STYRELSEN FÖR

VINTERSJÖFARTSFORSKNING

WINTER NAVIGATION RESEARCH BOARD

Research Report No 110

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Use of Drones in icebreaker operations – a feasibility study

Finnish Transport and Communications Agency	Swedish Maritime Administration
Finnish Transport Infrastructure Agency	Swedish Transport Agency
Finland	Sweden

Talvimerenkulun tutkimusraportit — Winter Navigation Research Reports
ISSN 2342-4303
ISBN 978-952-311-493-7

FOREWORD

In this report no 110, the Winter Navigation Research Board presents the results of the study on usage of drones in icebreaker operations. The drones can provide real-time information about the ice conditions which is essential for the icebreakers when planning icebreaking operations. The study reviews the user needs, describes different types of drones and summarises the characteristics of available sensor types.

According to the study, the Unmanned Aircraft Vehicles or Drones can reduce costs with a ball-park estimated saving of 2 to 13 k€/icebreaker/month. The study concludes with suggestions on how to proceed pinpointing the main open questions that should be resolved before investment decisions regarding possible drone-based systems can be made.

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

Helsinki and Norrköping

May 2020

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RESEARCH REPORT

Draft, v. 28.8.2019

VTT-R-00416-19

Use of Drones in icebreaker operations - a feasibility study

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Confidentiality:	Restricted
Date:	28.8.2019

About photo on the cover page:

The picture is taken from the helideck on board icebreaker Urho in July 2019 in Helsinki. Patrik Raski and Ronald Lindberg from AVARTEK ky are preparing their professional drone for a test on how the icebreaker hull is affecting the orientation sensors on the drone. Photo © Robin Berglund

Report's title

Use of Drones in icebreaker operations - a feasibility study

Customer, contact person, address Finnish Transport and Communications Agency, Lauri Kuuliala, PO Box 320, FI-00101 Helsinki, Finland	**Order reference** W19-5 DronIce
Project name DronIce	**Project number/Short name** 122534/DronIce
Author(s) Robin Berglund, Lauri Seitsonen	**Pages** 55/54
Keywords Drone, UAV, UAS, Ice monitoring, icebreaking	**Report identification code** VTT-R-00416-19

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 – what is the state-of-the-art in UAS technology and what could the development of new types of sensors, power sources, automation and communication offer. And what is the legislation that would govern the use of drones for ice surveillance in the Baltic Sea.

This feasibility study reviews the user needs, describes different types of drones and summarises the characteristics of available sensor types. The necessary elements of an operational system, are described. The legal framework applicable to operations involving drones, is summarised, including the plans for harmonisation of the rules on EU-level.

A ball-park estimate of the savings that can be obtained by reducing unnecessary icebreaker transits because of better real-time information, is 2 to 13 k€/icebreaker/month (with some estimates as high as 20 k€/mth. The investment cost for a high-end drone may be 50 -70 k€ plus investments in command, control and processing. Thus there is a potential to build a UAS with a reasonable ROI, but pilot projects are needed to reduce the uncertainties in both the benefit and cost estimates.

The study concludes with suggestions on how to proceed pinpointing the main open questions that should be resolved before investment decisions regarding possible drone-based systems can be made.

Confidentiality	Restricted, will be made public

Espoo 28.8.2019

Written by	**Reviewed by**	**Accepted by**
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Preface

The DronIce feasibility study, funded by the Swedish – Finnish Winter Navigation Research Board (Project number: W19-5 DronIce), was done during spring 2019 and finalised in autumn 2019. The study included interviews with experienced icebreaker officers to gain an understanding of the needs and possibilities to use drones in icebreaking operations. The icebreakers are using satellite images operationally since many years and the information provided by the satellite based active microwave Synthetic Aperture Radar system is very valuable when planning the icebreaking operations and giving advice to the merchant ships navigating in wintertime in the Baltic Sea. Still, there are situations when drones could provide additional information and thus help the icebreakers to save costs by better route selection or providing correct information to ships navigating in drifting ice, where the conditions may sometimes change quite rapidly.

The study is written by Senior Scientists Robin Berglund and Lauri Seitsonen at VTT Technical Research Centre of Finland.

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

A summary of the User needs has been compiled and delivered to the Steering group earlier.

The comments and guidance of the Steering Group is greatly acknowledged. I also want to thank Tomas Årnell from Swedish Maritime Administration for arranging and hosting a meeting in Stockholm and Tuomas Taivi from the Finnish Transport Infrastructure Agency for providing data about icebreaker activities that have been used as basis for my analysis. The images and advices from Jonni Lehtoranta from the Finnish Meteorological Institute are highly appreciated.

Espoo 28.8.2019

Robin Berglund

Contents

1. Introduction

The focus of this feasibility study, called Dronice, is on the possibilities and benefits from utilizing UAV:s (drones) for optimal route planning and tactical navigation in icebreaker operations. The goal of the study is to provide background information on how the icebreaking operations could benefit from drones as a complement and enhancement to the existing means of ice monitoring and if there are other ways of utilizing drones in icebreaking operations.

Previously, manned helicopters were used for ice reconnaissance, but now regular Synthetic Aperture Radar (SAR) satellite images have replaced them as the main information source for ice situation. However, the space-borne observations require a complementing data source that can offer data with high resolution and during time gaps of satellite image services.

The feasibility study starts with a User Needs consolidation section. This was done in the form of interviews with the users and by conducting a web survey directed to the captains and mates on board the Finnish and Swedish icebreakers. The requirements of a drone system is described in the next section, where the environmental conditions are described as well as requirements regarding the information acquisition and provision to the users.

Examples of drone alternatives is handled in chapter 5. Sensor alternatives that can be used as payloads is handled in chapter 6. Telecommunication issues are the subject of chapter 7. In chapter 11 legal constraints are described and the report is wrapped up with an outline of how to proceed.

Limitations

This is a feasibility study with no new pilot trials. The targeted geographical region is limited to the Baltic Sea although some of the icebreakers have been involved in operations in the Arctic and Antarctic regions and may be so in the future also. The conditions and needs in those polar areas, are however, very different from operations in the Baltic Sea and the needs are then determined by the goals of the activities of the company or organisation that has commissioned the icebreaker for specific purposes.

2. Definitions

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

ATC	Air Traffic Control, part of ATM
ATM	Air Traffic Management
BRLOS	Beyond Radio line-of-sight
BVLOS	Beyond Visual line-of-sight
DAA	Detect and Avoid
Drone	a synonym to a UAV
FMI	Finnish Meteorological Institute
GNSS	Global Navigation Satellite System

GPU	Graphics Processing Unit is a special stream processor used in computer graphics hardware. Can be used for efficient parallel processing in algorithms involving matrix operations
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.
Model aircraft	A Model aircraft is an unmanned aircraft that is used for recreational or sports purposes. A Model aircraft can be either remotely piloted or autonomous.
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.
RPA	**Remotely piloted aircraft (RPA).** A subcategory of an *unmanned aircraft. An RPA is a UA which is piloted from a remote pilot station.* RPA will be subject to all the same equipage and certification requirements as manned aircraft operating in the airspace/or conducting procedures; they will have the same separation standards. In other words, RPA act like and are treated like manned aircraft. *(ICAO)*
RPAS	Remotely Piloted Aircraft System. This term is preferred by the international aviation-related agencies like the International Civil Aviation Organization (ICAO). *A remotely piloted aircraft, its associated remote pilot station(s), the required command and control links and any other components as specified in the type design. (ICAO)*
SAR	Synthetic Aperture Radar OR Search And Rescue
UA	**Unmanned aircraft (UA).** *Any aircraft intended to be flown without a pilot on board is an unmanned aircraft. They can be remotely and fully controlled from another place (ground, another aircraft, space) or pre-programmed to conduct its flight without intervention. (ICAO). This does not include model aircraft (Traficom)*
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. User Needs

3.1 Scenarios

The objective of the User needs task was to identify the situations where drones could be useful in icebreaking operations. The methodology consisted of interviews of experienced users and a questionnaire that was sent to the icebreaker masters and officers in Sweden and Finland. Based on the answers, the situations where drones could be of use, can be grouped into the following categories:

a. When the icebreaker supervises ships

b. When the icebreaker is engaged in tactical ice navigation

c. other situations

In the following, the scenarios are described more in detail.

a. When an icebreaker supervises other ships, normally the icebreaker is stationary in a drift ice area outside the fast ice (in positions like Bjuröklubb, off-Luleå, the Quark). Sometimes this can last for up to 14 days. The icebreaker informs merchant ships which waypoints they should follow. These waypoints are also available on a dedicated website and on certain services designed to instruct ships engaged in winter navigation in the Baltic Sea. To ensure that the leads are still navigable, a drone could be used to check the condition of the lead before a ship is instructed to use that lead. It is also important to check if the ice has drifted, and if so, if there is a need to change the ice waypoints that have been given, or will be given, to the ships. The waypoints given to the merchant ships could thus be verified using drones and possible problematic parts, “bends”, in the channel could be identified and positions of these bends alerted to the ship so that the ship could take proactive actions in order to reduce the risk of getting stuck as the ship then would have to wait for icebreaker assistance to proceed. The channel inlets (“ränninslag” in Swedish) are important - the merchant ship has to find the channel inlet to the fast ice and a navigable channel in the drift ice field has to be found to/from this inlet.

   After weather changes or strong winds, the ice situation should be checked - are there new leads or old ones that have closed?

   To measure the ice drift (for verification of the ice forecast or for nowcasting purposes or for estimating ice pressure, which is often correlated to strong ice drift), it would be useful if the drone could land on the ice for at least ½ minute enabling a real-time observation of the ice drift speed and direction.

   The distance between icebreaker and drone could be up to 20 NM and a flight time of 2 hours would be desirable.

b. In tactical ice navigation, the icebreaker would benefit from a higher look-out position that would give the possibility to look ahead for 5 km. A camera on a drone hovering 100 m above the water level could give this view. At this height, the camera would be above steam fog - which often reduces the visibility from the icebreaker bridge.

   Sometimes there is a need to check if a route is still navigable - this is then done in advance before setting off, i.e. when the icebreaker has been idling and is intending to begin an assistance operation or going to a position where a ship needs assistance.

c. Other situations when a drone could be used:

   i. to check the condition of instruments high up in a mast

   ii. to transport small objects between an icebreaker and another vessel

iii. to document damages on other ships (caused by ice or accidental contact between ship and icebreaker) or examples of wrong ballast levelling

iv. to check the ice condition around a ship that reports having problems while trying to proceed along the given route and calls for icebreaker assistance

3.2 Estimation of quantitative benefits

The potential benefits were estimated by asking the respondents to give their subjective estimate of how many hours the icebreaker could save by sending a drone instead of going on-site with the icebreaker itself. Assuming a fuel consumption of 50 tonnes/24 hours and a fuel price of 500 €/ton, the potential savings would be as listed in Table 1.

Table 1 Estimated savings per month in tonnes of fuel and corresponding cost per icebreaker based on the user answers.

Estimated savings per month (tonnes)	Lower quartile (Q1)		Median		Mean		Upper quartile (Q4)	
Minimum	0.5 t	0.25 k€	2t	1 k€	4.5 t	2.2 k€	5.5	2.8 k€
Typical	4 t	2 k€	20t	10 k€	17.1t	8.6 k€	25	12.5 k€
Maximum	11.5 t	5.7 k€	20t	10 k€	26t	13 k€	40	20 k€

A more detailed report of the User Needs is given in a separate document, here included as an Appendix.

4. Unmanned Aerial Systems (UAS)

Unmanned Aerial Systems for remote sensing consist of the following elements (adapted from [1]):

- The Unmanned Aerial Vehicle (or drone), is the flying part of the system (the aircraft segment of the system). This vehicle can then be remotely controlled or contain different capabilities of autonomous flying. The following functionalities of the UAV can be identified:
    - Flight navigation – autopilot functionalities to keep the aircraft on the desired track and to perform controlled steering actions. Includes the navigation sensors (position, attitude and time information, interaction with the propulsion system and steering elements). Transponders (to make the drone visible to other aircrafts) and Collision avoidance elements may be part of an advanced navigation system.
    - Data acquisition – obtaining data using payload sensors (cameras, etc.), control of the payload and storage of the payload data.
    - Data processing – the obtained data can be processed on board – or relayed as such to the ground segment. It is important to include sensor position data

    and possibly other metadata. On board processing may reduce the amount of data to be transferred to the Ground segment. Processed image information can also be used to guide the drone flight path in an autonomously flying drone (the drone could be programmed to follow a lead based on camera input).

- The Ground segment, with the following functionalities:
    - Mission planning – very important to get useful results
    - Aircraft control –remote control of the aircraft, monitoring of the performance of the aircraft
    - Sensor control –control of the payload (cameras..)
    - Ground segment data processing –necessary processing and analysis of the (payload) data
    - Data distribution –distribution of the processed data to the users and possibly other stakeholders
- The communication element (C2 Link), which is the connecting part between the ground segment and the aircraft segment. The communication element may utilise some communication infrastructure like cellular networks or satellite communication if a direct communication link between the aircraft and the ground station is not sufficient or feasible. In other words, the terms RLOS and BRLOS are often used, where RLOS (Radio line-of-sight) means that direct communication is possible and BRLOS (beyond radio-line-of-sight) when it is not.

The processing depends on the needs of the users – for the icebreakers and for mapping of ice, there is no need to perform accurate photogrammetric mapping. The real time aspect is more important, what is the situation right now and also, what changes can be observed compared to the conditions one or two days ago. To enable comparison with earlier satellite images or reported observations from other ships, the images should preferably be processed to enable comparison of the positions of distinct ice features and a quantification of width of leads, size of ice floes and, possibly, the height of the ridge sails in a ridged ice field. These needs could be satisfied using direct sensor orientation (DiSO) a.k.a. direct georeferencing – type of photogrammetric processing, where the image is mapped to a ground reference using orientation information on the sensor and the camera is precalibrated. This is in contrast to the majority of how UAS imagery is processed today, i.e. using the InSO methods (indirect sensor orientation) where orientation and calibration parameters are derived solely from photogrammetric measurements and ground control points. [2]

The RPAS Yearbook by van Blyenburg [3] contains a vast world-wide inventory of UAS. This inventory shows the growing supply of UAS – and the largest group, the mini-UAS which are defined by an operative range of less than 10 km, allowed to fly below the ceiling of segregated airspaces, have an endurance less than 2 h and have a max Take-off weight (MTOW) of 30 kg, features **662** referenced systems (490 in 2013). The following chapter only shows some examples of possibly relevant UAVs – with no implication that the examples would be the most suitable for icebreaking operations.

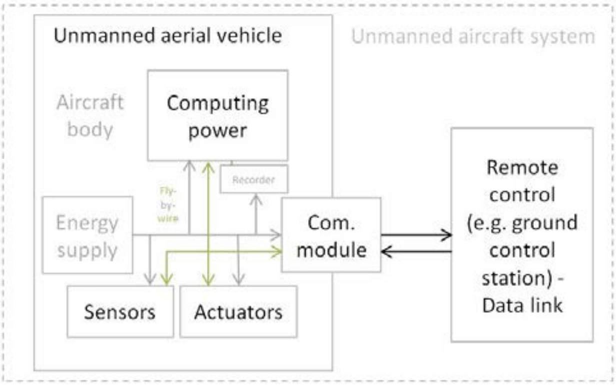

Figure 1 General physical structure of an UAV. By Maxorazon - Own work, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=46770255

5. Types of UAVs

UAV:s come in many shapes (see [3]) The most common type is a multicopter (multirotor) with at least 4 rotors. An advantage of having more than 4 rotors is that it provides some redundancy. A rotor failure for a multicopter with more than 4 rotors may not be disastrous but still enable controlled landing. Fixed wing UAVs have a longer range and enable faster flight speed than multirotors. A third category are the tethered drones (or balloons) which are either lighter-than-air or have a tether providing the drone with the necessary power to keep the drone flying to a limited height.

