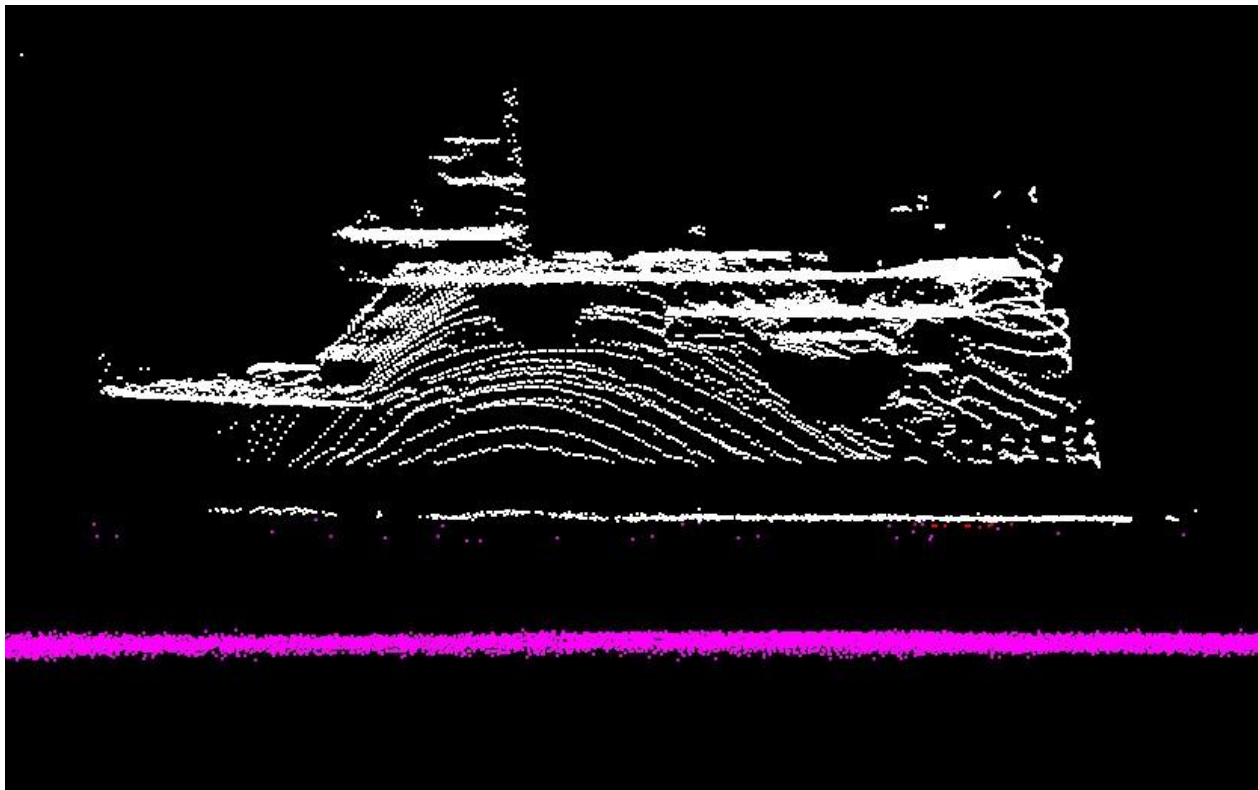


# Test of bathymetric LiDAR in Denmark

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## Introduction

Among its goals, BLAST seeks to explore new and innovative solutions to the management of coastal areas. A lack of accurate and up-to-date geographical information on shallow-water areas is among the obstacles to comprehensive and effective coastal management.

### **Growing interest in shallow-water areas**

Bathymetric surveys have traditionally relied upon the use of waterborne vessels. However, few of these vessels have a small enough draught to efficiently access or survey shallow-water areas. Historically, a lack of high accuracy survey data of shallow-water areas was less problematic; navigators couldn't access these areas anyway, so demand for detailed nautical charts of these areas was not pressing.

In recent decades, however, new uses of shallow-water areas have emerged. They have proven ideal for the development of offshore wind turbine capacity and the harvesting of natural resources. Further, the spectre of climate change and needs for environmental monitoring have increased the pressures on coastal zones the world over. As a result, interest in highly accurate depth information for the coastal region has grown precipitously.

