Scientific Applications of Unmanned Vehicles in Svalbard (UAV Svalbard)

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1. Introduction

The main objective of this State of Environmental Science in Svalbard (SESS) report is to generate an overview of the research conducted in Svalbard with unmanned vehicles. Funding is provided by the Svalbard Integrated Arctic Earth Observing System (SIOS). The report covers unmanned vehicles that travel in air, on the water surface, and underwater. However, due to their prevalence, the main focus will be on aerial systems. This report aims to capture the applications of these unmanned systems in Svalbard and develop recommendations for the future.

This report follows in the footsteps of earlier publications on the use of unmanned vehicles in polar regions. A general overview of unmanned aerial vehicle (UAV) applications in the Arctic, prepared by a working group from the Arctic Monitoring and Assessment Program (AMAP), also gives guidelines for operations in the Arctic (Crowe et al. 2012, Storvold et al. 2013). Bhardwaj et al. (2016) prepared an overview of UAV applications in glaciological applications. An update of this report that was recently published extends the scope to the cryosphere sciences (Gaffey and Bhardwaj 2020). The latter also identified Svalbard as a hotspot for arctic UAV operations. This SESS contribution is unique for its focus on Svalbard and for including not only UAVs but also other types of unmanned vehicles. This allows for a more specific analysis with dedicated recommendations for the Svalbard area.

1.1. Motivation

When compared to the lower latitude regions, global warming occurs significantly quicker in the Arctic (Arctic amplification) because of numerous feedback processes that occur between the atmosphere, the ocean, and the cryosphere (Serreze and Barry 2011). A significantly enhanced sea-ice reduction rate, recession of glaciers, changes in the thickness of the permafrost active layer, and increased activity of morphogenetic processes (e.g. marine, slope) have been observed in the Arctic and Svalbard in recent decades. Due to its specific character and climate conditions, the Arctic is an important study site for contemporary climate change processes, their feedback, and environmental consequences. The easy access to Svalbard makes it an excellent site for a wide range of polar research disciplines and long-term monitoring programs.

Unmanned vehicles are important tools for conducting research in the Arctic, especially in the field of climate change. This emerging technology allows obtaining complementary datasets to established observation methods such as satellite-based remote sensing and ground observations. Therefore, the use of unmanned vehicles in Svalbard is an important component to develop and enhance the knowledge of current changes in the Arctic and on a global scale.

1.2. Terminology

Different expressions are used to denominate unmanned aircraft. With origin in the military, the terminology "drone" is now used synonymously with all unmanned airborne systems. In scientific applications, the most commonly used expression is unmanned aerial vehicle (UAV), which refers to the airborne vehicle itself. Taking into account the infrastructure belonging to the UAV, such as autopilot and ground control station, the expression most frequently applied is unmanned aerial system (UAS). More recently, the expression remotely piloted aircraft system (RPAS) was introduced by the International Civil Aviation Organization (ICAO) and is used for unmanned vehicles that are controlled and commanded by an operator at a ground control station. Furthermore, the terms unoccupied vehicles or uncrewed vehicles are sometimes used. In this report, the terms "UAV" and "drone" are used synonymously to describe airborne systems.

Several types of marine unmanned vehicles exist. Remotely operated underwater vehicles (ROVs) are controlled by a pilot, whereas autonomous underwater vehicles (AUVs) do not require an operator or are partially navigated by a pilot (e.g. seagliders). Unmanned surface vehicles (USVs), sometimes also called autonomous surface vehicles (ASVs), are vehicles that travel on the water surface.

1.3. Types of unmanned vehicles

1.3.1. Multirotors and helicopters

A large range of aerial drones falls under the "multirotor" category. Their common denominator is three or more motors with directly mounted propellers, see Figure 1. They are controlled by adjusting the power directed to each motor when compared to a helicopter that has a collective and controls the aircraft by adjusting the propeller pitch. Multicopters vary in size from a few grams to several hundred kgs. Their main advantage is their mechanical simplicity (the only moving parts are the ball bearings in the motors). Purely battery-operated multirotors typically have an endurance of 20–40 minutes. Multirotor drones are easy to deploy and some can carry quite a large payload despite not being as large as fixed-wing drones, but extra payload weight reduces endurance. Multirotors are extremely flexible at the cost of reduced range and endurance compared to fixed-wing drones. The biggest manufacturer of commercial (off-the-shelf) multirotor drones is DJI, see Figure 2. They offer several systems that range from small four-rotor (quadcopters) drones weighing a few hundred grams to larger six-rotor (hexacopter) drones with a maximum take-off weight of almost 10kg. These systems are typically very easy to fly and do not require extensive amounts of training. They are mostly operated within the visual line of sight (VLOS) and are typically remotely piloted with low degrees of autonomy.

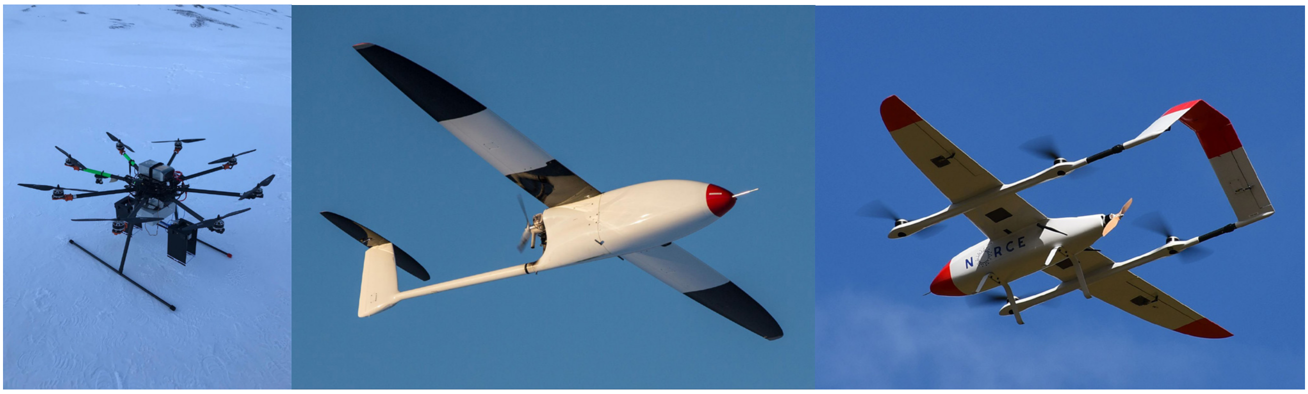

Figure 1: Example of multirotor (left), fixed-wing (middle), and VTOL hybrid (right) used for scientific data collection and part of the SIOS infrastructure (Photos: NORCE).

Figure 2: Example of off-the-shelf drones from DJI: Phantom 4 Pro (left) and Mavic 2 Pro (Photos: Richard Hann).

1.3.2. Fixed-wing

In fixed-wing drones, the aerodynamic lift is generated by wings, see Figure 1. They are much more energy efficient compared to helicopter and multirotor drones, as the lifting surface is larger and can be optimized to a particular airspeed and wingload. This gives fixed-wing UAVs a much longer range and endurance compared to multirotor drones. The main disadvantage of fixed-wing drones is that they have a minimum airspeed required to stay aloft, i.e. they cannot hover in place. Also, for take-off and landing, fixed-wing UAVs require either a runway or catapult for take-off (small fixed-wings can be thrown manually) and a runway or a net for landing. The operation of fixed-wing drones requires a good amount of training and experience. The endurance is typically one to three hours for purely battery powered systems, whereas combustion systems typically have an endurance of 3–8 hours. Combustion systems can be designed to fly up to 24 hours or longer. The size of fixed-wing drones used for scientific applications will typically vary from 0.5kg to a few hundred kg, with a few exceptions (e.g. NASA operates the Global Hawk at 15t for science missions). Fixed-wing UAVs exhibit typically a high degree of autonomy and can be operated beyond visual line of sight (BVLOS). The main advantage of fixed-wing drones is their ability to cover large distances, to stay aloft for extended periods, and to reach high altitudes (up to several kms). Fixed-wing UAVs have a long history and have, for example, been already used in the 1970s for meteorological research (Konrad et al. 1970).

1.3.3. VTOL Hybrid

Recently, drone designs combining the vertical take-off and landing (VTOL) capabilities of multirotors with a range of fixed-wing have become available, see Figure 1. This design especially benefits operations conducted from ships or field stations, as one does not need runways or catapult and net landing equipment. A VTOL UAV has typically less range and less payload capacity compared to a fixed-wing aircraft of the same size and weight.

