Integrating Activities for Advanced Communities

D8.5- Guidelines for drone usage in arctic environment

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Publishable Executive Summary

This document contains guidelines for station managers and the TA user community on best practices and standards for the use of drone technology at Arctic research stations. The content has been developed in cooperation between industry, academia, authorities, researchers and station managers with the intention to facilitate the process of introducing drones as a tool to enhance research activities.

The guidelines provide some of the most common best practises to follow when operating a drone and specifically when applying it in an Arctic environment.

Best practices include the following areas:

- Specification of types of drones from the market for different purposes
- Common considerations for using drones, specifically with focus on the Arctic climate
- Safety issues in relation to the use of drones
- Briefly about legislation
- Specification of best sensor types for different purposes

By following these guidelines, it is expected that some of the most common mistakes might be omitted and that there is a reasonable understanding of the entire scope related drones, which includes limitations, legislation, and possibilities, before introducing drone systems into the organisation.

The guidelines are intended primarily to make it possible for a beginner, who is new or relatively new to the topic, to easily get started with drones and clearly understand which main subjects to focus on. At the same time, also an advanced user should be able to find several things that will increase the knowledge about drones and how to operate them in Arctic environments.

Acronyms

ATC	Air Traffic Control
BVLOS	Beyond Visual Line of Sight
CTR	Controlled Traffic Region
COTS	Commercial Off-the-Shelf
GNSS	Global Navigation Satellite Systems
RPAS	Remotely Piloted Aircraft System
UAS	Unmanned Aircraft System
UAV	Unmanned Aerial Vehicle
VLOS	Visual Line of Sight

1. Introduction

1.1. *Background*

Drones, or Unmanned Aerial Vehicles (UAV), have become an important tool in environmental research during the last years due to their ability to make observations, including remote sensing, at low costs and at intervals determined by the user. With appropriate sensors, drones can be used for different types of remote sensing for various land surface, aquatic and atmospheric measurements. Consequently, they can extend the study area of research stations and facilitate up-scaling of environmental observations from plot scale to catchment scale. Further, sensors on drone platforms can also be used in combination with satellite-borne sensors to scale up to the regional scale and beyond.

Drones are especially applicable for arctic research. The Arctic consists of vast areas with very limited infrastructure and often inaccessible places, which makes it difficult to gather spatial environmental information at regular intervals and with minimal environmental impact on the ground. With drones it is possible to make such investigations, and due to the very limited population density in most of the Arctic, drone operations can be carried out with less risk than is the case in areas more densely populated. At the same time, drones can increase safety in the field by avoiding walking over mountains, ice, snow and wetlands.

In the near future it is probable that drones will be considered as part of the equipment operated routinely by research station staff and visiting scientists.

1.2. *Purpose of the document*

Regardless of any type of mission or geographic position where a drone should be used, there are common guidelines and knowledge to be followed prior to using it.

This document is produced for station managers and the user community and contains guidelines on best practices and standards for use of drone technology at arctic research stations. The document provides some of the most common guidelines to be followed when operating a drone and specifically when applying it in an arctic environment.

Best practices will include the following areas:

- Specification of types of drones for different purposes
- Common considerations and guidelines for using drones and specifically with focus on when using in cold climate
- Safety issues in relation to the use of drones
- Briefly about legislation
- Specification of best sensor types for different purposes

1.3. *Method*

Interviews, surveys and a workshop have been conducted in order to better understand the need among Artic environmental researchers, especially related to specific research areas and related field activities.
A compilation of best practice and experience from the collective drone community have been embedded in the overall reporting.

Experiences from these activities together with extensive work to elaborate on specific topics related to drones, suitable sensors, and legislation has laid the foundation for the guidelines in this document.

1.4. *Terminology*

The term Unmanned Aerial Vehicle (UAV) refers to an aircraft without a human pilot onboard. This is also the general meaning of the more commonly used term drone.

The term Unmanned Aerial Systems (UAS) refers to a complete system, i.e. the drone including all the peripherals, e.g. remote controller and ground station equipment, needed to operate the drone.

Remotely Piloted Aircraft Systems (RPAS) is another term that sometimes is used to describe the same as UAS.
This document will mainly use the general term drone.

2. Hardware guidelines

This chapter will give a general idea on how to get started with utilizing drones for environmental research purposes within the Arctic region. The document will cover several aspects in general. However, for more detailed information there will be references to other INTERACT documents and also external resources.

