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LASER SCANNING IN ARCTIC SEA ICE RESEARCH

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ABSTRACT

Development of offshore installations in ice covered areas requires knowledge of geometrical characteristics of above water parts of sea ice ridges and icebergs. A novel tool to attain this data is laser scanning. The quality, precision, speed and amount of data from laser scanning are much greater than that from traditional methods such as use of theodolite for reconstruction of surface morphology. This paper presents our experiences using the laser scanner Riegl VZ-1000 in sea ice research applications in the high arctic. The applications include data from ice ridges and icebergs. Focus is put on methods to extract useful information from the large amount of data collected. It includes description of ridge sail characteristics (orientation of ridge lines, their length, local width and height, sizes of ice blocks), calculation of icebergs volume. Possibilities to combine the geometrical data from the scans with temperature measurements are also discussed.

INTRODUCTION

With the increase of industrial activity in the arctic there is an increasing demand for data and knowledge about ice, ice ridges and icebergs. One possible powerful tool acquire large amount of geometrical data in this field is laser scanning. In this paper we evaluate the feasibility to use a laser scanner in sea ice research.

Laser scanning

Terrestrial 3D laser scanning is a fairly new powerful surveying tool. The laser scanner is capable of recording several millions of highly exact 3D points in a matter of minutes. The generated point clouds provide a significantly higher level of true geometric completeness and detail of the scanned site than traditional surveying tools and it has proven to be an effective tool in mining (Huber D. F., Vandapel N. 2003), surveying (Slob S., Hack R. et al., 2004) and archaeology (Ruther H., Chazan M. et al., 2009) among others. In arctic sea ice research 3D laser scanning have so far not been used (to the authors knowledge). The closest connection to earlier work is monitoring of glaciers where laser scanners have been utilized with success (Schwalbe E., Maas H-G., 2008, Bauer A., Paar G., et al., 2003). We believe that the 3D laser scanning can be a useful tool in the arctic sea ice research. Both as a replacement in tasks previously performed with traditional methods but also as a tool for attaining data previously hard or impossible to record. An example of the former would be reconstruction of surface topography of ice ridges which previously has been done using theodolite. For this task the scanner should both be faster and provide much more data than the traditional method. Coastal sea ice and its tidal movements is another area where the scanner should be more efficient and precise tool than methods previously used. An example for the latter is detailed 3D mapping of the part above waterline of icebergs.

Riegl VZ-1000

The terrestrial laser scanner used for the measurements was a Riegl VZ-1000 which is part of Riegls V-line 3D Terrestrial Laser Scanners. It uses a narrow infrared pulsed laser beam in conjunction with fast rotating multi-facet polygonal mirror to acquire fast and precise laser ranging. The pulse repetition rate (PRR) can be set in five steps between 70 and 300 kHz which determines maximum range and the measurement rate (1400m for 70 kHz and 450m for 300 kHz). The Riegl VZ-1000 incorporates On-line Waveform Processing together with time of flight measurements to be able to detect and process multiple echoes from the same direction, which means complex structures, fences, wires and vegetation can be handled. The minimum measurement distance is 1.5m. Accuracy (conformity with actual value) is reported to be 8mm and precision (degree to which further measurements show same results) 5mm (RIEGL VZ-1000 datasheet, 2011). A high-resolution, full-frame, calibrated Nikon D700 is used to automatically acquire RGB images for natural colouring of the point clouds and textures during post-processing.

PERFORMANCE IN THE ARCTIC

The field data presented in this article was recorded on and around Svalbard. As the laser scanner is not specifically designed and had not previously been used under the sometimes harsh weather conditions in the high arctic much of the first field season was used to determine its feasibility. The supplier specifies the operating temperature to 0°C up to 40°C and storage temperature to -10°C up to 50°C (Riegl, 2011, 3D Terrestrial Laser Scanner Riegl VZ-1000 Technical Data).

On Svalbard the normal mean of transportation is snow scooter. To fulfil the minimum storage temperature of the scanner while being transported a large insulated aluminium box heated by car seat heater powered by a car battery was used. This proved sufficient for all our excursions, keeping the scanner temperature above 0°C, during the field season of 2012. This was however a fairly mild winter on Svalbard with temperature rarely going below -20°C.
Once started the internal electronics and moving parts of the scanner provided enough heat to keep it well above 0°C in all our measurements. It was used without problems for shorter periods (less than 1h) down to -20°C and was kept running continuously for six hours in -15°C with quite strong winds (keeping an internal temperature of around 9°C).