A comparison of multirotors, fixed wing drones and aerostats is summarised in the table below (adapted from www.inertiallabs.com)

Multirotor	**Fixed wing**	**Aerostats (tethered balloon systems)**
Advantages:		
+ Maneuverability	+ Flying range	+ relatively low cost
+ affordable	+ stability	+ rapid deployment
+ Compact size	+ less vibration	+ Can operate 24 hours per day, with few weather limitations
+ ease of use	+ Linear flight	
Drawbacks:		
- Vibration	- Larger take-off zone	- high winds may be a problem
- Flying range	- challenging to land on small area	- very limited range (tether)
	- Higher price	- the tether itself requires extra attention to avoid getting “mixed-up” with masts and other superstructures on the ship.
	- Challenging to fly	- resupply of helium may be difficult in some areas

Fixed wing UAV:s provide longer flight distances, but are harder to land when space is limited, as on an icebreaker. Take-off from a mobile platform is possible using a catapult arrangement.

A VTOL aircraft (Vertical take-Off and Landing) has both wings and rotors that can provide vertical lifting force at take-off and landing. This lifting force is either realized by only turning the rotors or the whole wing in an upward position, or then the aircraft is equipped with two sets of propellers - one set providing lifting force and another providing the forward thrust.

Figure 2 Two VTOL drones, the left by the Swiss company Wingtra AG (wingtra.com) the right by the Dutch company Vertical Technologies (www.deltaquad.com)

Although fixed wing aircrafts have a higher flight speed than multicopters, the fixed wing and VTOL aircrafts are more sensitive to wind than multicopters, which makes take-off and landing more challenging for a VTOL than a multicopter.

UAV:s can also be characterised by the way they are powered. Usually Lithium-ion batteries are used, but the range and operating time can be extended by using hybrid solutions where a combustion engine operates a generator providing the electrical power for the rotors. A battery is then also included as a fall back for safe landing in failure situations. A drawback of hybrid solutions is the noise caused by the combustion engine – but this is not an issue for icebreaker operations. Fuel cells could be a solution in future drones – fuel cell technology is being developed and may be a viable alternative for drones in the near future – especially in cases where silent operation is important.

Figure 3 To the left the hybrid BOXER drone by the Finnish company AVARTEK ky, which has a combustion engine enabling a flight time of 2 hours with 8 kg payload, to the right a fuel cell powered drone by the UK company Intelligent Energy ltd (www.intelligent-energy.com)

Tethered balloon systems (aerostats) are tethered balloons (or other lighter-than-air craft) that gain lift though the use of buoyant helium gas, deployed from mobile or permanent platforms. By combining the balloon with a kite-like wing (as the Helikite by Sandy Allsopp, http://www.allsopphelikites.com/) the aircraft exploits both wind and helium for its lift. A tethered balloon can be deployed to altitude of up to 6 000 m and can thus provide excellent tactical support to an area of operations, potentially covering a few hundred km. Using a Helikite at higher altitudes (higher than 150 m) requires permission from aviation authorities. Clouds are a restriction to the usefulness if the sensor is an optical (or thermal) camera.

Using tethered drones from an icebreaker is challenging if the drone should be operable when the icebreaker is moving. The strong wind may restrict the length of the tether to some tens of meters because of the wind pressure on the tether line.

Figure 4 A 35 m ^{3} Allsopp Helikite in flight (http://www.allsopphelikites.com/)

6. Sensors

6.1 Payload sensors

6.2 Optical sensors

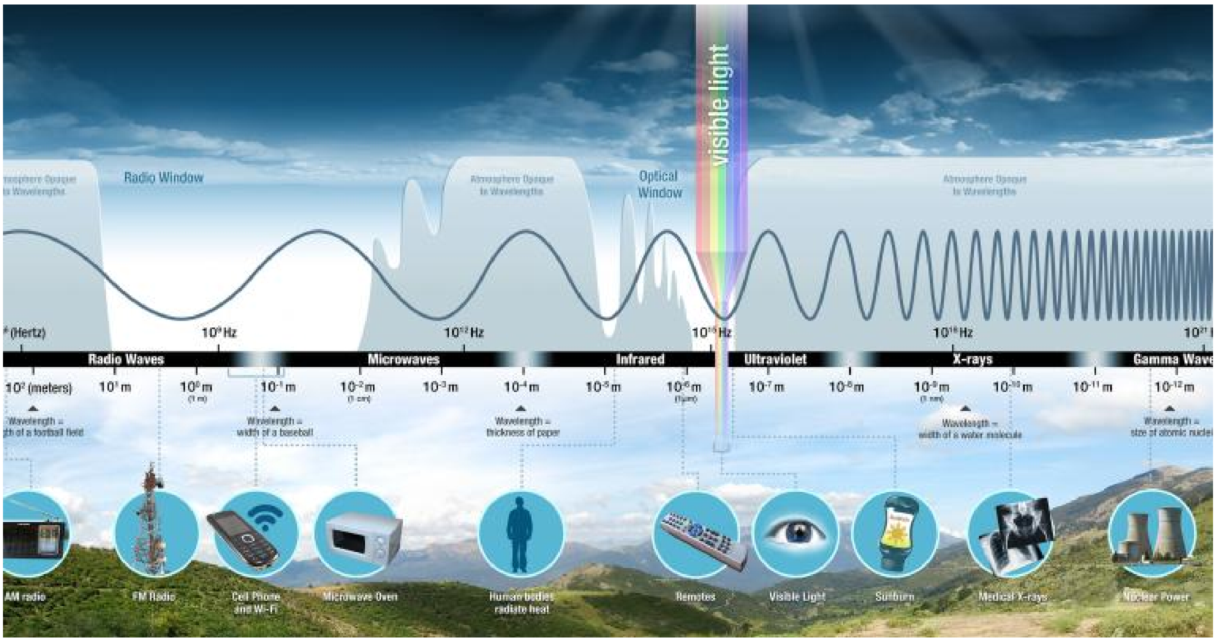

Figure 5 The electromagnetic spectrum [4]

Optical sensors are sensitive to electromagnetic radiation around the visible range of electromagnetic radiation (Figure 5).

The spectral regions of passive optical sensors can be divided into ultraviolet (UV), visible (VIS) and near-infrared (NIR). Optical sensors include hyperspectral sensors, multispectral imaging systems, still and video cameras, UV and NIR sensors [5]

A video camera can provide real time information about the scene and act as guidance for a remotely controlled aircraft. The resolution depends on the camera and the telemetry capabilities. A HD camera has the resolution of 1280 x 720 (or 1920 x 1080 for Full HD) a 4k UHD camera a resolution of 3840 x 2160. Operating the drone interactively guided by a real time video stream – is called FPV (First-person view). In FPV the video captured by the drone is transmitted to goggles, a headset, a mobile device or another display.

For photogrammetric processing of the captured images, normally a lens with a fixed focal length is used – otherwise calculation of the calibration parameters of the lens as part of the postprocessing of the material, is difficult to do.

An interesting option is a camera for low light conditions where new technologies like ICCD (Intensified CCD) and EMCCD (electron-multiplying CCD) provide imaging at very low light levels. However, these special cameras may require cooling down of the sensors and are thus quite expensive and less robust. New technologies are emerging, such as the QIS (Quanta image sensor), but these are not yet ready for operational use. [6]

Ordinary optical cameras are sensitive to wavelengths corresponding to visible light. These cameras are sensitive to the reflectance of light where the source usually is daylight. Other wavelengths may be of interest, such as thermal radiation where the source is the electromagnetic radiation emitted by the object itself.

Visible (VIS 0.4–0.74 µm), and Near Infrared (NIR 0.74–1.4 µm) sensors can be used during daylight hours. Short-Wave Infrared sensors (SWIR 1.4–3.0 µm) are effective from daylight hours to dusk.

SWIR is also effective in hazy or foggy conditions.

Multispectral cameras provide information in several spectral bands (4-16). In hyperspectral cameras the number of spectral bands is higher – several hundreds. Hyperspectral cameras have been used in agricultural and forest monitoring applications as well as for detecting oil spills [5]

When monitoring of ice, snow and water, however, hyperspectral cameras offer very little, if any, advantages compared to normal RGB or IR cameras.

6.3 Infrared sensors and radiometers

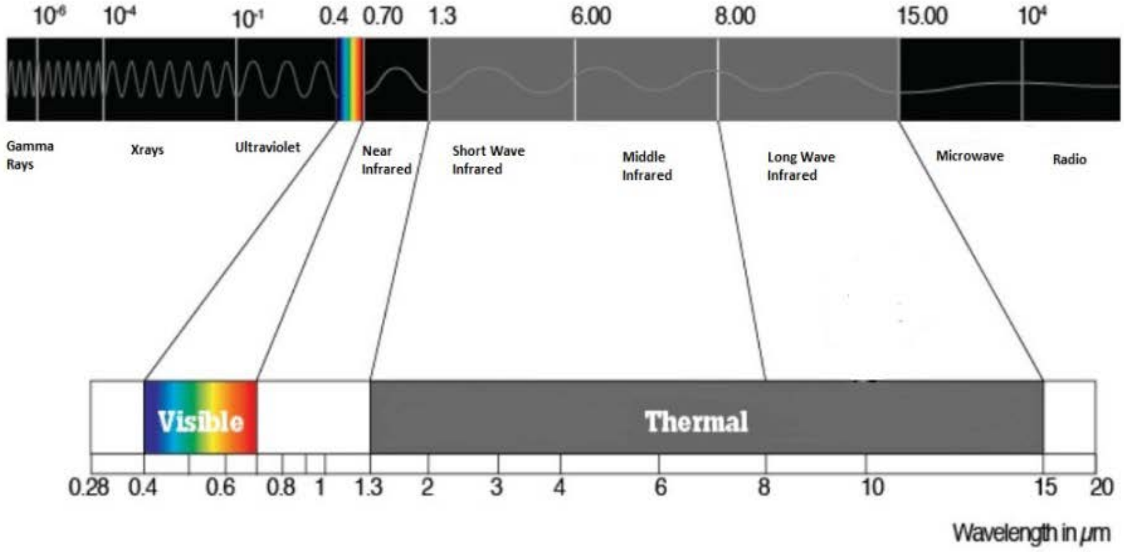

Figure 6 The visible and infrared parts of the electromagnetic spectrum (from www.dronezon.com)

A thermal camera can be used to identify and measure temperature difference of objects. Also, as the radiation emitted from a surface depends on the emissivity of the object surface, objects of equal temperature can be distinguished if the objects have different emissivities. When considering differentiation between water and snow, the emissivity coefficient of these are quite close to each other (0.99 and 0.98). However, if the ambient temperature is less than the freezing point of water, open water can be distinguished quite clearly from ice. The temperature could also - if the ice is not covered with snow - indicate the thickness of the ice if the ice is thin. A thermal camera can be used independent of light conditions and is - to some extent - less sensitive to light snowfall and haze. Fog can, on the other hand, affect the thermal calibration of the camera giving temperature readings that do not correspond to the temperature of the emitting surface [7].

Passive microwave sensors or microwave radiometers (MWRs) measure emitted radiation with wavelengths in the range of millimetres. As with thermal detection, these sensors are sensitive to the emissivity of the surface. In the microwave region (20 – 70 GHz) there is quite a big difference in the emissivity of water and ice and microwave radiometers could thus be used to distinguish open water from ice. The spatial resolution of such a sensor (imaging radiometer) is, however, not enough for the identification of useful details - like width of lead.

Stereocameras – using a pair of synchronised cameras - enables the distance to the objects to be estimated in the same way as humans do. When combined with special processing units, a 3D model can be constructed in real time. There is a maximum distance for estimating the depth, which is determined by the distance between the cameras (stereo base) and the resolution. One example is the ZED stereo camera by Stereolabs [8] where the video feed from two cameras are processed by a GPU and the developers claim to be able to obtain depth maps with up to 2.2 kpixels in real time with a maximum depth of 20 m.

Another approach is to utilise the motion information in creating a 3D model. The Structure from motion (SfM) is a photogrammetric range imaging technique for estimating threedimensional structures from two-dimensional image sequences that may be coupled with local motion signals. [9]

Even if discrete photos do not provide 3-D information as such, overlapping images can be postprocessed to produce an orthorectified map with 3-D information (see Table 8). Normally this is done on a server where and when the images have been uploaded, but technically this could be done on the Drone thus drastically reducing the need for data transmission.

6.4 Radar and other active sensors

In general, Radar sensors are active systems, i.e. the transmitter generates an electromagnetic pulse (usually) and the backscattered signal is then detected by the sensor. Radar systems include Side-Looking Airborne Radar (SLAR), Synthetic Aperture Radar (SAR), X-Band (Marine Navigation) Radar and Ground Penetrating Radar (GPR).

The advantage with microwave active radar systems is their independence of ambient light conditions and that the signal penetrates clouds and fog. Side-Looking Airborne radar has been used from aircrafts for ice monitoring, but as the spatial resolution depends on the length of the antenna, use of SLAR requires quite large antennas restricting the use to fixed-wing planes. SAR uses the forward motion of the sensor platform while taking into account the Doppler shift of the collected signal to synthetically increase the antenna aperture. Synthetic Aperture radar is the most important instrument for ice monitoring from space, although airborne SAR instruments do exist. Examples of such systems are given in the table below (Table 2).

Table 2 Examples of synthetic aperture radars for UAS (from [2])

Manufacturer and model	**Spectral bands**	**Weight (kg)**	**Transmitted power**	**Resolution (m)**
IMSAR, NanoSAR B	Ku	1.58	1 W	0.3 .. 5
Fraunhofer FHR Miranda-35	W		0.1	0.15
NASA JPL UAVSAR	L	200	2000	2
SELEX Galileo PicoSAR	X	10	-	1

Lightweight SAR systems for near-real-time use have been difficult to design because of the heavy processing requirements to obtain SAR-based images, but progress is to be expected in this field because of advances in utilising GPU processors for the processing. [10]

A marine radar is primarily used for navigation purposes and is also an important source of ice information. The range of ship-borne radar is limited to approximately 8–30 km, largely determined by the height of the antenna. Suppliers like Furuno and Consilium, provide add-on processing units that integrates the signal over a longer time to detect the structure of ice up to a radius of 3 NM. [11].

Ground Penetrating radar using short pulses (an Ultra Wide Band - UWB) has been used to detect objects embedded in snow when carried on a drone. Also ice thickness measurements have been conducted using such a device, but the sensor has usually been very close to the ice (on a sledge or similar) [12], [1]. The technology has a potential for pointwise ice thickness measurements. Still, the technology is not mature enough for operational use.

A technology based on detecting the strength of the magnetic field caused by eddy currents generated in conducting water below the ice, has been utilised in the EM sensor system. This method has thus been used to measure ice thickness remotely [13]. The distance to the water below the ice cover is estimated based on electromagnetic induction and eddy currents. The distance to the surface of the ice is measured using a laser and the difference, which is the ice thickness, is calculated. The weight (tens of kilograms) of such a sensor is, however, an obstacle for using it on a drone.