2.1. *A holistic approach*

A general outcome from interviews with Arctic environmental researchers is that research is performed in so many different fields that there is no single drone system that will fulfil the opportunities that have been identified. As a consequence, there will be a need for different types of drone systems for different applications such as small area coverage vs large area, taking samples vs taking photos, every day utilization vs once in a while missions, etc.

It is suggested to take on a holistic approach when trying to find a drone solution for a specific research application. This approach should include a life cycle perspective for the entire drone system so that it fits into the overall organisation (maintenance, logistics, reliability, versatility, safety, security, legislation) as wells as for the specific research purpose.

Another option, if the organisation is unfamiliar to the drone technology, is to start at a small scale. There are very good and affordable options on the market today with many advanced features that will help in assisting the drone pilot and also contribute to give a fast and useful result.

2.2. *Different types of drones*

The following section relates to the Drone Technology chapter in (Gustafsson, Bendz, Ader, Axelsson, & Isacsson, 2018) and gives a brief and general overview on different types of available drone platforms and a short explanation on how they can be useful for different purposes.

2.2.1. Quadcopter

The quadcopter is propelled by four rotors. The airframe of a quadcopter is a simple design and can be of different setups, Figure 1 shows a typical X4 quadcopter, which is the most common design among the commercial off-the-shelf (COTS) drones today.

Figure 1. The Parrot Bebop 2 drone is a small and cheap quadcopter drone.

Some pros and cons related to quadcopters, or X4 drones, are summarized in Table 1.

Table 1. Pros and cons for quadcopters.

Pros	Cons
Cheap	No redundancy in case of rotor failure
Efficient, lightweight and compact	Payload is limited
Uncomplicated construction	
Relatively fast	

2.2.2. Hexacopter

The hexacopter can be configured in different setups but common for all is that it will have six rotors. The most popular design is with the X configuration. An example of this type can be seen in Figure 2.

Figure 2. A hexacopter with the common X configuration, the Walkera Tali H500.

The hexacopter has several advantages compared to the quadcopter. The pros and cons with the hexacopter are summarized in Table 2.

Table 2. Pros and cons for hexacopters.

Pros	Cons
More power, which enables heavier payload	More expensive
Six rotors will give redundancy	More bulky and heavier
Good stability	Less efficient

2.2.3. Octocopter

The octocopter will have eight rotors and can be configured in different options as can be seen in Figure 3. The X8 sometimes called quad X8, to the right in the picture, will be a bit more compact aircraft, with a little bit less weight than the octocopter to the left. It is difficult to tell which one is the most commonly used as they have a bit different characteristic but generally speaking they are both very stable and redundant aircraft for demanding users and high-end applications.

Figure 3. The octocopter comes in two different designs; octocopter to the left and quad X8 to the right.

Table 3 summarizes pros and cons for the octocopter.

Table 3. Pros and cons for octocopters.

Pros	Cons
Heavy lifter, large payloads	Bulky and difficult to transport and store
Very good redundancy with eight rotors	More hardware, more complicated
Excellent stability	Requires a lot of power, shorter flight time
	Expensive

2.2.4. Fixed wing aircraft

Fixed-wing aircraft will need to stay in motion all the time and will be more suitable for missions with less precision flying, but with more requirement on large winds withstand and longer flight endurance. Figure 4 shows a small fixed wing drone for recreational use.

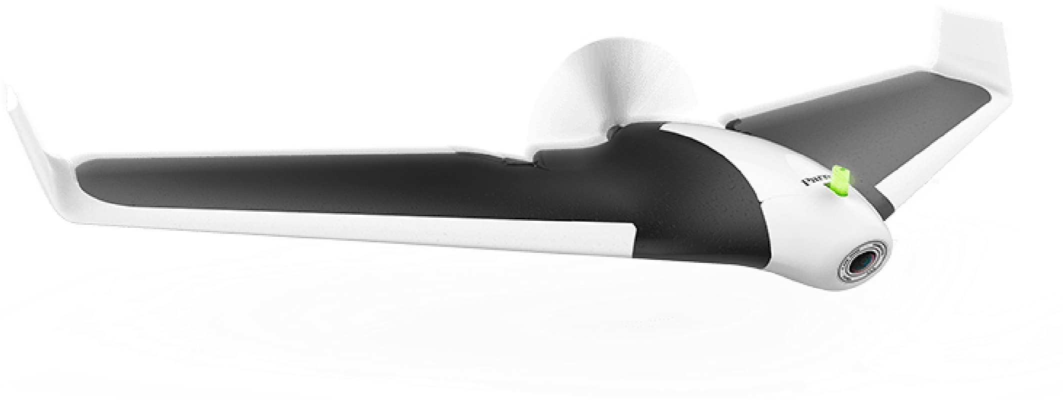


Figure 4. A Parrot Disco fixed wing aircraft.