The scanner relies on diffuse reflection from the target to receive a signal back to be able to calculate the position of the surface hit. As clear ice has a high specular reflectiveness and little light is diffusely reflected the laser scanner does not work well on it. If a signal is received or not depend heavily on the angle of incidence but also on how clear the ice is and the roughness of its surface. As such the application of the scanner on ice is limited. No systematic trials have been made but we have test where the scanner was able to generate data from a glacier front with reasonable efficiency up to 500 meters away. However areas with clear ice will be missing from the data set. With sea ice the situation is a bit better as the ice is usually covered by snow which reflects a larger part of the light diffusely than ice, although still not a very large part. The problem while scanning sea ice is rather the angle of incidence which if scanning from the sea ice itself (which is usually best since if no land is present and any other scanning position will probably have some motion relative to the sea ice) tend to get very large since the scanner is located only between 1 and 3 meters above the sea ice surface. This greatly limits the range for scanning and usual ranges for our scans are 200 to 400 meters.

The terrestrial laser scanners are mainly made to scan stationary objects and even slowly moving objects can prove problematic for precise and long range scanning where it can take up to an hour for a single scan to complete. As an example 360° scans of the sea ice in Sveabukta in Van Mijenfjorden on Svalbard with duration of approximately 30 minutes clearly shows a discrepancy between the start and end data of the scan as a result of tidal movement during that time period. This means the data in the entire scan is a little bit warp do to the tidal motions, however probably not enough to cause problems in most application. Another complication is when scanning from a non-stationary position as for example a ship as then, depending on the speed of the motion, the warping of the data can be rather substantial. Another limiting factor for scanning is precipitation. While the scanner can still be operated in light snow the snowflakes will cause spurious data points. These will usually have to be removed by hand in post processing, which is rather working intense depending a bit on the application. In heavier snowfall or rain scanning is not recommended.

APPLICATIONS

Ice ridges

The mapping of the surface topography of ice ridges have traditionally been done using theodolite (see e.g. Shafrova and Høyland, 2008) and to some extent imaging. The laser scanner can provide much more data of higher quality in a much shorter time. The idea is that geometric information such as ridge orientation, length, local width and height of sail as well as quantifying the surface morphology would be possible from the 3D point clouds attained.
Below an example of scanning data and possible analysis can be seen. The example is of an ice ridge in the Fram Strait made in September 2012 using three separate scans.

