Practical guidelines for scientific application of uncrewed aerial vehicles in Svalbard (UAV Svalbard 3)

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1. Introduction

The objective of this report is to develop guidelines and standards for conducting research with uncrewed aerial vehicles[1] (UAVs) in Svalbard. This work follows two previous chapters on the use of uncrewed vehicles in Svalbard in the 3rd (Hann et al. 2021) and 4th (Hann et al. 2022) SESS reports. In accordance with their recommendation, guidelines for data storage and data sharing are collected with the intention to make drone-based research results transparent and usable for long-term studies. Furthermore, we present a comprehensive framework for the planning of drone fieldwork, along with practical recommendations. Last, several recommendations are given on how SIOS could further strengthen the use of UAVs in Svalbard for scientific applications.

2. Data storage and data accessibility

One of the key recommendations from the last SESS chapters on the scientific use of unmanned vehicles in Svalbard was the need to develop guidelines for the storage and accessibility of data. The previous work revealed that, currently, most datasets are not published alongside papers, and remain largely unavailable for further re-use. This is considered as the largest and most important unanswered question in the field. Also, key supplementary information on the acquisition and processing steps in papers that use drone data is frequently missing. The produced data and scientific work thus often fall short of the principles associated with findability, accessibility, interoperability, and reusability (FAIR) data (Wilkinson et al. 2016) and scientific best practices. In consequence, transparency and reproducibility of the work are lost. In particular, the potential for long-term findability, accessibility, interoperability, and reusability of the data is severely reduced. Essentially, this means that the opportunity to build long-term monitoring datasets from ongoing research with drones is severely limited. A theoretical example for this could be a case where a glacier area is mapped in a drone mission and later on, the glacier starts to surge – the availability of pre-surge data would be crucial input to understand the underlying surge mechanics.

In Svalbard, SIOS has well-defined general guidelines for metadata, paradata, and data sharing that provide a first step towards standardising the archiving of scientific (meta)data. Where available, the guidelines draw from community-established standards, whilst relying on custom metadata conventions for fields where no standards exist, e.g. for drone-based mapping.

Clear guidelines also exist for the fields of biology, oceanography, and glaciology. However, such guidelines do not exist yet that address the documentation needs for UAV-derived datasets or processing workflows. To rectify this situation, we recommend the establishment of standardised data structures and para-/metadata formats for UAV-related data, supplementing existing field-specific conventions. In addition, there is a need to establish a standard for the publication of photogrammetry data (James et al. 2019). Photogrammetry-derived data are increasingly important for the digitisation and characterisation of the earth's surface, with digital outcrop models (DOMs), digital elevation models (DEMs), and orthomosaic maps being frequently used in Svalbard for digitisation of landscape geomorphological characteristics, glaciers, geological outcrops, and cultural heritage sites.

The wide-scale applicability of UAVs both complicates the standardisation of (meta) data structures and requires it. The process of standardisation is likely to involve a multi-disciplinary

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[1] Note: Following the terminology of the original chapters, the terms "UAV" and "drone" are used synonymously. Other common terms are unmanned aerial system, remotely piloted aircraft system (RPAS), unmanned aerial system (UAS), unoccupied aerial vehicle, or uncrewed aerial vehicle.

approach, an effort that requires a scientific platform to connect people and allow for discussions. There is a potential for learning from similar activities in other fields (e.g., CARARE metadata scheme for 3D cultural objects; (D'Andrea and Fernie 2013)).

Until a comprehensive list of standards is developed, we recommend the minimum requirements outlined in Table 1. The list is mainly intended for the most common drone-based results in Svalbard, i.e. generation of DEMs, DOMs, and orthomosaic maps, but is also generally applicable. It is partly based on learnings from the UNIS-led Svalbox project, which aims to compile and acquire key data sets and publications to provide an interactive 3D geoscientific database of Svalbard with a focus on research and education (Senger et al. 2021). DOM data are openly published, and the para-/metadata are made available through the Svalbox Digital Model Database REST services and Svalbox Zenodo group (Betlem et al. 2022). At this stage, we do not suggest specific file types for the data; however, this should be discussed in the future.