Some of the pros and cons for the fixed wing drone type are shown in Table 4.

Table 4. Pros and cons for fixed-wing drones.

Pros	Cons
Excellent performance in strong winds	Needs to be in constant motion, no precise positioning
Efficient and long flight time	Bulky to transport if large wings
Redundancy thanks to gliding capability	Can be more difficult to take-off, operate and land
Lightweight	
Large payload capacity	

2.3. *Finding the proper level of ambition*

This section outlines the different choices to be made in selecting a suitable drone system according to specific needs and level of drone readiness.

Even though many drone and drone systems on the market are focused on photography rather than carrying sensors for individual purposes, the use of such drones will add experience and knowledge for the drone technology. This can be the gateway to the world of drones, and experiences from this entry level can later be useful to move forward to find more advanced and adapted solutions.

For a user that is completely new to drones, and are planning to operate drones, the unconditional first stage will be to start learning to fly. An excellent way to do this is to purchase a simple and cheap drone.

Figure 5 shows a generalized three-step staircase for a drone user, where each new step corresponds to more advance types of drones and drone missions. For a novice drone user, it is highly recommended to undergo the first stage in order to feel comfortable with handling a drone system before continuing to the next level.

Figure 5. Three stages to follow when planning for using drones in the research activities.

First stage

Even though a new drone user may have future plans for advanced project, which will require high-end drones, the first step should probably be to buy a COTS drone for recreational use. There are a several examples of these aircrafts described in (Gustafsson, Bendz, Ader, Axelsson, & Isacsson, 2018). Many of these drones come equipped with cameras, and can thus be used for taking photos, and eventually construct 3D models from the photos.

The pilot must ensure that the operation will be performed in parity with the current legislation, which is likely to follow these basics:

- *Where* – never near airports or in restricted zones
- *When* – there is no risk for other persons or property
- *How* – always within safe altitude and distance

The price interval for a ready-to-fly system for this purpose will start at 1000 Euros but should probably not cost more than 2000 Euros excluding accessories.

Second stage

The pilot may, after a certain amount of experience of both flying and studying legislation, feel comfortable to use professional or larger drone systems, which should indicate a readiness to move on to the second stage in Figure 5.

The drones used at this stage may be the same as in the first stage, i.e. COTS drones for recreational use, but it can also be enterprise drones and solutions. These more advanced drones might be equipped with sensors built for a specific research purpose. The sensors might be of high value, and therefore a skilled and experienced pilot that is aware of the regulatory framework is preferred in order to minimize the risk of losing the sensor and the drone system.

A typical price range for such a system would be more than 2000 Euros and can also easily reach up to 10 000 Euros or more, especially if sensors, accessories and spare parts are added.

This kind of drone system will probably also utilize some kind of post processing software and hardware.

This stage should be performed before or if moving on the third stage.

Third stage

The third stage is reserved for the more advanced drone systems and flight missions. At this stage the skills and experiences of the pilot will be crucial, thus this is a prerequisite in order to continue to this stage.

Operations may include advanced flying, flying BVLOS or during long periods of time. The operation may also involve deviation from common legislation, which may require applying for specific permissions by authorities in order to follow national drone legislation.

The attached sensors may be advanced and expensive and require drones with high reliability and skilled pilots.

The types of drones at this stage are custom made or at least non-mass-produced drones or complete systems.

Ground stations, peripherals and other accessories are likely necessary and expensive.

Specific trainings will probably be needed in order to operate the aircraft and its corresponding hardware. Thus, service level agreements can be a good choice to maintain a good functionality.

A price for this kind of system may start relatively low, from a few thousands but can exceed more than 10 000 Euros.

The user should not move to this stage before the second stage has been completed. If using a complete drone service this may of course be overridden.

2.4. *Choosing the right drone solution*

If a drone acquisition is to be made, it is important to first consider the many general advantages and disadvantages with both COTS drones and customer-built ones, as well as with drone services. This chapter will highlight some of the pros and cons related to the three different solutions to consider before making a decision on buy, build or rent.

The definition between the drone options is not always clear, as one drone may fit the description for both a COTS and a custom-built drone and a custom-built drone may be operated and used by someone else that will provide the drone service.