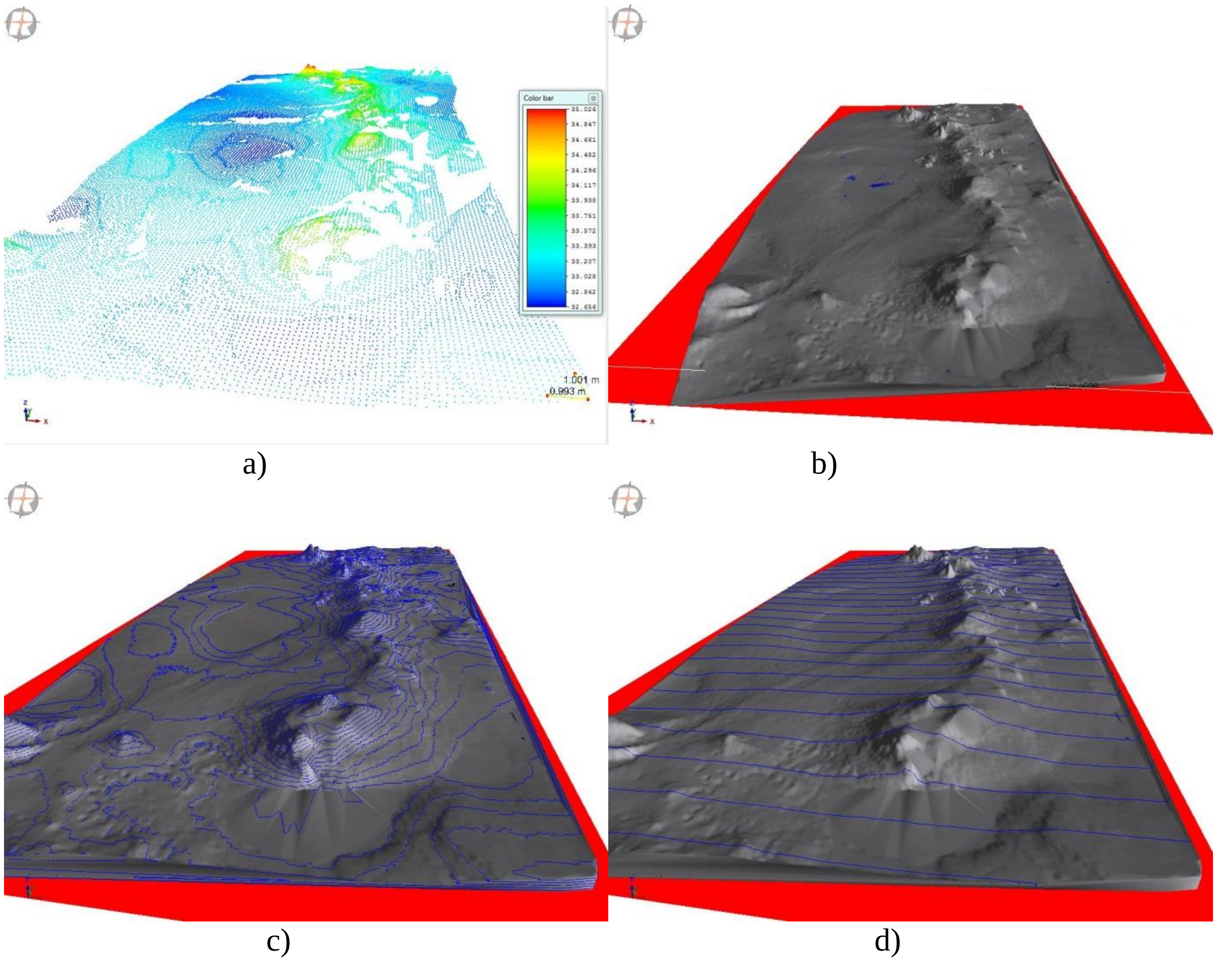


Figure 1. Example of data from an ice ridge in the Fram Strait.
a) Point cloud after merging three scans, colour by height with scale from 32.6 to 35.0m above an horizontal plane at arbitrary height, b) Flat horizontal plane and triangulation of the point cloud in the direction perpendicular to the plane, c) Added contour lines of the height with distance 0.1 m, d) Cross sections of the triangulation with distance 2m in a direction perpendicular to the ridge.