As part of the publishing practice, all data sets should include a processing report and/or quality assessment of the data, including a comparison with legacy data. The published digitised Festningen profile is a good example of how this can be done, including the integration with a para-/metadata database and open publication of source and product data (e.g. Senger et al. 2022).

Suitable storage locations of such data need to offer three key characteristics. They must offer free access for the end-users, allow for the storage of large datasets, and guarantee long-term storage. Currently, there are a large number of databases that can be used for this application. The following is a selection of the databases that are most commonly used for the archiving of data from Svalbard; additional data centres are listed in the SIOS guidelines for metadata and data sharing[2].

Table 1: Recommended information to be included in datasets.

Metadata	Acquisition: • Vehicle type: what was the brand and model of the drone • Date & time: when were the data obtained • Location: where were the data obtained (coordinates of all field sites), including the coordinate system (i.e. EPSG code) • Altitude: at which altitude were the data obtained and how was altitude measured • Sensors: what type, brand, and model of sensors were used • Weather: temperatures, precipitation, cloud cover, and wind information • Authorship: role and affiliations of those involved in the acquisition • Coverage: how large an area was mapped • Image overlap: how much horizontal and vertical overlap exists between pictures • Camera angles: at which angle where pictures were taken (nadir or oblique) Processing: • Software: which software was used and which version number • Workflow: documentation of the whole processing sequence, including applied processing parameters • Authorship: role and affiliations of those involved in the processing
Raw data	• Images: especially for mapping and DEM generation missions • Ground control points: type, coordinates, and coordinate system of all points used • Other data: depending on the mission type
Products	• Final products: e.g. orthomosaic maps, digital elevation models, textured mesh • Processing reports: information about what processing settings were used to obtain the final products
Optional	• Flight and attitude data: drone flight logs and/or automated flight plan • Images that display the flight path and selected parameters • Crash or malfunction reports

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[2] https://sios-svalbard.org/sites/sios-svalbard.org/files/common/sdms-guidelines4providers.pdf

Zenodo: Zenodo is a general-purpose open repository developed under the European OpenAIRE programme and operated by CERN.

NorStore: The goal of NorStore is to develop and operate a persistent, nationally coordinated infrastructure that provides non-trivial services to a broad range of scientific disciplines that have a variety of needs for storing and publishing digital data.

Dataverse.no: A national, generic repository for open research data from researchers from Norwegian research institutions.

PANGAEA: The World Data Center for Earth & Environmental Science, located in Germany, operates as an Open Access library for free publishing.

Arctic Data Centre: The primary data and software repository for the Arctic section of the US National Science Foundation's Office of Polar Programs.

3. Framework for planning drone-based fieldwork

UAVs have emerged over the last couple of decades as a very efficient tool for collecting data for many environmental applications, including landscape mapping, monitoring, and sampling. In Svalbard, the biggest use case is the generation of DEMs and orthomosaic maps. A full overview of all work conducted is given in Hann et al. (2022) and can be accessed online[3]. In this context, the biggest advantage of UAVs is closing the gap between high-resolution satellite data and direct field-based observations. UAVs offer excellent flexibility in terms of temporal and spatial coverage, as well as resolution, with all three aspects controlled by the platform and sensor used, operator experience, weather conditions, and legal regulations. However, there are still applications where high-resolution satellite data will be better suited (e.g. mapping of areas larger than several km^2). Similarly, direct observations or ground-based time-lapse cameras can be more efficient for long-term monitoring (e.g. monitoring of avalanches or ice cliff retreat). Therefore, there is a need for a framework for planning UAV-based activities, first to ensure that UAVs are the optimal solution, and second to propose a uniform approach that will ensure that the gathered result can be compatible with future work (AMAP 2012; Ewertowski et al. 2019). In this section, we focused on a framework consisting of several steps, including (1) a definition of the survey aims; (2) a selection of the appropriate platform in compliance with local air traffic regulations; (3) transportation and preliminary activities; (4) pre-flight checks and setup; (5) conducting the survey; (6) post-flight checks; and (7) data processing and storage. In addition to this, the following references are recommended for planning drone activities: AMAP (2012) and Hann et al. (2021) for an overview of key capabilities of UAVs for science; AMAP (2015) and UNOLS (2021) for practical operational and piloting guidelines; Ewertowski et al. (2019), James et al. (2019) and Śledź et al. (2021) for guidelines for using structure-from-motion photogrammetry in general. As part of the Svalbox project, the UNIS Arctic Geology department also offers an (online) module (unisvalbard.github.io/Geo-SfM) with best practices for the acquisition and processing of photogrammetry data, including DEM, DOM and orthomosaic generation. The best practices include the use of ground control points (GCPs), differential GNSS and Agisoft Metashape.