1.3.4. Remotely operated underwater vehicles

The origins of this technology dates back to the 1950s, when the first vehicles of this type were used to retrieve lost torpedoes. The following years brought further modernization and expansion of ROVs, mainly in military applications. This technology became indispensable in the oil industry and eventually became an invaluable tool in scientific applications. ROVs are most often built on an open frame with floats attached, with strong light sources and digital cameras transmitting the image directly to the operator's monitor (see Figure 3). Propulsion is usually implemented with electrically driven propellers. ROVs are usually well-balanced and do not require the use of ballast tanks. In addition, they are connected by an umbilical cable with a platform located on the surface or an underwater hangar. Power and data transmission are supplied to the vehicle via the umbilical cable, often with the use of optical fibre technology. ROVs have many classes depending on the weight/size of the vehicle, the depth to which it is able to operate, or the vehicle equipment. Such a movable underwater platform provides a wide range of installation possibilities with various types of measuring equipment: cameras, specialized sensors of physicochemical parameters, manipulators allowing for various types of work or obtaining samples, sonar, acoustic camera and many others. However, the most frequently used devices are high-resolution video cameras that allow for a non-invasive observation of the sea bottom, water column, and the bottom surface of the ice. Most vehicles of this type have an acoustic ultra-short baseline (USBL) navigation system that allows determining the position of the vehicle in relation to the platform from which it was launched (ship, platform, shore, sea ice). If the planned operations are very precise (taking samples from a specific place on the bottom or mooring inspection), the ship should be equipped with a dynamic positioning system. Depending on the complexity of the vehicle, it may have one or more trained operators responsible for individual navigation manipulators.

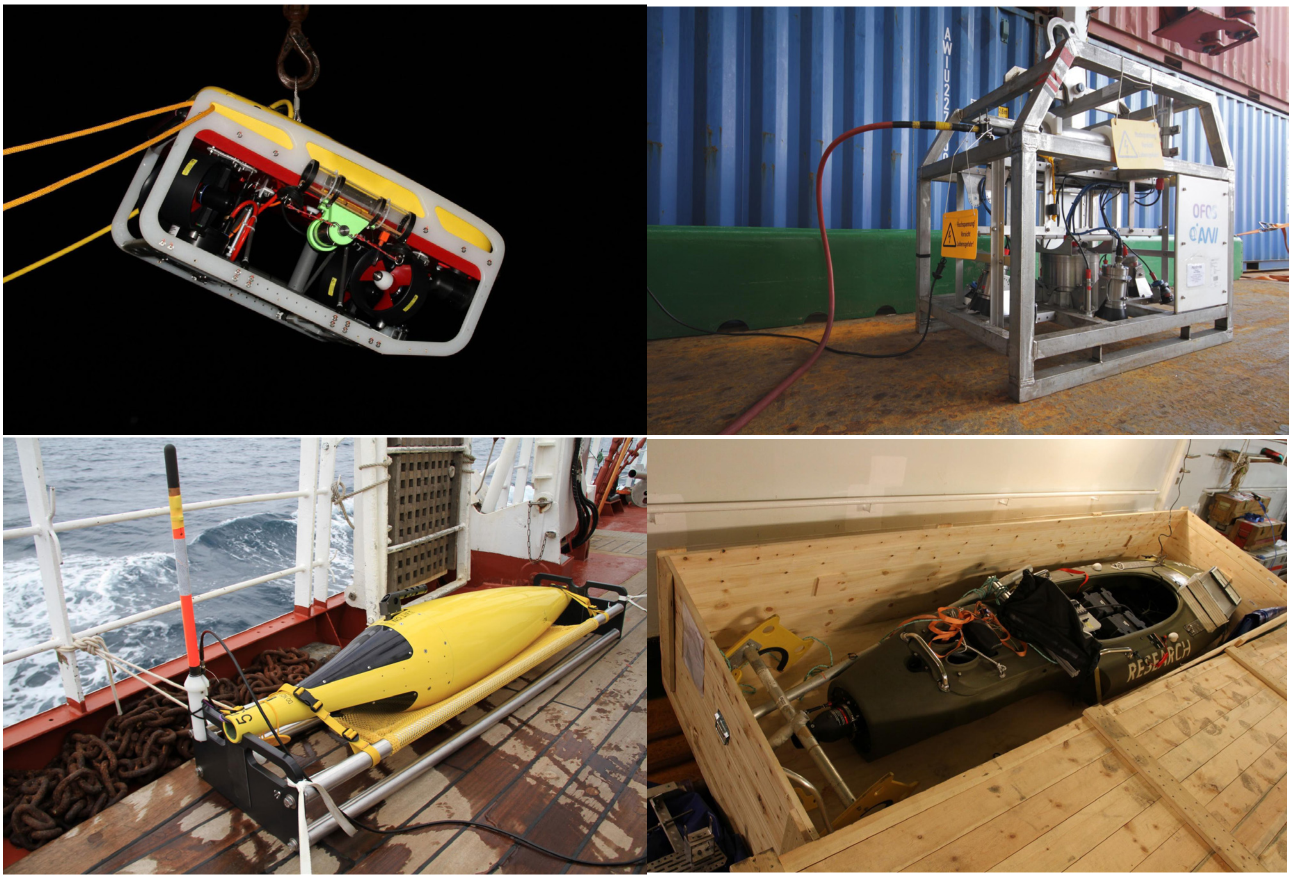

Figure 3: Example of ROV (top, left), drop camera (top, right), AUV (bottom, left), and USV (bottom, right) used for scientific data collection (Photos: Kajetan Deja).

1.3.5. Autonomous underwater vehicles

As in the case of ROV, the history of this type of construction dates back to the 1950s. In the beginning, these were mainly military-related structures. The advent of modern electronics, efficient power sources, and artificial intelligence has led to an increasing degree of autonomy and the development of autonomous underwater vehicles (AUVs), see Figure 3. The vast majority of AUVs resemble a torpedo, which is dictated by low hydrodynamic resistance (drag) as well as a minimizing of the possibility of catching on underwater obstacles. Typical AUVs contain a battery, electric drive motor, control electronics, and a range of oceanographic instruments (e.g. conductivity, temperature, pressure, pH-value, fluorimeter, sonar, a camera with lights). Some vehicles of this type have a foldable robotic arm. The vehicles are able to carry out missions autonomously after launch. The battery capacity is the main limitation of the operating time, depending on the vehicle class, up to several hours. The exception here is underwater gliders whose missions can last up to several months – mainly due to the lack of an active propeller. These gliders move by changing their buoyancy, which allows for submersion and ascent, and the change of trim and presence of wings allow for forward movement. Electricity is needed in this case mainly to change the centre of gravity, for e.g. by pumping water or oil. Data are sent to the satellite during ascent – this AUV subtype is "controlled" by the pilot. Vehicles of this type have revolutionized the market, making it possible to perform tasks related to bathymetry or habitat mapping at much lower costs and unprecedented efficiency. They are excellent in all kinds of inspections and are a very important research platform in modern science related to the study of the oceans. Drop cameras are another technology that is often used, but it has been excluded from this report as it is a passive system that does not move on its own, see Figure 3.

1.3.6. Surface vehicles

These are remotely operated vessels (boats) of various sizes. Most often, the units are several meters long and are equipped with an electric drive with a generator, see Figure 3. They can also use solar and wind energy (saildrone). Remotely controlled units of this type play an increasingly important role in Arctic research. They often allow for a doubling of the studied area and shorten the time needed to collect data when compared to traditional methods that use only a research vessel. They made it possible to enter dangerous waters such as glacier bays or very shallow waters. Due to the high flexibility of the solutions used, they can be adapted to any environmental conditions and are widely used in polar areas.

1.4. Relevance of unmanned vehicles for Arctic research

1.4.1. General

UAVs for scientific data collection have multiple benefits (Pajares 2015). Compared to manned aircrafts, the environmental footprint is orders of magnitude smaller when it comes to noise and fuel consumption, especially in small observation sites. In addition, UAVs are particularly well-suited to bridge the gap between single-point measurements and satellite remote sensing, as both spatial and temporal resolution are highly flexible. Such observations are important for creating consistent time series of surface products like snow albedo, vegetation indices, and biomass/primary production estimates. Satellite-based remote sensing in the Arctic is often limited by the presence of persistent cloud covers and the lack of sunlight during the winter. UAVs also allow access to areas that are dangerous or impossible to access, e.g. crevassed glaciers (Hann et al. 2019). Additionally, UAVs allow a higher flexibility in used sensors and measurements methods, e.g. ultra-wide band radar to measure properties like snow depth and snow water equivalent on land and on sea ice.

One key challenge in using airborne remote sensing generally is the vegetation, buildings, and other obstacles that cover or hide the Earth's surface and the space above it (Gaffey and Bhardwaj 2020). Therefore, the observation of rock structures, animals, or landforms is often obscured or even impossible. Arctic regions with their lack of higher vegetation, large settlements, and other natural and man-made structures are therefore ideal for aerial remote sensing. Also, the risk of damage, either on the vehicle (UAV) or on the third person's property, not to mention health or life, a common threat in the densely populated areas of Europe, is significantly lower in the vast, obstacle-less plains of the Arctic.

The remoteness and natural character of the Arctic is another reason for the frequent exploitation of UAV technology (Solbø and Storvold 2013). Mountainous areas, often glacierized, steep cliffs, rock faces, and practically no infrastructure effectively limit the accessibility to many areas except through small boats. However, the operational range of the UAVs (especially fixed-wing), which may exceed several kilometres, allows one to quickly, cheaply, and without any special equipment access to observe many of these remote sites (Stuchlík et al. 2015). Certainly, observations are limited to visual and/or other optical or thermal recordings, but this may be enough for many research tasks.