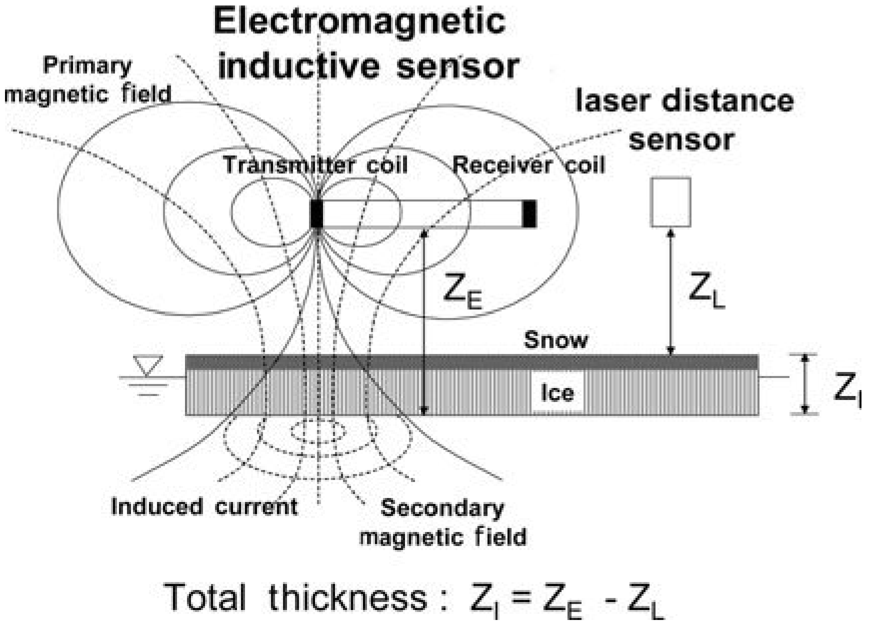

Figure 7 Principle of E/M ice thickness sounding [14]

LiDAR (Light detecting and ranging) is commonly used to make 3-D representations of an object. A drone can carry a lightweight LiDAR and scan the surface of the ice. Thus, the shape of the surface of the ice can be detected and modelled. This could be advantageous when quantifying the height of the sails of the ridges in a ridged ice field. Potential problems when using LiDAR on ice could be caused by ice surfaces reflecting the light beam away and also missing reflections from open water. Most LiDARS use a pulsed light wavelength of 905 or 850 nm. Some manufacturers use a wavelength of 1550 nm, mainly because a laser at this wavelength is allowed to operate with higher power without being a risk to the human eye. For detection of snow and ice, a wavelength of 1550 nm does probably not give any advantages compared to the more common 905 nm wavelength – actually the reflectance of snow is much lower at 1550 nm than at 905 nm (See Figure 8).

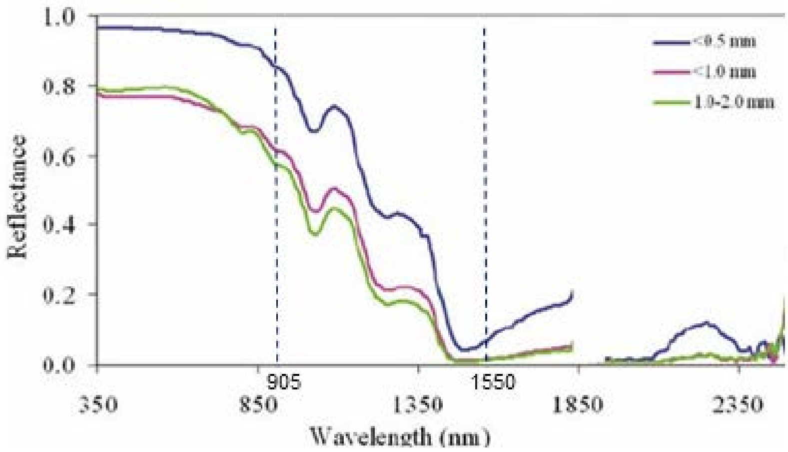

Figure 8 Snow reflectance for varying grain sizes.(Lines at 905 and 1550 nm added by the author) [15]

Safety issues are a concern for terrestrial LIDARS. The power of the pulsed laser beam is restricted to ensure that it can cause no harm if a person is accidentally looking into the laser when being active. This restriction is less stringent for LiDARS flown from an aircraft.

There are many LiDAR manufacturers on the market. Specifications of one example product are shown in Table 3 below.

Table 3 Main characteristics of a commonly used LiDAR (VELODYNE VLP-16 LW)

Channels	16
Measurement Range	100 m
Range Accuracy	Up to ±3 cm
Vertical Field of View	30°
Vertical Angular Res	2.0°
Horizontal Field of View	360°
Horizontal Angular Res	0.1° – 0.4°
Rotation Rate	5 Hz – 20 Hz
Power	8 W
Weight	830 g
Wavelength	903 nm
Operating temperature	-10°C .. +60°C

The price of such an instrument was about $4.000 (Jan 8, 2018). About the resolution: When used from a drone, the instrument would be tilted 90 degrees whereby the “vertical resolution” in Table 3 would correspond to the direction of the flight and the parameter “horizontal angular resolution” would be the resolution perpendicular to the flight path. Flying at a height of 50 m, a 0.1° resolution would mean approximately 10 cm spacing between the laser points on the ground.

Time-of-flight cameras

A Time-of-flight camera is a range imaging camera system that is based on the technique to resolve the distance between the camera and the object for each point of an image by measuring the round trip time of a light pulse provided by a laser or a LED. It thus works like a scannerless LiDAR. The spatial resolution of ToF cameras is generally low, about 320 x

240 pixels for commercially available devices. A drawback is that the system is sensitive to ambient light (cannot be used in daylight conditions) and has a limited range. [16]

6.5 Summary of payload sensors

Table 4 Summary of sensors

Sensor	**Purpose**	**Advantage**	**Disadvantage**
Videocamera	For real-time monitoring and guidance of the drone, First-person-view.	+ inexpensive + useful/necessary for interactive guidance	- No quantification of distances or heights - not necessary if the drone is flying according to a preplanned route - if used for FPV, a separate observer is required (usually).
Optical camera	For accurate imaging	+ standard equipment, thus low-cost + enables photogrammetric processing	- cannot be used in low light conditions - photogrammetric processing takes time
Stereocamera	To get an instant depth perception	+ useful for height estimation of ridges etc.	- requires special processing - works only on a limited range - cannot be used in low light conditions
Thermal camera	To enable imaging during low light conditions	+ if ambient temperature is low, open water and thin ice can be seen well. + less sensitive to foggy conditions + useful in Search-and-Resque situations for detecting objects (people) warmer than the ambient temperature	- lower resolution than optical cameras - more expensive than optical cameras - requires temperature differences to distinguish features i.e. not so useful when ambient temperature is near zero.

Microwave radiometer	To distinguish between open water and ice	+ not dependent on light conditions	- large footprint, no details - only 1-D signal
GPR/UWB radar	To estimate ice thickness	+ not dependent on light conditions + a method to obtain an estimate of ice thickness	- large footprint – must fly quite close to the ice surface - technology requires development - difficult to interpret signal if there are many frozen layers - only 1-D signal
EM measuring device	To estimate ice thickness	+ enables ice thickness measurements off the ice surface + widely used in ice research	- too heavy for drone use - only 1-D signal
LiDAR	To obtain a point cloud from which ridge height and surface roughness can be determined	+ a relatively fast way to obtain accurate surface topology information + LiDAR instruments are available for drone use with a mass of less than 1 kg. + works well at night and low light conditions + technology is advancing fast driven by the interest to develop self-driving cars	- quite expensive - backscatter/ reflections from ice and open water may be a problem (i.e. low reflection coefficient) leading to areas with no signal - requires high processing capacity/ high bandwidth to obtain results in near real time
Time-of-flight camera (ToF)	A ToF camera could be used to get a quantitative measure of the ice surface – especially height of ridges (example manufacturer: Infineon)	+ a low cost alternative to other distance measuring techniques (LiDAR)	- only for short ranges (max 5 m) - rather limited pixel resolution

When evaluating the usefulness of a LiDAR (and other sensors) we should keep in mind the User’s needs - to estimate the navigability through the ice field, i.e. the position of a lead or crack, the position of the ice edge, the degree of ridging, the extent of a ridged ice field and current ice drift velocity and direction. The sensor(s) should thus enable the user to do the following analysis: distinguish between open water and ice, identify and quantify ice ridges (height and density of ice ridges, degree of ridging), estimate ice thickness and ice drift as well as the position and width of leads. To be able to do this independent of light conditions is an advantage, but not a compulsory requirement.

6.6 Other sensors/devices

6.6.1 Transponders and navigation sensors

Transponders are needed to identify and localise the drone, which is useful for collision avoidance and when the drone is used to guide other ships or vessels in a rescue operation. A Maritime AIS transponder would enable visibility to other ships. Also in Search and Rescue (SAR) operations, manned SAR planes usually have AIS transponders on board. Thus, AIS could be used as a secondary collision avoidance system besides ADS-B. Showing the drone position as an AIS target could be used to share the information to many parties involved such as other ships and on scene coordinators in a rescue situation. [17]

(If the weight (ca 200 g) and needed power is an issue for the drone, the position and other information could be generated as a virtual AIS target by the UAS control station which is aware of the drone position.)

Automatic dependent surveillance—broadcast (ADS–B) is a surveillance technology in which an aircraft determines its position via satellite navigation and periodically broadcasts it, enabling it to be tracked. The information can be received by air traffic control ground stations as a replacement for secondary surveillance radar, as no interrogation signal is needed from the ground. (Wikipedia). An ADS-B transponder would give the UAV visibility to other aircrafts, which is a compulsory safety feature when flying BVLOS.

For take-off and landing, infrared distance measuring sensors would be useful. This kind of sensors are used on advanced commercial drones.

Distance and proximity can also be measured using ultrasonic transducers (compare with parking assistance in cars).

Other sensors that have been suggested, are temperature and atmospheric pressure sensors. A variant of this is a barometric altimeter.

6.6.2 Positioning, attitude control

The “autopilot” loop in an UAV reads repeatedly the aircraft’s position, velocity and attitude from the navigation system and uses these parameters to feed the flight control system to guide the aircraft. [18]

The UAV determines its position using a GNSS positioning device. Standard components exist to utilise GPS, GLONASS, BeiDou and Galileo satellite navigation systems. For more accurate positioning, RTK (Real-Time Kinematics) technology is used. In RTK, a local fixed reference station is needed whereby the errors due to atmospheric conditions can be compensated for. When used from a mobile base (a ship) – normal RTK technology cannot be used because of the requirement of a fixed position for the reference station.

Using overlay networks (like DGNSS) or Network RTK, the positioning accuracy would be accurate enough for most applications. In Finland, the open DGNSS service can be used in real time and it enables about half meter precision. Currently, however, the RTK service offered by the Finnish National Land Survey (NLS) is only available for research purposes.[19].

The drone also has to have an IMU (inertial measurement unit) *which is an electronic device that measures and reports a body's specific force, angular rate, and sometimes the magnetic field surroundings the body, using a combination of accelerometers and gyroscopes, sometimes also magnetometers.* (Wikipedia). High-end IMU:s use fiber-optic gyros (FOG) while low end IMU:s are based on MEMS (Micro-Electro-Mechanical Systems) gyros. MEMS IMUs are ideal for smaller UAV platforms and high-volume production units, as they can generally be manufactured with much smaller size and weight, and at lower cost. FOG IMUs use a solid-state technology based on beams of light propagating through a coiled optical fibre. They are less sensitive to shock and vibration, and offer excellent thermal stability, but are susceptible to magnetic interference. Quartz MEMS IMUs use a one-piece inertial sensing element, micro-machined from quartz. The technology features high reliability and stability over temperature. [20]

Low cost IMUs are based on magnetometers, and are thus susceptible to local magnetic field variations, which may cause problems when operating from a ship with a hull made of steel. This problem has been experienced in trials on the icebreakers when the control system of the UAS has warned of unreliable sensor input due to strong magnetic variations, which could affect take-off and landing of the drone on an icebreaker.

For landing and take-off purposes UAVs can be equipped with proximity detectors (also used for collision avoidance and Obstacle detection). The technique used by commercial drones is often based on a combination of many techniques (sensor fusion).

Consumer and professional drones have utilised infrared and sonar sensors for proximity detection. This technology is also used when landing or for keeping the UAV on a given height above the terrain.

A technology called SLAM (Simultaneous Location and Mapping) is a process whereby a robot or device can create a map of its surroundings, and orient itself properly within this map in real time [21]. For commercial systems like the Mavic APAS (Advanced Pilot Assistance System), there is a note, however, that APAS may not function properly over water or snow.

7. Communications

An UAV needs two types of communication capabilities - communication for command and control of the UAV and communication needs of the payload.

Table 5 Characteristics of radio links [22]

	Link speed	**Criticality**	**Latency**
C2 = command and control	~100 kbps	High	<3s
Payload needs	typically 1.5 - 5 Mbps	Low	Depends on mission: 100 ms to not significant

Normally there is a direct radio link between the UAV and the controlling unit (Radio line-of-sight). In areas with good cellular coverage, a datalink using 4G/LTE modems is also feasible. In special cases, communication over a satellite link could be the solution (although a rather expensive one).

Table 6 Comparison of various transmission technologies for terrestrial communications [23]

	802.11p for ITS	Wifi	LTE/4G	5G mmW	VHF digital radio	HF
Spectrum	5.9 GHz	2.4/5 GHz	450 MHz–3.7 GHz	24–86 GHz	30–300 MHz	3–30 MHz
Bandwidth	10 MHz	20/40 MHz	From 1.4 to 20 MHz	Up to few GHz	25 kHz channels, can be bundled together e.g. to 100 kHz	Up to 48 kHz
Max. bitrate	27 Mbps	600 Mbps	75/300 Mbps for UL/DL	Up to 20 Gbps	VDES: up to 307 kbps in ship-to-ship or ship-to-shore, 240 kbps for satellite link	Up to 240 kbps
Tx range	< 1 km	Typically < 100 m, up to 10 km with fixed service	Typically < 2 km, up to 70 km with directional antennas	< 10 m for 60 GHz Wifi, tens of kilometres with fixed links	Up to 85 km	Thousands of kilometres
Cost	Cheap	Cheap	Expensive	Cheap (Wifi), Expensive (Cellular)	Cheap	Cheap

For the icebreakers in the Bothnian Bay, cellular network coverage is available only near the shoreline as shown in Figure 9.