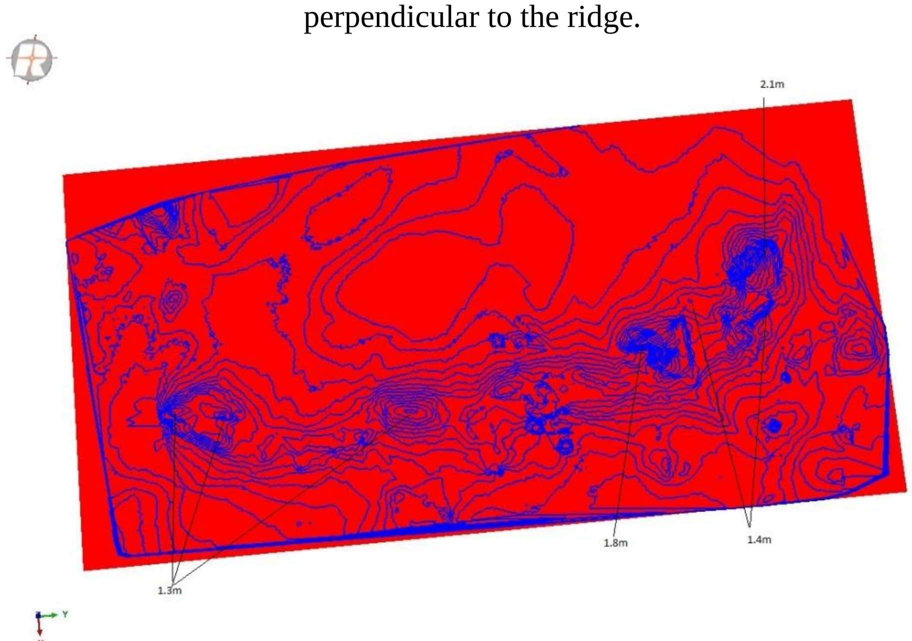
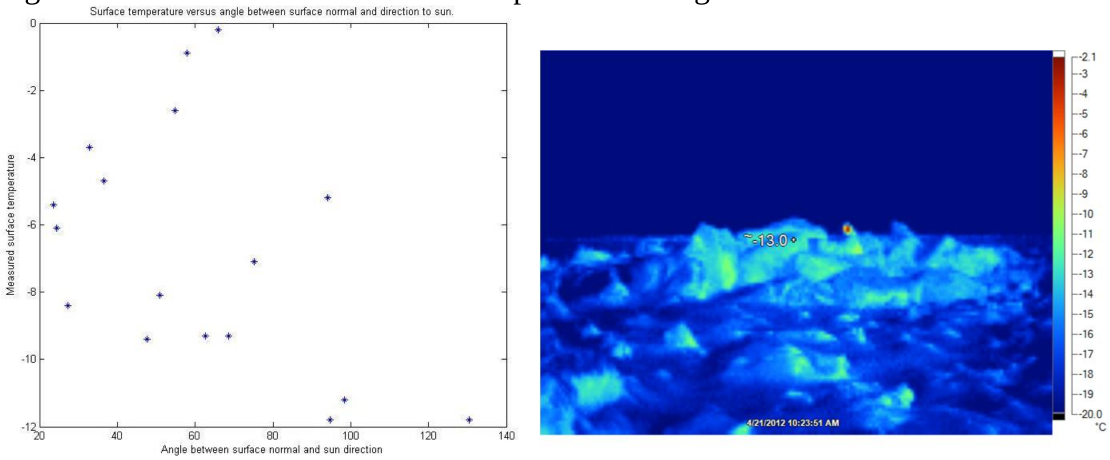


Figure 2. Top view of the contours lines of the ridge in Figure 1 with added height information of the highest points measured from lowest point in scan.

The amount of work of attaining a full 3D point cloud of an ice ridge by laser scanning depends on the surface structure of the sail of the ridge. A sail containing more rubble or large blocks will pose a much more challenging scenario than a more smooth sail with less rubble. The reason is that large blocks and rubble in general tend to block the line of sight of other parts of the sail making it hard to record the entire surface structure by a reasonable number of scans. While an older ridge with a smooth sail might only need two scans, from opposite sides, to completely catch its entire structure a younger ridge with more rubble might require many more and even then it might be hard to catch all the patches in the middle of the ridge because of blocked line of sight. The size of blocks in a ridge can be estimated in the point clouds but it needs to be done by hand since no automated algorithm for that exists. This is rather time consuming and if it is possible it is probably faster to do it in the field.

The geometrics of the scans could potentially have other application. We tried combining the 3D point clouds with handmade measurements of surface temperature at different points of the ridge in the Barents Sea. The 3D point cloud was then used to create planes/patches locally at the measuring points. The normal vector of these patches was then compared to the angle of the sun at that time. The air temperature during the measurements was -10.5°C.



a) b)

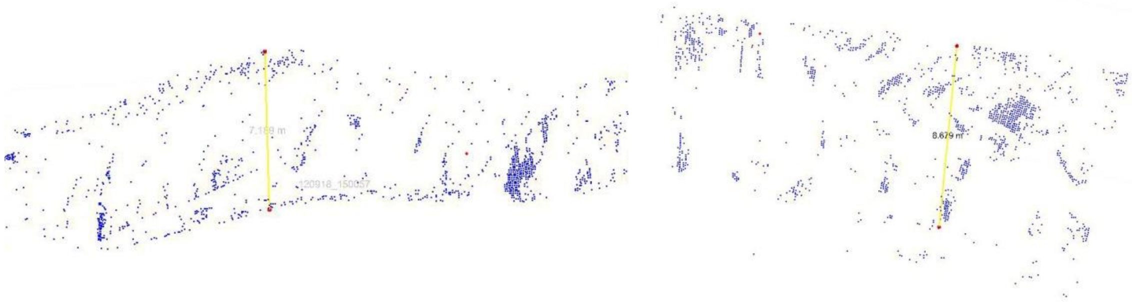
Figure 3. a) Ice ridge surface temperature (°C) versus angle between surface normal and direction of sun(°). b) IR image of the ice ridge.