The undeniable benefit of using underwater vehicles is the ability to observe the environment at depths inaccessible to a diver as well as the analysis of many distant places in a relatively short time. Underwater vehicles also enable minimally invasive observations of the behaviour of animals (observations for many hours). They are well suited for observing the marine environment, where the patches of flora and fauna are natural and point measurements do not give a full picture of the species composition in a given place. Underwater vehicles are a good complement to traditional measurements, giving a wider view and supplementing them with additional observations. They allow for an insight into areas of very poor visibility, typical for glacial bays and glacial estuaries. USVs allow measurements in the close vicinity of a glacier, impossible to perform from a ship for safety reasons. Underwater vehicles are not limited by a specific Arctic light regime and can be used even during the polar night, thanks to the use of artificial lighting or radar.

A general list of technical and operational challenges of using unmanned platforms in polar environments was presented by Kramar (2019). An operational handbook for scientific users of UAVs in the Arctic was produced by the AMAP workgroup (Storvold et al. 2015).

1.4.2. Data resolution

One key benefit of UAVs is their ability to close the "resolution-gap" between ground-based and satellite-based observations. The data resolution of observations typically depends on optical (sensor resolution, lens focal length), environmental (visibility, cloudiness, wind, sun position), and technical (gimbal/sensor stabilisation, flight velocity, flight altitude) conditions. Figure 4 shows the typical resolution of different remote sensing techniques. Satellite-based observations can range from a resolution of approximately 1–100m, while most products available for the scientific community are on the scale of 20m. In contrast to ground-based observations, this resolution is very coarse and introduces a challenging "gap". In-situ UAV observations are well suited to contribute to filling this gap. This is mainly related to the lower operational altitude, possible due to those platforms. Such airborne systems can easily provide resolutions in the order of magnitude of 10cm.

The data resolution for ROV, AUV depends mainly on the class of the device and thus the possibility of installing better sensors, both optical – mainly cameras (size and type of sensor, the possibility of changing the focal length) – and measuring environmental parameters (e.g. fluorometer, STD probes) or equipment using sound waves (e.g. sonar, acoustic camera).

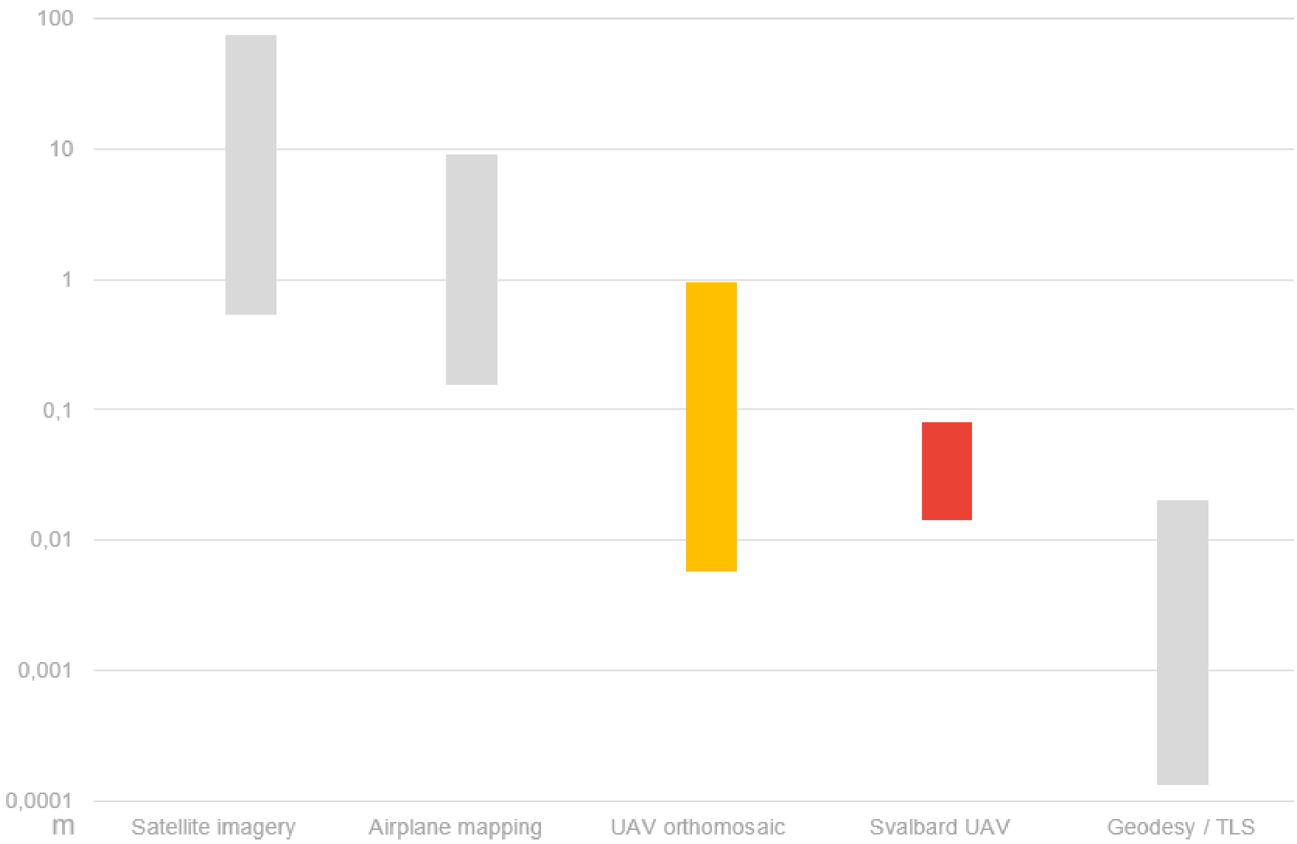

Figure 4: General overview of approximate image/data resolution using various mapping techniques: satellite, airplane, UAV, and terrestrial laser scanning (TLS). Based on this reports database (Svalbard UAV) and literature: Rothermel et al. (2020), Turner et al. (2016), Nex et al. (2014), Westoby et al. (2012), Smith et al. (2009), Prokop et al. (2008), Park et al. (2019) and Goncalves, and Henriques (2015).

1.4.3. Observations of the atmospheric boundary layer

UAVs, especially fixed-wings, are also suitable to fill in a missing gap in atmospheric research: They provide high resolution measurements on small scales, typically up to an altitude of 2km and a horizontal range of a few km, with some long-range applications. This typically requires sophisticated UAV operations. The modern miniaturized data processing units allow measurements with up to 1 kHz resolution.

For studying the exchange processes between the surface and the atmosphere, measurements less than a few 100m above the ground are very important. UAVs are very flexible compared to ground-based measurements like meteorological masts or remote sensing applications (Martin et al. 2011), and they are easier to operate close to the surface than manned systems, which usually have to adhere to a specific minimum flight altitude. Further, the flexibility of UAVs allows making observations at remote locations, which may contribute to enhanced databases for weather forecast (Sun et al. 2020). For investigating specific atmospheric processes, UAVs contribute to local-scale data that can be embedded in larger-scale measurement networks and serve to validate satellite data and numerical simulations with lower spatial resolution. In many large atmospheric projects, UAVs have been deployed to contribute data in small scales.

In addition, UAVS offer the advantage of flexibility concerning the choice of light-weight sensors. Depending on the application, UAVs are equipped with meteorological payload, aerosol sensors, chemical sensors, air sampling capabilities, measurements of radiation, and surface temperature. Last but not the least, for some applications like sampling volcanic eruptions, manned airborne measurements would be too dangerous, but UAV observations are possible, for e.g. (Nicoll et al. 2019).

1.5. Svalbard – a hotspot for unmanned vehicle research across the Arctic

Since 1920, Svalbard has a special status related to the international Spitsbergen Treaty. The regulations of the treaty allowed the signatory states the peaceful use of the area. Therefore, many national and international research facilities fostered cooperation and facilitated the spread of new technologies in various research projects, making Svalbard an important research hotspot.

Another important fact that attracts the researchers using UAVs is the unique natural environment of Svalbard. When compared to the lower latitude regions, heavily glacierized islands with easily perceptible effects of on-going climatic changes on the receding glaciers and related activation of slope and fluvial processes on vast, newly deglaciated areas are very suitable for a temporal observation of these changes (Hartvich et al. 2017, Bernard et al. 2018). Also, the natural processes, to a much smaller degree, are affected by anthropogenic activities. Therefore, monitoring of the state of the glaciers is very important in order to learn about the processes determining its changes, namely the fast degradation of the cryosphere (Bernard et al. 2018). Combining traditional research results with modern UAV methods can be done for modelling the state of cryosphere and the development of scenarios of its changes for much larger areas of the Arctic (Nehyba et al. 2017, Gaffey and Bhardwaj 2020).

It is not only glaciers, snow, and rocks that are studied using UAVs in Svalbard. Glacier runoff also affects the structure of the water layers and supplies huge amounts of suspended sediment to the water column. The use of underwater technologies allows monitoring the presence of Atlantic species that are more often increasingly found in the waters of Svalbard and to study the adaptation and the behaviour of macrofauna or plankton organisms to life in this extremely dynamic and difficult environment. Additionally, the rapid changes in the environment are followed by the dynamic reactions of plants, animals, and other life form populations.