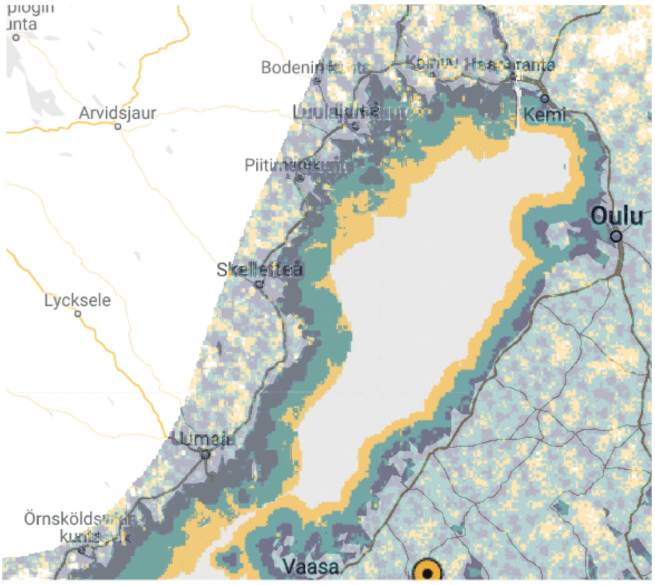

Figure 9 Example of cellular coverage over Bay of Bothnia, operator: TELIA. Orange areas shows maximum extent with basic data communication capabilities, 3G or 4G. (www.telia.fi and www.telia.se)

Note that the payload communication requirements could be decreased by local processing (i.e. processing on a computer on the drone itself) of the sensor data. For example: for a good 3D processing, an image overlap of 60 – 80% is recommended. If the processing is done centrally, the amount of data to be acquired and transferred is 2 – 5 times the amount of data coming out as the result of the processing. This may not be a problem if the capacity of the communication link is high enough, but a higher link capacity requires transmitters that are more powerful and better antenna arrangements.

A table showing the data transfer estimates for data related to an autonomous ship – which is not exactly the same as for a drone – is shown in Table 7.

Another notable feature is that if/when the UAV could (and would be allowed to do so) fly autonomously, this would also reduce the need for a continuous Command & Control link.

Table 7 Data transfer estimates related to an autonomous ship [23]

System	Single file/Image (kB)	Update rate (Hz)	Compressed bit rate (kbps)
Radar/AIS plot	375	0.4	100
Video	200–500	1–10	150–1500
HD video	2600	2	800–1500
LiDAR	up to 200 000	1	1000–2000
Infrared	330	1–10	300–1000
Mechanical sensors	12	0.1–1	1–10
Control data	Remote control, rendezvous	1	1–10
General GMDSS data	Varies		10

7.1 Allowed frequency bands

A drone or remotely piloted aircraft is controlled wirelessly from the ground. The flight control may be a radio transmitter or a more complex control and command station with a video display. Using command and control links, the remote pilot on the ground can control the aircraft and receive real-time information about the aircraft systems, such as the rotational speed of motors.

The most commonly used frequencies for controlling drones (from ground to air) are the ones for **licence-exempt** radio equipment (2.4 or 5.8 GHz). The same frequencies can also be used for the payload devices (a camera or other sensor) that the drone is carrying. Other frequency bands suitable for controlling drones and remotely piloted aircraft can be found in the Traficom's Regulation 15 (for Finland). Note that the frequency **1320 MHz** is only meant for sending video feed from aircraft to the ground. Using this frequency **requires a radio licence** that can only be obtained for a fixed period.

For more information, see [24].

7.2 Use of mobile cellular network frequencies

Generally, it is not allowed in Finland to use mobile network terminals on board an airborne drone, unmanned aircraft or other aircraft unless it is specifically allowed in the Finnish Traficom's Regulation 15.

According to Traficom’s Regulation 15, authorities and major critical infrastructure providers may use mobile communications necessary for performing their tasks on board aircraft without a licence. This arrangement is fixed-term until 30 September 2020.

With the consent of mobile operators, Traficom may also exceptionally grant a **radio licence** that enables using mobile devices for command and control links, payload connections or calls on board aircraft when flying at low levels.

8. Environmental conditions: temperature, wind, visibility, length of day

The environmental conditions are demanding for UAVs operating in wintertime. Looking at the statistics regarding lowest daily temperature at the lighthouse Kemi 1 during winter months (Figure 11) a limiting temperature of -15 °C would exclude 10% of the days, which could be taken as a reasonable limitation. To be safe on the temperature side, a limit of -20 °C would be desirable. A minimum of 15 m/s as maximum wind speed for operations would enable operations for 85% of the time, whereas 10 m/s (as gust wind speed) would be exceeded 40% of the time. (see Figure 10). Considering operations from a moving platform (i.e. the icebreaker), the **relative** wind speed is the important parameter. A ship speed of 10 knots adds (or subtracts) up to 5 m/s to the winds measured from a fixed position. This limits the time window when drones can be used. Icing is also a problem that may be hard to overcome (de-icing sprays could be used). The visibility limitations can to some extent be mitigated by using thermal cameras, but also these are hampered by snowfall.

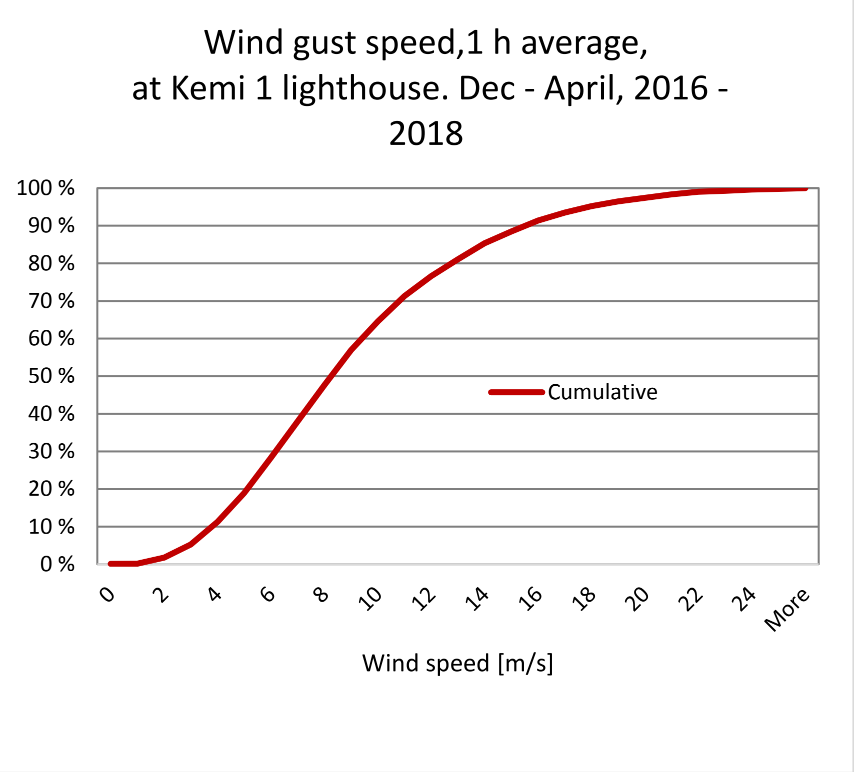

Figure 10 An example of the wind conditions at sea, Bay of Bothnia, Kemi 1 lighthouse measured from wind gust speed (data from FMI).

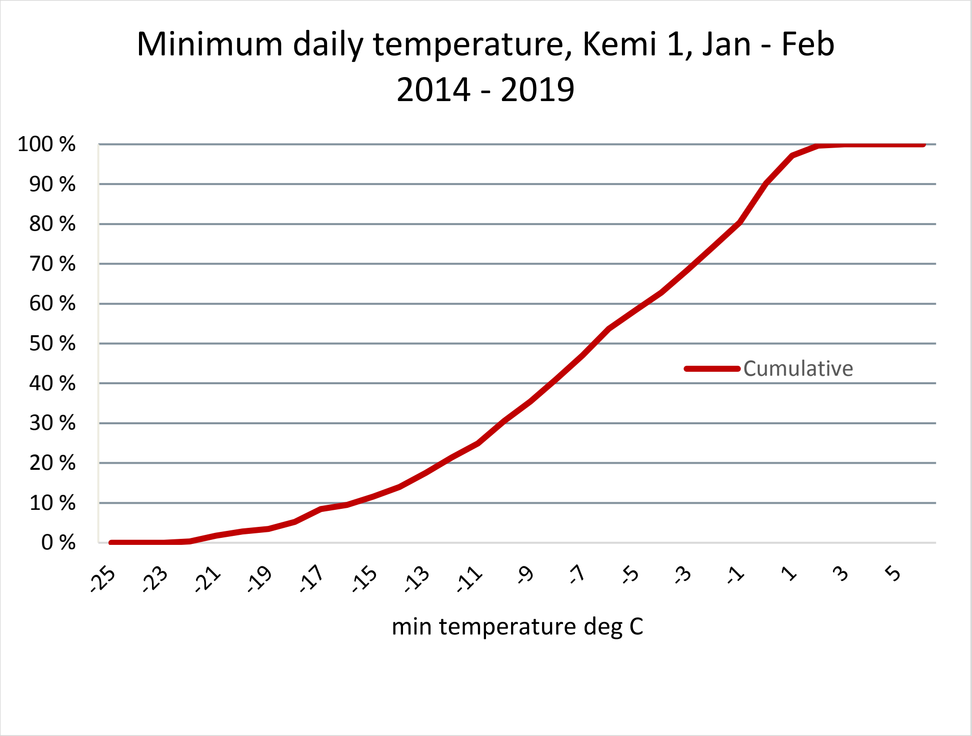

Figure 11 Minimum daily temperature at lighthouse Kemi1 during January and February 2014 – 2019. (data from FMI).

Regarding the lighting conditions at the target latitudes, the length of the day varies as a function of the time of the year as shown in the figure below.

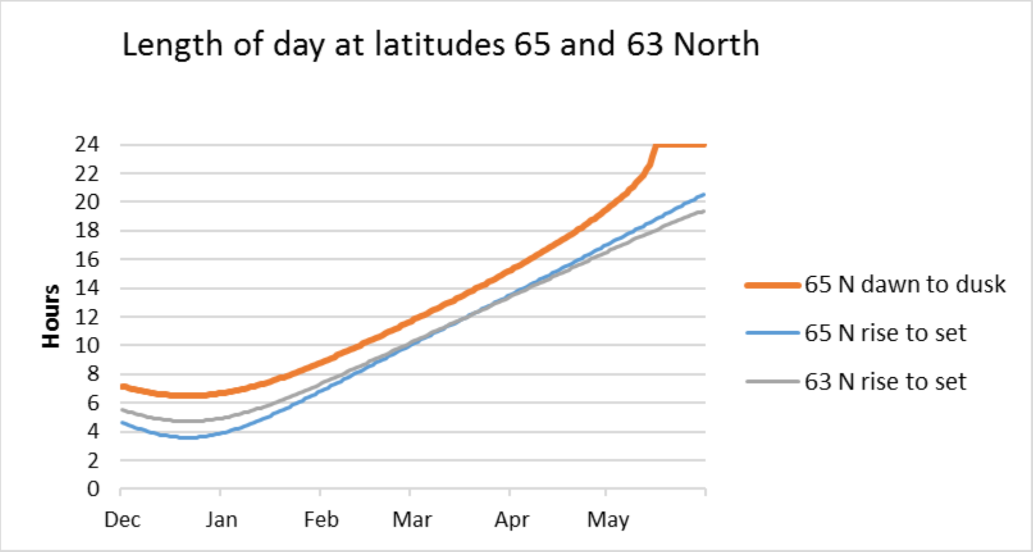

Figure 12 Length of day at latitudes 63 and 65 North from 1st December to 31 st May. 65 N corresponds to the Northern part of the Bay of Bothnia. Dawn and dusk are defined as the moments when the sun is at 6 degrees below the horizon. Durations calculated using a procedure by NOAA (http://www.srrb.noaa.gov/highlights/sunrise/sunrise.html)

The conclusion is that already from the beginning of March, the lighting conditions enable use of an optical camera for 12 h per day. In April the conditions are even more favourable. There is not that much difference of the length of day between 63 and 65 degrees North. In the beginning of the season (December – January), however, optical cameras are usable only for one third of the time. It may also be noteworthy to recognise the relatively long twilight time during which the camera light sensitivity is important to prolong the time of operations.

9. Identification of potential frequently used flight areas

Operations beyond line-of-sight (BVLOS) require a permit from the authorities. Until there is a regulation framework in place that specifies the criteria for allowing an unmanned aircraft to fly in a non-segregated airspace, temporary danger areas is the mechanism to use for enabling a safe BVLOS flight. Then the authorities activate a temporary danger area (TEMPO-D) to warn other aircrafts about an aircraft that does not have the ability to give way to other aircrafts in the same airspace. These areas can be predefined and then activated on a short notice. There are certain areas that would benefit from ice monitoring with a short time of notice and those potential areas are the inlets to the channels and the shipping lanes. The problem is that the location of the shipping lanes vary depending on the ice conditions, and so is the case with the inlets, as the fast ice / drift ice border is not static. Thus it is difficult to exactly specify limited areas in advance where there would exist a special need for drones to be allowed to fly as the need arises from the dynamic ice conditions that depend on wind directions and strength.

9.1 Areas where the icebreakers have been idling

To estimate how often the icebreakers are stationary, although not in port, allowing drones to be conveniently used for targeted ice monitoring, we analysed data containing times and locations of icebreaker idling events provided by the maritime authorities for the icebreaking season 2018 in the Bothnian Bay. Using this data we created a heat map showing the frequency of idlings during the ice season January – April 2018. The result is shown below (Figure 13). The majority of the idlings do occur relatively close to the coastline, but a significant number of idlings occur farther out in the Bothnian Bay. A concentration of idling events can be identified in the Quark, outside of Kokkola, Raahe and in the vicinity of Kemi1 lighthouse, north of the Hailuoto island, east of Luleå, north of Bjuröklubb and off-Piteå. A closer analysis of the areas here could be used as basis for the definition of a limited set of areas that could be activated when BVLOS drone flights would be considered necessary.

As the mechanism of using temporary danger areas still requires a significant amount of bureaucracy, the use of this mechanism is restricted to pilot trials until a more dynamic and automatic mechanism is in place ensuring safe operation of BVLOS flights in a non-segregated airspace.

The size of the gridcells in Figure 13 below is about 22 x 20 km ^{2}.