As can be seen the results are not very conclusive but with some good will a surface temperature decrease with higher angles can be seen. Better precision for the temperature measurement and the colocation of the measuring spot between field and point cloud (in this case done by using photos taken while measuring and subsequently locating the spot in the point cloud) would be necessary for conclusive results.

Icebergs

Two instances of scanning of tabular iceberg were performed during the SAMCoT ODEN research cruise to the Fram Strait in September 2012. The first iceberg had quite icy surfaces especially on the sides and it was therefore problematic to get good scanning data from it. The pulse repetition rate was tried on both 150 kHz and 300 kHz (max range 350 and 500 m respectively) to determine if it had any effect on the quality of the data. The reason to test the two highest pulse repetition rate was to limit the impact of the fact that the scanning was done from aboard a ship. This meant that fast data recording was important to limit the effect of heave, pitch and forward motion of the ship as well as motion of the iceberg itself on the quality of the scans.

Figure 4. Pictures of the first iceberg.



a) b)

Figure 5. Two scans of iceberg 1. In a) PRR is set to 150 kHz and in b) to 300 kHz. Angular resolution is 0.04° and approx. distance to iceberg edge 130 m
Estimated height of iceberg from scans 6.7 m in a) resp. 8.7 m in b).

Only the side of the iceberg were visible in the scans. This is most probably a result of the angle of incidence being smaller when hitting the side than the top since the top of the iceberg was snowier and should therefore have better diffusive reflection properties. The wave pattern that can be seen in the left picture of figure 5a is a result ship heave. From these scans it’s not totally clear how PRR affects the results but the left 150 kHz scan seems to contain a little more points which indicates that using lower PRR might provide more data.

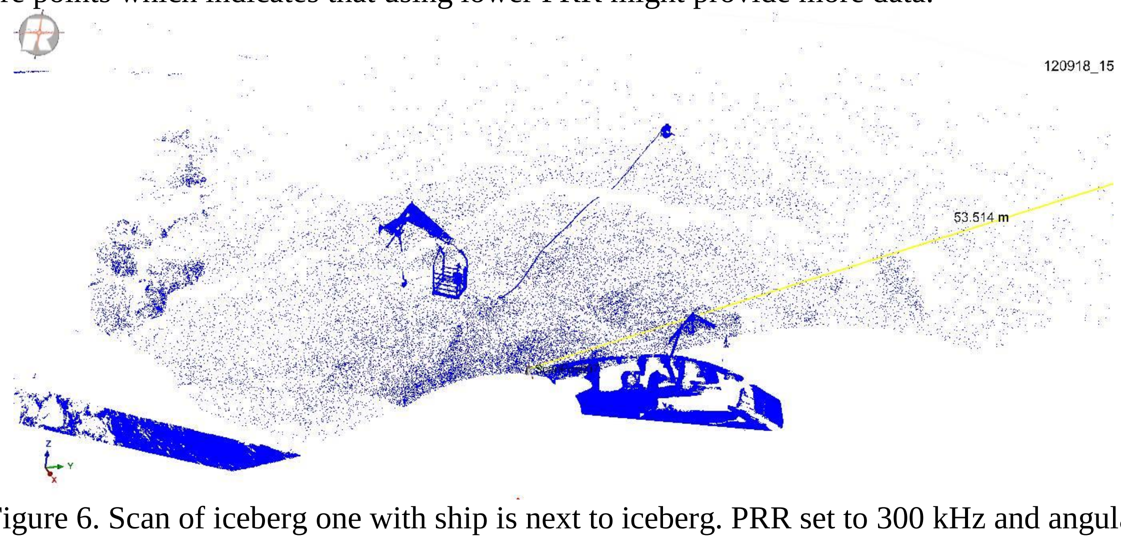


Figure 6. Scan of iceberg one with ship is next to iceberg. PRR set to 300 kHz and angular resolution to 0.04°

The above scan was taken when Oden was located just beside the iceberg while a tracking buoy was deployed on its surface. It is a clear example of the difference in the reflective properties of iceberg surface (snow and ice) and clothes, a rope and parts of the ship. The ice berg shows only sporadic points while the other is clearly depicted. To the lower left it can also be seen that turbulent water shows up in scans in contrast to calm water.