2.4.1. COTS drone

A COTS drone is often a commercialized product produced in high quantities and easy to obtain from a regular store. There is enterprise or professional COTS drones that are adapted to specific needs and have a high price, but this comparison is simplified by delimiting them to the simpler drones targeted to a larger audience. The COTS drone market will of course have a wide span and price range, starting from a few hundred Euros for a popular recreational model to several thousand Euros for a high-end one made for professional use. Table 5 shows some general advantages and disadvantages that are specific for the family of COTS drones.

Table 5. Generalized advantages and disadvantages with COTS drones.

Pros	Cons
Quick and easy to obtain	Professional support and service needs to be dealt with separately
Relatively easy to learn how to fly independently	No adaption to specific assignments
Comparably low price	Not that versatile
Spare parts available	Training needs to be arranged separately
Help from user communities, if popular model	May be expensive if used only once
Available to the user at all times	User will have equipment responsibility
	Additional sensors may be a limitation to mount

2.4.2. Custom built drone

A custom-built drone is often ordered from the manufacturer and adapted to the customer's specific need. The acquisition of such a system can include flight training to ensure using the product to its full potential. These training sessions vary in time, some last a few hours while others can last for more than one day. In some cases, the customer needs to travel to the manufacturer in order to attend the course. It is also common that a service level agreement is included in the deal, where the customer can send the drone back for service or upgrade if necessary, making custom built drones a semi-service. Table 6 shows generalized advantages and disadvantages with custom built drones.

Table 6. Advantages and disadvantages with custom built drones.

Pros	Cons
Adapted to specific needs	Can be expensive depending on choice
Service and help available	Need to set aside time for training
Training included to ensure using the drones full potential	Large UAV's may need certificate and permission to operate
Higher level of quality	Several steps to obtain the drone
Large range if needed	Expensive if used only once
Favourable when frequently used	Untested, user will need to do all development.
Available to the user at all times	May suffer from lack of user community

2.4.3. Drone services

A drone service includes a professional drone pilot with access to the specific equipment needed to perform the drone flight mission. The pilot will travel to the location of interest and perform the assignment. The service provider will take care of all hardware, software, accessories, permissions authorities etc., and do not need to be arranged with by the scientist as this will be taken care of by a pilot included in the drone services. Table 7 shows advantages and disadvantages with choosing the option called drone services.

Table 7. Advantages and disadvantages with drone services.

Pros	Cons
Relatively easy to obtain	Difficult to pre-plan due to uncertain weather and similar circumstances
No need for any training	Can be expensive if repeated or long-term service is required
Quality of work can be guaranteed	Less independence for customer
Doesn’t need to care about specifications like range and payload capabilities	Difficulties for the service provider to access the service location
Favourable if needed only once or a few times	
No responsibility for the equipment	

3. Operational guidelines for the Arctic

This chapter will focus on how to operate a drone that is about to or already has been acquired. Focus will be on typical challenges and issues related to using drones in the Arctic region and will cover only a few more general operations required to take-off with a drone.

Figure 6 illustrates and summarizes a general guideline for operating drones in the Arctic. The main characteristics are; the need for legislation awareness, general drone operational guidelines and specific notions for the Arctic application.

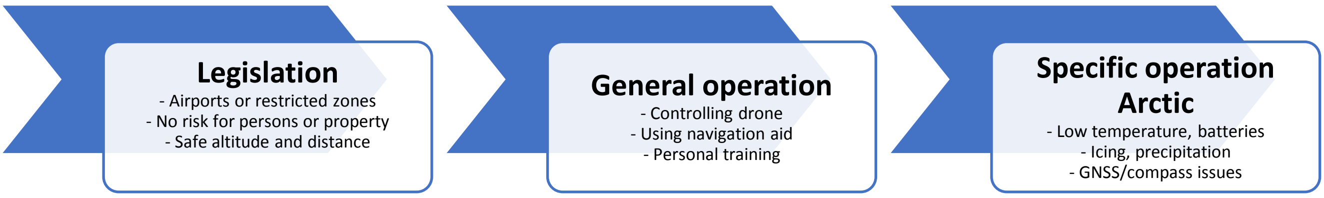


Figure 6. Generalized guideline to drone operation in the Arctic.

3.1. *Legislation and safety*

There is an INTERACT document that give guidelines to rules to comply with when flying drones (Axelsson & Ader, 2017). That document will give a detailed description regarding most of the legal situations in countries that are home to research stations engaged in INTERACT. This section will, like in (Axelsson & Ader, 2017), give a brief summary of the most important areas. Regardless if flying for commercial or recreational use these areas are as follows:

- Restrictions in the airspace and nearby airports
- Safe altitudes and distances
- Regulations from national aviation authorities
- Safety related to peoples and surroundings
- Insurance
- Local rules and regulations

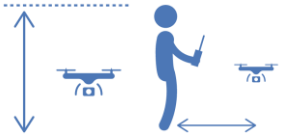
Restrictions in the airspace and nearby airports

Manned airports will establish a controlled airspace, which extends from surface to a specified upper altitude together with positions in longitude and latitude, forming a protective "box" around the airport.