3.1. Definition of the survey aims

Most UAV surveys include at least some kind of mapping, usually based on a series of images taken by UAV-mounted cameras, and their subsequent processing through the structure-from-motion (SfM) approach. Resultant data include dense cloud points and very detailed (cm to dm resolution) orthomosaic maps and DEMs, which can be used

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[3] https://sios-svalbard.org/UAV_Svalbard

for further analysis. The first question one needs to address is the purpose of the study, as that will indicate if UAVs are the best tool and will help with the selection of the platform. The main issue to be defined here is the area of the survey and the size of the targeted feature.

Due to limitations related to the combination of altitude, camera focal length, and camera sensor size, UAVs are most efficient at collecting data with ground sampling distance (GSD) between 0.01 and 0.30 m. Data requiring better resolution than 0.01 m can be collected using a UAV, but that will require a very low flying altitude (which translates into low flying speed and overall slow surveys); therefore, ground-based photogrammetry will be a cheaper and more efficient solution here. On the other hand, resolutions coarser than 0.30 m can be obtained from high-resolution satellites (e.g. WorldView or Pleiades series), which are cheaper and more efficient than ground or UAV-based observations.

Similar to GSD, also size of the studied area can potentially make use of UAV inefficient. UAVs' most efficient survey area is from 100 m^2 to 10 km^2. Smaller sites can be more efficiently surveyed using ground-based approaches, whereas satellite and conventional aerial data will be more economical for larger areas. If both the dimension of the targeted feature and the size of the area to be surveyed are within the suitable ranges (0.01 – 0.20 m GSD, 100 m^2 – 10 km^2 area), then it makes sense to use UAVs for surveys.

The definition of the survey aims should also incorporate the character of the survey, e.g. one-time mapping; change detection (in which case it might be worth installing semi-permanent ground control points); process-form geomorphological studies (which usually will include some additional data, e.g. ground-based time-lapse cameras); analysis of spectral signatures (which require multispectral or hyperspectral sensor, and thus typically large UAV platforms).

3.2. Selection of the appropriate platform in compliance with local terrain conditions and aviation traffic regulations

The type of the UAV platform should be selected according to the survey aims and adjusted to local terrain characteristics. More general information on typical UAV types is given in e.g. Hann et al. (2021).

Small multi-rotors (e.g. DJI Phantom and Mavic series) are very compact and can be easily transported in the backpack over large distances; therefore, they can be especially useful in remote parts of Svalbard. Moreover, they can hover over one place and take images even in very low light conditions (common in Svalbard). However, their main limitation is limited operation time (up to 40 minutes per battery pack), which usually means that additional batteries must be brough to the fieldwork, and a lack of ability to mount more sophisticated sensors.

Large multi-rotors (e.g. DJI Matrice series) are more capable in terms of available sensors (including LiDAR and multispectral cameras); however, they are heavier and larger and, therefore, harder to transport to remote locations.

Fixed-wing constructions can cover larger areas, are more resilient to high winds, and have much better battery efficiency; however, they are generally bulkier than small multi-rotors. Moreover, they cannot hang mid-air and usually require larger ground patches for a safe landing. Therefore, they are preferable to surveys that cover large areas (> 1 km^2).

