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Robin Berglund

Using Drones in icebreaker operations in the Baltic Sea – a demonstration

Finnish Transport and Communications Agency

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FOREWORD

In this report no 113, the Winter Navigation Research Board presents the results of the demonstration of three types of instruments to monitor the ice channel and level ice in the vicinity of the icebreaker. The real-time information about the ice conditions is essential for the icebreakers when planning operations.

The DronePilot project can be seen as a continuation to the DronIce study and it focuses on trials in real conditions to gain more experience in utilizing UAS technology in icebreaking operations.

The Winter Navigation Research Board warmly thanks Mr. Robin Berglund for this report.

Helsinki and Norrköping

June 2020

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RESEARCH REPORT

VTT-R-00413-20

Using Drones in icebreaker operations in the Baltic Sea - a demonstration

Authors: Robin Berglund

Confidentiality: Public

Date: 4th June 2020

VTT

About photo on the cover page: Icebreaker ATLE parked in the ice. A drone is seen in the lower left corner of the image. Photo: R. Berglund

Report's title	
Using drones in icebreaker operations in the Baltic Sea – a demonstration	
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Summary

Real-time information about the ice conditions is essential for the icebreakers when planning icebreaking operations. The availability of near-real-time synthetic aperture microwave radar satellite images have largely replaced the helicopters as means for obtaining ice information in a cost-effective way. Today, the development of Unmanned Aircraft Systems utilizing Unmanned Aircraft Vessels or Drones has made aircraft reconnaissance less costly. The question is – how could the state-of-the-art in UAS technology and new types of sensors, power sources, automation and communication be utilized in icebreaking operations. In the previous DronIce feasibility study these themes were elaborated. One conclusion was that trials are needed to gain experience in practise. The DronePilot project can be seen as a continuation to the DronIce feasibility study, now focussing on trials in real conditions.

The demonstration, conducted from the Swedish icebreaker ATLE on 13 – 17 March 2020 south of Karlsborg in the Bay of Bothnia, successfully tested three types of instruments to monitor the ice channel and level ice in the vicinity of the icebreaker. The instruments were LiDAR, thermal camera and a high-resolution optical camera. The images obtained showed that the condition of the channel could indeed be easily interpreted by an experienced icebreaker officer. To be really useful, there are several issues still that have to be solved. The drone should be able to safely take off and land on the ship, the wind tolerance should be better and the flying range should be several kilometres – i.e. flights beyond visual line-of-sight or on a higher altitude than the present limit of 120 m. Operating drones requires trained personnel on board. This could be a secondary role for the navigation officers, thus not requiring a full-time additional person. The personnel arrangements would still need elaboration, and a feasible solution may look different in Finland and in Sweden.

Confidentiality	Public

Espoo 5.6.2020

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Preface

The DronePilot demonstration project, funded by the Swedish – Finnish Winter Navigation Research Board (Project number: W20-2 DronePilot), was conducted in spring 2020.

The project is a follow-up of the feasibility study DronIce performed the year before. The demonstration focussed on gaining practical experiences under real winter conditions in the Bay of Bothnia utilising drones and advanced sensors.

Drones could provide valuable information for real time ice monitoring in situations where the icebreaker is supervising the traffic and has the responsibility to guide ships through the ice field. Especially navigating through, or finding a channel inlet, can be difficult for a ship without icebreaker guidance. A drone could then be used to obtain reliable information about the condition and exact coordinates of a channel inlet without going on site with the icebreaker, saving both time and fuel.

The trials demonstrated very clearly the requirements that the system should be robust and resilient regarding the disturbances that prevail in the vicinity of a large ship hull causing magnetic disturbances for the autopilot on the drone. Also the weather conditions and low light during the first winter months do pose a challenge making operations too risky, thus reducing the time window when drones can be operated.

On the other hand - both LiDAR and thermal images can provide the users with relevant information independent of ambient light conditions. Ideally, the system should include functionality to obtain the images in real time, but if not possible, then preferably within 30 minutes of return of the drone to the ship.

The project was implemented by a team lead by Robin Berglund from VTT Technical Research Centre of Finland. The team members were Patrik Raski from Eastern Post Oy/Avartek ky and Juri Klusak and Julian Teege from Orthodrone GmbH.

The project has been supervised by a Steering Group consisting of the following members:

Lauri Kuuliala, Finnish Transport and Communications Agency
Markus Karjalainen, Finnish Transport Infrastructure Agency
Tomas Årnell, Swedish Maritime Administration
Stefan Eriksson, Swedish Transport Agency
Anne Lönnqvist, VTT
Robin Berglund, VTT, secretary

The comments and guidance of the Steering Group is greatly acknowledged. I want to thank Tomas Årnell from Swedish Maritime Administration for arranging the trial on board icebreaker ATLE and especially captain Karl Herlin and his crew for hosting us on the icebreaker for several days in the beautiful wintry archipelago between Luleå and Karlsborg. I also want to thank our subcontractors Patrik Raski from AVARTEK ky and Juri Klusak and Julian Teege from Orthodrone GmbH for providing the sensors, drone, operating the drone in a safe manner and doing the processing of the data.

Espoo 5.6.2020

Robin Berglund

Contents

1. Introduction

The focus of the pilot trial, called DronePilot, was to gain experience of using different sensors from a drone in winter conditions typical in icebreaker operations. The trials were a continuation to the feasibility study, DronIce, reported in [1]. The pilot trial focussed on the practical aspects of using drones from an icebreaker, the capabilities of different sensors and the usability of the information that drones could provide.

The trial was conducted by a team consisting of Patrik Raski from Avartek ky, Juri Klusak and Julian Teege from Orthodrone GmbH and Robin Berglund from VTT.

The report describes the sensors used and the characteristics of the drone itself. For each sensor type, the results are described in the form of image examples.

A discussion with the users is reported and finally ideas on how to proceed are presented.

Limitations

The trials were conducted during a very mild winter. All arrangements were done to conduct the trials on board a Swedish icebreaker and on Swedish territory, therefore changing the area to the Finnish side with more severe ice conditions, was not an option. The sparse traffic, however, enabled more time to be allocated for the trials that had to be done from the surface of the ice because of safety reasons. Thus data was not obtained from ice ridges. Also, the drone pilot liability insurance conditions limited the trials to favourable weather and light circumstances prohibiting flights during three of the five days allocated for the trials.

2. Definitions

The most important acronyms and terms used in the report are listed below:

BVLOS	Beyond Visual line-of-sight
Drone	a synonym to a UAV
IMU	Inertial Measurement Unit. An inertial measurement unit (IMU) is an electronic device that measures a body's specific force, angular rate, and sometimes the orientation of the body, using a combination of accelerometers, gyroscopes, and sometimes magnetometers. (Wikipedia)
LiDAR	Light Detection And Ranging, an instrument that sends out laser pulses with a high pulse repetition frequency and measures the time between light transmission and reception of the backscattered pulse. Using mechanisms such as rotating prisms, the light beam is deflected and the environment scanned to obtain a 3D point cloud that can be processed into a digital elevation model.
Orthomosaic	An orthomosaic is a photogrammetrically orthorectified image product mosaicked from an image collection, where the geometric distortion has been corrected and the imagery has been color balanced to produce a seamless mosaic dataset.
SAR	Synthetic Aperture Radar OR Search And Rescue (depends on context)

UAS	Unmanned Aircraft System. The system consists of the UAV, a ground-based controller and a system of communications between these two
UAV	Unmanned Aerial Vehicle, commonly known as a drone, is an aircraft without a human pilot aboard. An UAV is the “flying” part of an UAS. In this report “UAV” and “Drone” are used as synonyms.

3. Review of the research questions

When initiating the pilot trial, several research questions were defined. The following table is a summary of the results with respect to these questions.

Table 1 Research questions

Question	How	Result (within this project)
How well can the channel ice conditions be estimated from a Drone?	By flying over the ice channel before in situ verification. The in situ verification can be done by going with the icebreaker to the location where the conditions have been observed OR by observing the performance of a vessel passing through that area.	A number of examples have been obtained using optical, thermal cameras and LiDAR scanning. The evaluation has been done by experienced users knowing the conditions. Quantitative indicators have, however, not been defined nor obtained
How usable are the optical/thermal images	Take pictures with both an optical and a thermal camera and compare. Do this during different light conditions.	Visual comparison has been done, but in good light conditions only. Even better results would be expected in low light conditions.
How useful is a LiDAR sensor and the images obtained	Fly over a channel and scan with a LiDAR, then process the image	LiDAR examples show the capabilities, but also that presently, postprocessing is computationally intensive and takes time
Is the stereo image useful?	Obtain picture pairs and process these into a stereo image, evaluate the result visually	No examples of this were obtained. It is possible, however, to generate such images synthetically afterwards, if needed.
How does the Drone manage in the prevailing environmental conditions?	Try flying in cold conditions, windy conditions and in low light conditions. (This is up to the evaluation of the drone pilot)	The liability insurance conditions prohibited trials in adverse weather conditions. The main problems in this trial were: magnetic interference (much

		because of wrong parameter settings in the Autopilot), strong wind gusts and cold conditions causing a need for extra warming equipment to keep the drone warm before flight.
How should the images be processed to help the interpretation?	Process images in different ways – show to the users	Some processing examples were prepared and shown in this report. A systematic evaluation of different processing algorithms is left for future research.
To what extent can a low cost drone be used?	Try using a low-cost drone in low light conditions, cold conditions, but also in good conditions. Obtain images and analyse these	A DJI Mavic 2 Pro with a 20 Mpix camera was tried in good weather conditions. Ease of use, good picture quality could make this kind of drone a useful device. The drone could also be used for examining equipment high up in a mast or for documenting conditions of a ship to be assisted
What are the possible savings ?	Figure out use cases and quantify cost and savings	No new numbers compared to preliminary figures, have been elaborated. The previous assumptions are still valid. The main savings come from reduced fuel consumption in situations where the icebreaker can guide a ship or ensure that the conditions are OK for an approaching ship without going with the icebreaker on-site. Pre-evaluation of a planned route in the ice field is another use case.
What improvements are needed to remove obstacles for operational use	Analyse trials with the professional icebreaker officers.	- improved resilience to magnetic interference to enable take-off and landing from/on the icebreaker deck - improved cold resistance - training of officers

		- higher degree of automation and autonomy of the drone - integration of the obtained geocoded images into operational systems (like IBNet) - AIS transponder on the drone - a basic set of tools to quantify channel width and ridge heights from the drone
What are the risks when operating a drone?	Identify risks and mitigation actions	- ground risks: collision with ship hull, masts and superstructure. Mitigation: trained pilots, proximity detectors, tested system for local positioning when landing and take-off - Risk to people: mitigated by minimizing number of people on deck when operating the drone - air risks: equip drone with ADS-B transponder and (for autonomous flights) Detect and avoid instruments. Obey regulations
What are the next steps	Sketch a Roadmap and discuss with the experts	The process is rather iterative by its nature, therefore it is difficult to lay out any long term plans within this project

4. Description of the trials

The trials were conducted on the ice outside of Karlsborg in Sweden from 13th to 16th of April 2020. During the 4-day trial period, two days enabled successful operations with the drone because of favourable weather and traffic conditions permitting the icebreaker to stay “parked” in the fast ice and not engaged in assisting activities. During the other days the wind was too strong, and snowfall prohibited flights within the permitted limits agreed upon in the liability insurance of the drone pilot.

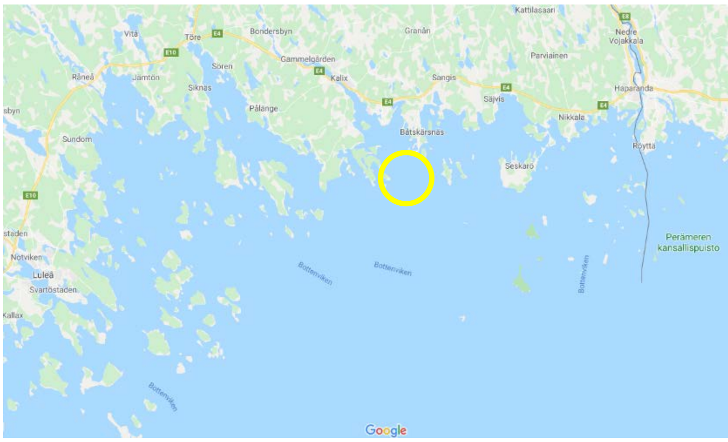

Figure 1 Trial areas

Table 2 Summary of trial days

Date	**Position of icebreaker**	**Weather and ice conditions**	**Focus of the trial**
14.3.2020	65° 41 ’40” N 23° 27’ 36” E	Sunny, < 10 m/s gusts. Fast ice, ca 40 cm ice thickness, a few cm of snow on the ice. - 4 to -5 °C	LiDAR trials
16.3.2020	65° 43’ 33” N 23° 24’ 13” E	Sunny, < 10 m/s gusts. Fast ice, ca 40 cm ice thickness, a few cm of snow on the ice. -3 to -1 °C	Thermal camera, High resolution camera

Figure 2 Overview of the trial area, view to the North. 14th March

Figure 3 Overview 16.3.2020 Latitude: 65.7° N, longitude: 23.4° E, Camera altitude: 115 m

Figure 4 Close-up of a piece of ice, 40 cm thick.