This box is named CTR or control zone, in USA airspace class D. The CTR is controlled by the air traffic control, ATC, which will coordinate all aircrafts in that airspace. All aircrafts need to coordinate with and get permission from the ATC to fly in a CTR.

Unmanned airports usually don't have any ATC and you need to coordinate directly with any manned aircrafts and pilots that are going to use that airport. UAV pilots must always give way to manned air traffic.

Every pilot should have an aeronautical chart for the area where flight activities are supposed to be performed. Aeronautical charts can be a bit complicated to understand for a person with no or less flight experience but there are online charts or apps that will show no-fly zones and information that is specifically adapted to UAV pilots.



Safe altitudes and distances

The height limit in the airspace nearby your field station may differ, but usually no flight above 120m/400ft should be performed as this will interfere with regular manned air traffic. Also consider that many INTERACT field stations do have regular helicopter or aircraft connectivity flying on low altitudes near ground.

Make sure that the aircraft is within line of sight (LOS) which means that it can be observed without any optical aids like binoculars or glasses all the time. Usually, no national regulatory framework on any INTERACT field stations allows flying beyond visual line of sight, BVLOS, without special permission or license from authorities.

Safety related to peoples and surroundings

Fly away and never over property or persons, as there is always a small risk of the aircraft falling down. An uncontrolled falling or flying aircraft can cause a lot of damage in an event of an impact.

Insurance

Accidents involving aircrafts can be costly. An insurance covers damage to third party property or persons. Legislation in some countries (all EU countries) demands a mandatory insurance when operating drones commercially. It is important to sort this out prior to the flight.

If flying within countries that are members of the European Union, the insurance must comply with the proper regulation (EC Regulation 785/2004).

Regulations from national aviation authorities
In many countries, flying a drone for a scientific or commercial business, might need a permission from civil aviation authorities. Make sure to follow the procedures to obtain a valid license or permission. There may be different categories depending on maximum take-off weight and speed of the aircraft. The authorities sometimes require maintaining a log for all completed flights.

Local rules and regulations
National parks, restricted areas, animal preservation areas and military areas are often marked in an aeronautical online chart, but some information needs to be obtained from additional sources. In some countries and INTERACT stations, there are exceptions for using drones for scientific research within restricted areas, which will make it a bit easier. Application for that permission may be necessary to do in advance.

3.1.1. Wireless communication

Ensure that the wireless communication between the drone and the remote control or ground station complies with the legislation for the specific country where the flight is going to take place.

(Gustafsson, Bendz, Ader, Axelsson, & Isacsson, 2018) will cover this topic more thoroughly.

3.2. *General operation*

3.2.1. First flight

If completely novice to drones, the user should consider buying a very cheap multirotor drone in the price range around 100 Euros. This will be an excellent way to learn the very basics of how to control a drone before moving further to any more expensive solutions.

Several different drones from the market will be described in chapter 3 in (Gustafsson, Bendz, Ader, Axelsson, & Isacsson, 2018).

There is, however, the possibility to begin with any drone, as they will work and interpret the commands from the pilot in more or less the same way.

This basic guide assumes that a multirotor drone is used where the instructions will be more or less generic for most drones and their hand controller that are available on the market. Fixed-wing drones are for most cases not recommended to begin flying with, even though there may be exemptions to this.

Prior to flight

- Read the basics on how to manoeuvre the drone with the hand controller. More details are available in (Gustafsson, Bendz, Ader, Axelsson, & Isacsson, 2018).
- Read and understand safety and legislation.
- Make sure to set return-to-home (RTH) before start (not applicable if using a basic drone without GNSS).
- Ensure a wide and open area for take-off operation and landing, without obstacles, wires, trees, etc. Take-off and landing spot should be flat and levelled.
- Assess weather conditions: visibility, precipitation and no or low wind speed.

Take-off and land

Figure 7 shows a generic hand controller that is used for controlling most of the multirotor drones today.