Additional consideration must be given to regulations and the recently introduced EU drone laws. For more detailed information about regulations, refer to Hann et al. (2022). Operations in the "open" category cover flights with visual line of sight (VLOS), low altitudes (below 120 m), with small UAVs (< 4 kg). This type of operation covers most mapping missions. More complex operations, e.g. beyond visual line of sight (BVLOS) or at higher altitudes, are subject to more requirements. Special notice should be given to the airspace restrictions when operating close to airports, bird cliffs, national parks, or Ny-Ålesund. Also, a process is currently ongoing to introduce new environmental protection act regulations that may limit drone usage in Svalbard in the future.

Preparation of a checklist and printed operation manual is also an element of good practice. We also advise registering and updating all equipment pieces prior to fieldwork. When planning fieldwork, several extra days should be included to allow for bad weather windows. Time for packing and unpacking should also be considered.

The cost level for such platforms is also an consideration. Small off-the-shelf drones are usually quite affordable (ca. 2 000–5 000 EUR). Large multi-rotor platforms are more expensive (ca. 10 000–30 000 EUR). Fixed-wing systems, especially custom-built systems, can be an order of magnitude more expensive than large multi-rotor solutions. Rental prices can range widely and are around 100-300 EUR per day for smaller systems. Pilots can be hired for 200-2 000 EUR a day, depending on the level of qualification required.

3.3. Transportation and preliminary activities

Two aspects of transportation must be taken into account–first, delivery of the UAV to Svalbard, which typically means as checked-in luggage on airlines or as cargo on a ship. Airlines limit the number of LiPo batteries one is allowed to bring, depending on capacity: batteries up to 100 Wh can be brought without limitation; two batteries with 100-160 Wh capacity are allowed per passenger; and batteries larger than 160 Wh must be shipped separately. In addition, some airlines have banned drone transport entirely. Sending UAVs as cargo takes substantial shipping time. The drone must be packed into a solid case that can withstand handling during transport. Overall shipping as cargo comes at high cost and with a substantial risk that the planned research schedule will not hold. Good practice suggests transporting spare equipment (e.g. second UAV, controller, propellers, cables).

The second issue is related to transportation within Svalbard. Depending on the scenario and available transport solution, UAVs might be transported by vehicle (e.g. in the vicinity of Longyearbyen), which allows for the use of large UAVs, or be transported on foot, which instead favours small constructions which fit into a backpack. Watertight and hard-case containers (e.g. Pelicases or Zarges boxes) are advisable for longer transportation. When travelling in the field, one should ensure that the batteries do not get too cold (e.g. by carrying them close to the body, or by using heated transport boxes).

3.4. Pre-flight checks and setup

Technical pre-flight checklists, typically provided by the drone manufacturer, should be used to ensure that the drone is ready for flight. Especially it needs to be ensured that propellers and batteries are mounted securely and that an appropriate home point and return-home altitude are set. Furthermore, the survey area should be explored to familiarise oneself with the local terrain conditions and potential obstacles or hazards. A suitable take-off and landing spot should be carefully selected. Flat areas, with few obstacles and good overview of the survey area are usually a good choice. Potential safe emergency landing spots should be identified in case missions need to be aborted. If automatic flight paths are used (i.e. pre-planned missions) , it should be ensured that the right mission and altitudes are chosen. Before flight, any camera covers and protection must be removed, and one must ensure that there is enough free data storage capacity on the SD card. Before take-off, camera settings should be checked.

For additional accuracy of DEMs, ground control points (GCPs) can be used. The decision if of whether GCPs should be used or not depends on the use case. Typically, GCPs need to be used when low absolute spatial errors are desired, e.g. when comparing between different data sets, looking at very detailed resolutions, or investigating change-processes. There are two basic options for GCPs: artificial targets (preferably machine-readable) that are placed around the survey area, or natural targets such as rocks or outcrops. The coordinates of GCPs need to be obtained with high precision, ideally with differential use of the Global Navigation Satellite System (GNSS) networks, e.g. GPS, Gallileo.