The scans of the second iceberg were done while the ship was at almost standstill at different positions around the iceberg. The distance to the iceberg was between 100 and 200m and the settings for all the scans taken were PRR set to 70 kHz and angular resolution of 0.05°. The reason behind these settings were the experience with iceberg 1 described above.

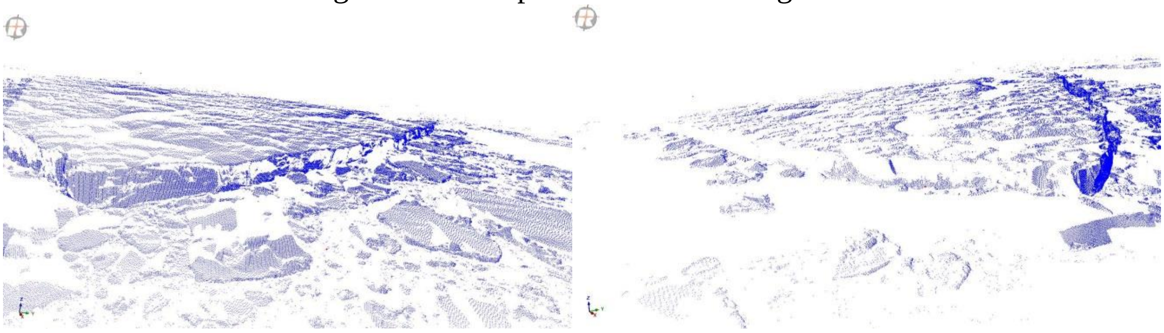


Figure 7. Two sides of iceberg 2 from the same scan. PRR set to 70 kHz and angular resolution to 0.05°.

The results of the second iceberg were much more promising. This is probably a result of the combination of a less icy surface of the iceberg and a lower PRR setting for the scanner. The scans where made during short stops under which the captain of the ship tried to keep is as still and steady as possible. Much less deformation of the scans due to heave can be seen. However even though the ship was supposed to be at stand still during these scans the warping due to ship and/or iceberg motion is still clearly visible. An example of the effect this can have can be seen in figure 8 where two different scans of the same iceberg have been overlaid.