### **Red-green laser surveying**

In BLAST, a number of new surveying techniques are being tested in various coastal regions. Among these is the testing of red-green laser technology as a future method of surveying shallow-water areas. By moving the surveying vessel from the water surface to the air, and conducting the survey from a low-flying airplane, the challenges of shallow water navigation can be bypassed.

BLAST's trial of red-green laser surveying was conducted in three locations with different characteristics – at a semi-protected area to the open Baltic Sea off the Danish island of Lolland in the region of Rødby, at a very unprotected area to the North Sea at the west coast of Denmark around Hirtshals and a well protected inshore area between Denmark and Germany in the Flensborg Fjord. Even before the survey started, however, it was already clear that, while red-green laser surveying may be the technology of the future, the climate and weather of the future may present constraints towards the use of the technology at all.

## Context

The main objective of the BLAST LiDAR test series is to investigate whether the LiDAR optics and geometry are fit for surveying North Sea coastal waters and more protected areas of the Danish coast with sufficient accuracy.

To the degree that such accuracy is not attainable, we aim to characterize the relative influence of the limiting factors, e.g. system maturity, ocean and atmospheric conditions, logistics etc.

Originally, the aim for the surveys was to bring land and sea together by combining the traditional multibeam survey and topographic LiDAR with the technology of red/green LiDAR to establish an integrated bathymetric and topographic model. This model was intended as a direct support for the aims for a number of the goals for the BLAST project:

- Support for land-sea integration (WP3)
- Support for 3D visualisation (WP4)
- Support for coastal defence (WP6)

The surveyors at the Danish Hydrographic Office have, for the purpose of analysing the red/green LiDAR survey, measured selected area of the test sites. On land, a nation-wide elevation model that was produced by traditional LiDAR 5 years ago was used as a reference frame.

As part of the BLAST project, there was an aim to share both the knowledge acquired in the project as well as the data collected from the red/green LiDAR survey from the different test sites. It is expected that the data will be used in both academic and other sectors.

## Pilot sites

At the launch of BLAST, the original plan was to survey two test sites – Rødby and Hirtshals. As a result of the many delays for the survey and the problematic environmental conditions of Hirtshals, the project decided to extend the number of test sites also to include Flensburg Fjord. The reason for choosing Flensburg Fjord was that the surveyors from the Danish Hydrographic Office, in cooperation with the German Hydrographic Office (BSH), were surveying Flensburg Fjord to the 6-meter depth contour from both the German and the Danish side. At the same time, both offices showed a great interest in examining new LiDAR technology.