3.5. Conducting the survey

The fieldwork crew should contain at least two persons: one pilot, operating the drone, and one designated polar bear guard. While the pilot should focus on conducting the mission, the polar bear guard should keep an eye on the surroundings not just for polar bears, but also other hazards, such as birds, weather changes, helicopter/airplane traffic, etc. For more complex missions, e.g. EVLOS or BVLOS, a third person acting as observer or mission operator is useful. During operations, special attention should be paid to the condition of the field crew concerning hypothermia or frostbite. Also, stress and tiredness can lead to carelessness and bad decision-making, and thus increase the risk of losing the aircraft.

3.6. Post-flight checks

After landing, the aircraft should be checked for any damage that might have occurred during flight or landing. If possible, data should be downloaded from the drone immediately and backed up without delay. It is an advantage if data can be reviewed in the field to verify the correct coverage of the survey area. Proper flight logs should be kept that include take-off and landing times, as well as some information about the mission and weather conditions.

3.7. Data processing and storage

For further information on data processing and data storage refer to section above.

3.8. Infrastructure

Limited infrastructure and access to UAVs are important barriers to the use of this emerging technology. Currently, there are several suppliers for UAV infrastructure in Svalbard. The following is a short overview of key stakeholders in this matter:

- The University Centre in Svalbard (UNIS) is offering the rental of drone equipment with optional pilot support for fieldwork, as well as extended support and planning for fieldwork operations (UNIS 2020). They offer a range of UAVs, consisting mostly of DJI systems with RGB and thermal cameras. The Svalbox project furthermore offers RGB-data acquisition and processing services.
- SIOS is offering access and funding to UAV infrastructure. SIOS is collaborating with the Norwegian Research Centre (NORCE) and UNIS to make these systems available to its partners.
- Ny-Ålesund: The first floor of the airport tower in Ny-Ålesund is set up to serve as a drone operation centre. Around Ny-Ålesund, a radio silent zone has been established due to a sensitive radio telescope. This makes it impossible to use the standard 2.4 GHz telemetry range for communication with the UAV within a radius of 20 km around the centre of Ny-Ålesund. Suitable alternatives are the commonly used frequencies of 484 and 868 MHz.
- Polish Multidisciplinary Laboratory for Polar Research (PolarPOL): Offers equipment for comprehensive studies of the structure and dynamics of the cryosphere and polar catchments, including quadcopter UAVs, fixed-wing UAVs, and GNSS systems.
- Polish Polar Station Hornsund: Offers no permanent UAV equipment or certified operators but can be used as a logistics hub. During the spring and summer seasons, the station is visited by seasonal expeditions which often use unmanned vehicles for their purposes.
- Nicolaus Copernicus University Polar Station, Svalbard (NCUPS): The station is equipped with: UAV, UAV real-time kinematic (RTK) system, GNSS system, and software (e.g. UgCS, DroneDeploy, Agisoft Metashape). Precise Digital Terrain Models are developed for the area of Kaffiøyra based on remote sensing sources, supported by UAV and precise GNSS measurements (also RTK and post-processing kinematic (PPK).

- Polar Station of the Maria Curie-Skłodowska University in Calypsobyen (Bellsund), is a seasonal station. Expeditions are equipped with: UAV, fixed-wing GNSS system, and software (e.g. ContexCapture/Bentley, Agisoft Metashape). Professional service with authorisation to use this type of device.
- Adam Mickiewicz University Polar Station (AMUPS), in Petuniabukta, is a seasonal station offering access within the framework of the International Network for Terrestrial Research and Monitoring in the Arctic (INTERACT). Available field equipment: UAVs multirotor, GNSS system, power generator.
- R/V Oceania is a research vessel belonging to the Institute of Oceanology of the Polish Academy of Science, that goes into the Arctic every summer. Expeditions are typically equipped with ROV, drop camera, AUV, and UAV.
- Czech Arctic Research Station operates a GNSS ground station in Longyearbyen and a GNSS ground station in Longyearbyen and Ny-Ålesund is made available via Kartverket.