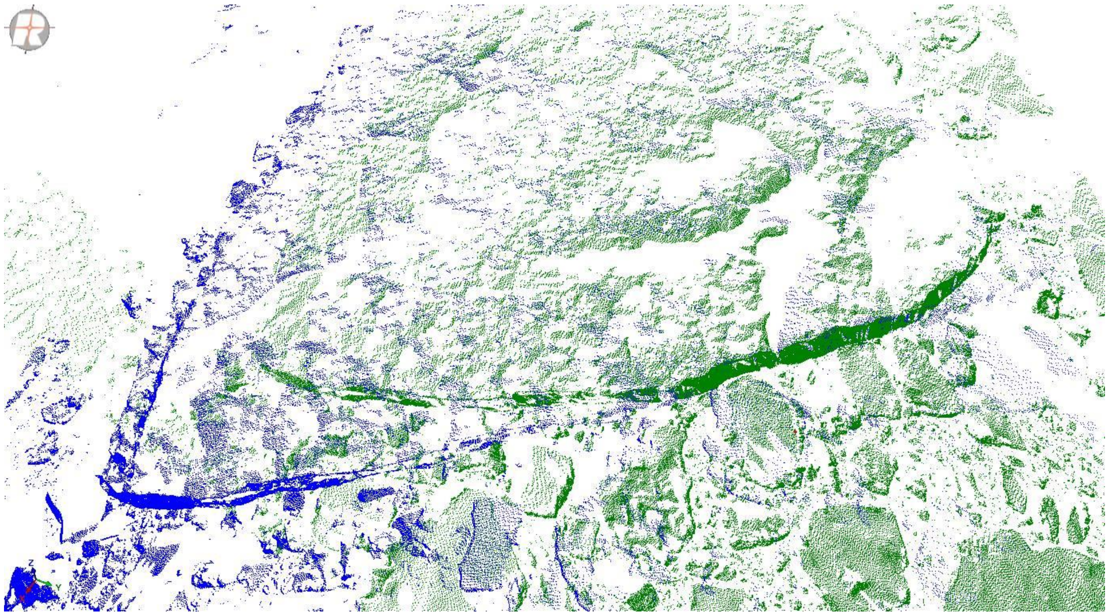
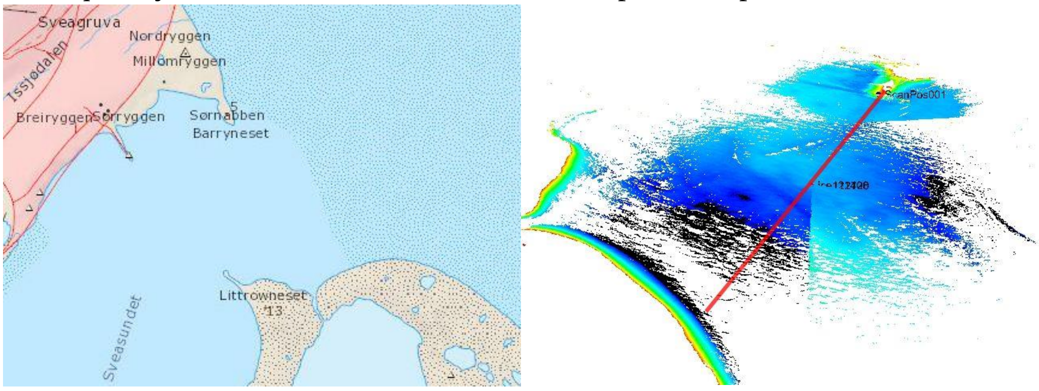


Figure 8. Two different scans, in blue and green, of the same side iceberg 2 registered/overlaid on each other based on the points on the side of ice berg to the right. The warping is an effect of the motion of the vessel and iceberg while scanning.

Coastal sea ice

Coastal sea ice is of increasing interest because of its effect of coastal structures. One potential important factor is the ice movements relative to the shoreline due to tide. A common research site on Svalbard in this field is Barryneset in Sveasundet in Sveabukten of Van Mijen Fjord (Caline, F., and Barrault, S., 2008). During March 2012 the laser scanner was used to survey the ice movements during a cycle from low to high tide by placing it on top of a cabin overlooking Sveasundet. Originally there was hope to record the entirety of the about 800 m wide inlet. However the range of the scanner when operated on a flat ice surface proved limited, in this case to about 200 m. A scan was made every half hour from approximately low to high tide, in total 11 scans were made. The next day three additional scans were made from the ice in the middle of the inlet. The scans from the ice were subsequently matched with cabin scans in attempt to complete the data set.



a) b)

Figure 9. a) Map of Barrynest in Sveasundet.
b) Scanning data coloured by height. ScanPos001 to the upper right is the cabin Ice122400 in middle is scan position on the ice.

RESULTS AND DISCUSSION

Ice ridges

As expected the laser scanner is an efficient tool to attain the surface topography of ice ridges. It can in some cases when the ice ridge contains a lot of large blocks be challenging to catch its entire structure but usually it’s no problem. The challenge is rather how to use the data. Volume measurement of the part of the ridge above the waterline is rather straightforward to do if freeboard is known at one position and the area in which the volume should be calculated is known or can be defined.