**Figure 1: The 3 test sites**

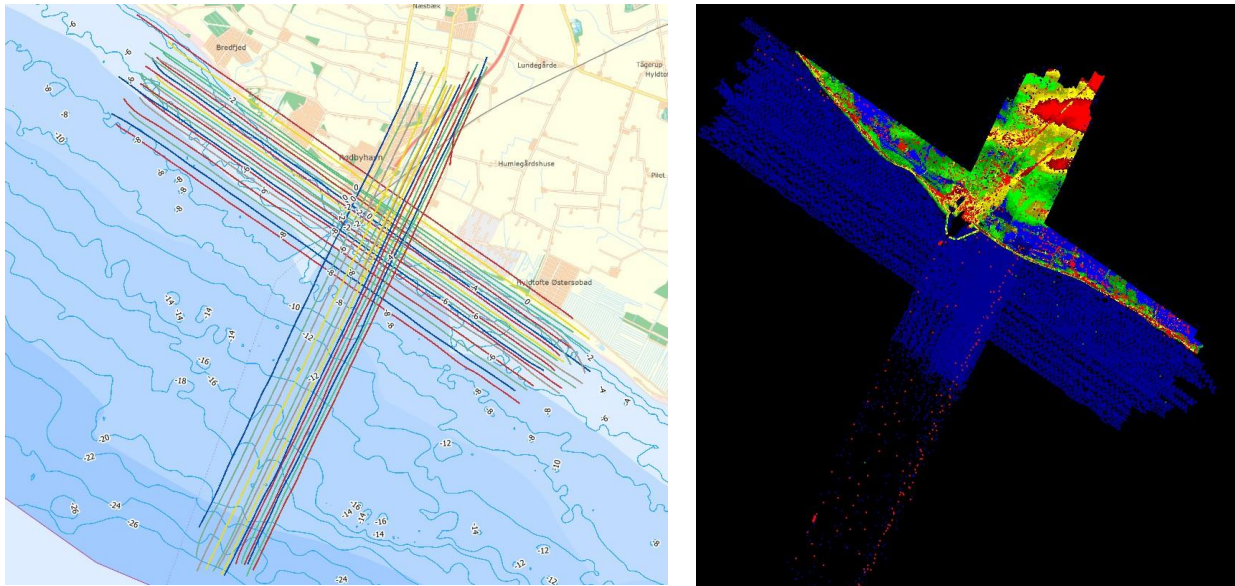
Test site A - Rødby

Test site B - Flensborg  
Fjord

Test site C - Hirtshals

## Rødby

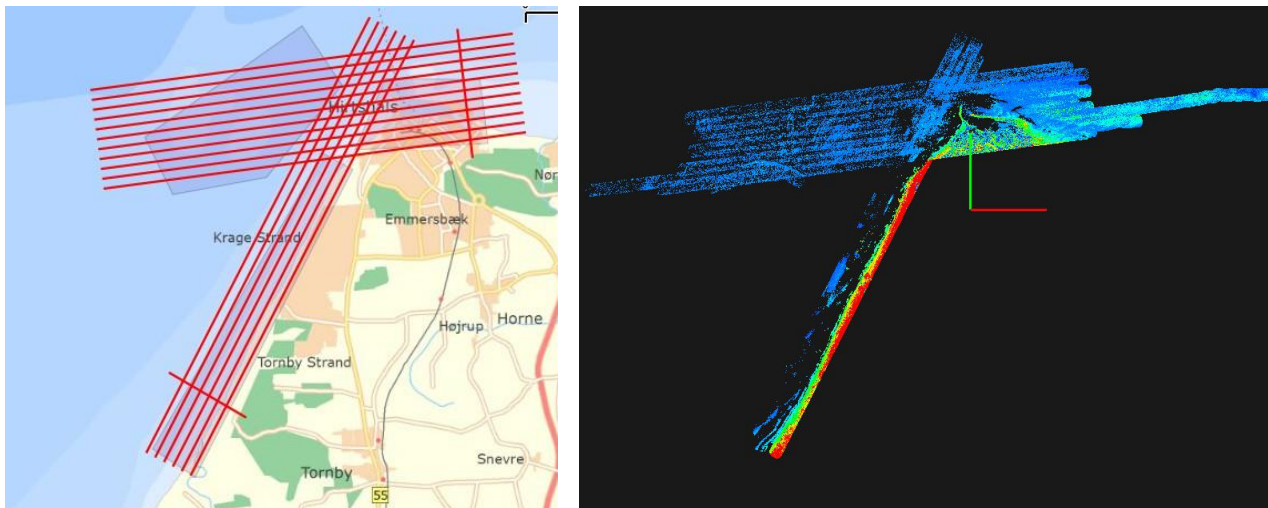
Typical Danish low-land inshore area with dykes and a mix of coastal protection and small natural beach areas. The sedimentation transport is limited. The sea bottom is primarily sand covered with marine vegetation. The inland consists of both cultivated areas and flooding areas.