Atmospheric research in Svalbard is focussing on local biogenic emissions and long-range transport processes from lower latitudes, as Svalbard is a relatively pristine environment. Svalbard is located in the Arctic vortex of low temperatures and demonstrates slow mixing of air masses compared to lower latitudes.

Finally, while being geographically relatively remote and isolated, Svalbard is still, compared to similar Arctic regions such as the Canadian archipelago, Severnaya Zemlya, or Franz Josef Land, easily accessible. The archipelago can be reached by commercial flight connections and is regularly visited by cargo ships. In addition, several well-equipped settlements and research facilities are also present there.

2. Results

2.1. Method

The main element of this report is a literature review on the scientific applications of unmanned vehicles in Svalbard. The first step was to identify publications in the peer-reviewed literature that included relevant information. Most of these publications were identified using Google Scholar with a combination of the following keywords: "Svalbard, Spitsbergen, unmanned aerial vehicle, UAV, unmanned aerial system, remotely operated aerial vehicle, RPAS, UAS, autonomous underwater vehicle, AUV, autonomous surface vehicle, ASV, remotely operated underwater vehicle, ROV, unmanned vehicle, drone". Furthermore, the databases of ResearchGate, Research in Svalbard (RiS), and Svalbox were accessed. The search was conducted in August 2020. Later publications are not considered in this study.

In a second step, the selected publications were investigated in-depth to identify the following key parameters for each study:

- Discipline: the research field of the publication;
- Publication type: the type of publication (article, conference paper, report, thesis);
- Research objective: main purpose of the paper;
- Fieldwork season: the date when the unmanned vehicles fieldwork was conducted;
- Fieldwork location: the location(s) where the unmanned vehicles fieldwork was conducted;
- Unmanned vehicle: the type of unmanned vehicle used;
- Platform name: the name of the unmanned vehicle platform;
- Sensor type: the type of sensors used on the unmanned vehicle platform;
- Post-processing: the software or approach used for post-processing of the sensor data;
- Countries: the origin country of the institutions involved in the research.

2.2. Database

Appendix 1 shows all publications that have been included in the database, along with a few selected variables. The full database is added as an electronic appendix to this report.

2.2.1. Type of unmanned vehicle

An overview of which unmanned vehicles were used mostly in Svalbard is given in Figure 5. The data show that the majority (>80%) of activities in Svalbard were conducted with UAVs. Most of the UAV work was performed with multirotor drones, of which nearly all were conducted with off-the-shelf technologies (i.e. DJI products like Phantom, Mavic, Matrice). This implies that these consumer-grade aircraft, which have a very low barrier, offer a substantial benefit to the scientific community. Fixed-wing UAV operations, which are much more complex due to the requirements in logistics, infrastructure, and trained personnel, were also used intensively. Underwater vehicles and surface vessels are available to a much smaller group of scientists because they are very expensive and require the use of a ship, which additionally increases the costs and limits the availability of this type of research to oceanographers. Moreover, the use of ROV is quite complicated and time-consuming. Surface vehicles are more increasingly used in projects enabling the safe sampling of the zone at the front of glaciers that is inaccessible with traditional sampling. There are fewer published works on the use of underwater technology than UAV due to the limitations in the availability of this type of equipment.

2.2.2. Products

Generally, the most common products are datasets collected using UAV-mounted optical sensors, such as photomaps, digital elevation models (DEMs), digital surface models (DSMs), digital outcrop models (DOMs), and thermal or other special maps derived from the observed data. Other types of results are represented by point or profile measurements of meteorological, aerosol properties or atmospheric chemistry data. In some cases, observations of life form behaviours are made. Rarely, air, soil, sediment, or biological material samples are collected from otherwise inaccessible sites. The overview of the product type frequency is given in Figure 6. It has to be noted that there is an uncertainty as not all papers specify the observed data production parameters.

By far, the most common product is an orthophoto (or orthomosaic) map, usually based on digital photographs from visible light cameras. Other types of sensors used for construction of photomaps are IR (infrared), thermal, and multispectral. Often, the orthomosaic map is not the final product but an input into further analyses or processing (therefore, it is sometimes difficult to differentiate it from the derived or special maps category). The orthomosaic maps are used in a variety of research domains, ranging from geology through glaciology and biology to human sciences.

In geomorphology, geology, and glaciology, the DEM/DSM is usually the main goal product, used for further analyses of slope, structures, volume, surface area, and their temporal changes.

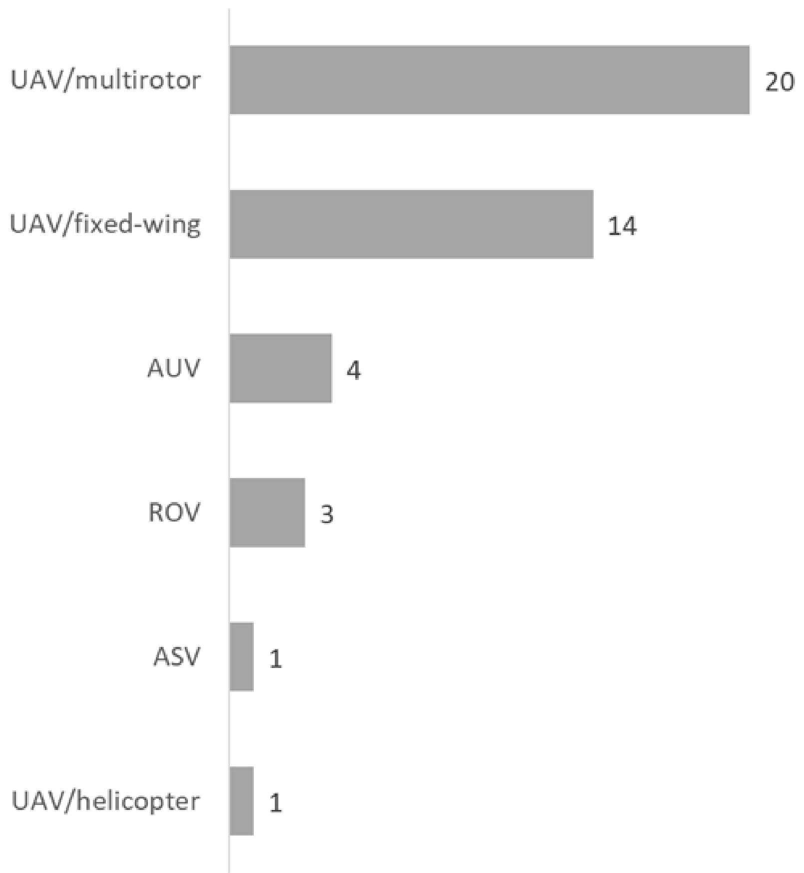

Figure 5: Overview of the different types of unmanned vehicles identified in the database.

The collection of photos, captured by piloted or programmed flight, is usually processed using structure-from-motion technique (SfM, a computerized development of stereoscopic analysis relying on raw computational power of current computers), performed in a specialized software (e.g. Pix4D, Agisoft Metashape, MicMac). As a result, DEM/DSM models are created in various forms (mesh, raster, point cloud, etc.).

Next, a rather wide group of results represents various maps. Often, the maps are derived from orthomosaics, most commonly observing movements of ice, either tracking the individual floating ice blocks (Leira et al. 2017, Albert et al. 2017, Linge, 2019) or extent of glaciers (Hodson et al. 2007, Solbø and Storvold 2013, Howe et al. 2019), mapping of crevasses (Hann et al. 2019), or snow (Stuchlík et al. 2016). Autonomous floating or underwater vehicles are used for bathymetry measurements (Ludvigsen 2018, Howe 2019) or biosphere observations (Hirche 2015, Deja 2019).

Finally, some papers concentrate on the technical side of the UAVs, testing various sensors, settings, or innovative UAVs (Crocker et al. 2012, Fischer 2019, Lampert et al. 2020) or the data processing, visualization, and analyses (Stodle et al. 2014).

A key finding throughout all results is that there seem not to be any standards for how the results and processing methods are documented. Typically, very little information is given on the exact method of data acquisition and processing – mostly just the name of the software. In addition, the results of the publications are typically not made available to the scientific community, which raises issues related to long-term data storage and open-access.

Other uses were recorded in 20% of the papers. Among these, the most frequent use was measuring physical parameters of the atmosphere, such as temperature, humidity, gas and aerosol concentration, etc. (Berman et al. 2012, Bates et al. 2013), either at certain points or in profiles.

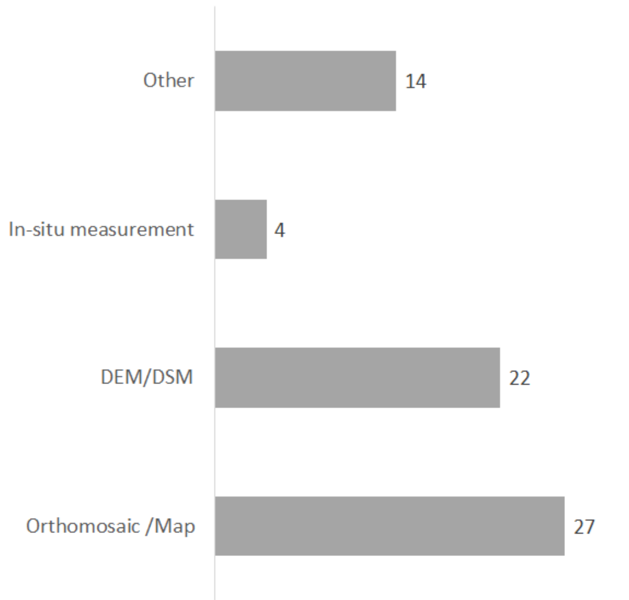

Figure 6: Overview of the different types of products identified in the database.