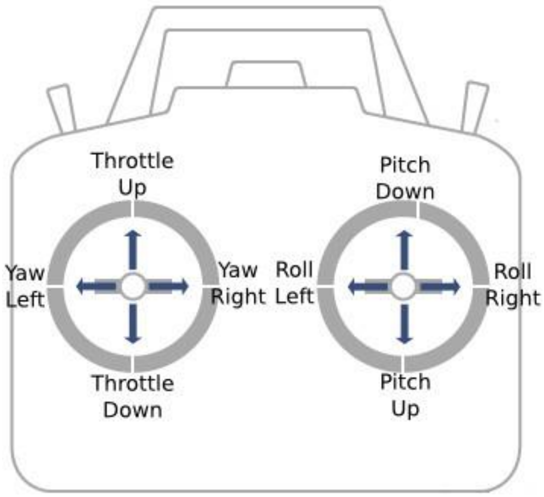


Figure 7. A generic hand controller for a multirotor drone.

- Start the rotors according to instruction from the drone manufacturer. Usually this is made by pushing both sticks of the hand controller simultaneously down in each "corner".
- Take-off by pushing the throttle stick upwards. This should be performed firm and distinctively without hesitation to avoid sudden wind gusts to set the drone out of control nearby the ground. The throttle is the only stick that is needed to get the drone in the air.
- Hover in the air, a few meters above the ground.

- Use the throttle stick to adjust the altitude a few meters to get a feeling for the throttle sensitivity.
- Pull the throttle back down to zero and let the drone land at the same spot.
- Repeat the sequence several times until confident.

Usually there is another option in the software of the drone that allows the drone to automatically take-off by pushing just one button. Likewise, it is possible to land by just a touch of a button from the controller software.

Flying in any direction

Next step is to learn to control the drone with the sticks for pitch, yaw and roll.

- Take-off and bring your copter to a hover a few meters above ground.
- Push the right stick forward to fly it a bit forward.
- Pull the right stick back to bring it back to its original position.
- Continue with the right stick to the left to move your copter a bit to the left and continue to do all the movements of the two sticks and watch the corresponding movements of the drone.
  The yaw will make the drone turn around its own axes and consequently "reverse" the pitch and roll sticks.

The above was a description of the basics to get going with a multirotor drone. There are many more features to cover on a modern drone, for example several different and advanced flight modes that will assist the pilot to follow terrain, vehicles or persons, waypoints, etc. In addition to that, there is specific software for drones that is used during a flight. It is not possible, in this guide, to describe all these features on the many different drone that are on the market today.

3.2.2. Navigation

Global Navigation Satellite Systems (GNSS) will support with positioning, which will make the flight mission easier to control and also gives the advantage of automated missions. Fixed-wing drones can do with only GNSS or even without any other aid than visual navigation, even though most of today's aircraft will come equipped with both compass and GNSS.

Even if drones today are very dependent of working GNSS, it is still possible to fly without GNSS support. In fact, every pilot should know how to manoeuvre a drone without aid from GNSS as it may, suddenly and during a flight, become reality if GNSS is interfered, intermittent or else corrupted, something that is actually pretty common to happen.

GNSS will support the drone, especially a multirotor drone, to hover in one spot during strong winds. Without GNSS support, the aircraft will immediately drift away with the same speed as the wind.

Therefore, practicing a scenario, flying without GNSS support in a controlled situation should be mandatory for all pilots. Most drones can manually turn off GNSS support, which allows the pilot to practice flying without this aid.

Strong winds may also result in an unwanted fly-away, as the propulsion of the motors may not be able to exceed the amount of power needed to bring the aircraft back towards the wind. One solution, if this situation happens, can be to lower the drone as close as possible to the ground, where the wind usually is weaker.

The pilot should always prepare for a few options to bring the aircraft back or, in the worst case, do an emergency landing, in the event of too strong winds.

Before any mission begins and before take-off, the pilot should assure that a RTH point is set. Most drones will support this feature, which will make sure that the drone will return to the point where it started in case of lost communication between the drone and the remote controller. The RTH will usually also be activated if the battery level is too low. During RTH, the drone will initialize a specific, preset, altitude. This altitude must exceed any obstacles that might block the estimated flight path back to the home point.

RTH will rely on the GNSS and that's of course a reason to make sure that the drone will have sufficient signal strength from the GNSS satellites and that the drone will indicate that it has its position locked.

3.3. *Specific operation in the Arctic*

3.3.1. Navigation - compass and GNSS

Multirotor drones will need compass to be able to navigate safely and correctly. Due to the magnetic inclination and prior to take off in any Arctic mission, a calibration of the compass is highly recommended. This can be performed usually with support from the software features inside the ground station or remote controller.