The ice situation was as shown in the satellite picture below (from IBNet)

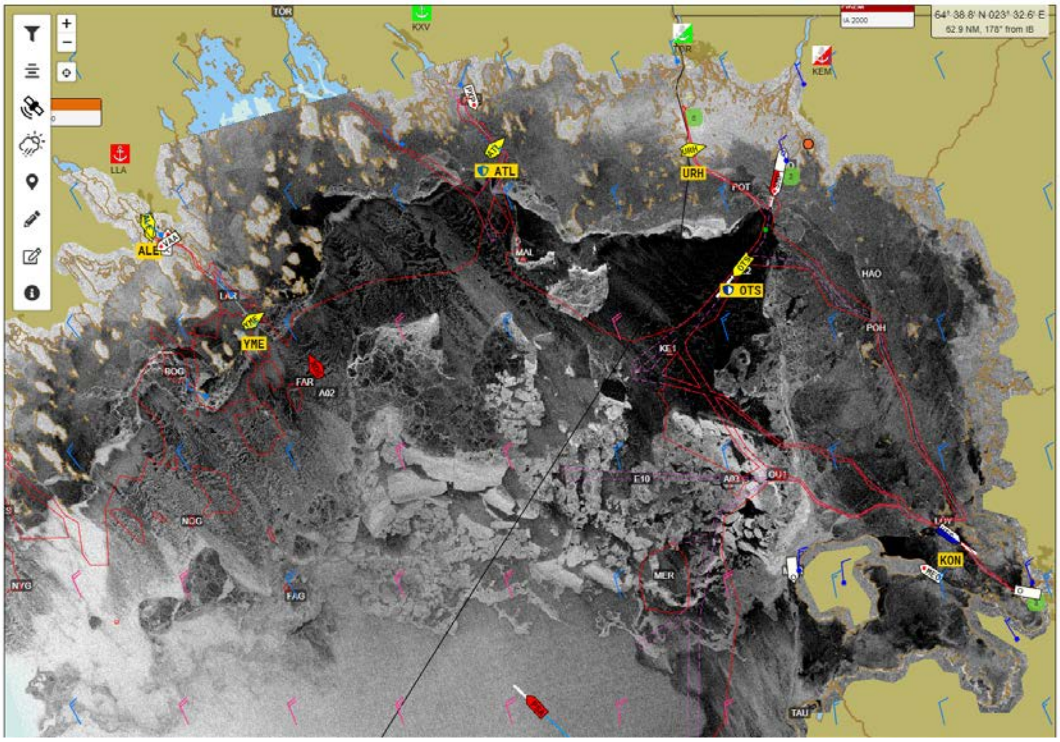

Figure 5 Ice situation in the morning 13.3.2020. Sentinel-1 image shown on IBNet terminal. Atle shown as a symbol ATL

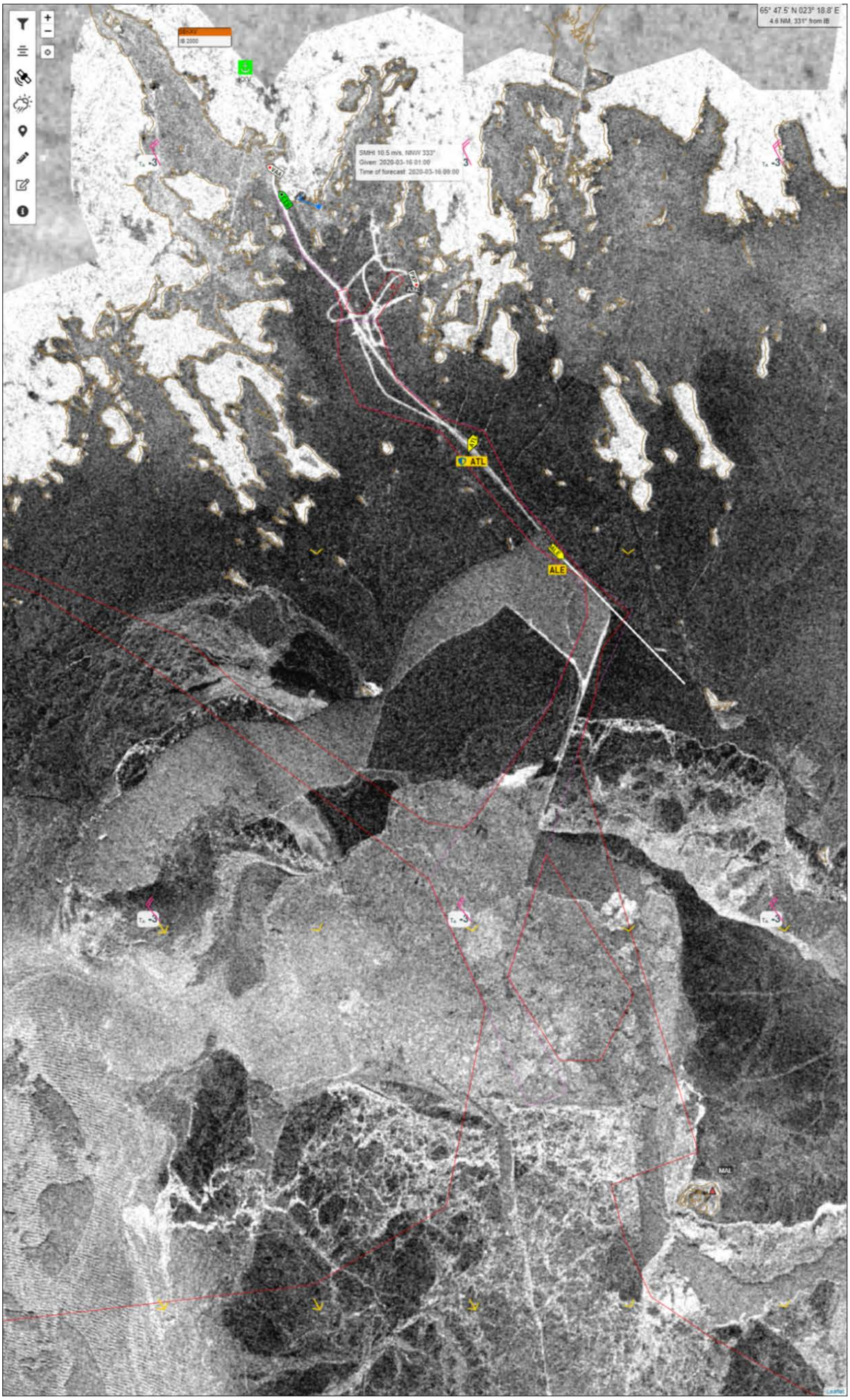

Figure 6 Ice situation on Monday 16.3. ATLE is shown north of icebreaker ALE, who is moving SE (approximately in the position of the trials of 14.3). A large ice floe is drifting southwards and an area of open water has opened north of the floe

The ice charts

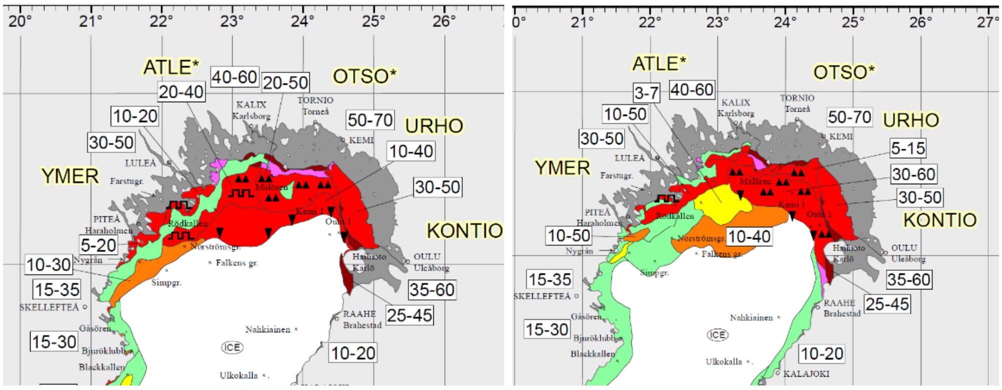

Figure 7 Ice charts from 13th and 16th of March (from SMHI)

4.1 The Drone

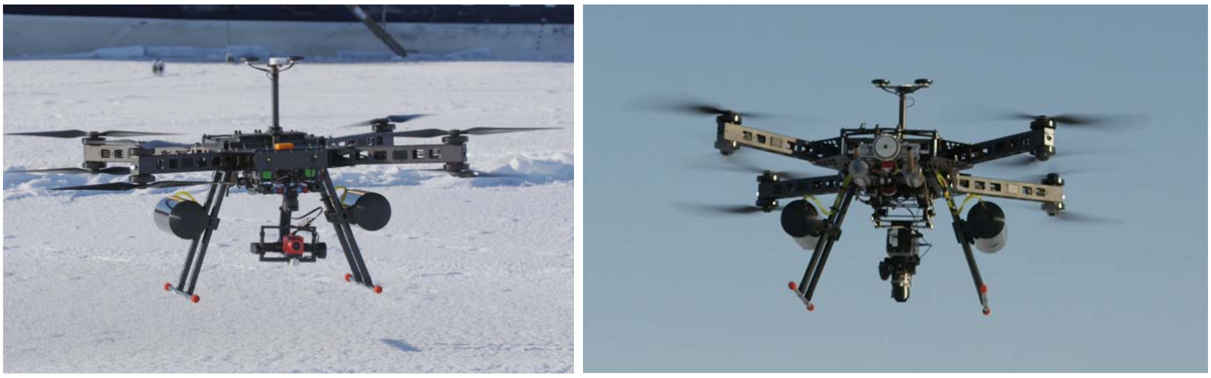

Figure 8 The AVARTEK Boxer hybrid drone.

The drone used in the trials was an AVARTEK Boxer Hybrid drone, which is a combustion engine /electric hybrid drone with 8 electric motors. The electronics is built using Arducopter 4.0.1 firmware with a hexCUBE flight controller.

The drone can carry payloads with a total weight of up to 5 kg. The sensors are controlled by a control computer that has its own communication link to the ground station.

The length and width of the drone is 1050 mm (1750 mm with propellers). The height is 800 mm and the maximum take-off mass is 24.9 kg.

The operating time is typically 2 hours or more.
Budgetary price (payload not included): 50 - 70 k€

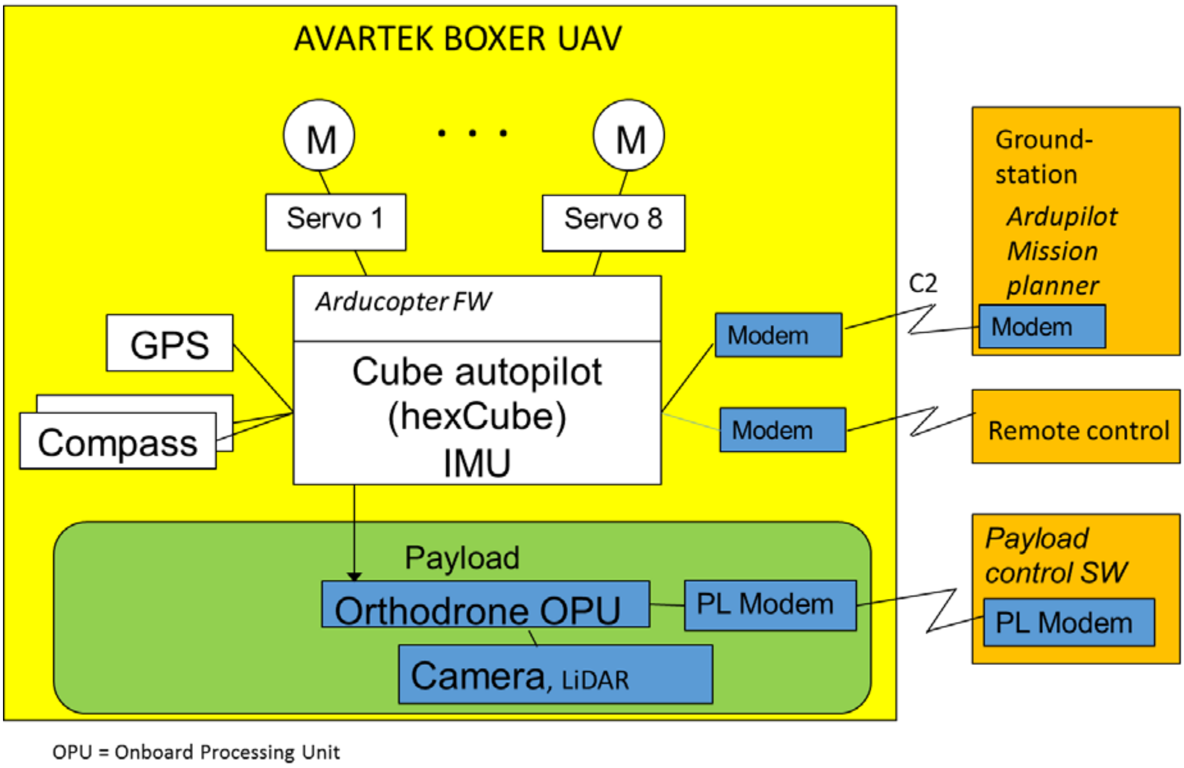

Figure 9 Building blocks of the AVARTEK Boxer Hybrid drone

4.2 LiDAR

The LiDAR used in the trial was a RIEGL miniVUX 1UAV [2]. The LiDAR has the following specifications:

Laser pulse repetition rate	100 kHz
Typical operating flight altitude (natural targets rho > 20%)	100 m
Accuracy	15 mm
Precision	10 mm
Max effective measurement rate	100 000 measurements/s
Wavelength	Near IR (905 nm)
Laser beam footprint	160 mm x 50 mm @ 100 m
Temperature range	-10 °C up to +40 °C (operation)
Budgetary price	150 – 180 k€

Figure 10 RIEGL miniVUX-1UAV with APX-20 UAV IMU

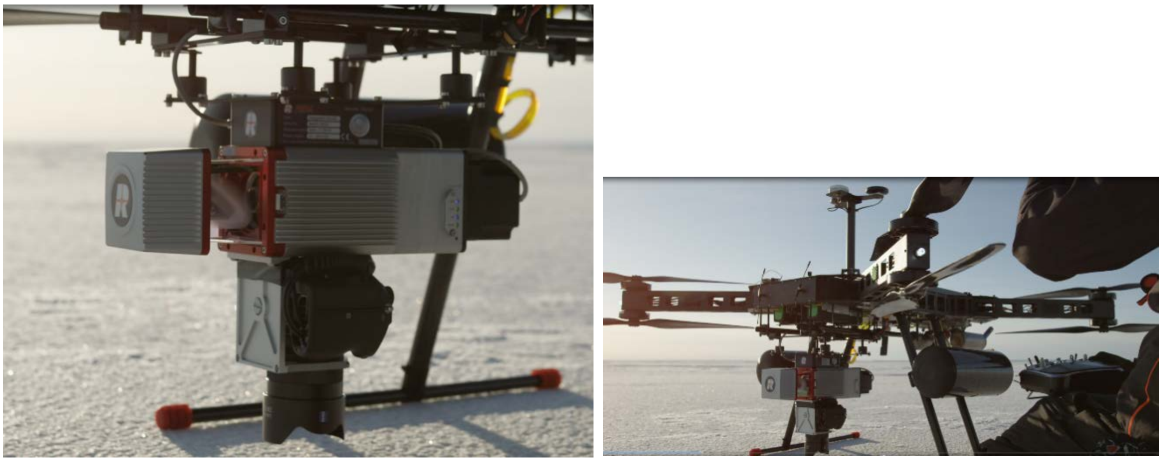

Figure 11 miniVUX LiDAR attached under the drone. The camera under the LiDAR is used to monitor the area scanned by the LiDAR.