4. Practical guidelines

Despite the undeniable advantages and versatility of unmanned systems, there are several challenges that responsible operators should be aware of. Using drones in the Arctic and Svalbard is a more difficult task than at mid-latitudes and is also associated with higher risks. From our experiences, the following special issues need to be considered for UAV operations in Svalbard.

Compass and GNSS issues: especially some off-the-shelf products (e.g. DJI Phantoms) are sensitive to any problems with GNSS and the onboard magnetometer compass. Magnetic interference errors occur often in Svalbard. In manuals, DJI frequently informs that their product should not be used in polar regions, which may lead to problems with the warranty in case of an aircraft crash. Solar activity can lead to ionospheric scintillation causing changes in the magnetic field that can confuse the drone's autopilot. The potential for disturbance of the Earth's magnetic field caused by solar winds (Kp-index) should be checked before take-off in polar regions. User experience also shows that the Longyearyben GNSS ground station may be difficult to pair with in RTK mode, yet still provides key data for PPK.

Air temperature and wind speed: low air temperature is a key limiting factor, especially during cold seasons. The operating temperature range of older generations of the most popular platforms starts from 0°C. However, it is possible to use DJI Phantom/Mavic series in sub-zero conditions. There might be a problem with turning on engines if the battery temperature drops below 15°C. It is recommended to keep batteries as warm as possible, also whilst charging, as lower temperatures may prevent the batteries from fully charging. Notice that flight time in low air temperatures is also severely reduced. Solutions can consist of insulation or active heating, as presented in Lampert et al. (2020). Light platforms are also more susceptible to high wind speeds and gusts. Operation in strong winds will draw more energy and reduce flight time. Strong winds can also lead to fly-away of the drone, especially when paired with GNSS issues. Wind profiles in Svalbard may be unpredictable due to large orographic diversity. Plastic, such as that in cables or 3D printed parts, becomes very brittle in the cold and can easily break.

Precipitation and atmospheric icing: due to the interaction between oceanic circulation – land relief, and a large proportion of glacierised areas, Svalbard is characterised by high relative humidity in the atmosphere. Fog or low cloud levels significantly reduce the extent of the VLOS operations. Supercooled water in clouds, fog, drizzle, or rain can cause icing on the vehicle's surface and lead to a rapid crash (Hann and Johansen, 2020). Heavy snowfall can also lead to failures. Additionally, marine aerosols contain solid impurities (e.g. salt) which harm fragile electronic parts (rusting, rotor damage).

Wildlife: some birds like the black-legged kittiwake (*Rissa tridactyla*), Arctic tern (*Sterna paradisaea*), Arctic skua (*Stercorarius parasiticus*), great skua (*Stercorarius skua*) or glaucous gull (*Larus hyperboreus*) can be aggressive towards aerial platforms or pilots, especially during nesting. Mammals (polar bears, reindeer, foxes, seals) are usually afraid of engine noise (Palomino Gonzalez 2019). All drone operations need to avoid exposing the wildlife in Svalbard to extra stress. Note that there are restrictions to accessing bird cliffs in national parks. Polar bear safety should always be a key consideration for fieldwork planning.

Light conditions: UAVs experience the same limitations of the light conditions as optical satellite remote sensing. In Svalbard, the dark season (also referred to as 'polar night') several months, which means that optical sensors are mostly useless between October and February. Even during polar day surveys, the low solar angle may affect operations by shading (caused by varied land relief). Flying over extremely dark or bright, highly reflective surfaces (e.g. fresh snow cover) may cause problems with obstacle avoidance systems.

Ground Control Points (GCPs): proper distribution of the GCPs may be particularly challenging over inaccessible areas such as glacier crevasse fields. Because glaciers are constantly in motion, it is recommended to place several markers also on unglaciated surfaces. Use of shiny coated markers may obstruct the processing stage because of solar reflection, especially on sunny days. Alternatively, UAVs with GNSS correction technology, e.g. RTK and PPK systems, can be used to eliminate the necessity of large numbers of GCPs across difficult terrain. The use of few points then suffices for the determination of absolute errors.