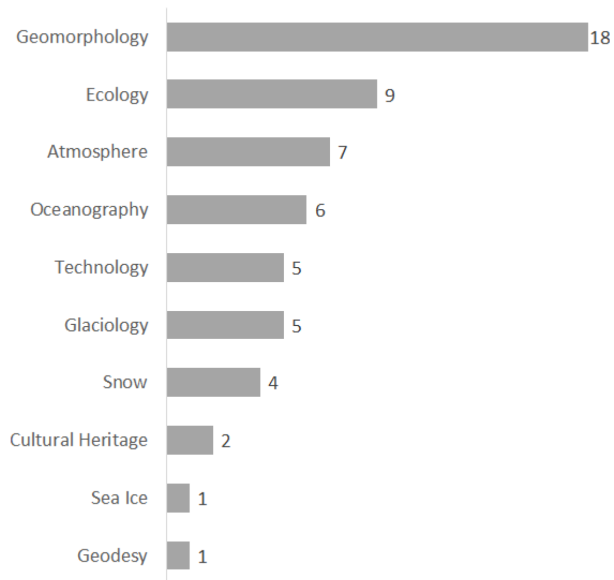

Figure 7: Overview of the different disciplines identified in the database.

2.2.3. Disciplines

Each publication was assigned to one or more disciplines and this distribution is shown in Figure 7. This figure indicates that most of the work with unmanned vehicles has been conducted for geomorphological purposes. The advantage of getting a bird's-eye perspective for describing geomorphological features is clear and explains why this discipline has adapted quadcopter UAVs into their work early on. Similarly, the advantages of using UAVs in the field of atmospheric research are obvious. This field mostly utilized fixed-wing UAVs with specialized sensors for in-situ measurement of atmospheric parameters. The fields of ecology and oceanography are the disciplines that make the most use of ASV, ROV, and AUV technologies.

In general, the datasets indicate that unmanned vehicles offer potential to be used in many different scientific fields. However, the degree of utilization is very different between disciplines. The cryospheric disciplines (snow, sea ice, glaciology) seem to underuse unmanned vehicles, which could indicate a larger potential for growth in these fields in the future.

2.2.4. Sensors

The use of different sensor types onboard unmanned vehicles for fieldwork in Svalbard is shown in Figure 8. Since most activities were conducted with off-the-shelf UAVs, it is not surprising that the most frequent sensor type are visual range (RGB) cameras. To a lesser degree, unmanned vehicles were used to obtain in-situ measurements, in particular in atmospheric research (aerosol and meteorological parameters). Very few vehicles used more sophisticated remote sensing instruments like radars, lidars, or hyperspectral cameras. These sensors have clear benefits to many scientific fields and the fact that they are used to a low degree may indicate that the high price and lack of off-the-shelf availability may be a limiting factor. The large number of other sensors indicates that there is also a large degree of customized and specific instrumentation developed and deployed on the unmanned vehicles.

2.2.5. Countries

The graph in Figure 9 shows the country affiliation of all authors' institutions, where each country is only counted once per publication. Countries with less than three publications were summarized

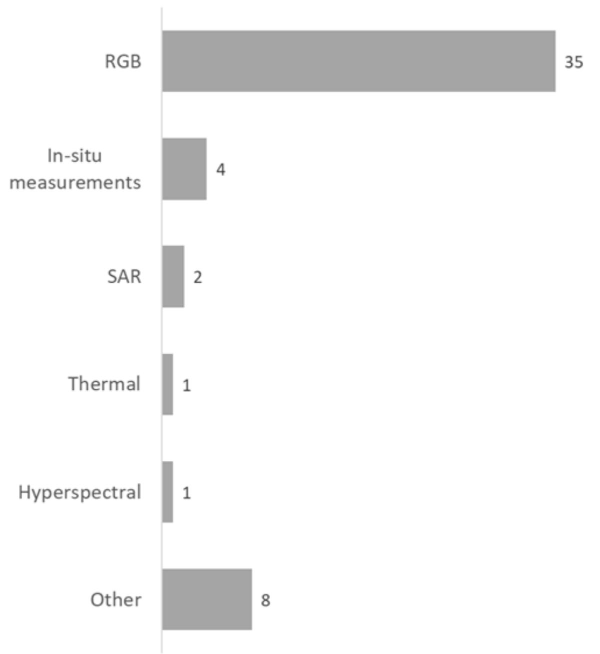

Figure 8: Overview of the different types of sensors identified in the database.

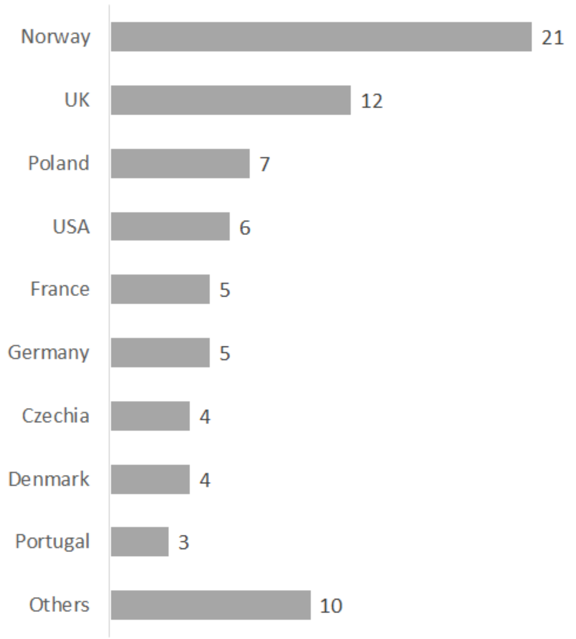

Figure 9: Overview of the different countries identified in the database.

as "others". The overview data show that a large number of countries are involved in unmanned vehicle research in Svalbard and that the majority of publications included a Norwegian contribution, followed by contributions from the United Kingdom (UK) and Poland.

2.2.6. Fieldwork time

Figure 10 shows the timeline of unmanned vehicle fieldwork activities obtained from published sources. The data indicate that the use of unmanned vehicles in Svalbard started as early as 1998 and that a more frequent use started from 2008. Most activities seem to have been carried out between 2014 and 2016. This coincides with the release of the first commercial off-the-shelf quadcopter drones (DJI Phantom in 2013). Furthermore, it should be noted that the low number of activities in the last few years may be related to the fact that this report only considers published data. The natural "lag" between conducting fieldwork and publishing the results is likely to explain the low frequency of activities.

The data also show that most of the fieldwork has been performed during the summer season, followed by the spring and fall seasons. Only one field campaign was conducted in winter. This distribution indicates that fieldwork is conducted mostly during the times when access to field sites is the easiest (summer: boat, spring: snowscooter) and daylight is available.

2.2.7. Fieldwork location

Figure 11 shows a map presenting the location of the fieldwork that is described in the published, peer-reviewed papers related to unmanned vehicles in the region of the Svalbard archipelago. We decided to exclude the Fram Strait, where several activities were conducted (eg. Crocker et al. 2012). UAV surveys were focused mostly around three sites: Kongsfjorden, Adventdalen, and Billefjorden. One study concerned eastern Bjørnoya. The geographic extent of the report covers 74°23' N – 80°09' N and 10°59' E – 19°15' E. This shows that there are several hotspots for unmanned vehicle activities in Svalbard. On the one hand, this indicates that these sites could be used in the future for long-term monitoring activities. On the other hand, this means that a large area of Svalbard is not benefiting from these novel technologies yet.

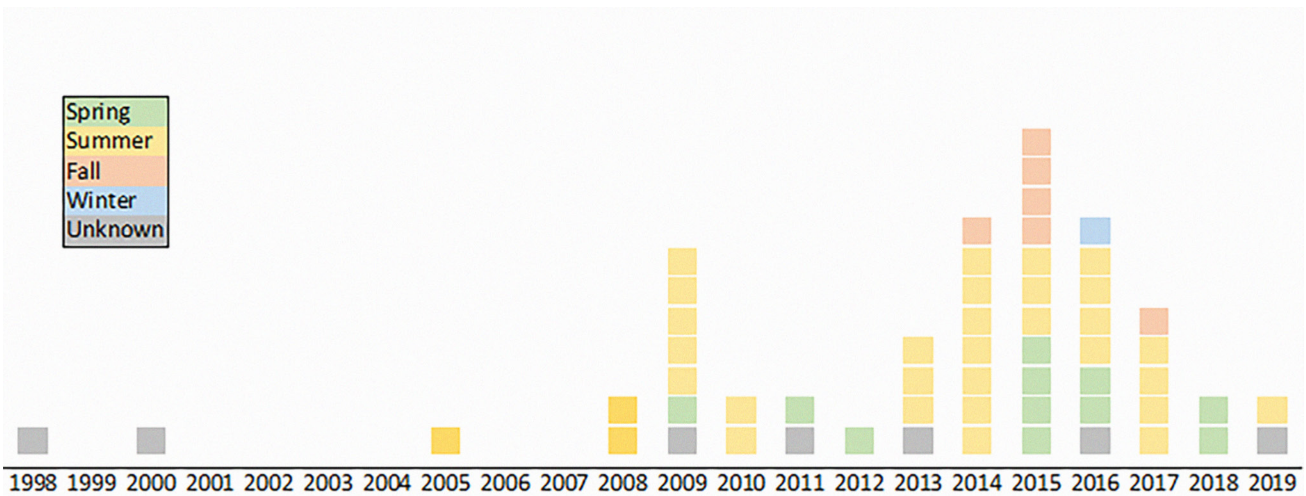

Figure 10: Overview of the timeline and seasons of fieldwork identified in the database.