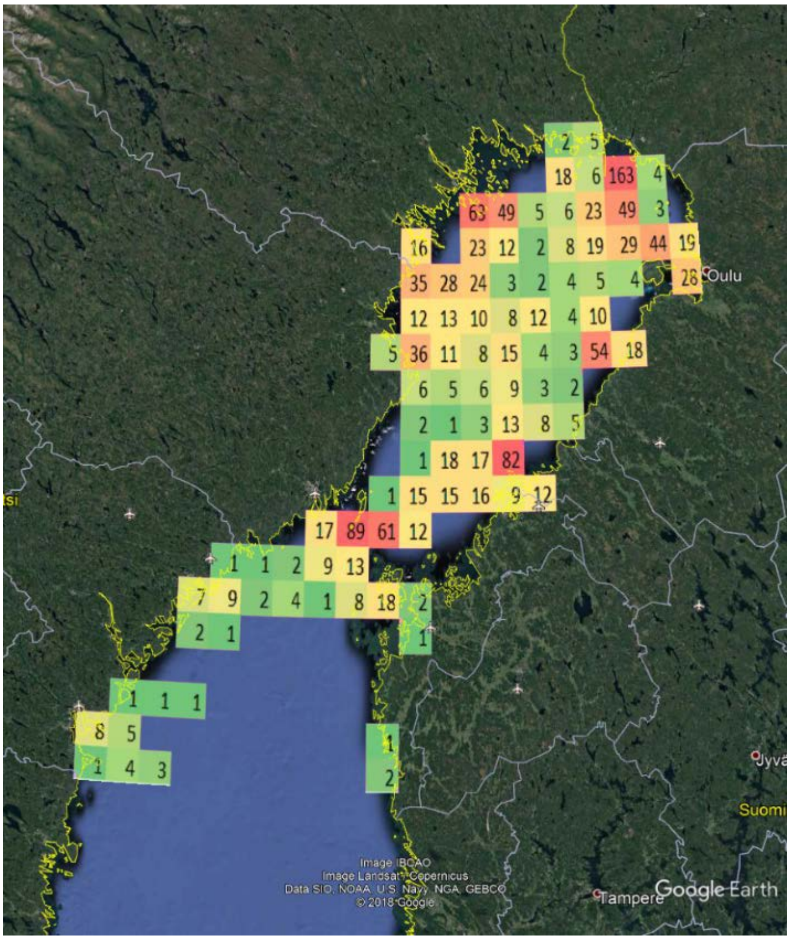

Figure 13 Number of icebreaker idling events during the period January – April 2018. A coarse grid is used (0.2 x 0.4 degrees) with idling in port filtered out. The data is from the Finnish Traffic Administration – the IBNet system. (Courtesy of Tuomas Taivi, Finnish Transport Infrastructure Agency)

10. Other requirements

10.1 Overall system

Figure 14 shows an example of a UAS architecture which highlights the fact that there are many elements to be considered in an operational system. The payload computer performs the on board processing and communicates using radio links with the Ground Control Station

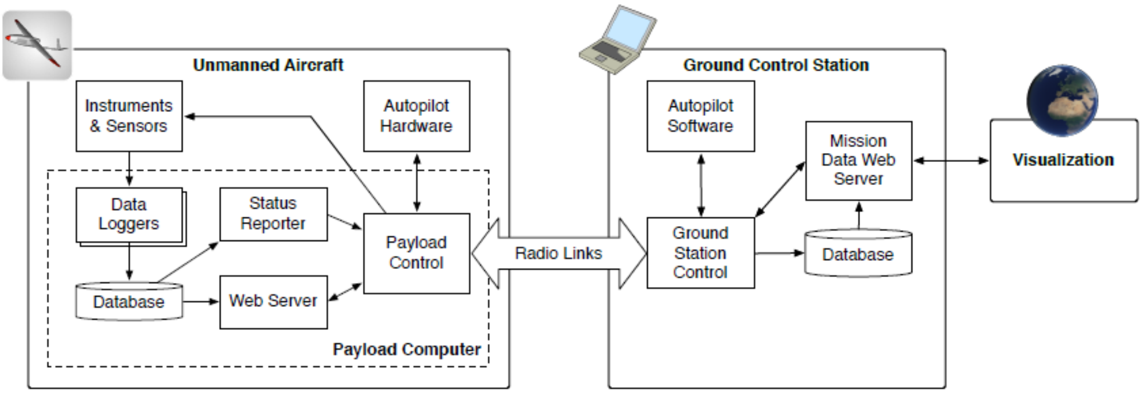

Figure 14 Overall system architecture example (Norut [25]).

Table 8 Processing levels in photogrammetric processing of camera images

Acquire image	The process starts with a camera that takes individual images
Visualisation of image	The individual images are displayed as such to the user
Stitch images together (mosaicking)	This processing step needs the images to be rectified and calibrated to form a contiguous mosaic.
Generation of orthomosaic (orthorectification)	This processing step removes the effects of image perspective and relief effects so that the resulting image is planimetrically correct. The orthorectified image has a constant scale wherein the features are represented in their 'true' positions. Orthorectified images have the necessary metadata about the Spatial Reference System attached so that the coordinates of each pixel can be easily calculated. Thus an orthorectified mosaic is usually done by first orthorectifying the images and then stitching these together.
Production of DSM & DTM	A series of overlapping images can be processed so that the height information obtained from the images taken at different viewing angles, is extracted. The result may be a Digital Surface Model, which shows the top of the features on the ground. In the context of ice monitoring, the DSM would show the ridge sails and freeboard of floating ice. In the DTM (Digital Terrain Model), the local features are removed and thus a DTM would show the ice sheet elevation relative to a common vertical datum.

10.2 On board processing requirements and possibilities

High end consumer grade drones do have quite advanced local processing capabilities that are used for collision avoidance and object tracking using the on board camera. The processed information is not available for external use, however.

The advantage of doing local processing, for example on board orthorectification, would be to reduce the need for data transmission. Technically this is possible, but not yet operationally available. Some examples of local processing can be found in connection with the stereocamera by Stereolabs [8]

This field is advancing very rapidly due to the increase of processor capacity and the possibility to utilise the same software libraries on the on-board computer as is used for processing on a desktop computer. Considering the lack of fixed reference stations (for RTK) and no ground control points with known positions, performing on board orthorectification is a challenging task requiring research and development before an operational solution is available.

An interesting possibility is on board processing of Synthetic Aperture radar signals, which would enable utilisation of small microwave radar systems on board drones. [10]

10.3 Integration and presentation requirements

To maximise the usability of drones, the observations should be easy to interpret. An ideal system with the main sensor being a camera, would present the images orthorectified on a map, making it easy for the users to quantify the width of leads and distances between ridges and other features that would help the navigator to estimate the expected difficulties to be encountered when going through the ice field. The system should be designed so that the user would find it easy to compare these orthorectified maps with the most recent satellite images. This would help the users to quantify ice drift and positions of leads in drift ice.

This leads to a requirement regarding positioning accuracy – as the geolocation accuracy of the processed images taken from a drone is limited by the accuracy of the positioning instrument on board the drone, a normal GPS accuracy is not enough for precise determination of ice drift. On the other hand – if the ice drift is measured by comparing to a SAR satellite image, the resolution of the images used today are about 20 m, which is well in line with the positioning accuracy of a normal GPS positioning device.

To enable interactive steering of the drone, a real-time video link is needed. This is necessary, for example, in the case when the drone is used to guide a ship to points of interest, such as bends in a fairway.

10.4 Operational requirements

The ideal setup would be a drone monitoring autonomously a predefined area or following a lead in the ice. The current status is, however, that a dedicated person has to be engaged in controlling the drone when it is flying (required by authorities). Also the airspace has to be reserved and other aircraft warned when flying BVLOS. Hopefully this will change as a consequence of common EU regulations when using aircraft with the required instrumentation to both warn other aircraft (transponder) and being able to give way automatically in case of possible conflicts.

When using the concept of a tethered drone, the operation may be more automatic. Still, launching and retrieving a tethered drone or balloon, requires manual intervention and surveillance. A special issue for a tethered balloon is to organise the supply of helium gas, as the balloon has to be refilled at regular intervals.

On the other hand, when asking the users about manual assistance during launch and landing, they do not consider this a problem.

To enable operations during low light conditions, either very sensitive or then infrared /thermal cameras could be used.

10.5 Quantification of requirements

When identifying requirements of UAS to be used in operational icebreaking operations, it is fair to keep in mind that drones are complementary to other sources of information – mainly satellite SAR images. Satellite images provide an overall view of the ice situation covering optimally all of the Bay of Bothnia in one image. The disadvantages of satellite images are the limited resolution, sometimes outdated information and difficulties in interpreting the ice conditions correctly. Drones can provide more detailed information on demand, but they have a limited area coverage and thus cannot compete with satellite images for obtaining an overall view. A quick exercise illustrates this point:

The area that can be covered by a drone is determined by the flight altitude, speed, camera optics, and needed imaging resolution. The resolution depends on the features that should be distinguishable. Assuming a 2000 pixel cross-track width and 10 cm ground resolution, a 200 m swath width is achievable. If the drone proceeds with 15 m/s, height of 150 m and field-of-view 67 deg, and an overlap of 75% between images, the time between pictures is 3.3 s. The net area coverage is then 0.3 hectare/s. During a 2 h flight the total area would be 22 km^{2} . This clearly indicates that a drone is only suitable for **directed, specific small area surveillance**. The area can be compared to the Bothnian Bay area of 36.800 km^{2} . Another comparison is the 200 x 410 = 82.000 km^{2} area of a Sentinel-1 satellite EWS image or 40 x 40 =1.600 km^{2} area of an ICEYE SAR satellite image.

The following table summarises the high level requirements of a UAS:

Table 9. Summary of UAV /UAS requirements

Environment		
	Temperature	The drones should be possible to operate in temperatures down to -15 °C. At Kemi lighthouse during the last three years, minimum temperature has been less than this for only 11% of the days in January and February. (See Figure 11)
	Wind	The wind limit should preferably be up to 15 m/s. The wind gust speed has been less than this for 85% of the days at Kemi lighthouse. (See Figure 10)
	Icing	Capabilities to reduce risks of icing by de-icing measures (de-icing sprays, heated rotors..)
Operations		
	Max distance	20 NM (from user surveys)
	max flight time	2 hours (from user surveys)
	Autonomous operation	The ideal system would be fully autonomous, but in practise this is probably not possible to attain within the next 5 years. At least take-off and landing have to be manually controlled by a trained operator.
	Failsafe operations	The drone should be able to return to a safe position in case of loss of communication. This is a problem if

		the drone is operated from a moving platform, i.e. a moving icebreaker
	Autolanding	Not important when operated from an icebreaker.
	GPS waypoint navigation	Part of the control logic

11. Operational and regulatory aspects

11.1 General trends/stakeholders

As a result of growing interest in utilizing the possibilities and business opportunities that drones may offer there is a pressure to ensure that new opportunities can be exploited without endangering the safety and security aspects related to drone-based aviation.

The Stakeholders in the Regulations process are

- On International level
    - ICAO (International Civil Aviation Organisation)
      ICAO is a UN specialized agency, established by States in 1944 to manage the administration and governance of the Convention on International Civil Aviation (Chicago Convention). ICAO works with the Convention's 192 Member States and industry groups to reach consensus on international civil aviation Standards and Recommended Practices (SARPs) and policies in support of a safe, efficient, secure, economically sustainable and environmentally responsible civil aviation sector. (www.icao.int)
    - JARUS (Joint Authorities for Rulemaking on Unmanned Systems). JARUS is a group of experts from the National Aviation Authorities (NAAs) and regional aviation safety organizations, gathering regulatory expertise from all around the world. At present, 59 countries, as well as the European Aviation Safety Agency (EASA) and EUROCONTROL, are contributing to the development of JARUS work products. The objective of JARUS is to provide guidance material aiming to facilitate each authority to write their own requirements and to avoid duplicate efforts including a risk assessment template that will be mandatory for the "specific" category in the future EU regulations. (http://jarus-rpas.org/)
- On European level
    - EASA
      The mission of The European Aviation Safety Agency EASA is to promote the highest common standards of safety and environmental protection in civil aviation. The Agency develops common safety and environmental rules at the European level. It monitors the implementation of standards through inspections in the Member States and provides the necessary technical expertise, training and research. EASA provides expert advice to the EC in the field of civil drones and drafts the future European drone regulatory framework. The Agency works hand in hand with the national authorities,

    which continue to carry out many operational tasks, such as certification of individual aircraft or licensing of pilots.

- On National level
    - Parliament (in Finland and Sweden respectively) – decides on national laws and regulations.
    - Traficom (in Finland), the Finnish Transport and Communications Agency is an authority in licence, registration and approval matters
    - Transportstyrelsen (in Sweden), the Swedish Transport Agency, has the overall responsibility for drawing up regulations and ensuring that authorities, companies, organisations and citizens abide by them.

The status on drafting of Regulatory Framework is as follows [26]:

On 28th February 2019 The EASA Committee voted unanimously to approve the European Commission's proposal for an Implementing Act to regulate the operations of Unmanned Aircraft Systems (UAS) in Europe and the registration of drone operators and of certified drones.

The Implementing Act is accompanied by a Delegated Act, which defines the technical requirements for drones. It was adopted by the European Commission on 12 March 2019 and sent to the EU Parliament and to the EU Council for the mandatory 2 months scrutiny period. Since no objections were raised by the EU Parliament or by the EU Council, common European rules on drones, **Commission Delegated Regulation (EU) 2019/945** [27] & **Commission Implementing Regulation (EU) 2019/947** [28] were published on 11 June and entered into force 20 days later. The purpose of these rules is to ensure that drone operations across Europe are safe and secure. The regulation will become gradually applicable starting from a year after publication. By 2022 the transitional period will be completed and the regulation will be fully applicable.

The applicability will be gradual according to a timeline that can be consulted on the EASA drone page. [26]

The operations of UAS in Europe are classified in 3 main categories depending on the risk level of operations:

- the **'open'** category is a category of UAS operation that, considering the risks involved, does not require a prior authorisation by the competent authority nor a declaration by the UAS operator before the operation takes place;
- the '**specific'** category is a category of UAS operation that, considering the risks involved, requires an authorisation by the competent authority before the operation takes place, taking into account the mitigation measures identified in an operational risk assessment, except for certain standard scenarios where a declaration by the operator is sufficient or when the operator holds a light UAS operator certificate (LUC) with the appropriate privileges;
- the '**certified'** category is a category of UA operation that, considering the risks involved, requires the certification of the UAS, a licensed remote pilot and an operator approved by the competent authority, in order to ensure an appropriate level of safety. This is largely corresponding to the category of manned flights.

The proposed regulation is focusing on the 'Open' and 'Specific' categories.

EU Member States must ensure the proposer surveillance of their markets to guarantee that mass-market products are compliant with EU harmonisation requirements. In the future, National Market Surveillance Authorities will be responsible for the enforcement of EU rules in the “Open” category. This is achieved by verifying that mass-produced drones placed on the market are labeled with the “CE marking” and sold with a Safety Information Notice.

In recent years, the need for traffic management focused on unmanned aircraft systems (UAS) emerged in many parts of the world. This UAS traffic management system (UTM) would ensure safe operation of a large number of drones at low-altitude (especially in urban areas). As traditional air traffic management (ATM) ensures the safety of aircraft operations at high altitude, so does UTM at a lower altitude. The Commission mandated the SESAR Joint Undertaking to lead the development of a UTM concept for Europe, called U-Space. A blueprint was released in June 2017 with a preliminary vision for the U-space. It consists of a set of services enabling complex drone operations in all types of operational environments.

The roadmap for U-Space looks as follows:

Figure 15 Roadmap for Sesar –Joint Undertaking supporting U-Space [29]

The different levels are described in the European ATM Master Plan [30]

U1 provides foundation services (e-registration, e-identification and pre-tactical geo-fencing) . The main objectives of these services are to identify drones and operators and to inform operators about known restricted areas. BVLOS operations will still be constrained.

U2 refers to an initial set of services that support the safe management of drone operations and a first level of interface and connection with ATM/ATC (Air Traffic Management/Air Traffic Control) and manned aviation. Some examples of BVLOS operations will become routine.

U3 will unlock new and enhanced applications and mission types in high density and high complexity areas. New technologies, automated DAA (Detect And Avoid) functionalities and more reliable means of communication will enable a significant increase of operations in all environments and will reinforce interfaces with ATM/ATC and manned aviation.

U4 focuses on services offering integrated interfaces with ATM/ATC and manned aviation and supports the full operational capability of U-space based on a very high level of automation.

The time plan for initial operating capability dates for development of U-space services at a scale is as follows (European ATM master Plan, SESAR –JU, :

U1	Foundation services	2019+

U2	Initial services	2022+
U3	Advanced services	2027+
U4	Full services	2035+

Thus in the next 5 years or so there will probably not be any dramatic changes in the operational context enabling simpler procedures to be taken when utilising BVLOS operations.