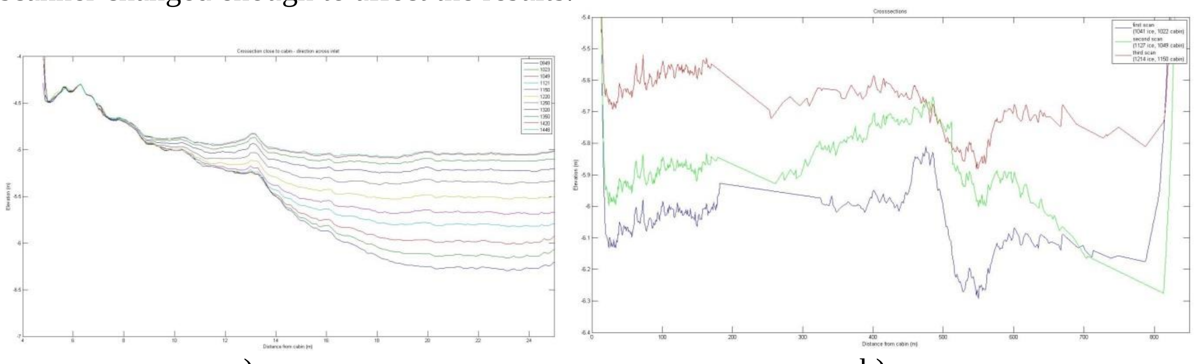
Integration with data of the structure of the ridge below the waterline seems vital for above waterline data to be of any significant use. Possible such data can be drilling or EM-antenna measurement of the ice thickness but also mechanical properties of ice samples could be related to the site of the sample on the ridge. For more extensive surveys of ice ridges laser scanning could be used to create statistics over the size, height and width of sail as well as major direction of ridge and possible more.

Icebergs

These first scans shows that laser scanning can indeed be used on icebergs. However there are a number of different complications. First of all the quality of the results depend heavily on how ice the surface of the iceberg is which depending on the iciness limits both the range at which the iceberg can be scanned and the number of points recorded. It is possible there exists icebergs that are not possible to scan at all but it's also quite possible there are others that will respond better than the ones presented here.

Another major limitation is the scanning from the deck of a ship which greatly degrades and warps the data because of motion. This can however, at least partly, be solved by connecting the scanner to an inertial measurement unit (IMU) (Böder V., Kersten T. P., 2011) which we hope to try in the future. However this still leaves the motion of the iceberg itself. This is much harder to get around and could potentially be a source of major degradation in case the iceberg is moving or rotating a substantial amount in the time frame it takes to make a scan (usually somewhere around 10 to 30 min).
One of the reasons it's interesting to scan iceberg is the potential to estimate the size of the part of the iceberg above the waterline which could then be used to estimate the total mass.
In our two cases it was not possible to find enough common data in the scans of the different sides of the iceberg to put them together into a full 3D model. This was mainly due to the warping effect of scanning from a moving vessel. However the estimation of freeboard of the iceberg is quite straight forward in the scans and for the second iceberg a scan catching the entirety of two sides together with the fact that the iceberg had rectangular shape could be used to get a very rough estimate. Free board between 6.5 and 9 m (at different points of the sides) and two sides of around 260m each gives an estimate of between 440000 and 640000 m^3.

Coastal sea ice
Although the range was limited a lot of data was recorded for the ice closest to the shoreline. The so called hinge zone or active zone is easy to survey in this manner. In figure 10a an example of cross section showing the motion of the ice in the hinge zone can be seen. The hinge movement are apparent with the ice furthest away from cabin first starting to move upwards with the ice closer to cabin joining the motion a bit later. Cross sections of the entire inlet were also made by combining scans from the cabin scans with the scans from the ice. The scans from the ice proved somewhat troublesome. The scanner was placed on a small ridge (can be seen in middle of bottom profile in figure 10b) caused by beaching of the ice on an underwater ridge. This ridge shape during scanning and therefore the direction of the scanner changed enough to affect the results.



a) b)

Figure 10. a) Cross-sectional results made from scanning data showing the movement of the ice in hinge zone from low to high tide. Elevation(m) on Y-axis and distance from cabin(m) on X-axis. b) Cross section of entire inlet. Elevation(m) on Y-axis and distance from cabin(m) on X-axis.

CONCLUSIONS

The feasibility of using a 3D laser scanner in an efficient manner in sea ice research has been investigated with mostly positive results. The scanner can handle arctic conditions as long as the temperature of the scanner can be kept above freezing. The range is somewhat limited on snow and ice but with knowledge and planning this can mostly be overcome. Care need to be taken that the scanner is sufficiently at still standing during scanning. Best is to scan from a totally fixed position which usually means land therefore it should be an ideal tool to study coastal sea ice. Scanning from the sea ice itself is also possible as long as no changes in ice surface shape occur. When scanning from ship a connection to an IMU is necessary for precise measurements.

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