**Figure 2: the flight lines and the survey results for Rødby**

## Hirtshals

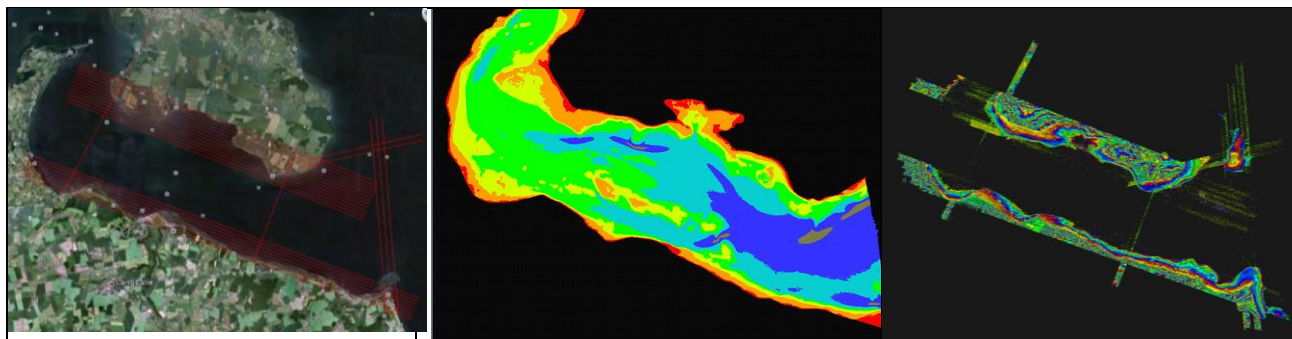
Dynamic sand area with a lot of sedimentation transport both at sea and on land. The area is exposed to strong westerly wind and occasional large waves. It a flat, wide sand beach with inland vegetation covered dunes. The sea bottom is primarily sand with limited marine vegetation.



**Figure 3: the planned flight lines and the survey result for Hirtshals**

## Flensburg Fjord

Well-protected Danish and German inshore area with natural protection and small natural beach areas. The sedimentation transport is limited. The sea bottom is primarily sand and clay covered with marine vegetation. The inland consists primarily of cultivated areas.



*Figure 3: the planned flight lines for Flensburg Fjord, the multibeam survey and the LiDAR survey result*

Subsequent to BLAST, KMS will continue to work with these data, with the intention of merging the multibeam (image 2), the bathymetric LiDAR (image 3) and the topographic LiDAR data to create a borderless elevation model that covers both land and sea.

## Process for collecting bathymetric LiDAR

Capturing topographic elevation models using LiDAR is a known, well-tested and well-documented technology used for mapping in Denmark on a national level. But using LiDAR for capturing bathymetric depth models is new and adds some extra challenges. As can be seen below, the project experienced several delays for the survey. The data from Hirtshals and Flensburg were received at the end of the BLAST project and will be examined subsequently.

Rødby	Hirtshals	Flensburg
April 2011 – Algae bloom	April 2011 – Algae bloom	July 2012 – Success
Juni 2011 – Technical issue	Juni 2011 – Technical issue	
February 2012 – Low clouds	February 2012 – Low clouds	
April 2012 - Success	April 2012 – Strong winds and waves	
	July 2012 – High turbidity	
	August 2012 – Partly Success (Chiroptera)	

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*Table illustrating the different attempts to survey the three test sites (Pelydryn, AHAB).*

The three surveys were all done using Hawkeye II except the final attempt in Hirsthals, which was conducted with the new scanner Chiroptera.

### Environmental challenge

LiDAR is measurement with light, but where light performs uniformly in the air, using light for measurement in water adds some extra optical interactions that need to be taken into account:

First, the laser beam changes its angle when passing the waters surface. This directly influences the accuracy of the measurements in both x, y and z, and is something that needs to be handled when processing the measurements. It is also something that needs to be tested to assess the impact on the measurements and specifically when mapping rocks and other obstacles below the surface.

Second, light passing through water is very susceptible to sand, algae or other contaminants in the water, thus influencing the visibility in the water. As a measure for visibility the term “secchi” is used, where one secchi is the maximum depth of which the human eye can make out a specific shape. LiDAR systems today work from one to about three secchi depths and in the BLAST trials, two different systems were used, one working around one secchi and one working up to three.

### Technical challenge

Bathymetric LiDAR systems have existed for many years, but do not seem to have fully matured for surveys under Danish conditions. The technology in several of the systems is still on a developmental level, which results in less stable systems. In combination with the short periods of good weather with low winds and calm and clear waters that are typical of the Danish climate, this makes for a very challenging mix.

### Commercial challenge

Today, there are not many systems in operation in the EU. This fact challenges the feasibility of large-scale mapping, but it also results in a higher price for mapping. However, looking at the number of systems in development, it is expected that bathymetric systems will see great improvement within the next few years.