This will also lead to another important aspect to pay attention to, which is the fact that the GNSS signal strength can be lower around the poles due to the orbit of the satellites. This can affect the navigation of the drone negatively by means that if GNSS signal is lost, the drone will switch to a mode where its position must be controlled manually. A lack of GNSS signals will also lead to that features like RTH will not work. Again, this underlines the need for the pilot to undergo enough training to be able to fly the drone without GNSS support.

3.3.2. Human impact

As much as modern electronics will be affected by cold climate, humans will for sure also need to take preventive actions. Scientists working in Arctic regions are often aware of what cold climate will do to reduce manoeuvrability in hands and fingers and may have developed several tips and tricks to reduce the negative effect.

Since many remote controllers and ground stations for drones requires very small and careful fingertip movements it may become an issue to control the sticks on a remote controller gently even for a person that has adapted and is used to the climate.

Touch screen gloves are one option to be able to control a tablet or telephone connected to a drone. Figure 8 shows a typical glove that is used for sailing, which may be an option to allow for fingertip movements.

Figure 8. Gloves commonly used for sailing can be handy (Gill).

Another very simple but actually surprisingly well working option is to put the hand controller in an insulated box or something that best can be described as a large glove for the hand controller, as seen in Figure 9.

Figure 9. Hand warmer for the use of hand controller in cold climate.

3.3.3. Icing and precipitation

A risk factor for all types of aircrafts is icing. Traditional helicopter systems have solved these issues through automatic de-icing systems or by avoiding flights under meteorologically risky conditions which means that flying in temperatures around or below freezing point, when humidity is high, should be avoided.

There are no known COTS multirotor that have automatic deicing capabilities and the same can be assumed for COTS fixed-wing drones. For most cases, the advice is simply to monitor the weather condition to determine if it is safe to fly. Figure 10 shows typical icing on a propeller only after a few minutes of flying.

Figure 10. Icing on a propeller after only a few minutes of flying in risky weather conditions.

Issues related to icing and possible solutions against icing are further described in (Gustafsson, Bendz, Ader, Axelsson, & Isacsson, 2018).

Flight missions during precipitation should be avoided, although it might seem possible to perform the mission. The main reason for this is that the drone electronics may be damaged. The motors, which may seems to be the most vulnerable parts on a drone where they are mounted, will withstand lots of wet, as they are brushless. Unfortunately, the rest of the electronics won't.

Generally speaking, rainwater is not as bad for the drone as salt or brackish water. Light precipitation will probably not affect the flight mission instantly, but water and moisture that appears on the fuselage should be removed immediately after landing. Moisture inside modern electronics can give treacherous and intermittent errors at a later stage, which of course can be fatal for any airborne equipment.

Snowfall may have the similar effect as icing and particularly if the meteorological conditions are bad. Apart from that, flying in snowfall will reduce line of sight between the drone and the pilot, which will make it difficult to retain a safe flight mission. Snow may also affect sensors such as cameras that are used for FPV flying or the automatic obstacle avoidance systems on some drones.

Snow melting on a warm fuselage will result in the same effect as rainwater.
A drone that has been exposed to wet conditions or lots of humidity, should be inspected by a specialist.

3.3.4. Batteries

As most of the drones that will be used for support of scientific research in the Arctic are likely to be battery powered, it is important to remember at least one thing: flying drones in cold climate requires to keep the batteries warm prior to take-off. Many of the modern smart batteries will not allow the drone to take-off if the temperature is too low.

Increased take-off altitude adds another risk as motors on an aircraft must spin faster to produce enough lift, meaning even more power is needed, in turn accelerating battery drain.

A battery should not be below 15 degrees Celsius prior to take-off and this is also a threshold value where some manufacturers will prevent their drones to take-off.

Smart batteries, described further in (Gustafsson, Bendz, Ader, Axelsson, & Isacsson, 2018), will have a feature that monitors the temperature of the battery and displays it in the remote controller or the ground station as can be seen in the screenshot in Figure 11.

