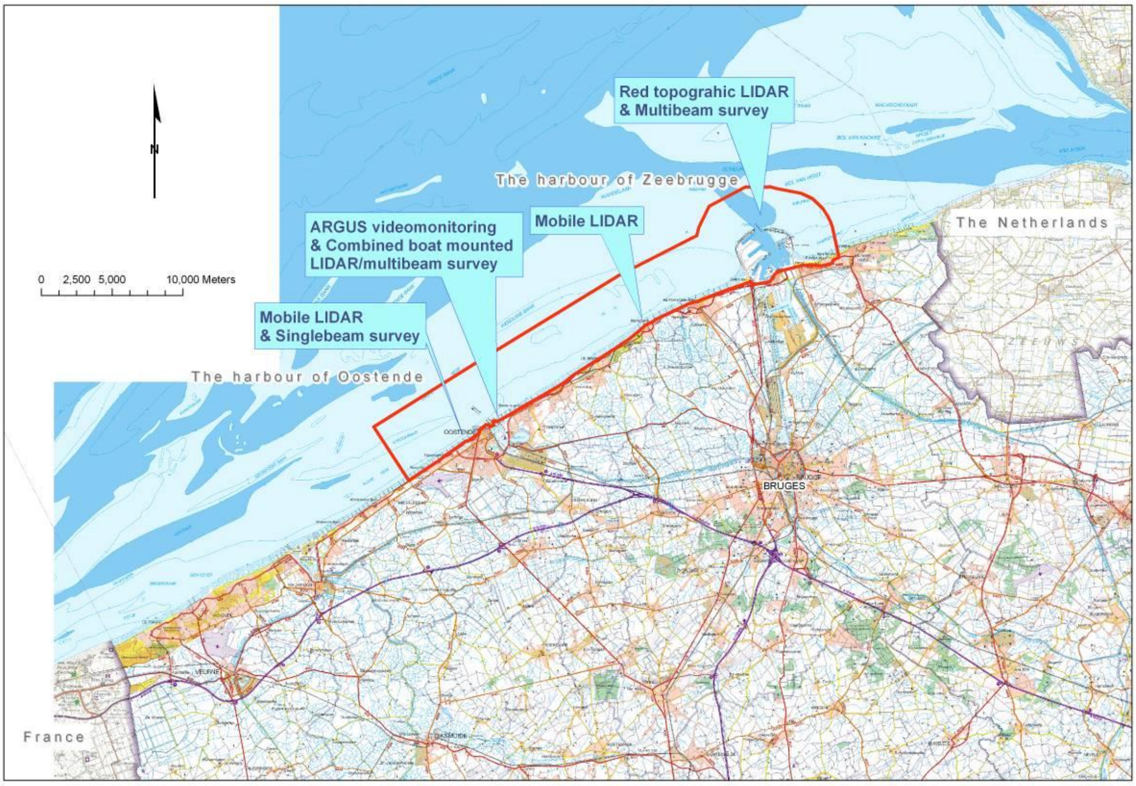
Norwegian Hydrographic Service • Aalborg University, Denmark
Agency for Maritime and Coastal Services, Belgien • Danish Coastal Authority, Denmark • Federal Maritime & Hydrographie Agency, Germany • Hjorring Municipality, Denmark • Jeppesen GmbH, Germany
Local Government, Denmark • Malardalen University, Sweden • National Space Institute, Denmark
National Survey and Cadastre, Denmark • Natural Environment Research Council, United Kingdom
Norwegian Coastal Administration • Seazone Solutions Limited, United Kingdom •T-Kartor AB, Sweden
TU Delfs, Netherland • UK Hydrographic Office, United Kingdom