### Challenges experienced

As the table above illustrates, the project experienced a wide variety of delays to the surveys. The primary source for delays consisted of environmental factors (cloud cover, strong winds and high waves). One of the more unusual delays was due to unseasonably pronounced blooms of *Chatonella* algae.

The first surveying flights over Lolland were timed for early spring 2011, late enough for frozen coastal waters to melt, and early enough to avoid the problems that green algae often present in the Danish waters once warmer weather has returned. Algae hampers

the laser surveying techniques from producing accurate results; the laser is either absorbed completely by the algae giving no usable return or, worse, reflected off the algae instead of the bottom surface, producing falsely shallow or entirely absent data readings.

While the survey planned for late April 2011 would otherwise have successfully fit into the window for ice- and green algae-free surveying, another unforeseen challenge arose: a sudden, massive brown algae bloom, which has not been observed in such quantities in Danish waters in a long time. Due to an unusually sudden shift from a long, very cold winter to unseasonably warm spring temperatures in mid-April, the brown *Chatonella* algae multiplied in the waters around Rødby, and most parts of the inshore waters of Denmark and the Baltic Sea, and reduced the visibility in the water to less than one metre. The red-green survey was consequently delayed until the *Chatonella* bloom had passed and settled, and accurate laser readings could be generated.

The challenges of the brown algae bloom have illustrated that, while red-green laser surveying likely produces more comprehensive, accurate survey results in low-water areas, atmospheric, weather and climate constraints can limit the performance of the technology.

## Results of the bathymetric LiDAR survey

In this section, results from the Rødby area are discussed.

### Point density and depth

On a flight line perpendicular to the shore, point densities on the seabed were measured. This was done to assess the depth at which the signal would become too weak to penetrate the water column and give a usable return from the seabed. Below is a chart showing the measurements:

Points per m2	Depth
0.20 ppm2	6.0 m
0.21 ppm2	7.5 m
0.22 ppm2	8.5 m
0.23 ppm2	9.0 m
0.19 ppm2	12.0 m
0.007 ppm2	13.0 m

As can be seen from the table, the depth of the water column does not seem to influence the amount of returns from the seabed until the depth becomes too great, at which point all returns are cut off. Looking at the point cloud, it is quite interesting how

suddenly the returns are cut off. It is unclear whether this phenomenon is related to the physics of the water or the electronics or algorithms in the system. The test does show that the equipment is well capable of achieving the required depth, and can be used for filling the gap between the coast and where the seabed is at a depth where ships can conduct surveys with multibeam equipment. However, this requires that the environmental conditions are permitting (clear water, ice free, calm surface etc.).

### Comparison of LiDAR data and digital land elevation model

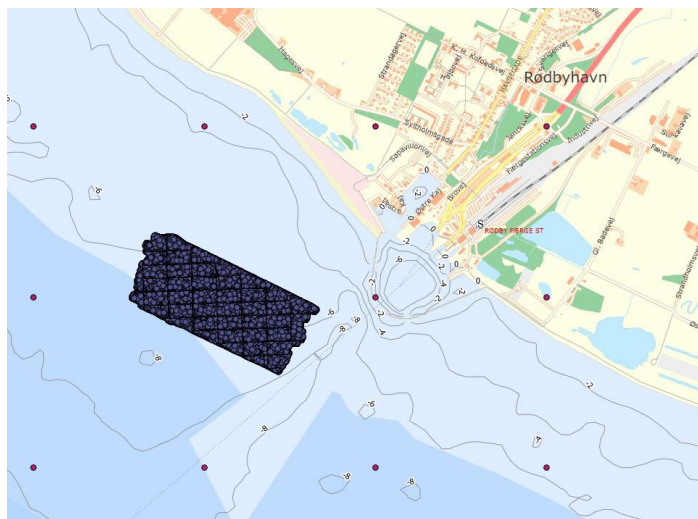
The LiDAR data acquired for land areas were compared to an existing digital elevation model of known statistical quality. This was done to achieve a reference from the LiDAR to a well-defined surface. The test was done on a flat horizontal surface covering an asphalted area of the harbour. This was done to establish the z quality. Gabled roofs were also measured for control of x and y coordinates.