4.3 Thermal camera

The thermal camera used in the trial was a IRS-I Self-contained Thermal imaging system [3]

Figure 12 Thermal camera IRSX-I640

The most important parameters are listed in the table below.

Table 3 IRSX-I640 Thermal camera parameters

Detector Resolution	640 x 512 pixels
Detector Type	Focal Plane Array, uncooled microbolometer
Spectral Range	7.5–13 µm
Pixel Size	17 x 17 µm
Frame rate	9 Hz
Lens focal length	19 mm
Hyperfocal distance	9.5 m (acceptable sharpness at a distance between 4.7m and infinity)
Object Temperature Range	Range 1: –25 to 135 °C, range 2: –40 to 550 °C
Accuracy	±2 °C or ±2 % of reading (10–100 °C @ 10–35 °C ambient temperature)
NETD (Noise Equivalent Temperature Difference) [1]	< 30 mK (f/1.0, range 1)
Operating temperature range	–40 to 60 °C (non-condensing)

[1] NETD is a measure for how well a thermal imaging detector is able to distinguish between very small differences in thermal radiation in the image.

Weight	270 g (w/o lens)
Budgetary price	25 k€

4.4 High resolution camera

A high-resolution aerial metric camera was used to capture images of the ice area. (A metric camera produces images on which you can perform accurate measurements after applying a simple perspective transformation).

Figure 13 Phase One ixM100 metric camera [4]

The purpose of using this kind of camera was to be able to see what benefits this kind of camera could bring in the intended context.

Figure 14 Drone with Phase One camera attached on the drone with a gimbal. Also an AIS transponder is attached to one of the legs (the small orange "tube" on the left leg).

The specifications of the Phase One iXM-100 camera (by Phase One Industrial) are as follows:

Table 4 Phase One iXM-100 specification

Resolution	11664 x 8750 pixels
Dynamic range	83 dB
Pixel size	3.76 µm
Effective sensor size	43.9x32.9 mm
Weight (incl. 80 mm lens)	1100 g
Temperature	-10°C to 40°C
Budgetary price	40 k€

4.5 Off-the-shelf drone

A DJI Mavic 2 Pro consumer grade drone was used as a comparison. The drone has a 20 MPix camera with a 1” CMOS sensor mounted on a gimbal. The operating time for this drone is 20 – 30 minutes. A video link enables real-time monitoring of the view on a tablet. The images and videos are stored on a local microSD card that can be inserted in an SD card slot on a computer (physical transfer of the microSD-card is often the fastest way of transferring the data) or downloaded using a USB cable directly from the drone, for further processing after the flight.

Figure 15 DJI MAVIC PRO 2 drone

Table 5 DJI MAVIC PRO 2 specifications [5]

Sensor	Optical camera, 20 Mpixels
Still image size	5472 × 3648
Aircraft weight	907 g
Dimensions	Folded: 214×91×84 mm (length×width×height) Unfolded: 322×242×84 mm (length×width×height)
Max wind speed resistance	29-38 km/h (8 – 10.5 m/s)
Operating temperature range	-10°C to 40°C
Remote controller Max transmission distance	CE: 5 km
Price	about 1.3 k€

4.6 AIS transponder

In one of the trial flights, an AIS transponder was attached to the drone. (Test use of this transponder was agreed upon in advance with the Maritime Rescue Coordination Centre)

Figure 16 AIS emergency transponder

Table 6 Technical specifications of the transponder (MOB1) [6]

AIS Transmit power	1 W
Frequency	161.975/162.025 MHz
Weight	92 g
Dimensions	134mm x 38mm x27mm
Messages	Message 1 (Position), Message 14 (MOB status)
Repetition interval	8 messages/minute Message 14 sent twice every 4 minutes
Price	300 €

The purpose of the test use was to see how this kind of AIS device would be shown on the ship's ECDIS (or ECS). The outcome was partially successful – the position of the drone was indicated, but the ECDIS system did not generate AIS trails between the observations – only discrete positions. It is unclear why this was the case – probably a feature in the ECDIS for these kind of AIS messages as the most important information for a Man-Over-Board message is the latest position (or the messages are sent at an interval that is too long for generating a trail because the interpolated positions would not be accurate).

5. Image examples

5.1 High resolution images

An image is shown below with the dimensions 11664 x 8750 pixels, taken on 16th March 2020 at 17:33 with an aperture f/5.6, 1/2500 s, ISO-160, focal length 35 mm. The high resolution image allows zooming in on fine details. 1 pixel is about 3 mm on the ground from this altitude using the specified lens.

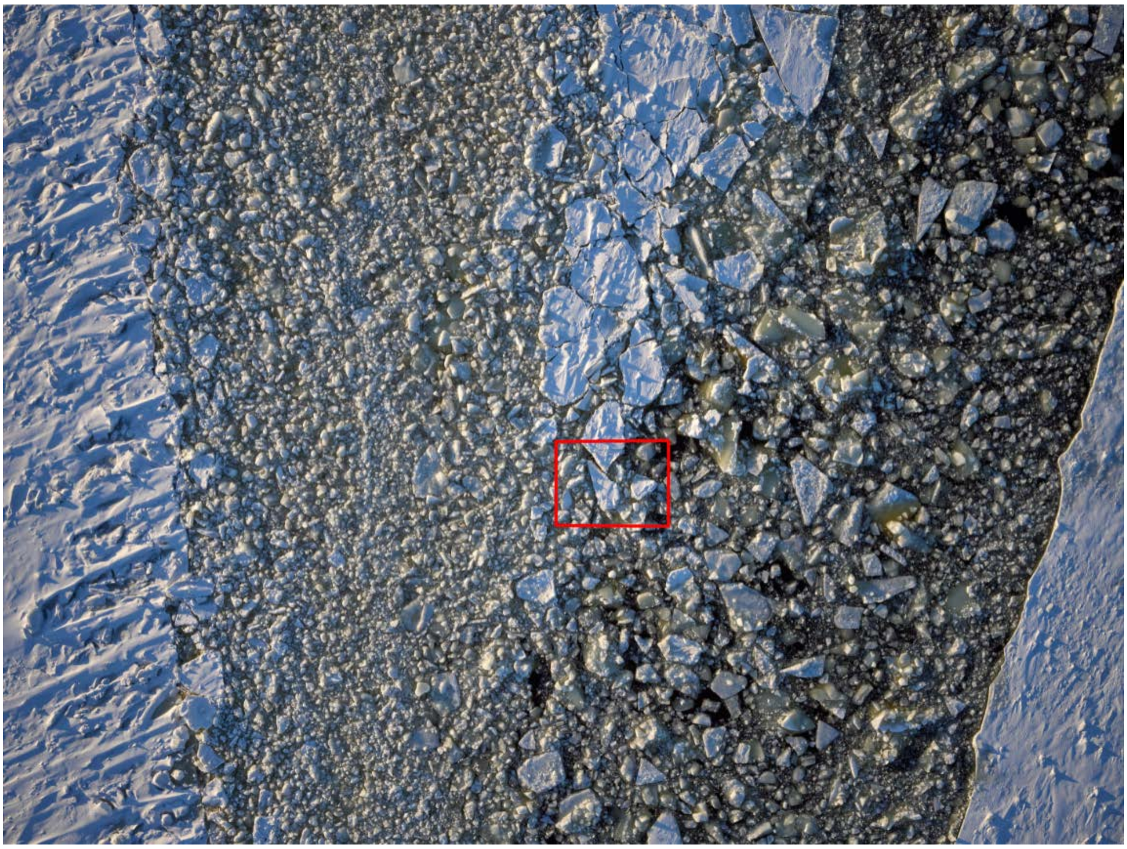

Figure 17 PhaseOne picture. Width on the ground is 35 m. The channel to the right is the fresh channel after icebreaker ATLE. The channel to the left is a bit older channel - the ice rubble has frozen, which can be identified from the greyish hue of the surface.

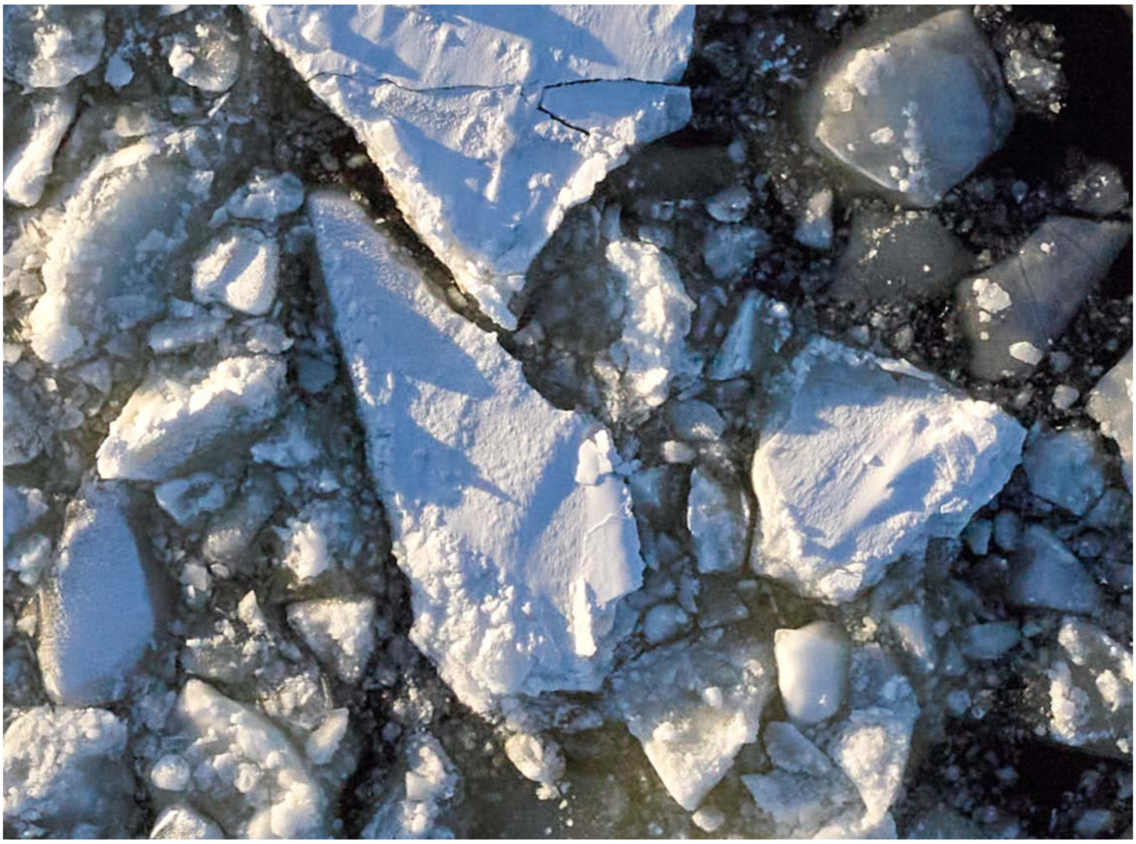

Figure 18 Detail in full resolution. Width of the image ca 3.5 m

The advantage of the high resolution is the possibility to digitally zoom in on details in the image. The camera has minimum geometric distortion, so it is easy to calculate distances, produce mosaics and process the images photogrammetrically. As the camera has a large and sensitive CMOS sensor, it enables acquisitions in unfavourable light conditions. However, the camera is a quite expensive.

Below some examples of photogrammetrically processed images, i.e. a point cloud is calculated from a series of images. The point cloud has been rendered into an elevation model, where small height differences (0 - 40 cm) are enhanced using a rainbow look-up table.