Test Areas - Techniques

Partner organisation : Maritime and Coastal Services

Contact person: Annelies Geldhof, annelies.geldhof@mow.vlaanderen.be

Country and exact location of test area: Belgium, from Oostende to Zeebrugge



Description of Test Area	**Scope of the result**
The Belgian Coast has a rather short coastline, but it is an area with many actors (tourism, nature, ports, coastal safety,…). The test areas are chosen in favour of these interests. The old city of Ostend lies beneath sea level. At this moment 2 new jetties are built and there are several projects for coastal defence. At Wenduine there will be a sand nourishment taking place to improve coastal safety, while the port of Zeebrugge is a major traffic crossroad. Along the coastline lie several "NATURA 2000" areas.	* coastal defence (WP6): - morphological studies - coastal safety controls - design of inundation measures - maintenance (nourishment volumes) * 3D visualisation harbour (WP4) * support for land-sea integration (WP3)

Monitoring within BLAST:	
Used techniques (indicate method and platform):	○ Airborne red topographic LIDAR (coastline + port of Zeebrugge) ○ Waterborne combined multibeam + boat mounted LIDAR (Oostende) ○ Mobile LIDAR mounted on a car (Oostende & Wenduine) ○ ARGUS videomonitoring (Oostende) ○ Singlebeam surveys (Oostende & BNCP)
Output data:	ASCI XYZ LAS-files