Variable ground conditions: Ground conditions can vary considerably between seasons in Svalbard, ranging from hard and frozen ground to wet and muddy. This can limit the possibility of UAVs to safely take off and land – in particular larger multicopters or fixed-wing aircraft.

A more general list of technical and operational challenges of using unmanned platforms in polar environments or for scientific purposes was presented by Kramar (2019) and UNOLS (2021). An operational handbook for scientific users of UAVs in the Arctic was produced by the AMAP workgroup (AMAP 2015).

5. Contributions to interdisciplinarity

One of the main findings in previous SESS chapters was that uncrewed vehicles have the potential to be beneficial to a very wide range of scientific disciplines in Svalbard (Hann et al. 2021, 2022). As such, there is a very large interdisciplinary interest in both UAVs and practical guidelines for scientific operations in Svalbard, particularly within the fields of geomorphology, ecology, atmosphere, oceanography, technology, glaciology, snow, cultural heritage, sea ice, and geodesy. As there are a wide range of users with different backgrounds, it is important to establish a common platform to share and discuss results and methods in a Svalbard context. Furthermore, there are key techniques (mainly structure-from-motion photogrammetry) that are used in many fields. There is great potential for synergy with UAVs on sharing platforms, methods, results, and more.

6. Recommendations for the future

6.1. Efforts to lower barriers for specific operations

Most areas in Svalbard are remote and uninhabited. This means that drone missions have lower risks compared to operations on the more densely populated mainland. This offers the potential to push for extending the operational envelope in Svalbard. In particular, the focus should be on the barriers of 120 m maximum altitude and the requirements for extended visual line of sight operation for simple operations. There are several ways this could be achieved within the current EU drone regulations, most easily with the development of special predefined risk assessments (PDRA) for Svalbard. SIOS should take a leading role in developing such frameworks, that will lower the barrier for scientists to conduct complex operations in Svalbard. Based on earlier work, two particular scenarios would be of high relevance for the Svalbard research community:

- Extended visual line of sight operations (with observer) for unmanned aerial vehicles below 4.0 kg and altitude below 120 m. Such operations are relevant for mapping activities to extend the distance the drone can travel from the pilot's location.
- Visual line of sight operations near take-off point with unmanned aerial vehicles below 25 kg and altitudes below 600 m. Pushing the maximum altitude from 120 m to 600 m is relevant for operations involving meteorological measurements and geological outcrop mapping.

6.2. Develop standards for data storage and data accessibility

A common standard for storage and sharing of data that were obtained with drones needs to be developed. This is required to unlock the full potential of such datasets – especially in the context of re-using data and building long-term monitoring datasets. Developing these standards is a community activity and requires dedicated funding and action to achieve. SIOS should facilitate discussions about this topic and take lead in organising a task force to develop a comprehensive standard for the scientific community.

6.3. Develop and provide a forum for drone users in Svalbard

A forum for scientific drone users in Svalbard should be developed. Since a wide and diverse range of scientific disciplines use drones in Svalbard, there is no natural forum. This diversity means that there is a need for an interdisciplinary platform where researchers with different backgrounds can come together to discuss, share experiences, develop best practices, etc. This would benefit experience transfer, development of standards, and help to build a knowledge base. Such a platform could also be combined with education and training activities. We suggest that the Svalbard Science Forum or the SIOS Polar Night Week could be used for this purpose. Also, reaching out to other stakeholders in this area, for example the Sustaining Arctic Observing Networks (SAON), is recommended.

6.4. Provide and fund training for basic and advanced drone use

Unmanned vehicles have a large potential to contribute to a wide range of scientific fields. Currently, there are only a handful of applications that are being used on a wide basis (mapping and surveying). Especially more complex and specific operations are currently only used by a few actors. We recommend that SIOS strive to offer opportunities to further develop drone applications and to lower the barrier for new users to implement drones in their research. This could be achieved, for example, by conducting workshops, offering infrastructure (UAV platforms), and funding for drone missions. This could also include providing information material in more compact form (brochure, website, etc.) about various topics. In particular information about regulations in Svalbard is of interest.

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