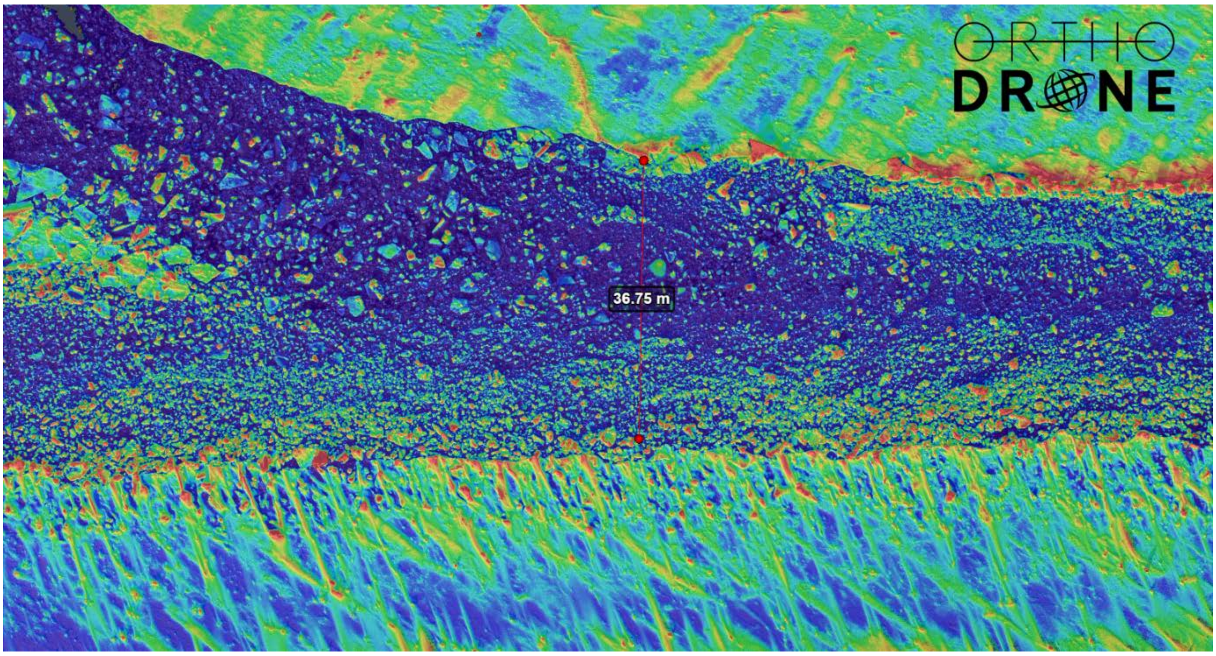

Figure 19 Pseudocoloured visualisation of point cloud. The point cloud visualisation platform has a measurement tool, here used to measure the width of the channel (36.75 m) at the channel intersection.

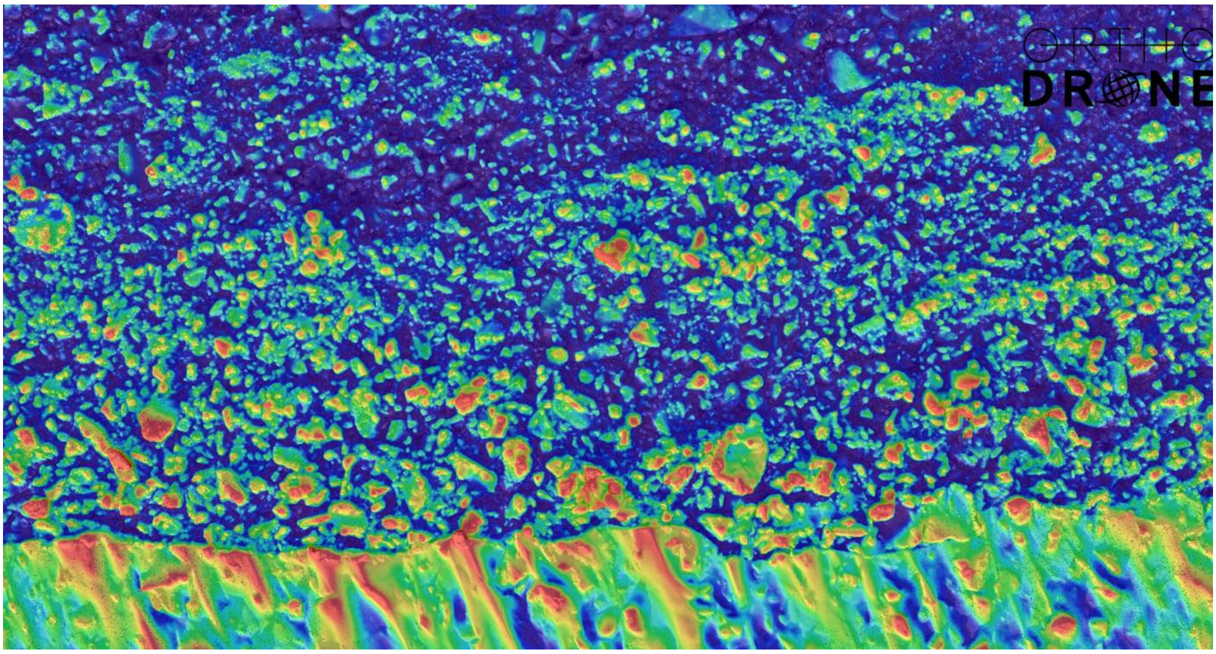

Figure 20 Zoom-in on the point cloud.

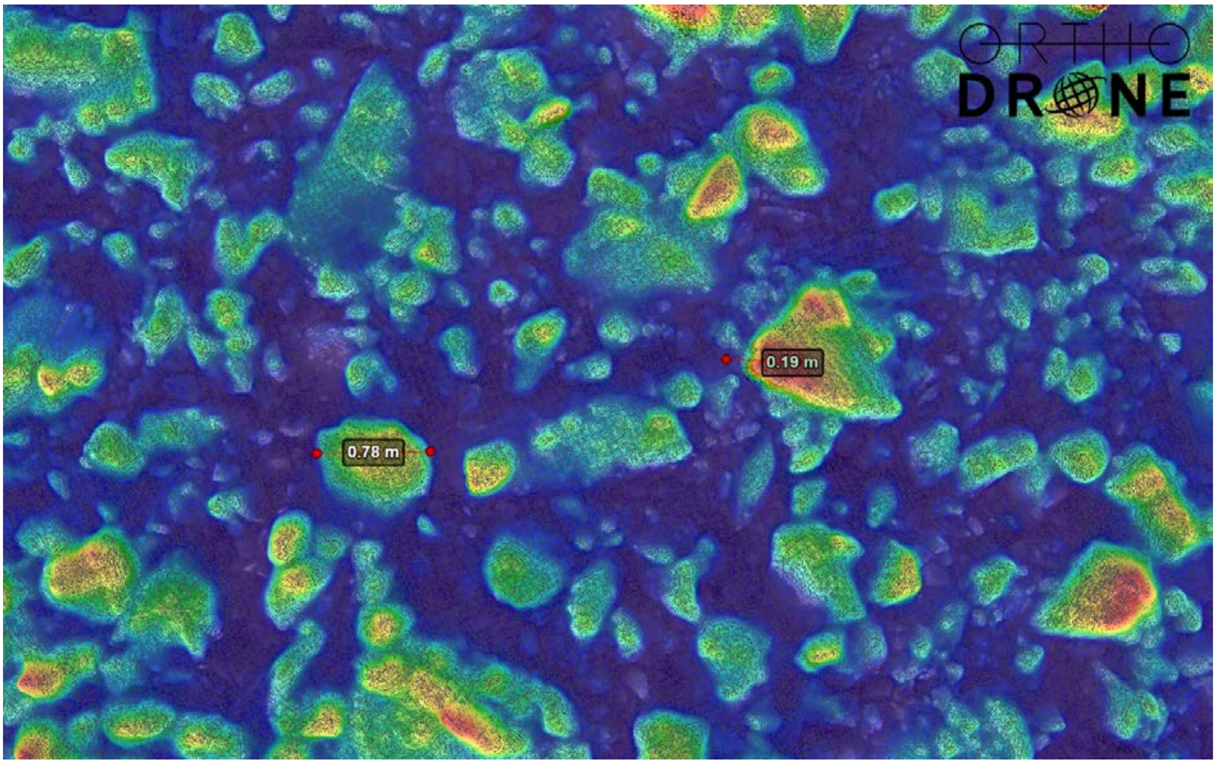

Figure 21 Photogrammetric processing into a point cloud enables numerical measurements both horizontally and vertically. To the left, the (horizontal) size of an ice floe is measured, to the right the height of the upper surface is measured with respect to the sea level.

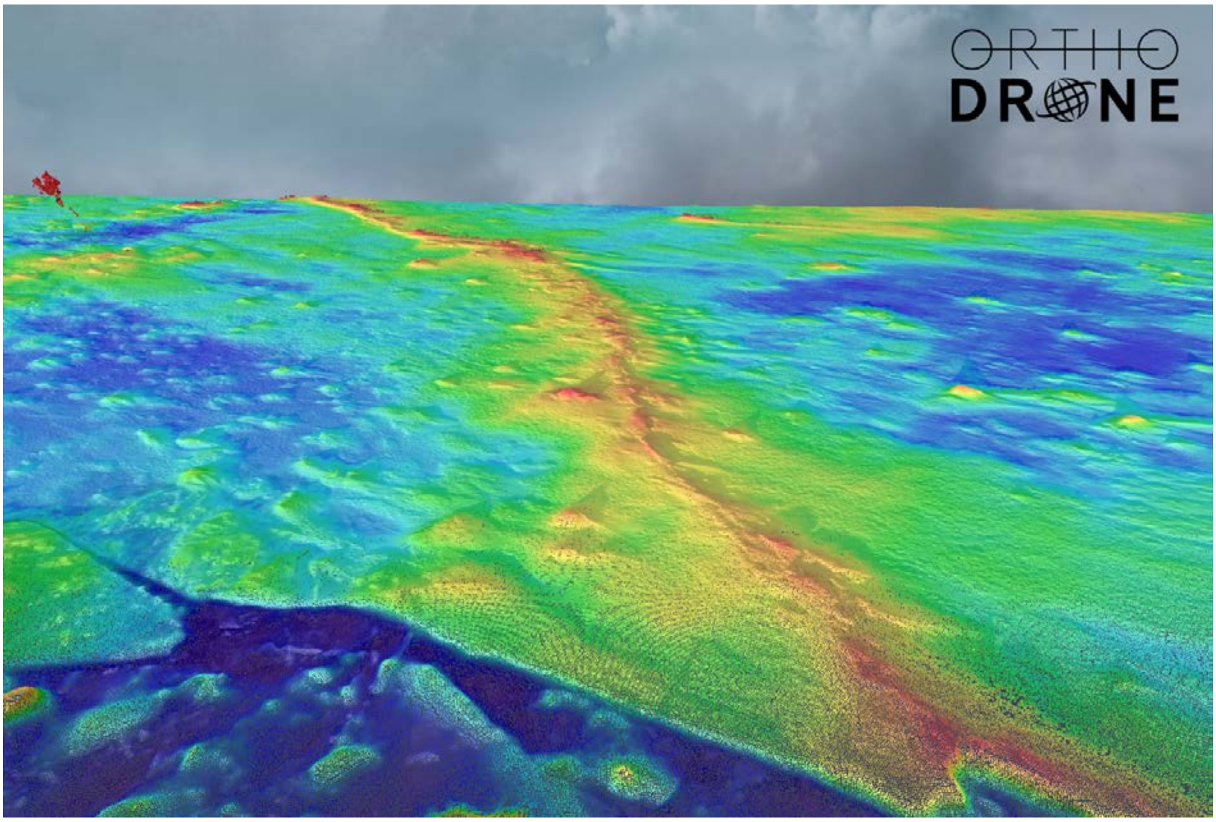

Figure 22 View of small ridge, sail height 20 - 40 cm

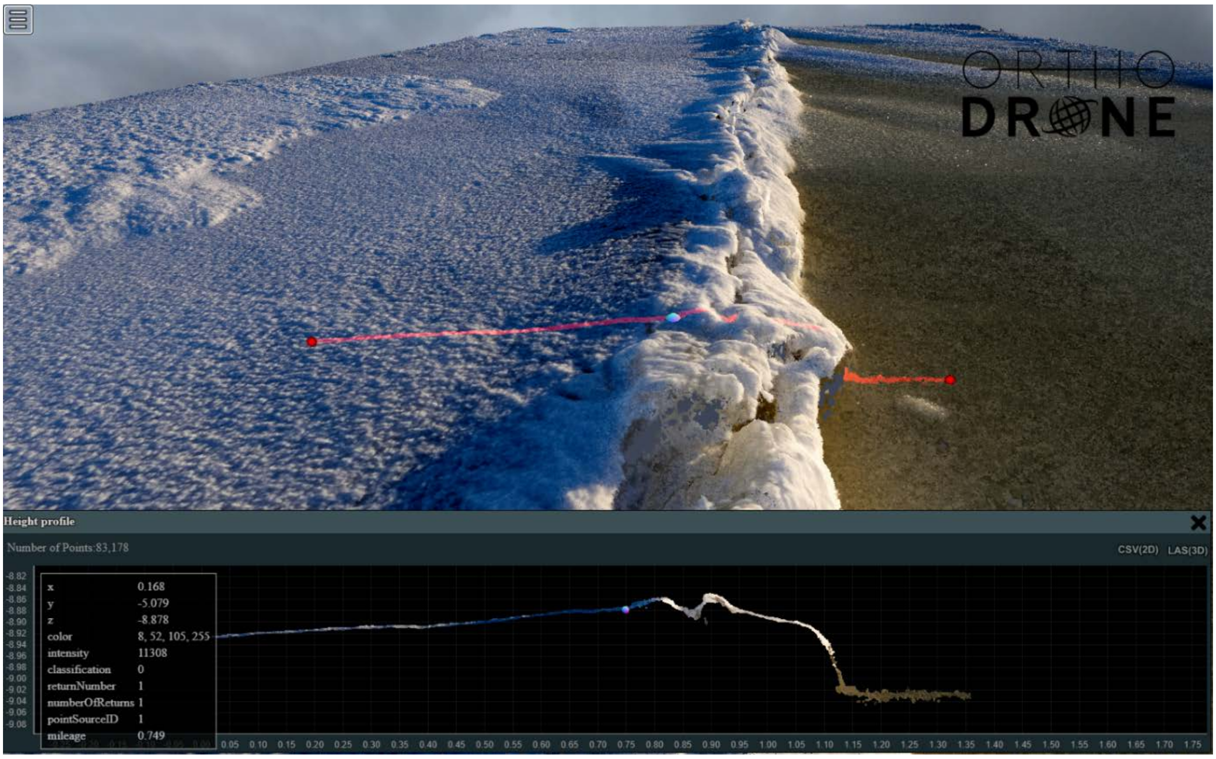

Figure 23 Photogrammetrically processed image showing a detail of the hummocked ice. A 2D profile is shown in the lower part of the image illustrating the vertical profile of the small ridge.