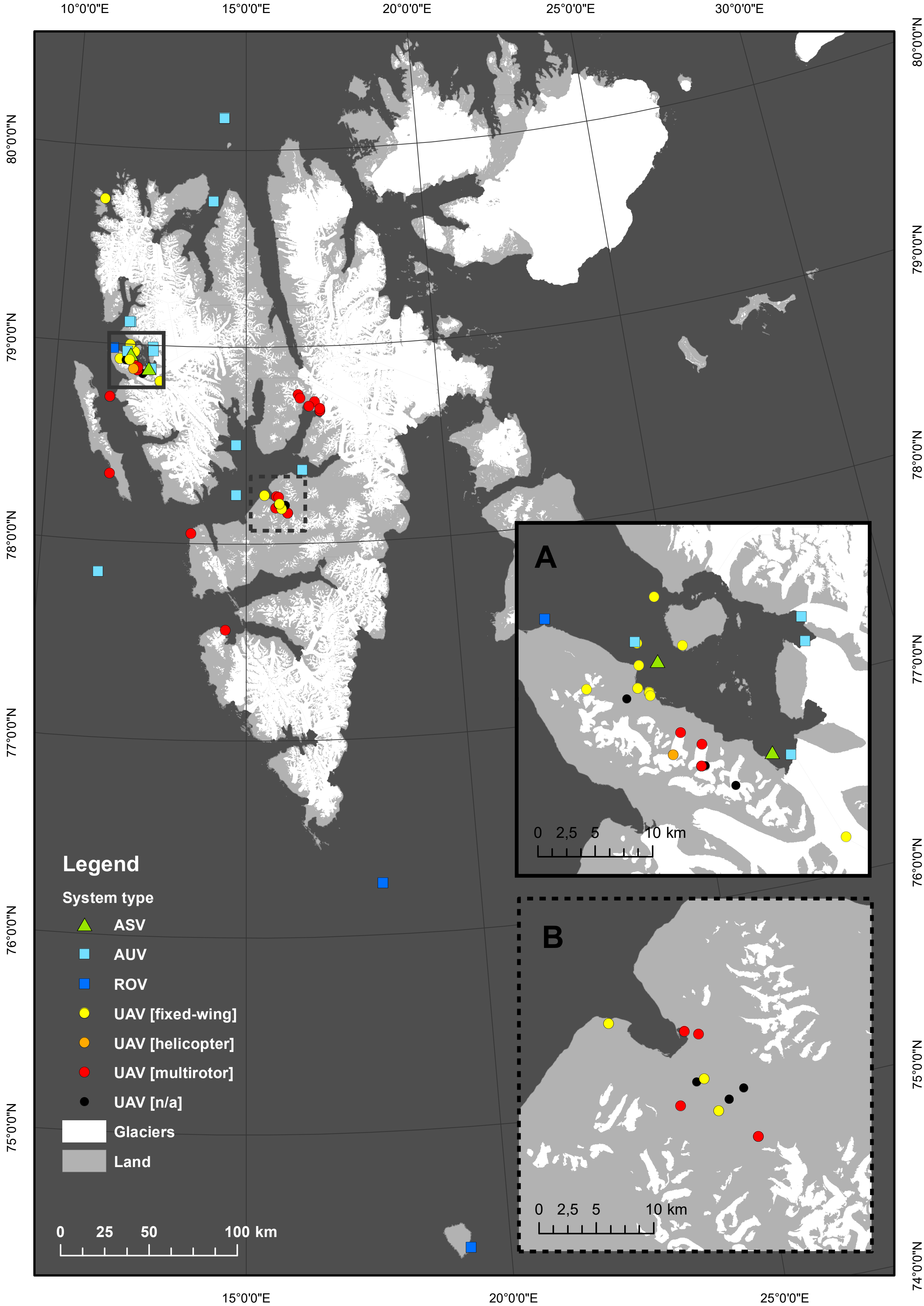

Figure 11: Location of study sites: A: Kongsfjorden region; B: Adventdalen region; ASV - Autonomous Surface Vehicle, AUV - Autonomous Underwater Vehicle, ROV - Remote Operated Vehicle, UAV - Unmanned Aerial Vehicle

2.3. Main conclusions

The results from section 2.2 lead to the following three main conclusions. The first conclusion is that unmanned vehicles offer great benefits for research in the Arctic and are used with an increasing frequency throughout a wide range of scientific disciplines by international operators. Though many disciplines already benefit from using unmanned vehicles, a large untapped potential still remains. Opportunities remain within intensifying the use of existing applications/disciplines, expanding the use to new applications/disciplines, and implementing the use of new types of miniaturized sensors (e.g. radar, lidar, hyperspectral).

The second conclusion is that two user categories of unmanned vehicles in Svalbard can be identified: advanced users and basic users. On the one hand, advanced users are operating complex and sophisticated vehicle systems for specific scientific purposes. Generally, the users of unmanned marine vehicles (ROV, AUVs, ASVs) and fixed-wing UAVs can be considered advanced users. Unmanned marine vehicles are complex in operation and require sophisticated infrastructure and logistics. The technology is applied for very specific research purposes, which, in Svalbard, were mainly on ecological and physical topics. In a similar way, fixed-wing UAVs are typically also complex to operate and require extensive infrastructure and trained pilots. Most fixed-wing UAVs have been used for atmospheric research or for mapping. Fixed-wing mapping activities were conducted mostly before off-the-shelf quadcopter products became widely available (around 2013) or in cases where large areas needed to be covered. Most fixed-wing operations are conducted beyond visual line of sight with highly autonomous systems.

On the other hand, basic users mostly operate off-the-shelf UAVs for mapping purposes. These small, budget, ready-to-fly multirotors were the most commonly used UAV types in Svalbard. These systems are cheap, easy to transport, and straightforward to operate. With a low level of autonomy, these systems mostly operate within the visual line of sight. Low cost means that researchers can, at least to some extent, test the UAV in different scenarios, even if some of these will result in crashes. The small size of most popular multirotors (e.g. Phantom/Mavic series) allows packing them up in a backpack and hiking for even several tens of kilometers – allowing easy access to remote sites in Svalbard. The operation of these UAVs is very intuitive and requires comparatively little training.

The third and last main conclusion is that most unmanned vehicle operations were part of short-term studies and in limited areas of interest. Typically, the studies focus on small areas, usually limited to 1–2 km^2. These datasets provide valuable input for many models and simulations but also have the potential to be used for long-term monitoring studies. However, the main limitation of this opportunity is that data are often not shared to the scientific community and stored without long-term potential. Furthermore, most activities were concentrated on very localized areas, mostly around Ny-Ålesund and Longyearbyen.

3. Connections and synergies with other SESS report chapters

The use of unmanned vehicles in Svalbard for remote sensing is a relatively new trend and offers solutions to closing the gap between surface and satellite observations. Therefore, this SESS chapter should serve as a general motivation for all SESS contributions and SIOS partners to evaluate the potential and benefit of using unmanned vehicles. In particular, future reports should assess how unmanned vehicles are used in their respective field, what potential they offer for the future, and how this potential can be unlocked.

4. Unanswered questions

4.1. Data

The documented use of unmanned vehicles in Svalbard is likely to only represent a fraction of on-going endeavours, as further supported by other reviews on the topic (Ader and Axelsson 2017, Gaffey and Bhardwaj 2020). A significant portion of activity remains beyond the scientifically published domain, i.e. without being peer-reviewed by the wider community and/or as remains hidden through limited access and/or being locally stored. This also applies to reports or theses written in the native language and stored exclusively in academic depositories. Proper care should be given to including such data in future assessments, while further criteria should be implemented for the inclusion of unpublished data. The latter is important given that workflows and reporting procedures remain far from standardised even in published work, and the inclusion of partial datasets may lead to increased ambiguity.