The European Aviation Safety Agency (EASA) has published a timeline regarding the expected development of the regulatory framework [26]

The main milestones are listed in the table below.

When	What
June 2019	Adoption of Implementing and Delegated Act. Start of transitional period.
October 2019	**Publication of Guidance Material (GM), Acceptable Means of Compliance (AMC) and first pre-defined risk assessments by EASA** (over sparsely populated areas, in Uncontrolled Airspace, BVLOS with Visual Air Risk Mitigation,..). Also contains the description of the risk assessment methodology called SORA that is required in the “specific category”.
	Publication of an Opinion by EASA proposing an amendment to the European regulation (Implementing Act) to add two standard scenarios to facilitate some operations posing a low risk only. For those the operator will be allowed to just send a declaration to the respective authority instead of applying and waiting for authorisation. The operations are: • Urban VLOS (Visual Line of Sight) VLOS in populated environment involving only active participants Below 120m Using UA up to 3m characteristic dimension; • Rural BVLOS (Beyond visual Line of Sight) Operations in sparsely populated areas using visual observers Below 120m Using UA up to 3m characteristic dimension;
June 2020	**Registration of UAS operators & certified drones becomes mandatory.** Starting from June 2020 all drone operators shall register themselves before using a drone: • in the ‘Open’ category, with a weight more than 250g or less then 250g when it is not a toy and it is equipped with a sensor able to capture personal data • in the ‘specific’ category . All certified drones (operated in high risk operations) shall be registered as well. The registration number needs to be displayed on the drone.
	Operations in ‘Specific’ category may be conducted after the authorisation given by the National Aviation Authority. Based on: • the risk assessment and procedures defined by the EU Regulation • Predefined risk assessment published by EASA as an AMC

June 2020 – June 2022	**Drone user can start operating in limited 'Open' category. Between June 2020 till June 2022:** • Drones with a weight less than 500g may be operated in an area where reasonably it is expected that no uninvolved person is overflown • Drones with weight up to 2 kg may be operated up to 50 m horizontal distance from people • Drones with weight up to 25 kg may be operated at 150 m horizontal distance of residential, recreational and industrial areas, in a range where reasonably it is expected that no uninvolved person is overflown during the entire time of the operation
June 2021	**National authorisations, certificates, declarations are fully converted to the new EU system** (end of transitional period)

11.2 Regulations in Finland, Sweden

The regulations in Sweden and Finland differ somewhat. The common European rules on drones that were recently published require a harmonization on national level, but the work is not ready yet. The new harmonized EU-wide rules will enter into force starting from 1 July 2020.

The main differences compared to existing regulations are [31] :

- The classification of drones into categories Open, Specific and Certified will be based on the risk level of the flight – not only on the characteristics of the drone itself
- The drone operators have to register themselves
- A training requirement of drone pilots is enforced
- The drones have to be certified (EU certification)

Also

- In general - no special permit is required for drones with a mass below 25 kg as long as the drone is operated within sight, below 120 m, and not above people (drones in the Open category).
- A permit has to be applied for BLOS flights, above 120m, or near people. These drones belong to the Specific or Certified category
- There are new competence requirements including both theoretical knowledge and practical skills to be certified as a drone pilot
- It shall be possible to uniquely identify a drone remotely. The position, height, speed and route of the drone shall be possible to obtain from a distance.

Presently, in Finland the rules can be summarized as follows [32]:

For operations within line-of-sight, the rules are as follows:

- If flight is far away from nearest airport, the maximum height is 150 m (will be lowered to 120 m)
- The flight shall not endanger any operations by rescue helicopters or other aircrafts

- The maximum weight of the drone is 25 kg
- The flight shall not cause any danger to people and their property
- The drone shall give way to all other aircrafts
- The drone shall be equipped with name and contact information.
- The operator shall have a liability insurance

The regulation OPS M1-32 stipulates in detail under what conditions a remotely controlled aircraft is allowed to be used in Finnish airspace.

When considering the case of using a drone from an icebreaker, the simplest way of operating the drone is to use it within line-of-sight. The distance is then limited and thus cannot be used for reconnaissance further away. For BVLOS use, the airspace has to be reserved and permission applied for.

> (from www.droneinfo.fi /11.4.2019/)
> Any other use than sports or hobby use of an unmanned aircraft is subject to the rules of unmanned aerial work. The minimum requirements are then:
>
> - Make a Notification on the use of remotely piloted aircraft to our online system and remember to update your information when you change your address or aircrafts. The notification costs 20€ / year.
> - Take an insurance against third party damages that fulfills the requirements in regulation (EC) 785/2004.
> - Mark all of your drones with a sticker that has the name of the responsible person and their contact information.
> - Keep a log of all flights that has the information required by OPS M1-32. Keep record of the log for at least 2 years.
> - Any occurrences involving remotely piloted aircraft, including accidents and serious incidents, must be reported to Traficom. Writing the report won’t lead to any legal charges as according to the aviation’s “Just Culture” principles the reports are looked in educational purpose.

Requirements for BVLOS operations: (from www.droneinfo.fi /11.4.2019/)

Create a written:

- description of the operations that includes information on the operating area and operating time as well as the flight altitudes and aircraft used;
- safety assessment that includes hazard identification, risk assessment and risk mitigation measures;
- Procedures for normal operations and emergencies.
- Description of the operation, safety assessment and operational procedures shall be sent to Finnish Transport Safety Agency before the flights. Documents should be sent to kirjaamo (at) traficom.fi with the email titled "RPAS risk assessment notification"
- Reservation of airspace should be sought at least 8 weeks before starting the operations. After the reserved airspace zone has been created the zone can be activated on the previous work day to the planned start of operations. The airspace reservation will create a temporary danger area that will be published as a map and NOTAM.
- To seek an airspace reservation send a message to ilmatila (at) traficom.fi and ask for more instructions.

11.3 Regulations in Sweden

Since 1st February 2018 there are new regulations concerning unmanned aircrafts. These regulations are summarized on the website of “Transportstyrelsen” [33]

The categories are as follows:

Category	Main characteristics	Permission
Cat 1	Mass < 7 kg	No prior permission for flights within line-of-sight (exceptions below)
Cat 2	7 -25 kg, within line-of-sight	Has to be applied for
Cat 3	> 25 kg , within line-of-sight	Has to be applied for
Cat 4	Beyond line-of-sight with a certified drone	Has to be applied for
Cat 5	Special permits, e.g. limited flights beyond line-of-sight	Has to be applied for

For a Category 1 Drone with a mass below 7 kg the rules stipulate that:

- The Drone should have an identification marking with the operator’s name and phone number.

- Every flight shall have an assigned pilot and the flight should be planned
- You should fly within line-of-sight, maximum height is 120 m
- Keep away from people, animals and real estate
- Do not fly above nuclear power plants, prisons, nature preservation areas or military areas.
- Give way from other flying aircrafts
- Do not fly nearer than 1 km from a helipad
- To not take offensive pictures or aerial photos without permission
- Be sure that the radio equipment is CE-marked and that allowed frequencies are used.

For other categories, a permit has to be applied for.

Considering flights from an icebreaker in the Bay of Bothnia, the areas that has to be avoided on the Swedish side are shown on a map:

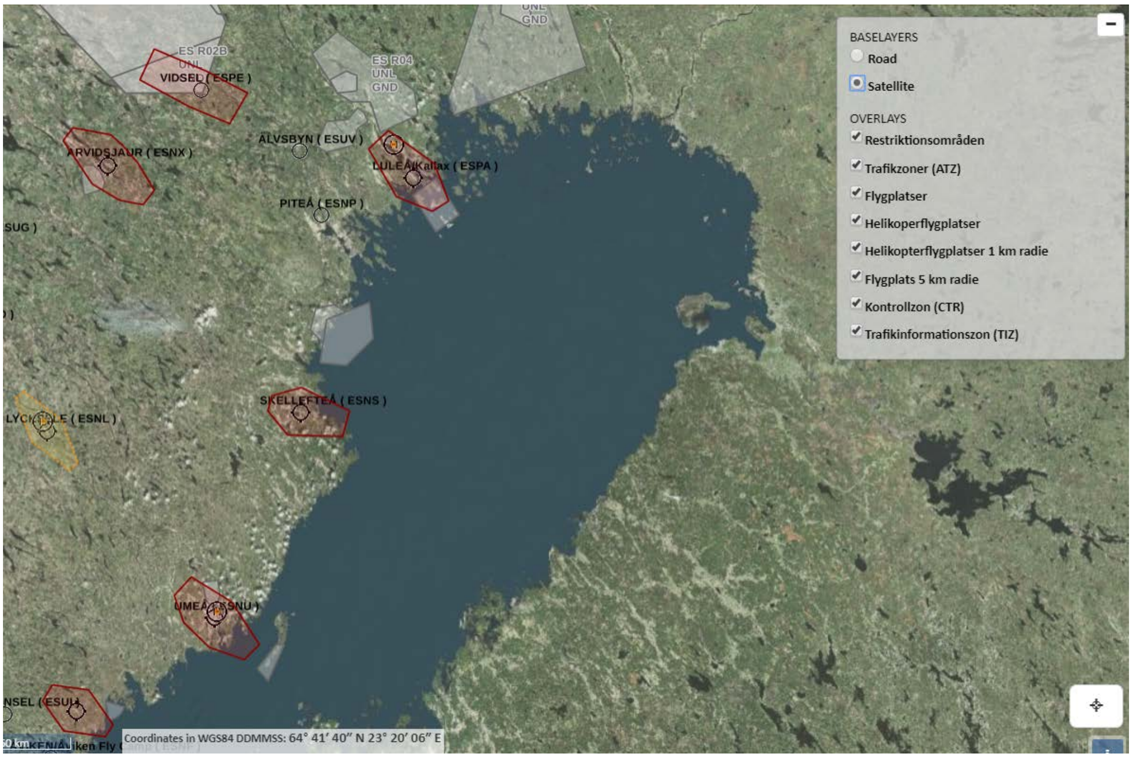

Figure 16 Map showing restricted zones on the Swedish side. [34]

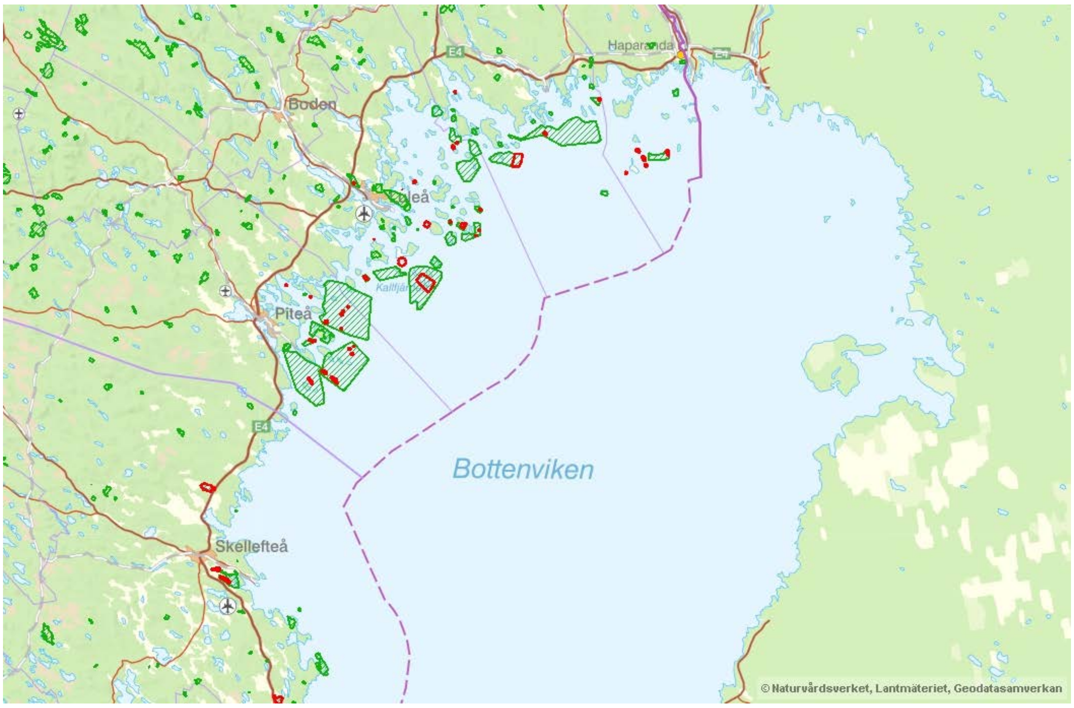

Figure 17 Nature preservation areas, Swedish side. (See [35]) These areas may have access restrictions during part of the year – typically when the birds nest – from May to July. This may affect drone activities in early May.

Exempt operations (www.transportstyrelsen.se)

The Swedish Transport Agency's Regulations (TSFS 2017:110) on Unmanned Aircraft do not apply to the following activities: customs, police, search and rescue, firefighting and coast guard operations, or accident investigations. These activities instead shall be carried out in accordance with special conditions issued by the Swedish Transport Agency (unless done in accordance with the requirements for category 1).

Apply for special conditions by e-mail to luftfart@transportstyrelsen.se. The following information should be included in the application:

- Organisation data, including name of the person responsible for air operations.
- The type of operations which will be carried out using unmanned aircraft.
- The type of unmanned aircraft, and its maximum take-off mass.
- Any relevant deviations from the rules.

Permits issued in accordance with previous rules will be valid until the period of validity stated on the permit expires.

Insurance:
The holder of a permit for unmanned aircraft operations is required to have an insurance in accordance with Regulation (EC) No 785/2004 of the European Parliament and of the Council of 21 April 2004 on insurance requirements for air carriers and aircraft operators. However, no insurance is required if the unmanned aircraft is used for private purposes (model aviation) and weighs less than 20 kg. Still, our recommendation is that you take out a third party liability insurance, since a regular home insurance usually does not cover damages caused by drones.

The insurance shall be a third party liability insurance covering third party injury and third party property damage, and it shall amount to 750.000 SDR (approx. 925.000 EUR)

In Sweden, flying unmanned aircrafts in category 2 and 3 requires that the pilot has completed training on the relevant type of unmanned aircraft system, and shall also pass the Swedish Transport Agency's skill test and theoretical exam before the permit is issued. (www.transportstyrelsen.se).