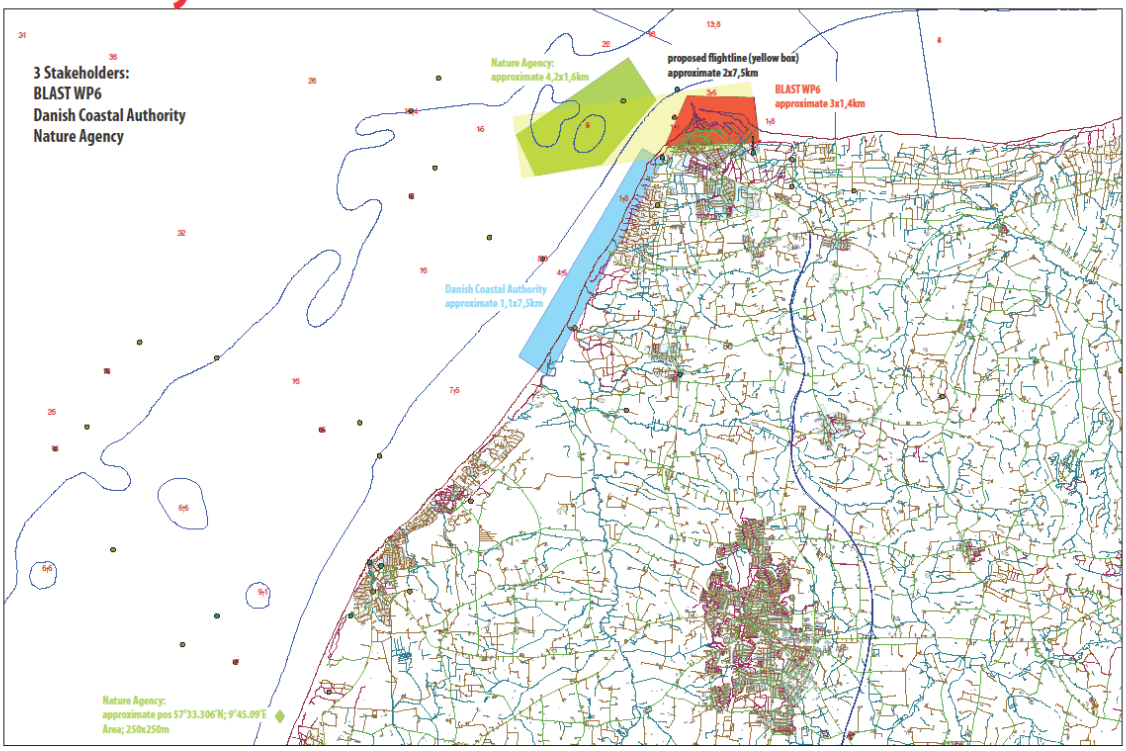
Test Areas - Techniques

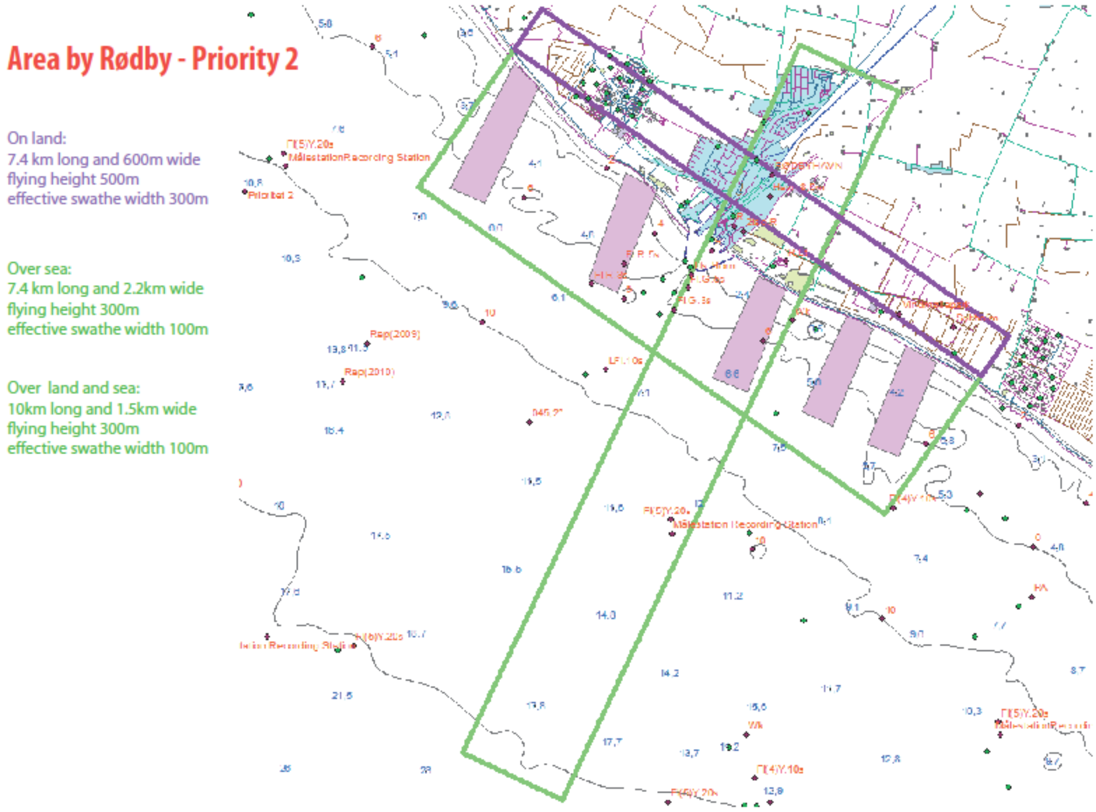
Partner organisation : National Survey and Cadaste, Denmark

Contact person: Rune Carbuhn Andersen, rca@kms.dk

Country and exact location of test area: Denmark – the coastal area around Hirtshals and Roedby

Area by Hirtshals





Description of Test Area	**Scope of the result**
Hirtshals: Dynamic sand area with a lot of sedimentation transports both at sea and on land. The area is exposed to strong westerly wind and sometimes big waves. It a flat, wide sand beach with inland vegetation covered dunes. The sea bottom is primarily sand with limited marine vegetation. Roedby: Typical Danish low land inshore area with dykes and a mix of coastal protection and small natural beach areas. The sedimentation transport is limited. The sea bottom is primarily sand covered with marine vegetation. The inland consists of both cultivated areas and flooding areas.	Investigation of the red-green LiDAR – the limitations, possibilities and functionality (WP3). Support for land-sea integration (WP3) Support for 3D visualisation (WP4) Support for coastal defence (WP6)

Monitoring within BLAST:	
Used techniques (indicate method and platform):	Airborne red-green LiDAR Multibeam for boat as reference data.
Output data:	Combined bathymetric model of sea bottom and elevation model of the land based coastal area. ASCI XYZ and LAS-files