Projects such as Svalbox (Senger 2019, Senger et al.2020) have enabled access to hundreds of drone-derived DOMs and datasets across Svalbard, yet mostly remain beyond the scientifically published domain. Many UAV-based projects have been conducted but not published yet, e.g. several Polish campaigns near Hornsund, and some have been scientifically published only after the data integration deadline of this study. These projects remain, however, mostly limited in scope to single disciplines, resulting in a highly fragmented data pool when considering Svalbard in full. Data are often stored locally with accessibility granted only through the local data owner. While many allow open access to the data for scientific use, the question of *how to encourage open access data policy as the standard in the field of Arctic UAV use* remains. As with more traditional data and sample sets, data and metadata are often lost along with the termination of the project, and it is therefore important to think about *how to guarantee long-term/permanent storage and availability of both data and metadata*, knowing the size of single datasets. Publicly providing the data after finishing the project could already be made mandatory during the process of application for UAV operations in Svalbard. This is already the case for several funding agencies such as the German Research Foundation, who require uploading the final processed data alongside the final report. Likewise, the Norwegian Research Council and the National Science Centre in Poland have introduced stricter requirements for open-access sharing of data. Also, US agencies (e.g. NSF, DOE, NASA, NOAA) have well-defined data sharing policies for funded projects.

Prior to determining fitting storage solutions, a draft requirement should be drawn up, covering the kind of data and metadata that should be published. A majority of works reviewed in this contribution did not offer the necessary processing metadata to reproduce the published results, even by offering access to raw data upon request. For scientific reproducibility, products and metadata should be available, including all the processing steps taken and processing parameters applied. Besides the raw data (e.g., images) and processing parameters, the metadata should always include the version and name of the processing software used. *What else should be included*, however, remains an unanswered question and probably requires the support and input of the wider community.

For example, only a handful of the included works provide dedicated processing reports that meet the bare-minimum requirement, even if the generation of processing reports has been available for most major photogrammetry processing software packages (e.g. Agisoft Metashape, Pix4D) for a while. Identifying this gap, the plugins for these processing tools are in active development that standardise the workflow, for e.g. (Betlem et al. 2020). These plugins include the generation of processing reports into a uniform approach. Furthermore, various reviews have outlined *dos and don'ts*, but these either target UAV data acquisition and processing in general (thereby disregarding common issues observed in the Arctic) (Eisenbeiss and Sauerbier 2011, Hugenholtz et al. 2016, Nex and Remondino 2014) or remain mostly disciplinedependent in favour of the outcome, e.g. DEM, digitised surface features (Bemis et al. 2014, Bhardwaj et al. 2016, Ewertowski et al. 2019).

4.2. UAV Regulations

The operation of UAVs is regulated by aviation authorities in order to ensure safety, security, and privacy. Until 2020, the national aviation authorities issued individual UAV regulations for their countries. In an effort to harmonize the regulations, the EU has introduced common regulations ('EASA' 2020). The new EU regulations were being planned to be implemented in July 2020; however, due to the COVID-19 crisis, the implementation was postponed until January 2021 ('Luftfartstilsynet' 2020). The Civil Aviation Authority of Norway has decided that Norway will follow the new EU regulations and extend them to Svalbard. After the implementation of the new regulation from 1st January 2021, there will be a gradual transition period where one can still operate after the old regulation and permits until 1st January 2022 (basic operations) and 1st January 2023 (advanced operations).

The introduction of EU-wide regulations is likely going to lower the threshold for more complex UAV operations in Svalbard for non-Norwegian institutions. However, flying drones for scientific purposes in Svalbard will be regarded as commercial operations under the new regulations – this could increase the barrier to conduct even basic operations in the future. In summary, it is unclear to *what extent the new rules differ from the current Norwegian regulations and how this affects future scientific operations in Svalbard*. This generates a large uncertainty for operators and may affect future projects should they not make the necessary adjustments to the new regulations in time.

5. Recommendations for the future

Based on the main conclusions in section 2.3, four recommendations are given below. In general, the recommendations aim to intensify the use of unmanned vehicles for scientific applications in Svalbard and to standardise methods.

The first two recommendations are aimed to promote UAV-based remote sensing in Svalbard. Two separate approaches are suggested for this purpose. The first includes making incentives to increase the number of users of basic drone applications. This may be achieved by lowering the barrier for researchers to get engaged in simple UAV projects, mainly using RGB imagery and off-the-shelf drones. The second is to establish successful use-cases from basic applications and support upscaling them to advanced activities. In practice, this could mean the use of more sophisticated sensors, larger UAV platforms, more complex missions, and larger coverage areas.

The other two recommendations focus on standardisation and open-access. Standardising methods is an equally important task as intensifying the use of drone-based data acquisition. This is because standards add confidence, transparency, repeatability, and scientific value to the data. Since UAVs are a relatively new technology with many new users, it is natural that a lack of methodical knowledge and standards exists within the scientific community. To overcome this gap, all stakeholders should be involved in the development of best-practice methods for conducting, processing, and sharing data from UAV-based activities.

Recommendation 1: Education, experience transfer, knowledge base, and training

Since unmanned vehicles are still a relatively new technology, education and training are key elements required to promote its use. We recommend an outreach program for SIOS partners to educate and train them in the use of unmanned vehicles but also support knowledge and experience exchange.

- Establish a forum or conference for users of unmanned vehicle technology in Svalbard to share their experience and knowledge.

- Provide education and training on the regulations related to unmanned vehicle operations in Svalbard (e.g. new EU drone law).

- Provide education and training on planning and conducting fieldwork in Svalbard with unmanned vehicles. This includes post-processing of data, data management, standardisation, and best practices.

Recommendation 2: Extend infrastructure and access to advanced systems

Today, there is already a wide range of disciplines, institutions, and researchers that use unmanned vehicles for research in Svalbard. This report shows that the majority of the work is conducted with off-the-shelf drones and RGB cameras. More sophisticated systems are more complicated to operate and substantially more expensive to obtain. We recommend extending the existing SIOS drone infrastructure to help promote the use of unmanned vehicles in Svalbard.

- Provide easy access to a wider range of platforms and piloting services. This can include, for example, access to real-time kinematic (RTK) drones, larger multirotor drones, fixed-wing drones and systems with advanced sensors such as thermal, multispectral, hyperspectral, lidar, and radar.

- Provide consultations on drone regulations and how to apply for specific drone operations that exceed the open category. Collaboration with the Governor of Svalbard (Sysselmannen), Longyearbyen Airport, and RiS to lower the barrier for complex drone operations also included.

- Consider setting up a fixed ground control point network with known coordinates for key sites near Longyearbyen.

- Provide access to electricity for charging batteries in the field.

Recommendation 3: Standardisation of UAV operations, data processing, and data dissemination procedures.

This report shows that there are challenges related to the way how the results from unmanned vehicle operations are reported in the literature. In general, there is a lack of transparency when it comes to the methods of data acquisition and data processing. This undermines the value and confidence of the research results. For this reason, we recommend the development and dissemination of a best practice standard that should include the following information:

- Develop standards for drone operations with manuals, templates, checklists, and risk assessments.

- Develop standards for detailed description of data acquisition methods and parameters (e.g. field site location, fieldwork dates, flight tracks, altitude).

- Develop standards for specification of the sensors, systems and software used for data acquisition (e.g. vehicle type, vehicle modifications, camera specification, post-processing software).

- Promote the publication of raw data and metadata (e.g. photos, raw measurements, coordinates of GCPs), software processing reports, projects files).

- Develop standards for data formats and metadata information.

Recommendation 4: Data storage and data accessibility

Most of the projects that were evaluated in this report were designed as short-term observations. The results from those studies, however, may be very valuable from a future-long term monitoring point of view (e.g. changes in vegetation, glacier recede, coastal erosion). Additionally, not all the collected data are published or are published after a significant time. In order to unlock the long-term potential, it is essential for data to be stored and shared.

- Develop a system to log past, existing, and planned projects with unmanned vehicles in Svalbard. This should aim to increase collaboration and allow establishing long-term monitoring datasets.

- Generate awareness in the scientific community about data storage and access issues.

- Facilitate for long-term data storage and sharing of data by informing about existing databases that can be used for developing new facilities to SIOS and its partners.

- Support requirements (for publicly funded data acquisition campaigns) to provide open-access to data and to secure their long-term availability.

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Appendix 1

Overview of all publications related to scientific unmanned vehicle operations in Svalbard.