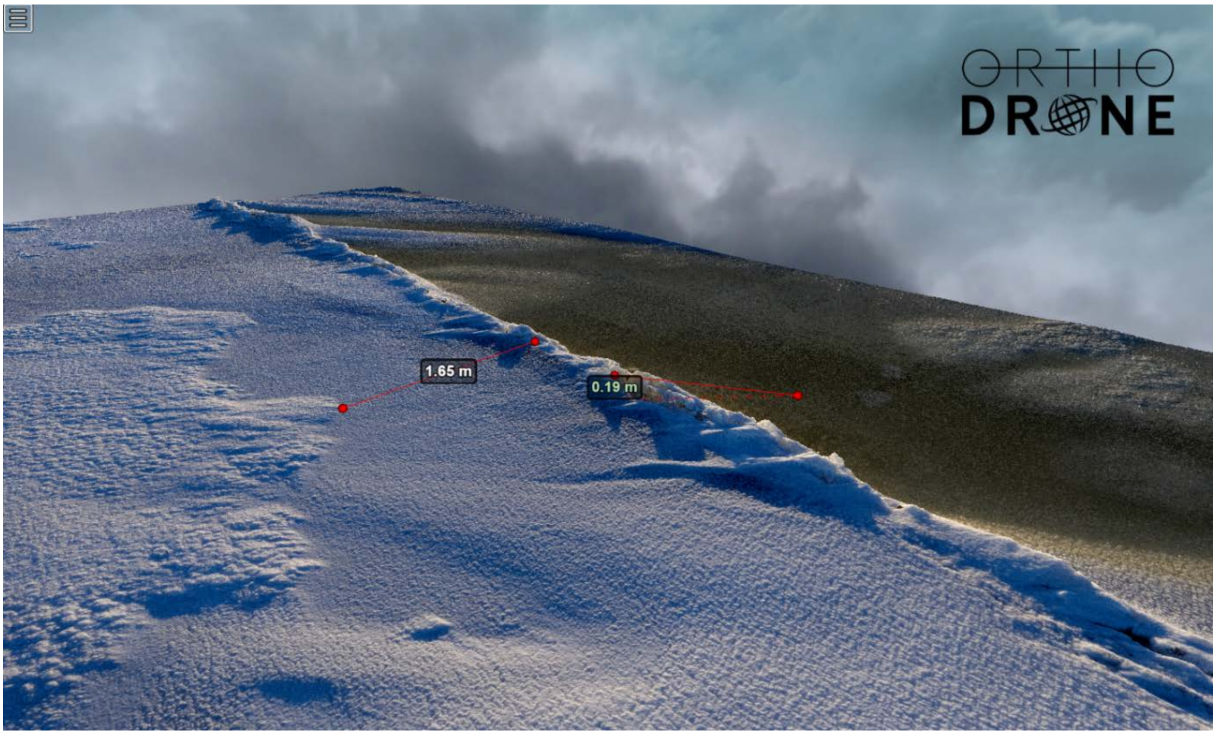

Figure 24 Dimensions of some features in the image.

5.2 Thermal images

A thermal camera enables observations in darkness without illumination. The resolution is an order of magnitude worse than when using an optical camera. Thus scanning of large areas is slow and details require close-up photography. One possibility is to use dual-camera set-ups, whereby contours are obtained from the optical image and the temperature information is taken from the thermal camera.

Below some example images:

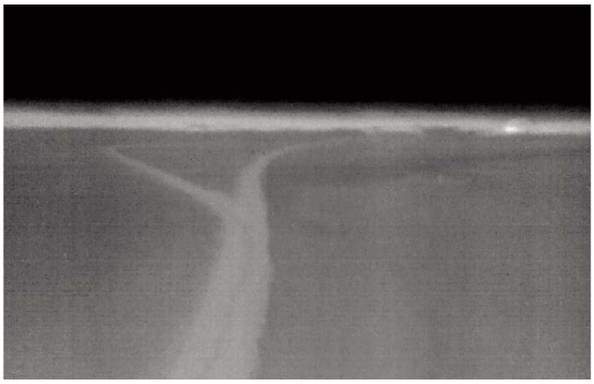

Figure 25 View towards the horizon in the North. The channel is clearly visible. Optical photo to the right, thermal to the left.

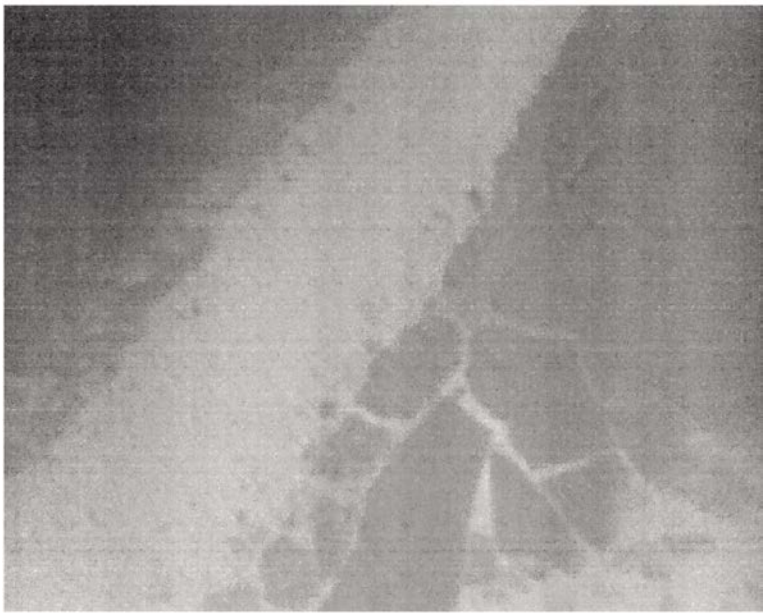

Figure 26 Channel

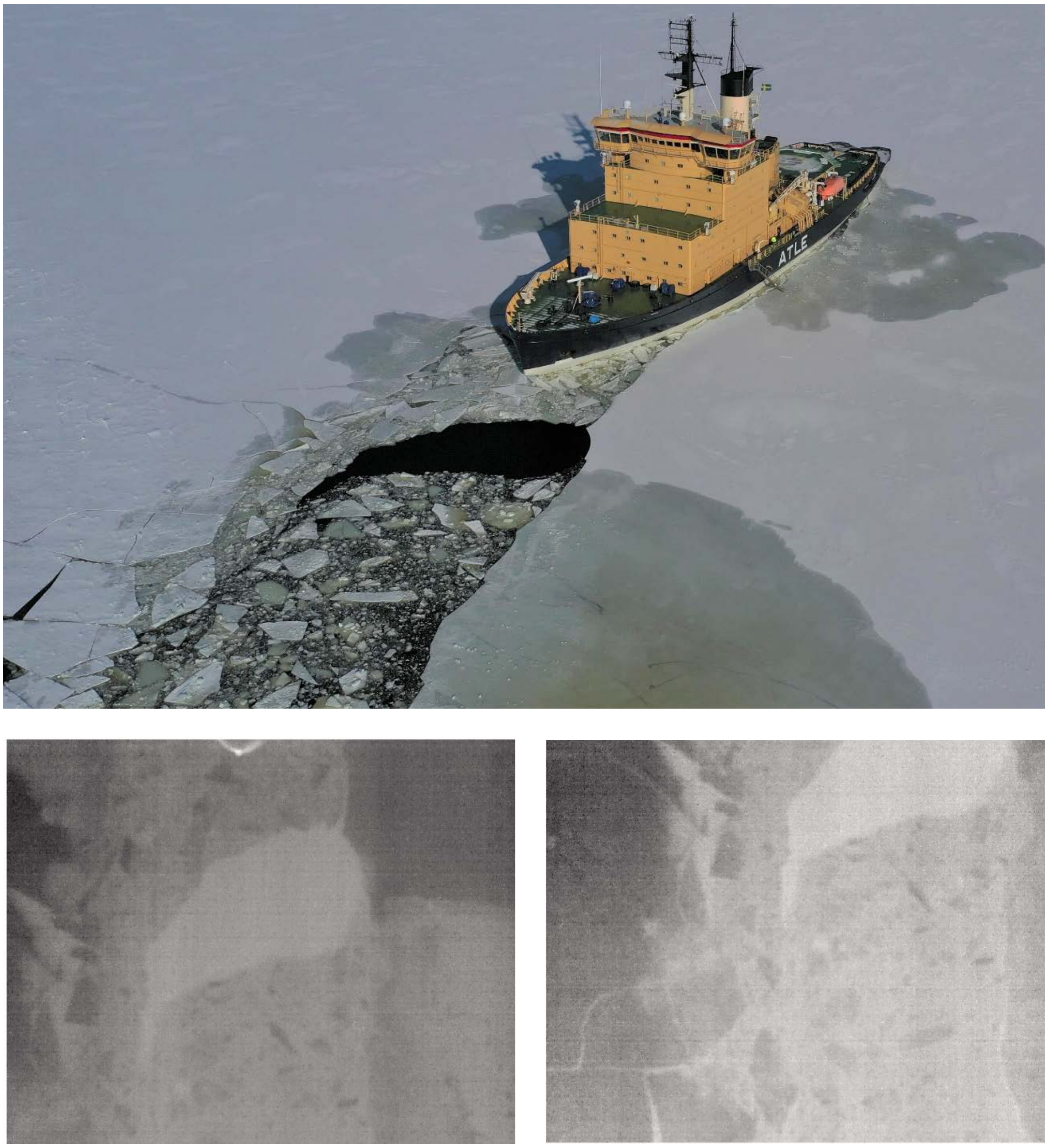

Figure 27 Open water area in front of the icebreaker stands out as a brighter area in the thermal image. The open water area is clearly seen in the optical image above, where the open water is dark. The wetted area to the right has different emissivity compared to the snow and the surface temperature is probably also a bit warmer than the snow although the water on top of the ice has frozen.

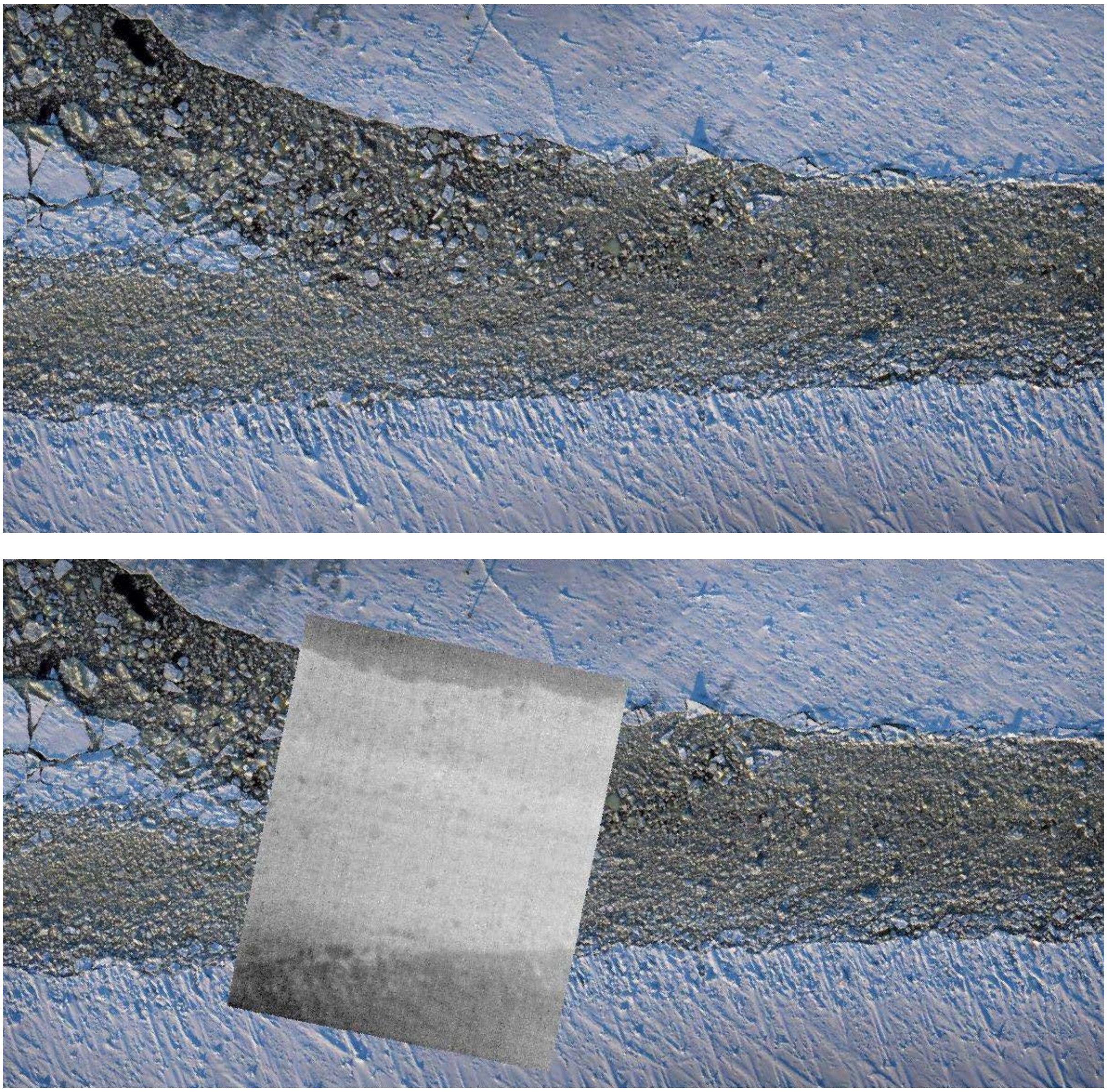

Figure 28 Thermal image overlaid on optical image. No visible difference between old and new channel so thermal images may not be so good at discriminating between refrozen channels and fresh channels. (The old channel is the lower one, the new one is the curved one.)