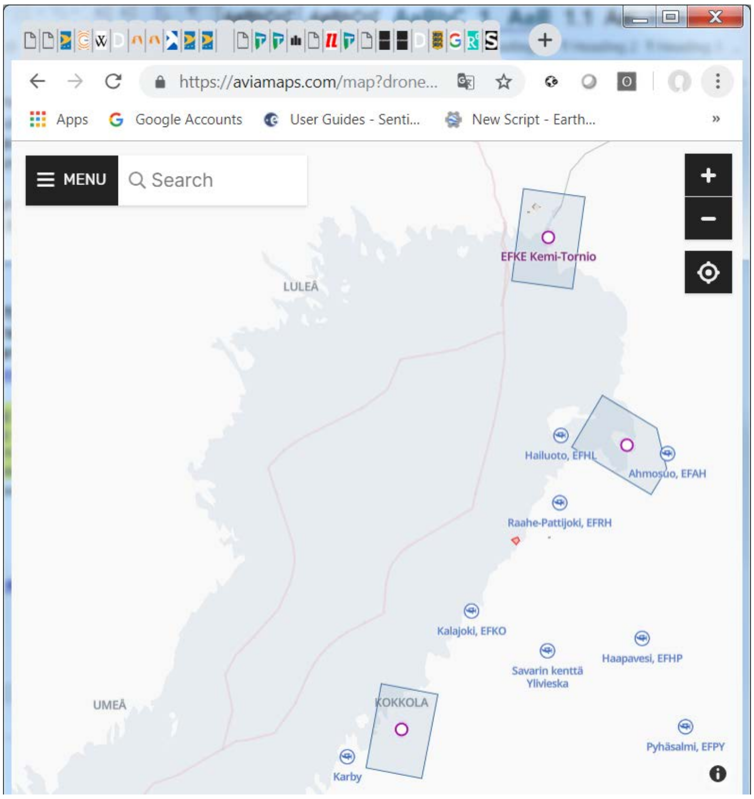

Figure 18 Screenshot of map based application showing current restriction areas for flying drones one the Finnish side of the Bay of Bothnia. (Courtesy of Juha Lindstedt, [36])

Note that this study is focussed on operations in the Bay of Bothnia. For operations in the Arctic there is a very good guideline available (Arctic Science RPAS Operator's Handbook, 2015) [37]

12. Organizational possibilities

Utilising drones for ice reconnaissance and for tactical ice navigation can be arranged in two main ways: by having the command and control centre on board or having the control situated on shore. Having a control centre on shore may be a viable option if the same information is needed by many user groups (like pilots, coast guard, port operators, shipping operators). The table below assumes that the drone can be flown in a BVLOS mode (necessary permits have been obtained and airspace reserved OR the drones are equipped with instruments and beacons allowing autonomous flight).

Table 10 Comparison of options to control the drone flights

Control centre on board	**Control centre on shore**
+ drone is dedicated to the needs of the icebreaker	+ possibility to use fixed wing drones
+ fast to reach nearby locations	+ drone can be shared between may users
+ direct telecommunication link to the icebreaker	+ suitable for areas that are prone to dynamic changes, i.e. “hot-spot” areas.
+ can be used while icebreaker is far away from the coastline	+ easier to handle service and maintenance
+ many inspections can be done within line-of-sight, easy to operate	? requires a minimum user base to become a viable service
- limited to multirotor drones because of launching and landing restrictions (VTOL may be an option)	- operating area limited by distance to control centre. This drawback could be mitigated by having several launch and landing sites along the coastline.
- needs trained operator on board	

Having the control centre on shore would require much larger investments, but – on the other hand – having a larger user base would share the benefits and thus form a larger paying customer base to recover the costs both for initial investments and for operations.

13. Roadmap - way forward

13.1 Vision of the ideal system

Forming the vision of an ideal system is relatively easy. It is a system that would operate autonomously in all-weather conditions day-and-night with very little manual intervention with an acceptable risk level providing easy-to-interpret near-real-time information on a map, which is accessible to the navigator. Technically these requirements are possible to meet, but the costs to build such a system would be too high. The challenge is to identify a cost effective solution that would justify the investments needed to build the system. The overarching need for information is to be able to estimate the ice conditions along the planned route through the ice field and to map the ice conditions to performance of ships' progress through the ice. In that context, drones may provide one element in the solution.

Development is fast regarding the technologies that enable more economic drone based systems. On the other hand, the development of space based systems is also progressing rapidly. A question is then to what extent the space -based SAR instruments would cover the needs for ice reconnaissance? The number of operational SAR satellites is increasing – both in the form of large satellites operated by national (e.g. the Canadian Space Agency) or international space agencies (ESA) as well as private companies (like ICEYE) providing timely information with high enough resolution to enable reliable interpretation of the ice situation.

A way of keeping the costs down is to share the benefits between many user groups – if these have common needs.

Drones could be used for local coverage of “hot spot” areas. Drones would then be used to acquire full resolution images that are sent to on shore servers and disseminated to the users. The users (icebreakers, pilots) could then be provided with the most recent view of the ice situation in those areas.

A cost-effective way of advancing the development is to participate actively in different pilot projects that usually can apply for co-funding from national or international funding instruments. The use case involving icebreakers can then be part of a larger project where novel and innovative solutions are tested out and the usefulness is evaluated. In the following a roadmap developed in the Research Alliance of Autonomous Systems (RAAS) is presented with the elements foreseen to be developed as enablers towards autonomous systems.

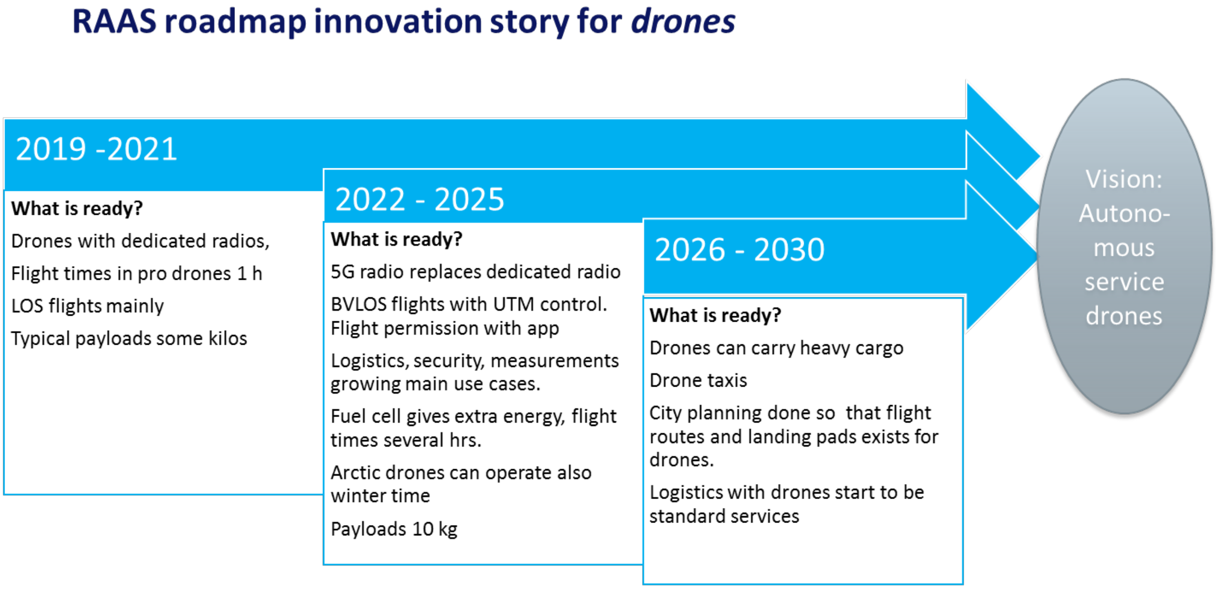

Figure 19 Roadmap towards drones providing autonomous services (Timo Lind, OUAS – Oulu University Autonomous Services). RAAS = Research Alliance for Autonomous Systems coordinated by VTT in Finland.

One concern on using drones is the requirement for a skilled operator supervising the flight. The concept of autonomous service drones would remove that barrier.

The roadmap in Figure 19 is oriented towards drone based services. The icebreakers could benefit from such a development. From the icebreakers’ point-of-view, the following items are of importance:

- BVLOS flights with UTM control - enables launch and operation of BVLOS flights on demand without prior reservation of airspace well in advance

- Fuel cells enabling flight times of several hours – although his can be handled already now using hybrid drones

- Development of drones suitable for Arctic conditions

Relevant research topics of those that have been suggested in a roadmap by RAAS (Research Alliance for Autonomous Systems, Timo Lind) would be:

- Winter-capable drone (2019-2021)
    - Rotor heating
    - Batteries which operate better in cold weather
- Higher battery capacity per weight (2019-2030)
- Long range solutions for drones (2019-2021)
- 5G radio usage (2019-2022)
- Autonomous flight concepts (2019-2024)
- Fuel cells in drones (2019-2024)
- Drone with advanced rotor concepts (better protection, etc) (2022-2024)
- Advanced new sensors in drones (Hyperspectral, Multispectral, …) (2019-2021)
- Edge computing / AI (2019-2024)
- Safety in drones (2019-2030)
- Cyber-security (2019-2030)
- Drone detection / forced landing (2019-2021)

The three last points are generic topics probably more relevant for use of drones over land areas and not specifically relevant for icebreaker use where the drones are flying in areas with very sparse population – but cyber security is important to take into account.

A more focussed roadmap is given below:

2019 – 2021	2022 - 2025	2026 - 2030
• *LOS flights mainly* • *Flight times typically 1 h* • First onboard preprocessing trials (edge computing) • Increase Drone-capability onboard including training ?	• *Use of 5G radio* • BVLOS flight with UTM (UAS Traffic Management. • Flight permission using app • Arctic grade drones • Fuel cells • Edge computing	• Autonomous drones scanning areas of interest • Information integration with ice information system

14. Trials

During the winter season 2019 no specific icebreaker based trials were conducted. However, drones have been used for ice monitoring by many research organisations earlier.

To investigate the processing capabilities offered by commercial software packages, VTT agreed with FMI to use the images acquired earlier during r/v Aranda's campaign 6 -9 March 2016 . Jonni Lehtiranta from FMI then operated a drone (DJI Phantom 3 with a FC300S camera, 1/2.3 " CMOS sensor, 12.4 Mpixels) .

For this study, three image sets were processed and a 3D model was created. The trials confirmed the following assumptions:

- creating a 3D model based on a series of camera photos with standard set of metadata included in the JPG-files (GPS-coordinates – Lat, long and height) is easy and straight forward using commercially available software.
- Without manually inserted control points, the surface tends to become curved
- Processing of a set of 30 images requires tens of minutes on a normal PC.
- The standard processing options of commercial software are not suited for near-real time processing
- Quite impressive overflight animations can be created based on a limited set of images.
- Tailored software development is needed to obtain tools to support measurement of object sizes in near-real time

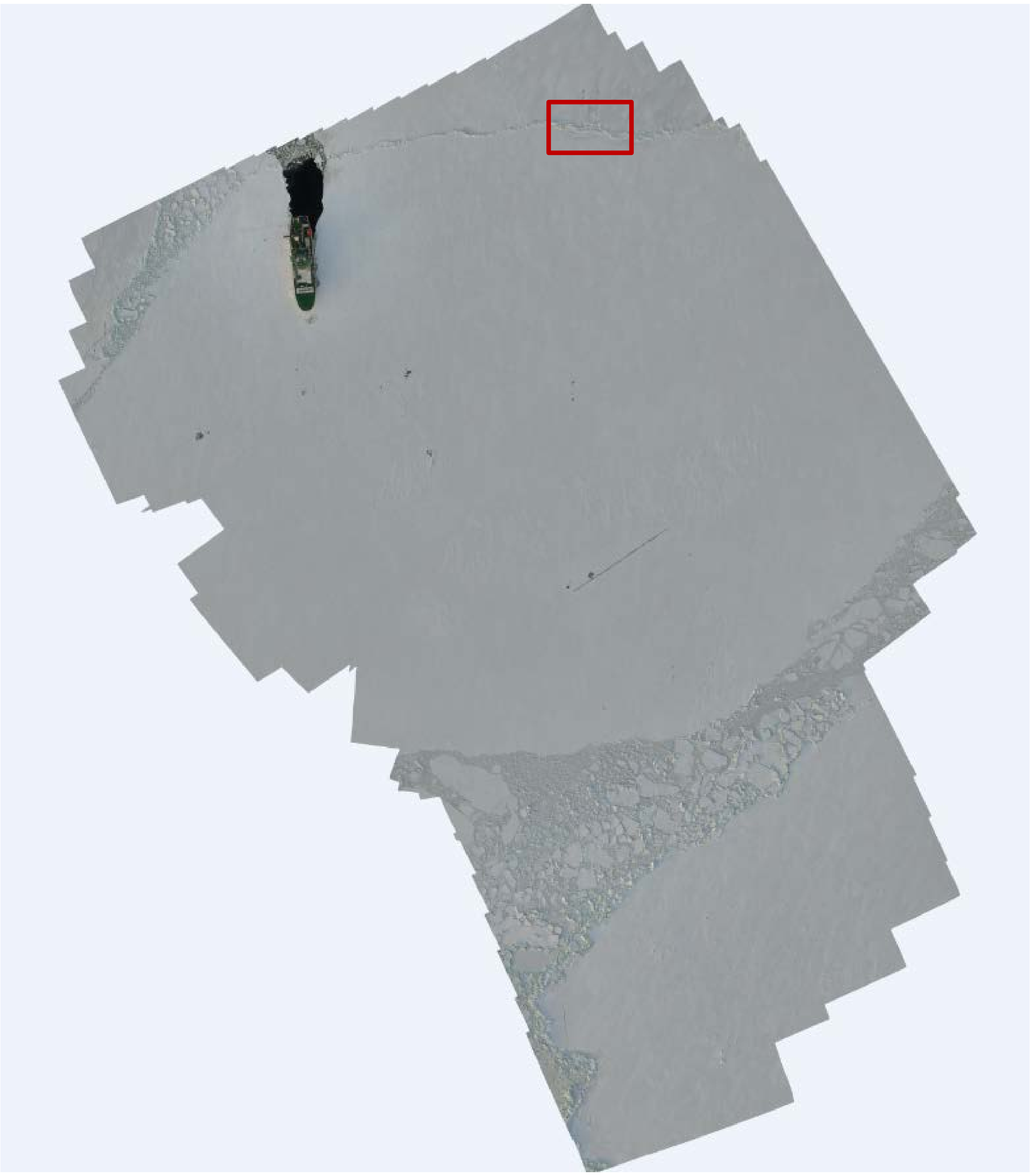

Figure 20 Mosaic made from over 100 individual images taken in the afternoon on 5 March 2016 in the Bay of Bothnia. R/V Aranda is seen in the upper left corner. Coordinates: 65 N 5 minutes, 24 E 12 min. The red rectangle shows the enlargement in Figure 21. Courtesy of Jonni Lehtoranta, FMI.