Title	Discipline	Fieldwork location(s)	Unmanned system	Publication type	Reference
A glacier respires: Quantifying the distribution and respiration CO2 flux of cryoconite across an entire Arctic supraglacial ecosystem	Glaciology, Ecology	Midtre Lovénbreen, Svalbard	UAV/ helicopter	Article	A. Hodson et al. 2007
The MicroASAR experiment on CASIE-09	Sea ice	Ny-Ålesund	UAV/fixed-wing	Conference paper	Long et al. 2010
Spatial and temporal variations of summer surface temperatures of high-arctic tundra on Svalbard — Implications for MODIS LST based permafrost monitoring	Atmosphere	Brøgger	UAV	Article	Westermann, Langer, and Boike 2011
The significance of depth and substratum incline for the structure of a hard bottom sublittoral community in glacial Kongsfjorden (Svalbard, Arctic)—an underwater imagery approach	Ecology	Kongsfjordneset	ROV	Article	Laudien and Orchard 2012
Profiling the Arctic Stable Boundary Layer in Advent Valley, Svalbard: Measurements and Simulations	Atmosphere	Adventdalen	UAV/fixed-wing	Article	Mayer et al. 2012
Greenhouse gas analyzer for measurements of carbon dioxide, methane, and water vapor aboard an unmanned aerial vehicle	Atmosphere	Ny-Ålesund	UAV/fixed-wing	Article	Berman et al. 2012
Mapping Svalbard Glaciers With The Cryowing UAS	Glaciology, Technology	Kongsvegen	UAV/fixed-wing	Conference paper	Solbø and Storvold 2013
Measurements of atmospheric aerosol vertical distributions above Svalbard, Norway, using unmanned aerial systems (UAS)	Atmosphere	Kongsfjorden	UAV/fixed-wing	Article	Bates et al. 2013
Use Of Unmanned Aircraft Systems (UAS) In A Multi-Scale Vegetation Index Study Of Arctic Plant Communities In Adventdalen On Svalbard	Ecology	Adventdalen	UAV/fixed-wing	Conference paper	Tømmervik et al. 2014
Polygonal pattern analysis on Mars based on Svalbard analogues	Geomorphology	Adventdalen (3 small sites)	UAV	article	Pina 2014
Unmanned Aerial Vehicle – Efficient mapping tool available for recent research in polar regions	Geomorphology, Technology	Nordenskiöldbreen	UAV/multirotor	Report	Stuchlík et al. 2015
Monitoring Cultural Heritage Environments In Svalbard: Smeerenburg, A Whaling Station On Amsterdam Island	Cultural Preservation	Smeerenburg	UAV/fixed-wing	Article	Thuestad et al. 2015
Assessing the impact of human activity on cultural heritage in Svalbard: a remote sensing study of London	Cultural Preservation	London	UAV/fixed-wing	Article	Thuestad, Tømmervik, and Solbø 2015

Determining Snow Depth Distribution from Unmanned Aerial Vehicles and Digital Photogrammetry	Snow	Breinosa	UAV/multirotor	Thesis	Cimoli 2015
Surface morphology of fans in the high-Arctic periglacial environment of Svalbard: Controls and processes	Geomorphology	Adventdalen	UAV	Article	De Haas et al. 2015
Land Cover Classification Using High-Resolution Aerial Photography In Adventdalen, Svalbard	Geomorphology, Ecology	Adventdalen	UAV	Article	Mora et al. 2015
Ice-cored moraine degradation mapped and quantified using an unmanned aerial vehicle: A case study from a polythermal glacier in Svalbard	Geomorphology	Austre Lovénbreen	UAV/multirotor	Article	Tonkin et al. 2016
Glacial geomorphology of the terrestrial margins of the tidewater glacier, Nordenskiöldbreen, Svalbard	Geomorphology	Nordenskiöldbreen	UAV/multirotor	Article	Ewertowski et al. 2016
Measurement of snow cover depth using 100×100 meters sampling plot and Structure from Motion method in Adventdalen, Svalbard	Snow	Adventdalen	UAV/multirotor	Article	Stuchlík et al. 2016
Near-bottom zooplankton aggregations in Kongsfjorden: implications for pelago–benthic coupling	Ecology	Kongsfjorden	ROV	Article	Hirche, Laudien, and Buchholz 2016
Quad-Polarimetric SAR For Detection And Characterization Of Icebergs	Technology	Kongsfjorden	UAV/fixed-wing	Conference paper	Akbari et al. 2016
Past and Present Glacial Sedimentary Environments in Krossfjorden, Western Svalbard: Glacier Front Evolution	Glaciology, Oceanography	Fjortendejulibuka	AUV	Abstact	J. Howe et al. 2016
Investigating snowpack volumes and icing dynamics in the moraine of an Arctic catchment using UAV photogrammetry	Geomorphology, Snow	Austre Lovénbreen	UAV/multirotor	Article	Éric Bernard et al. 2017
Using a small COTS UAV to quantify moraine dynamics induced by climate shift in Arctic environments	Geomorphology	Austre Lovénbreen	UAV/multirotor	Article	É Bernard et al. 2017
A UAV ice tracking framework for autonomous sea ice management	Technology	Ny-Ålesund	UAV/fixed-wing	Conference paper	Leira, Johansen, and Fossen 2017
UAV Path Planning using MILP with Experiments	Technology	Ny-Ålesund	UAV/fixed-wing	Article	Albert, Leira, and Imsland 2017
Application of Low-Cost UASs and Digital Photogrammetry for High-Resolution Snow Depth Mapping in the Arctic	Snow	Breinosa	UAV/multirotor	Article	Cimoli et al. 2017
A practical set of miniaturized instruments for vertical profiling of aerosol physical properties	Atmosphere	Ny-Ålesund airport and Kongsfjorden	UAV/fixed-wing	Article	Telg et al. 2017
Rise and fall of a small ice-dammed lake – Role of deglaciation processes and morphology	Geomorphology	Nordenskioldbreen / Adolfbukta	UAV/multirotor	Article	Nehyba et al. 2017

Title	Discipline	Fieldwork location(s)	Unmanned system	Publication type	Reference
AUV-based acoustic observations of the distribution and patchiness of pelagic scattering layers during midnight sun	Oceanography, Ecology	Norskebanken, Woodfjorden, Kongsfjordbanken and Isfjordbanken	AUV	Article	Geoffroy et al. 2017
Evaluation of the use of very high resolution aerial imagery for accurate ice-wedge polygon mapping (Adventdalen, Svalbard)	Geomorphology	Adventdalen	UAV	Article	Lousada et al. 2018
Drumlins in the Nordenskiöldbreen forefield, Svalbard	Geomorphology	Nordenskiöldbreen	UAV/multirotor	Article	Allaart et al. 2018
Evolution of high-Arctic glacial landforms during deglaciation	Geomorphology	Midtre Lovénbreen	UAV/multirotor	Article	Midgley et al. 2018
Circulation and exchange in a broad Arctic fjord using glider-based observations	Oceanography	Isfjorden, Nordfjorden, Sassenfjorden	AUV	Article	Fraser et al. 2018
Use of an Autonomous Surface Vehicle reveals small-scale diel vertical migrations of zooplankton and susceptibility to light pollution under low solar irradiance	Ecology	Kongsfjorden	ASV	Article	Ludvigsen et al. 2018
Detailed alluvial fan geomorphology in a high-arctic periglacial environment, Svalbard: application of unmanned aerial vehicle (UAV) surveys	Geomorphology	Dynamisk Creek alluvial fan	UAV/multirotor	Article	Tomczyk et al. 2019
Detection and characterization of icebergs in Kongsfjorden (Svalbard) based on ground-based radar images and additional remote sensing data	Oceanography	Kongsfjorden	UAV/fixed-wing	Thesis	Linge and others 2019
Latest Geodetic Changes of Austre Lovénbreen and Pedersenbreen, Svalbard	Glaciology	Austre Lovénbreen; Pedersenbreen.	UAV	Article	Ai et al. 2019
Drones and marine mammals in Svalbard	Ecology	Forlandsøyane Prins Karl Forland	UAV/multirotor	Thesis	Palomino Gonzalez 2019
Assessment of periglacial response to increased runoff: An Arctic hydrosystem bears witness	Geomorphology	Austre Lovénbreen	UAV/multirotor	Article	E. Bernard et al. 2018
Operational Framework for Rapid, Very-high Resolution Mapping of Glacial Geomorphology Using Low-cost Unmanned Aerial Vehicles and Structure-from-Motion Approach	Geomorphology	Hørbyebreen	UAV/multirotor	Article	Ewertowski et al. 2019
Seasonal Dynamics of Methane and Carbon Dioxide Evasion From an Open System Pingo: Lagoon Pingo, Svalbard	Atmosphere	Lagoon Pingo, Adventdalen	UAV/multirotor	Article	A. J. Hodson et al. 2019
Autonomous underwater vehicle (AUV) observations of recent tidewater glacier retreat, western Svalbard	Glaciology, Oceanography	Fjortende Julibreen (Krossfjorden), Conwaybreen, Kongsbreen and Kronebreen (Kongsfjorden)	AUV	Article	J. A. Howe et al. 2019

Reactivation of temporarily stabilized ice-cored moraines in front of polythermal glaciers: Gravitational mass movements as the most important geomorphological agents for the redistribution of sediments (a case study from Ebbabreen and Ragnarbreen, Svalbard)	Geomorphology	Ebbabreen	UAV/multirotor	Article	Ewertowski and Tomczyk 2020
The effects of tractor driving on arctic vegetation at Kapp Linné, Svalbard	Ecology	Kapp Linné	UAV/multirotor	Thesis	Magiera 2020
Integrated Assessment of Shoreline Change along the Calypsostranda (Svalbard) from Remote Sensing, Field Survey and GIS	Geomorphology, Geodesy	Calypsostranda	UAV/multirotor	Article	Zagórski, Jarosz, and Superson 2020
Iron cycling in Arctic methane seeps	Oceanography	Storfjordrenna, Bjørnøyrenna, Ullsfjorden, Hola trough	ROV	Article	Hong et al. 2020
Equifinality and preservation potential of complex eskers	Geomorphology	Hørbyebreen	UAV/multirotor	Article	Storrar et al. 2020
Unmanned Aerial Systems for Investigating the Polar Atmospheric Boundary Layer—Technical Challenges and Examples of Applications	Atmosphere	Ny-Ålesund	UAV/fixed-wing	Article	Lampert et al. 2020