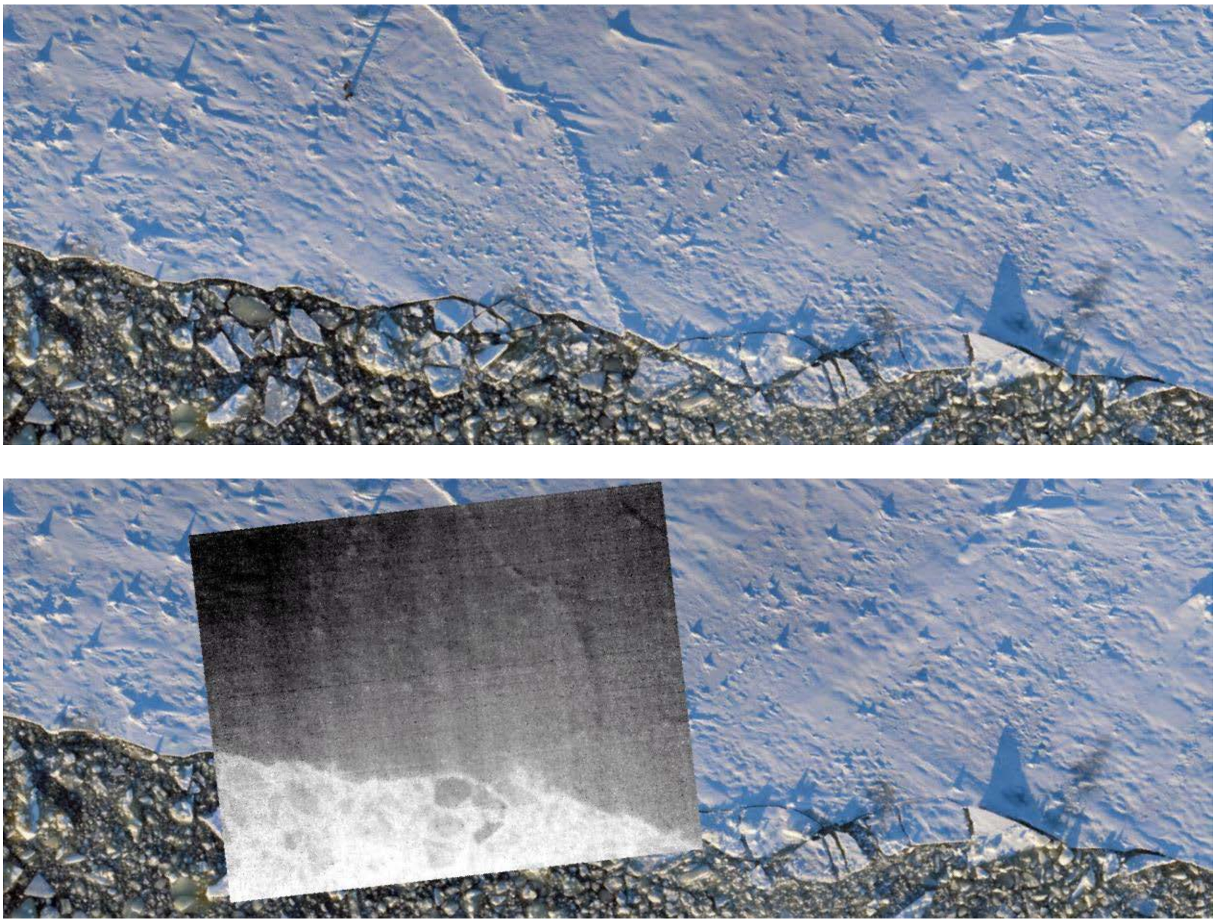

Figure 29 Thermal image and optical image. (Shadows that are clearly visible in the optical image, have no effect on the thermal image).

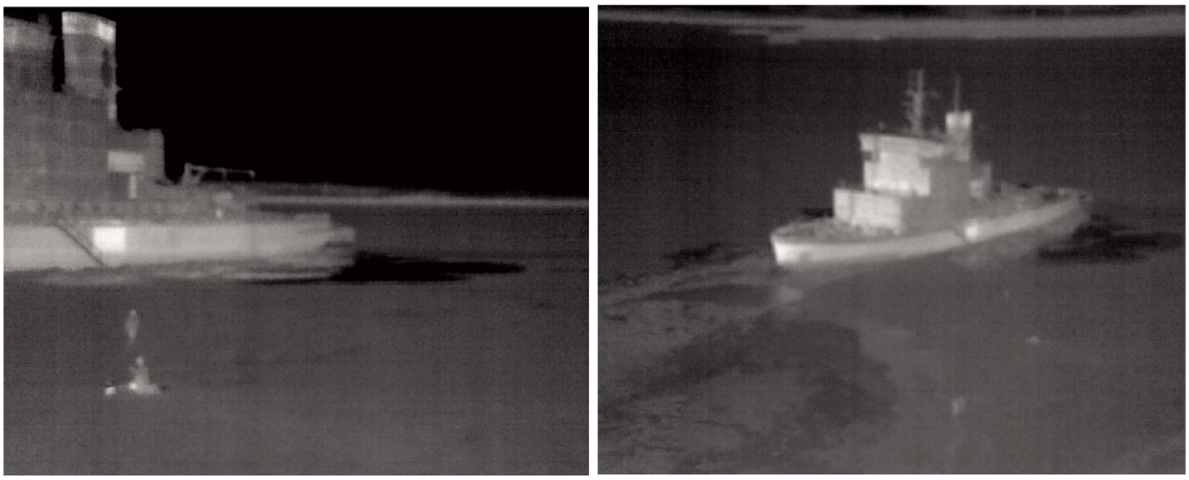

Figure 30 Thermal images showing icebreaker in the background and people in the foreground.

5.3 LiDAR

Below are shown some example images rendered from a LiDAR derived point cloud. Originally the number of points in the data was 72 million. The number of points is reduced to 6 million for the on line cloud used for the rendering. The rendering is done in a way that the lightness of each point in the rendered point cloud is determined by the intensity of the reflected laser pulse having a wavelength of 906 nm (near infrared). The images are rendered using a platform called “potree” [7] - here adapted and hosted by Orthodrone GmbH.

Figure 31 LiDAR based point cloud

Figure 32 LiDAR example. The viewing tool enables measuring of distances, heights, angles and volumes.

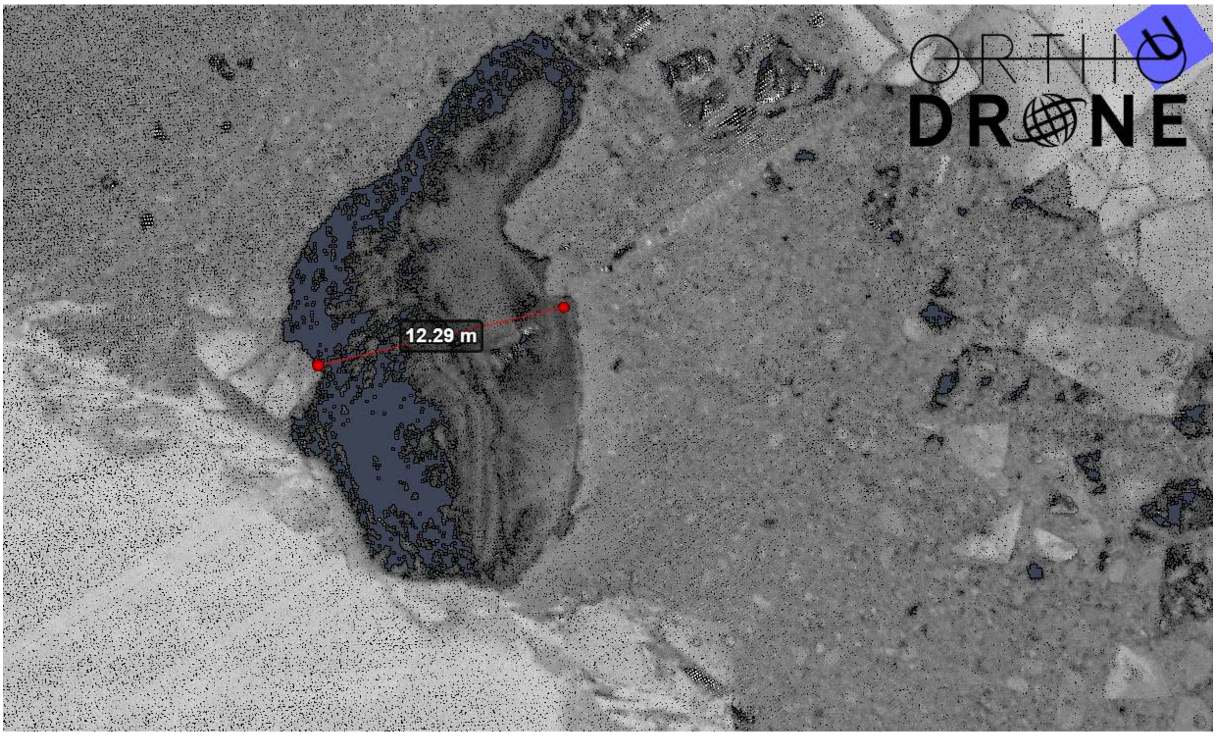

Figure 33 Example of open water patch in the lead. Water has lower reflectance, so there are missing points in the point cloud. The water in the patch has started to freeze.

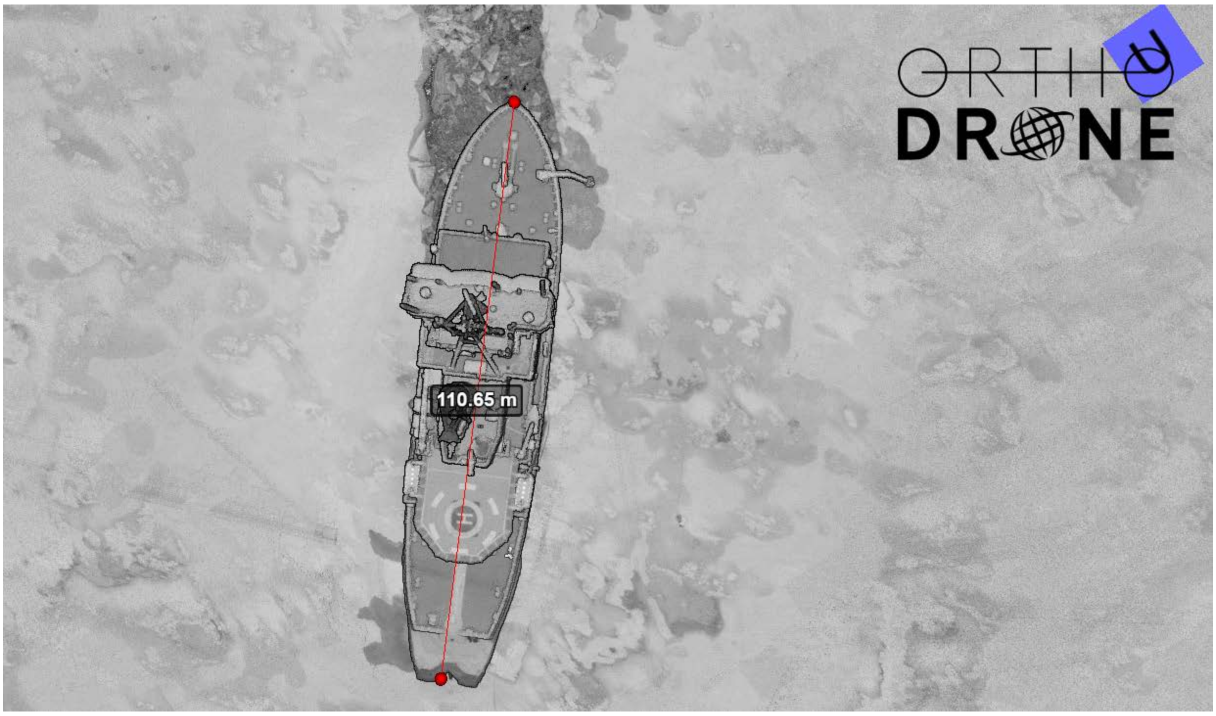

Figure 34 Checking geometric accuracy of the point cloud. The overall length of icebreaker Atle is 104.6 m, according to ship specifics (Wikipedia) but when the towing fork is included, the overall length is actually 110 m (Tomas Årnell, SMA). The position information of the LiDAR was corrected using RINEX data and should be fairly accurate.