The test on the flat horizontal surface showed a LiDAR data standard deviation of 12.2 cm, which is a little worse than expected, compared to our previous knowledge of red LiDAR for topographic mapping. On the other hand this might be expected given the characteristics of the test field. For the gabled roofs the LiDAR data was within 30cm of the data from the existing LiDAR measured elevation model, which is well within the expected accuracy. This shows that this setup is comparable with the standard LiDAR use for topographical mapping.

### Comparison of LiDAR and multibeam echo sounder data

Having established the reliability of the system based on the topographic part of the data, the next step was to evaluate the bathymetric measurements.

This next test was a comparison between a multibeam echo sounder and the bathymetric LiDAR data. For the test multibeam, echo-sounded points were compared to the LiDAR points classified as seabed. The test area was roughly half a square kilometre in area and contained some 400.000 multibeam points and roughly 170.000 LiDAR points. The depth of the water within the test field ranges from about 5m to about 9m.



As can be seen from the statistics, the standard deviation of 16 cm is not very much higher than the 12 cm achieved for land and is within the accuracy needed for using

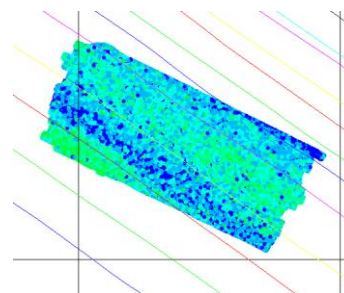
LiDAR for seabed surveying. This low standard deviation means that the LiDAR in fact traces the shape of the seabed.

422139	650656.380
422140	650538.515
422141	650538.378
422142	650519.916

Average dz	-0.545
Minimum dz	-1.830
Maximum dz	+1.080
Average magnitude	0.546
Root mean square	0.568
Std deviation	0.159

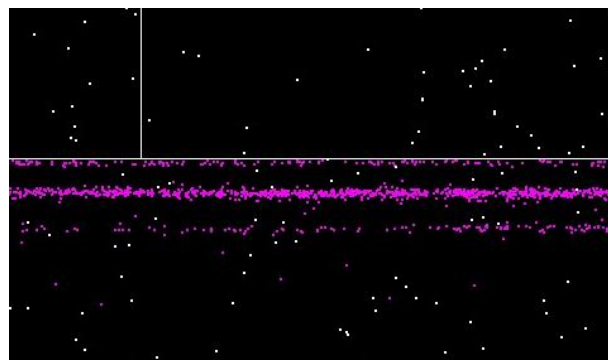
Looking at the layout of the differences between the multibeam and the LiDAR-measured model, some systematic behaviour can be seen. The difference in this case of over 0.5 m does not match the expectation of this technology, based on previous published results. This needs to be addressed in more detail to determine whether this

is a result of the seabed having changed in the time between the multibeam and LiDAR surveys, a result of the LiDAR technology, an artefact from the multibeam survey or just bad georeferencing in this test.



## Other findings

During the measurement of the point density, an odd artefact was seen in the point cloud. At the depth of about 12 m a “ghost” seabed at a depth of 7 m starts to appear growing stronger as the depth increases. At the depth of 13 m, only the “ghost” seabed is seen at a constant depth of 7 m. Within BLAST, we were not able to further investigate this phenomenon but will work on the assumption that it might be a result of a halocline.



## Conclusions

Since the surveys were completed so late in the project, it was not possible to evaluate the surveys in depth. At the time of writing, only the Rødby survey has been briefly reviewed, and a significant task lies ahead. But as seen the preliminary results reveal that the red/green LiDAR technology bears great potential to bridge the gap between land and sea. A very important issue that needs to be investigated is whether small objects can be adequately detected. This is crucial if these data are to be used for production of nautical charts.

Many unknowns still persist due to local environmental issues and the technology itself. The project members are confronting the challenges of being relatively early-adopters. The lure of new prospects in new technology makes moving forward into the “unknown” exciting. And as with any exploration, hurdles can’t always be foreseen – but they can usually be expected.

## Annex

Links to Pelydryn and AHAB and there specifications for equipment:

<http://www.pelydryn.co.uk>

<http://www.airbornehydrography.com/hawkeyeii>

<http://www.airbornehydrography.com/chiroptera>

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