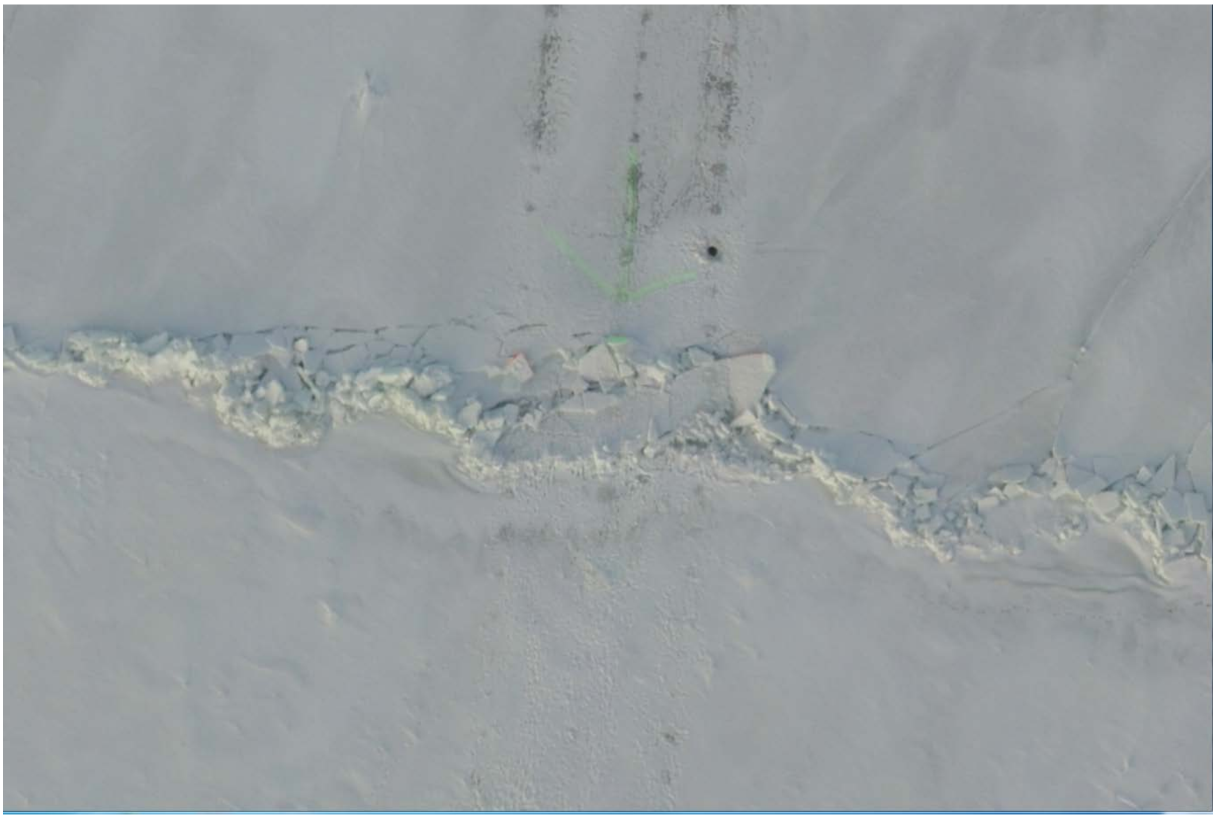

Figure 21 Detail of the mosaic above showing the ridge at the top of the image.

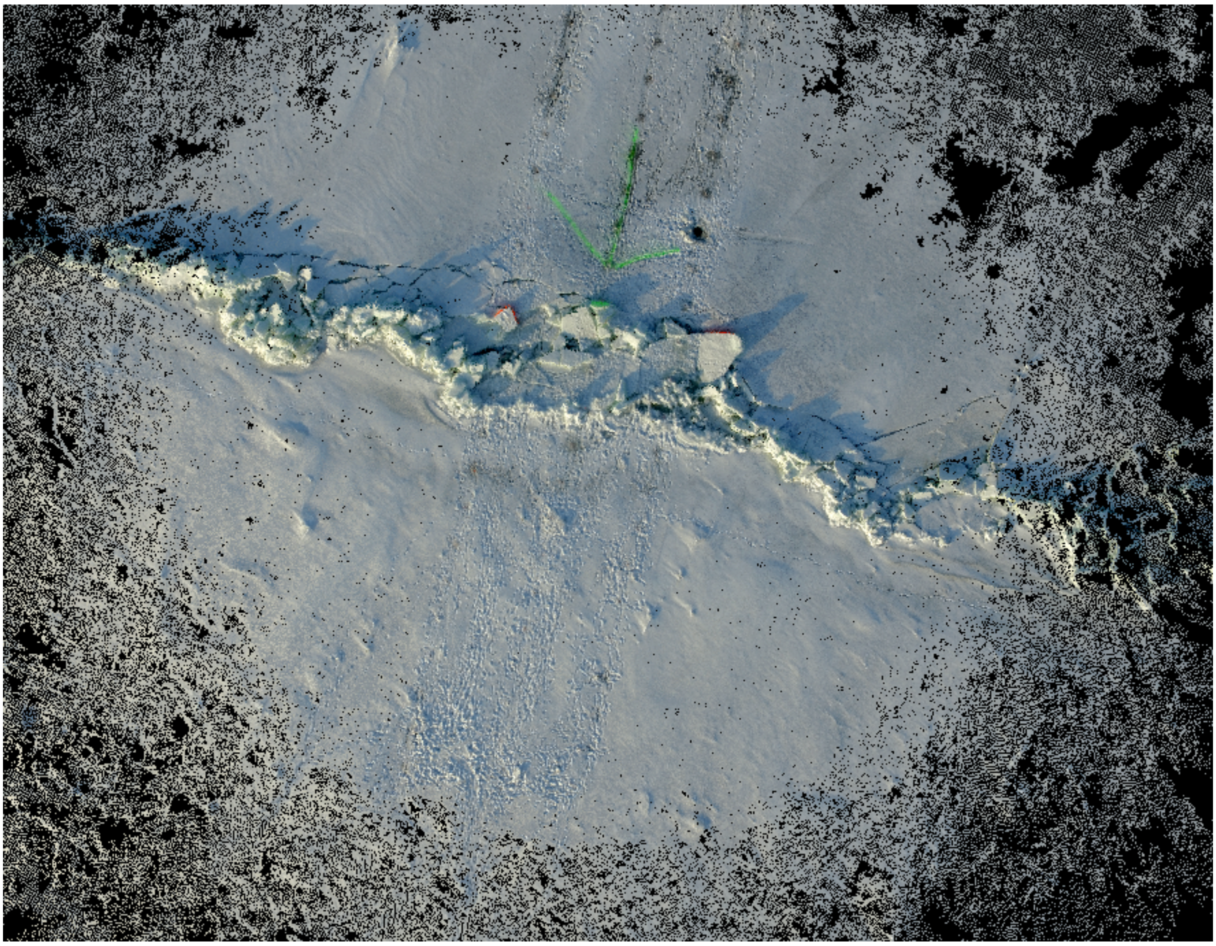

Figure 22 The same area, but now visualised from a point cloud. The point cloud is generated from a set of 30 images using the software Pix4D. (In a Point cloud the data consists of points in a 3-D space where each point may have properties like color and brightness. The point cloud can be visualised from different viewing angles and zoom levels and numerical quantities can be derived from the data)

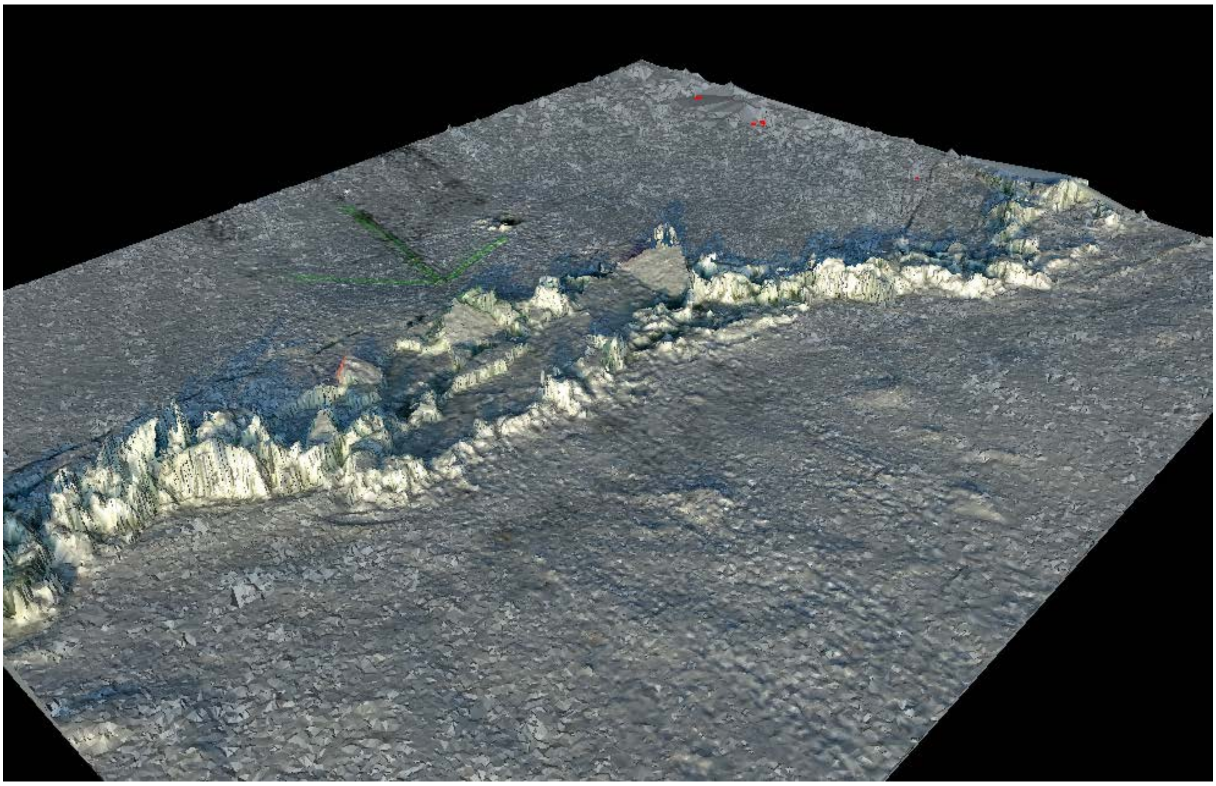

Figure 23 The point cloud enables a 3D visualisation such as this one. The figure shows a colour shaded TIN (Triangular irregular network) and a 1.5 time height-exaggeration (visualisation by FugroViewer, a 3D geospatial data viewer). The visualisation shows some artefacts at the edges of the ice blocks which may cause erroneous quantification results (estimated ridge heights, ridge volumes etc.)

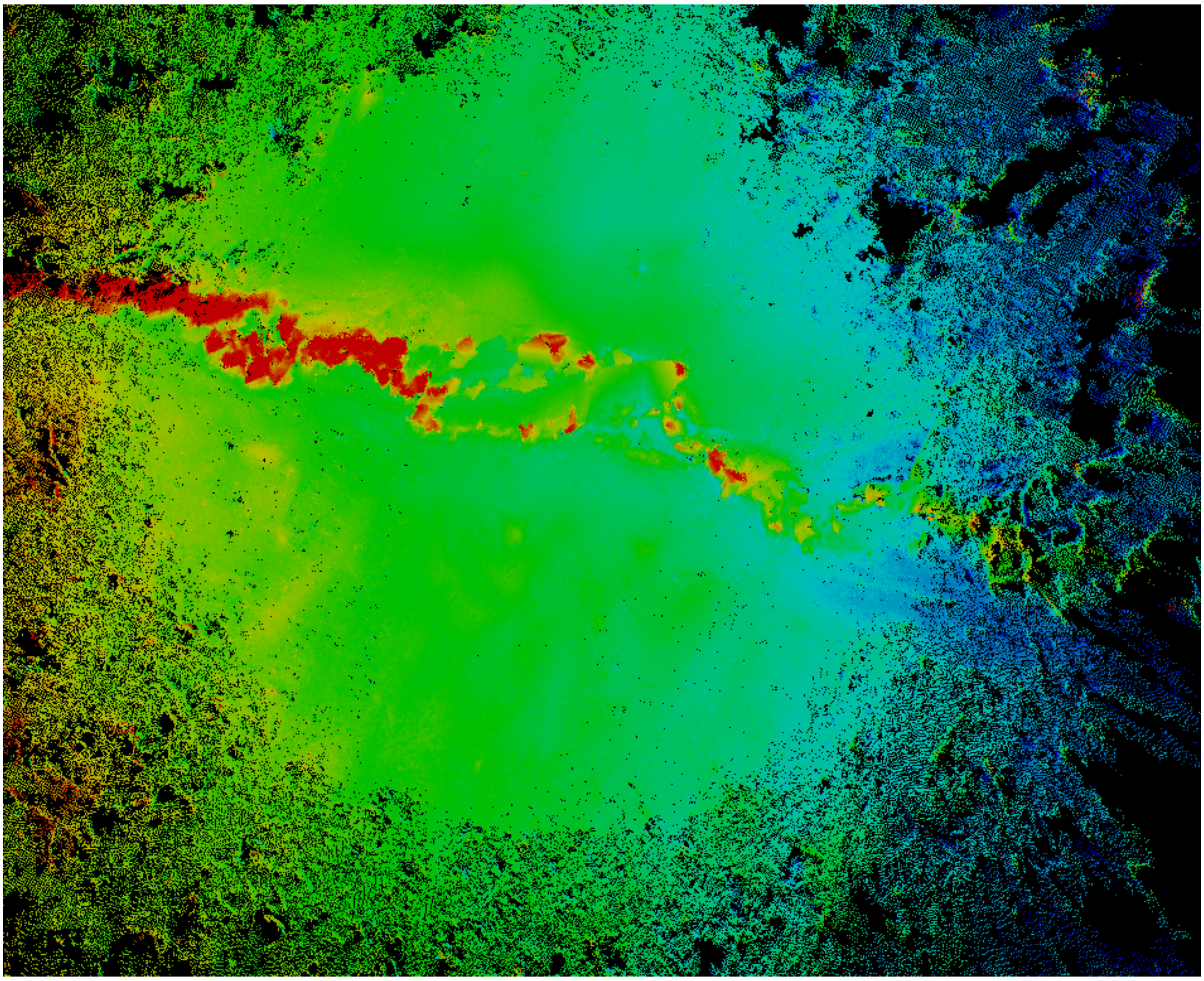

Figure 24 An example where the height is visualised using a rainbow color palette. This kind of visualisation could be used in combination with the optical image to highlight the ridges.

15. Results and conclusions

Drones can provide additional information to the icebreaking operations. Presently the use of drones is quite labour intensive, which limits the operational usability. Advances regarding autonomous drones flying according to easily defined routes and reporting back automatically - could change the scene. This would require BVLOS flights with UTM control and flights with longer duration. In arctic conditions, weather and icing do pose a problem which can be technically solved, but at what cost?

Consumer grade drones with normal cameras can be obtained for a few thousand euros. Special requirements regarding endurance and payload capabilities as well as connectivity to other systems cause the prices to be higher. Preliminary enquiries of the costs for a professional drone with long endurance is in the order of 50.000 €. Special cameras may cost several thousands – dedicated low light and thermal cameras tens of thousands (a SWIR camera is about 15.000 USD). If connectivity to other systems is required, the system must be tailormade.

Developing new capabilities and services requires investments and use of these services is not free either. An estimate of the benefits of improved ice information is the figure obtained from the experienced icebreaker captains, i.e. 2 to 13 k€/month/icebreaker. This rather low figure may be a consequence of the difficulties to fully envision the benefits of a drone-based system without actually trying out such a system in practise. A more accurate estimate can only be obtained via trials where different technical solutions could be compared in practise and the benefits systematically monitored.

The next steps depend on the willingness to invest in new technology. Here are some suggestions on how to proceed:

- A starting point would be to invest in commercial drones with a videocamera and a still camera and train at least 2 persons on each icebreaker that is equipped with the drone to operate the drone as a drone pilot. The drone could then be used in good weather conditions for VLOS flights (up to 0.5 km from the icebreaker).
- Organise or support a trial involving BVLOS drone flights using an advanced medium range drone (2 h) equipped with camera + videocamera and ADS-B transponder. The trial could involve DiSO processing of images enabling direct measurements of ridges and lead widths. The objective of the trial should be discussed with research organisations.
- Initiate trials involving companies where they would demonstrate the capabilities of their drone systems. Special attention should be paid on arrangements to ensure failsafe take-off and landing
- Systematic gathering of requirements during trials. What are the gaps in the present systems and to what extent can these gaps be covered by using drones?

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