Figure 35 Another example of a lead

Figure 36 The lead seen from a low perspective (the background is totally artificial)

LiDAR provides a point cloud from which 3D models can be derived. The result is not based on ambient light conditions, therefore LiDAR works well independent of light conditions. Drawbacks are a massive amount of data and lengthy processing times. LiDAR is especially useful when the target has many, partially overlapping reflecting surfaces (like the branches of trees in a forest), as the instrument can detect multiple reflections from these objects and produce information of surfaces that are partially hidden. When scanning a field of sea ice, the primary (and often only) reflection comes from the surface - thus handling of multiple returns is seldom needed. One exception could be a pressure ridge with blocks of ice with voids in between. In our trial, however, we were not able to find or scan that kind of ice in the test areas.

5.4 Off-the-shelf drone

Figure 37 Channel on 14.3.2020 from 8 m height

Figure 38 Channel from 21 m height

Figure 39 Channel from 39 m height

Figure 40 Channel from 48 m height

Figure 41 Channel from 61 m height

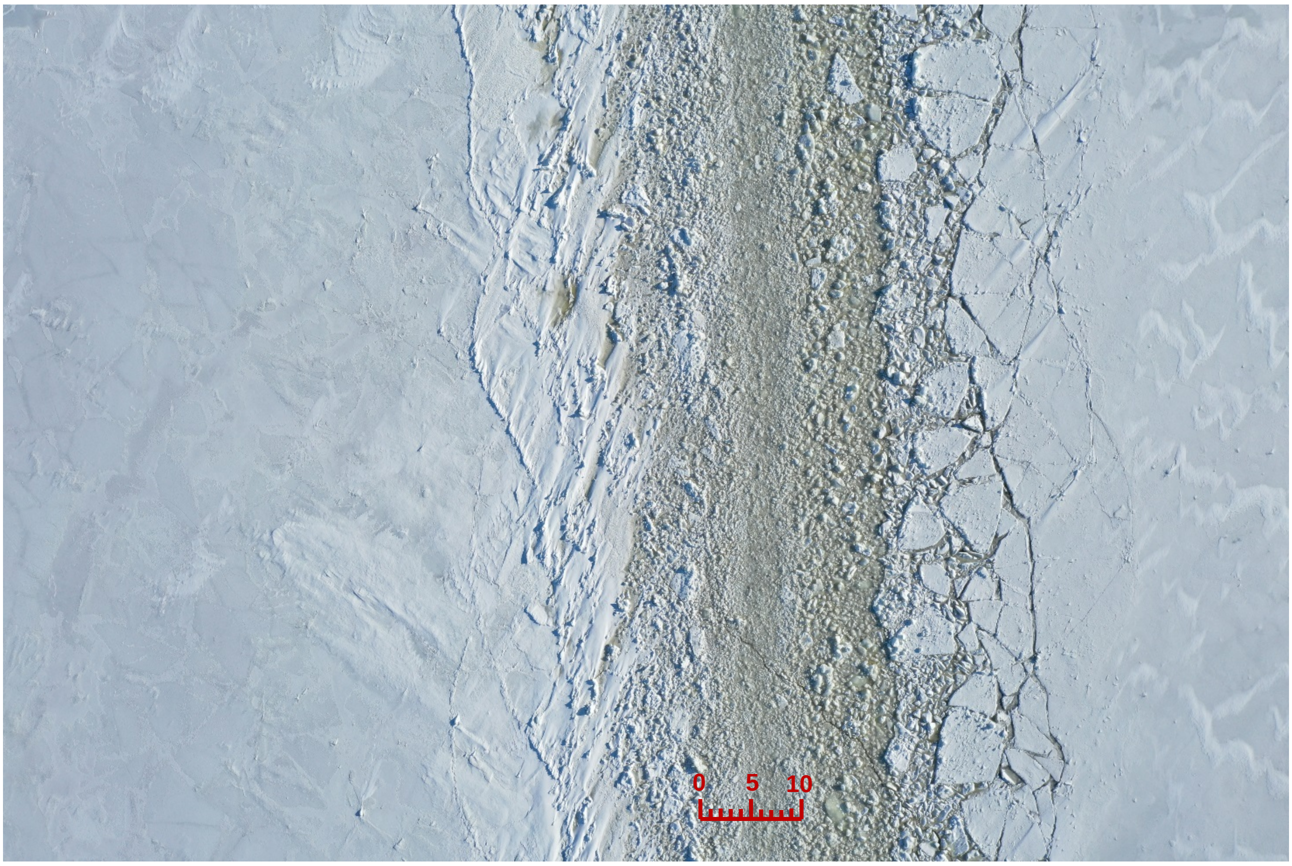

Figure 42 From 96 m height, width of image is 120 m

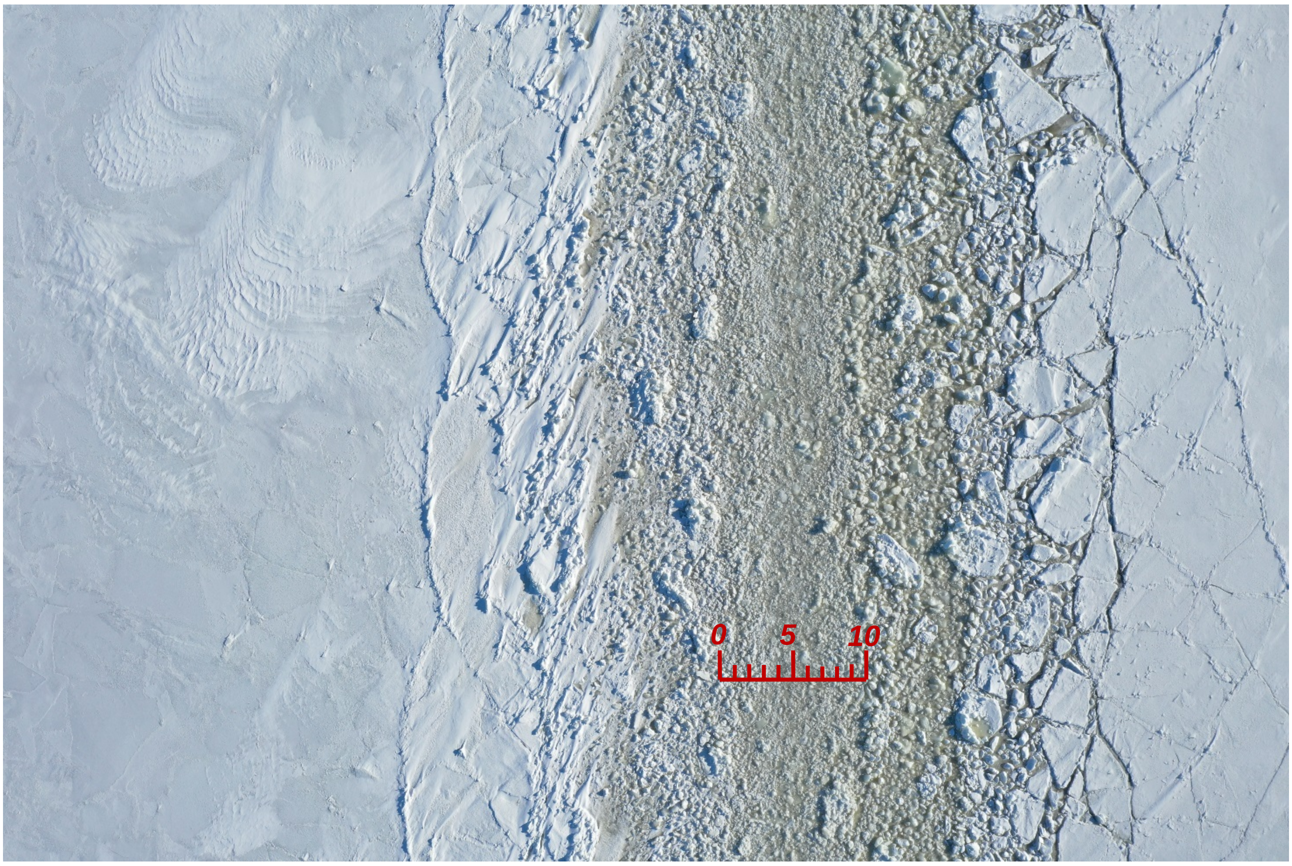

Figure 43 From 73 m height, width of image 91 m

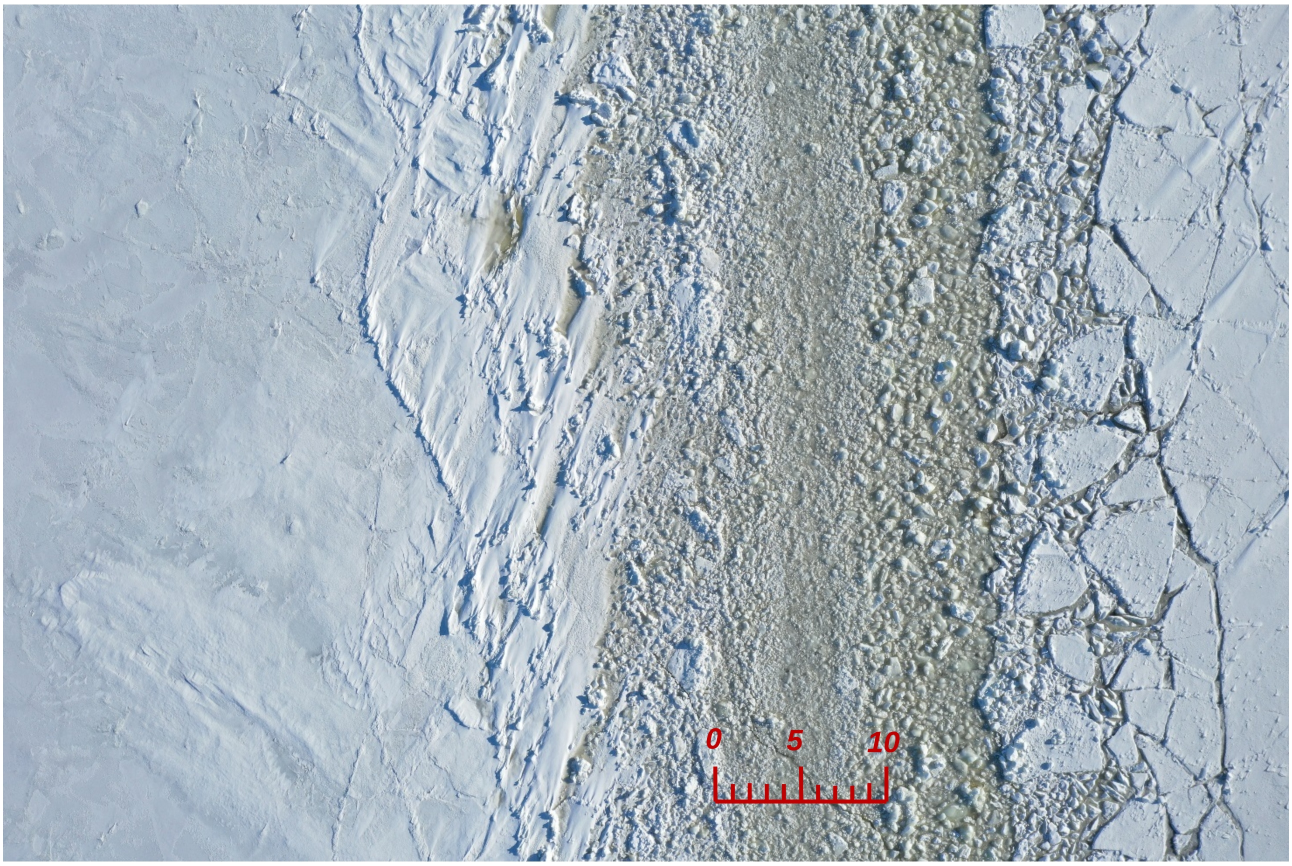

Figure 44 From 61 m height, width 76 m

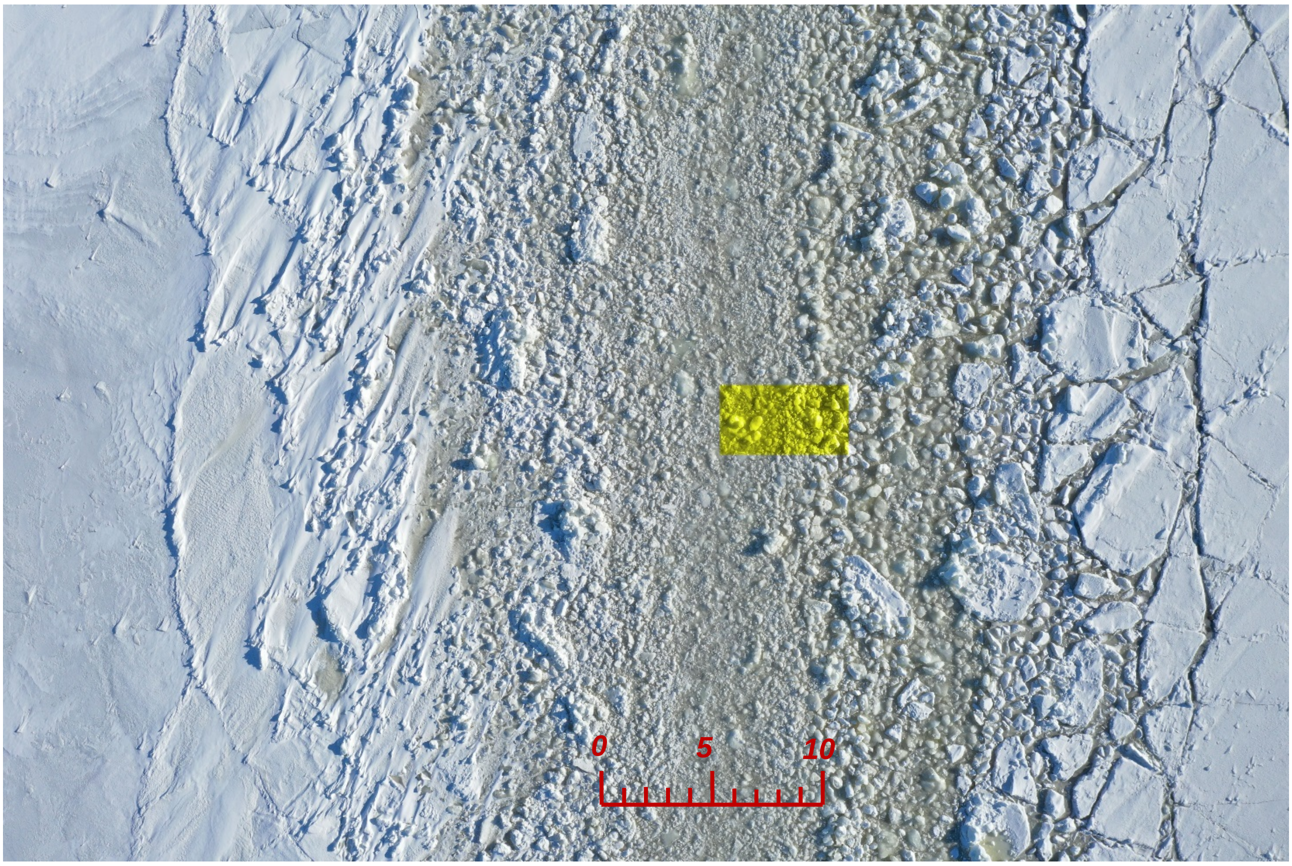

Figure 45 From 48 m height, width 60 m. Enlarged part (Figure 44) shown in yellow.

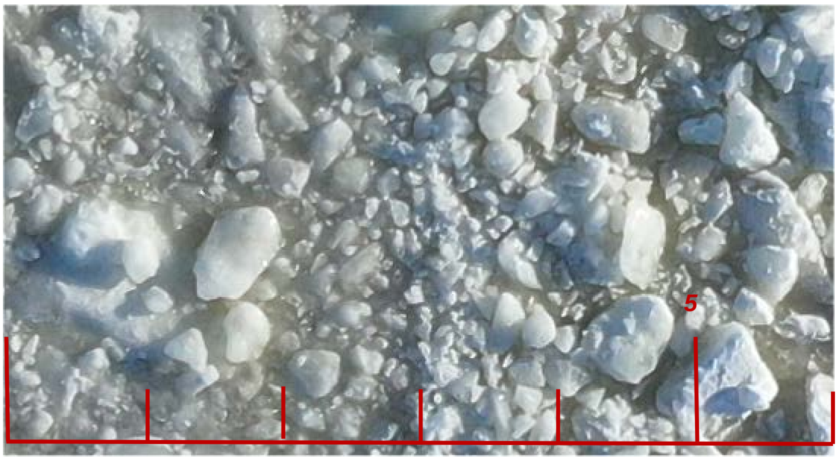

Figure 46 Part of the image above (Figure 43). Width of image 6 m. Taken from a height of 48 m.

The off-the-shelf drone worked very well - even when taking off from and landing on the icebreaker deck. The image quality in the good lighting conditions was very good - a versatile and easy-to-use tool indeed.

6. User comments

When discussing with the icebreaker officers, we received the following comments:

For the drone to be of real use, longer flight distances would be needed – the ship radar can see ridges and channels up to 12 NM – so a drone going beyond that would be useful. (On the other hand - a ship radar cannot measure the width of an ice channel - so a drone would give additional information for that purpose even from shorter distances).

To be able to have a look from high up (over 120 m) would be useful. Going up to 400 m would be great. This is question of permits - technically 400 m vertical height is no problem.

The capability to get images during low light conditions would definitely increase usefulness. In this respect a LiDAR solution would be great, but thermal images are also a possibility.

The main use cases here would be to ascertain whether the channel is narrowing – indicating ice compression – or widening. The state of the channel can – to some extent – be deduced from visual inspection of the optical images of the channel, but having a measurement tool (overlaid on the image) for measuring the channel width, could be of help.

The other use case would be to determine if the ice field has started to break up and in that case, the updated position of ice floes that are drifting from the rest of the ice field. And also if there are new openings are these openings located so that they can be utilised for ships leaving or approaching?

A related use case is to check the position and condition of the channel inlet - is a ship that is approaching, able to find the correct inlet as the drifting ice may have shifted the position of it and is the channel at the inlet navigable considering the capabilities of the approaching ship?

An AIS transponder is definitely useful to add to the drone, but it should be an ordinary Class A (or B) transponder that can be tracked on an ECDIS (or ECS).

Organisational aspects: a trained drone pilot is needed on board at least in the next few years to fulfil the regulation requirements regarding operating a drone in the Specific Category. This person could be a bridge officer – or bridge officers could be given the necessary training. A flexible scheme for allocating duties on the bridge depending on the situation could incorporate the role of a drone pilot without having to increase the staffing requirements with one full-time person.

7. Regulatory aspects

On EU-level there are new regulations entering into force starting from 1 July 2020. There will be a transition phase during which intermediate rules apply, but starting from July 2022 the EU regulations apply. The situation regarding icebreaker operations is eased by the fact that the needs are outside of urban areas. The category not requiring any permits is the Open category, which is meant for low risk operations. However, there are cases where the Open category is not enough and the operations need to be done in the Specific category. Two cases where operations would have to be done according to the Specific category are:

- Flying beyond visual line-of-sight (BVLOS)
- Flying at altitudes higher than 120 m

In the Specific category the drone pilots have to be certified, but the certification process is not complicated.

The Specific category is for operations considered to have a medium risk and which require authorization by a competent authority ahead of the operation– either by the means of following a standard scenario or by an individual risk assessment following the SORA methodology, detailing how the mission will be conducted safely.

The Certified Category classifies operations with high risks: this means they require a certified drone, a licensed pilot and an organization approved by a competent authority.

Until July 2020 pilots can still operate under the current national regulations. The pilots can then apply for a permit or exemption based on these regulations.

From July 2020 onward you can still use previously obtained permits and exemptions up to July 2022.

After July 2022 only the EU regulations are valid.

These regulations will make operations easier, especially in cross-border operations – compared to the situation today.

For detailed instructions in Sweden, please have a look at the web-pages by Transportstyrelsen https://www.transportstyrelsen.se/dronare. See also information about specific category https://www.transportstyrelsen.se/sv/luftfart/Luftfartyg-och-luftvardighet/dronare/nya-regler-fran-1-juli-2020/tillstand-for-dronare/kategori-specifik/

In Finland, up-to-date information is published on the web-pages: https://www.droneinfo.fi/fi maintained by the Transport and Communications Agency Traficom.

8. Results and conclusions

The results do confirm that there is a potential in using drones for icebreaking operations. Optical images are excellent if the lighting conditions are favourable. Infrared (thermal) images do show many advantages – not the least being usability in low light conditions. Infrared images may be somewhat difficult to interpret – a detailed evaluation of this cannot be done based on the limited material obtained so far. LiDAR technology gives excellent data of the 3D characteristics of the ice field. Also, although the reflectance from open water is low, causing missing data points from open water areas, this is probably not a problem as the features of interest always involve ice or snow. An advanced hybrid drone as the one tried out here, does offer long endurance and would enable flights over longer distances. The trials involving an off-the-shelf drone did turn out amazingly well in the prevailing light conditions.

The technology is not yet mature enough for operational use in an economical way. The main reason is the lack of autonomously flying drones at an affordable price. Also, both route planning and viewing of results should be automatized and integrated into or at least interfaced to existing tools as far as possible. The situation may change in the coming years as the EU drone legislation enables actors to operate in EU countries without excessive administrative barriers. This will increase competition and also lower the price of tailor made drone solutions. A possibility worth studying is the use of off-the-shelf drones equipped with dual cameras (thermal and optical).

9. Way forward (suggestions for further discussions)

The pilot trial gives some experience regarding the present possibilities. As technology advances quite fast in this field, there is a need to follow up what is happening. The icebreaking operations have special requirements that have to be considered when looking for a feasible solution. The recommended approach is iterative so that the rapid technological advances can be utilised in the best way. This small scale trial can be seen as one iteration, now the question is what the second iteration would look like.

Step 1:

- Off-the-shelf drones are procured and basic training given to a group of people (icebreaker officers) to enable efficient and safe operations. Software for processing of images and displaying them on a map, is obtained. Basic exchange of geocoded images between the icebreaker IBNet system and the processed drone-obtained images is planned and implemented. This exchange may be implemented by importing images from the "drone system" to IBnet or vice versa (from IBnet to the drone system). A third option is to enable export of geocoded images (mainly satellite images) from IBnet to a third party GIS system into which geocoded material is imported from the drone system also.

- Permissions are acquired to enable flying at higher altitudes than 120 m and for flights beyond visual line-of-sight.

Step 2:

- A tailored system is planned, preferably as a cooperation between the Swedish and Finnish maritime authorities. This project might benefit from the joint planning and building of the next generation icebreakers. The process could start by issuing a Request for Information to drone operators/manufacturers to get better knowledge of the existing offering. This information is then used for cost/benefit analyses of a drone based sensor system and for allocating a reasonable budget for this (sub) system.

In the cost/benefit analysis the drone-as-a-service should be kept in mind. A land based operator could offer drone flights on demand with fixed wing equipment. The cost for such a service model depends on the number of users and may have the drawback of long waiting times for the service. (If many base stations are established, they decrease waiting times, but increase costs). Finally, the satellite based alternative should not be forgotten. New players offering commercial on demand SAR imagery may fulfil many of the needs for information. The spatial resolution of such imagery will not be high enough for accurate monitoring of lead widths, but certainly enough for determining possible drift of ice channels or position of ice floes over reasonable large areas without requiring any launch or operation of unmanned aircrafts.

10. References

[1] Berglund R. , Seitsonen L. *DronIce - Using drones to support icebreaker operations.* VTT Research Report VTT-R-00416-19 (2019). To be published in the Winter Navigation Research report series.

[2] RIEGL miniVUX1 UAV www.riegl.com

[3] Thermal camera IRSX-I640 www.automationtechnology.de

[4] Phase One ixM100 metric camera. https://industrial.phaseone.com/

[5] DJI Mavic Pro 2, www.dji.com

[6] MOB1 Emergency transmitter, http://www.oceansignal.no/

[7] potree http://www.potree.org/

APPENDICES:

APPENDIX 1:

Day-by-day plan/log

Day (in April 2020)	Task	Priorities	Postprocessing	Who does what
Thursday 12:th	Arrival on board in Luleå. Departure from port. Safety rehearsal			All
Friday 13:th	Safety review with officers		-	All
	Unpack & prepare Boxer and sensors	BOXER, LiDAR	-	Juri & Julian
Saturday 14:th	Try Mavic Pro drone	Secondary importance	Examine footage	Robin
	Prepare and execute BOXER flights with LiDAR sensor	LiDAR	Start LiDAR processing	Juri & Julian
Sunday 15:th	Preliminary processing of LiDAR data AND optical images	LiDAR quicklook of Channel & Ship	Processing of the LiDAR pointcloud data	Juri & Julian. Show result to Robin and to Atle Master (Karl)
	Prepare for IR-camera – try it from icebreaker to look at ice and water	Keep in mind preparation for flying IR-camera next day	Store some example images	Juri, Julian. Patrik takes pictures of operations. Show Karl and deck officers the results
Monday 16:th	Prepare for BOXER flight over leads with thermal camera	**Remember that we have to use the narrow time window when weather permits flying!!**		Juri & Julian
	FLY with BOXER and thermal camera. **Test using AIS transponder (if allowed, and not jeopardizing main test)**	**This is important**	Store and show. Video and still images?	Juri & Julian & Patrik
	Fly with MAVIC (VTT Mavic) over lead: Heights:	Secondary importance	Store and record heights	Robin

	- 40, 80 and 120 m - go 500 m away and back along channel/lead - video camera looking forward - one video looking downward (on return from 120 m) - still pictures downward – only for visual inspection. 10 pictures per leg (50m spacing between images – not enough for photogrammetric processing, but that is not needed)			
Tuesday 17:th	Wrap up. Discussion with deck officers. Pack and prepare for return. (Pilot tugboat to Karlsborg, taxi to Luleå)			All
Wednesday 18:th	Return from Luleå			