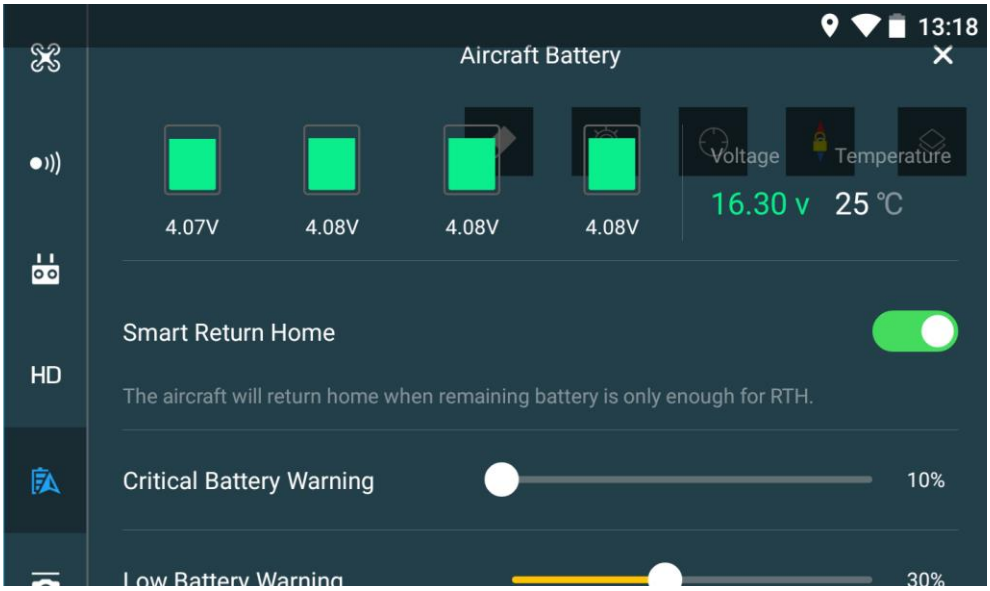


Figure 11. Battery status showing temperature and voltages for the individual cells in DJI Go App.

This feature is also used by the drone for receiving data from the battery during a flight and feeding the pilot with continuous and relevant information.

3.3.5. Preheating batteries

There can be a real challenge to maintain batteries preheated, especially when a field mission lasts for several days. Batteries will also have a certain amount of mass, which will require a large amount of energy and time to reach the correct temperature for a cold battery that has not been preheated before.

The simplest option is to keep batteries close the body, inside clothes, which should be possible when carrying just a few of them.

A few cheap hand warmers that can be bought on the market is a good idea to use. They are activated the moment they are needed and some of them can be recharged by boiling them into water for some time. There are also some hand warmers that are producing their heat from a slowly and controlled burning flame, even though this option really can't be recommended as this would be to expose the lithium batteries to a certain risk. For all cases, extreme caution should be observed when preheating batteries with unknown or uncontrolled heat sources.

Another good idea is to transport batteries inside a simple and cheap cooling bag. There are both soft and hard cases that can be used for this purpose. Soft cases tend to be less effective than the hard cases and the best option is probably to use polystyrene or polyurethane insulated hard cases that will withstand cold and keep the inside warm for a long time. Inside the box, hand warmers can be stacked between the batteries. These should be activated well ahead of the schedule of a planned flight.

Another option is to use an electrical cooling bag with a Peltier radiator. They are very cheap and most of them can be used as a heating box just by changing a switch. These boxes operate from a standard 12 V outlet that can be found in vehicles, boats or snow scooters but unfortunately, they are well known for their lack of efficiency, which means that they will drain the hosting battery very quickly. Peltier cooling bags should only be used when there is enough power from the host i.e. when an engine is running.

Some drones and their batteries even have built in battery heater. Still, preheating or keeping the battery warm with any of the options described above will save more energy.

The above is some of the options for keeping the batteries warm, but one should not forget to also keep the accessories, like tablets or telephones, that are supposed to be used together with the remote controller, warm.

3.3.6. Controller inputs

Minimize heavy control inputs or flying at high speed as this will require a large current from the batteries. If the batteries are a bit cold, this can cause a sudden voltage drop. While flying, the batteries will heat up, allowing a better and more reliable power output and less risk of voltage drops. Voltage drop is always a risk factor as it tends to occur suddenly, without any notification.

It is also important that the batteries stay warm during the flight. This will actually not be the major issue since the batteries will keep or even raise their temperature as long as they are continuously discharged through the provisioning of power to the propulsion.

3.3.7. Sunshine and high contrast

Snow and high contrast will smooth out any contours between snow and part of ground that is darker. It can be very difficult to watch a monitor and by the next second try to locate a drone in the sky, surrounded by the intense light from direct and indirect, reflecting sunlight.

A few of the options to mitigate this problem can be:

- Use of FPV googles.
- Locate the remote control and ground station as well as the pilot inside where cover from sunlight can be achieved.
- Use a hood (Figure 12) or cover for screen.
- Use monitors, tablets or telephones with specifically high brightness.

Figure 12. A hood to reduce incoming sunlight and increase visibility on the screen (DJI).

3.4. *Basic checklist for flying drones in the Arctic*

There are a few basic things that a pilot always should make sure to sort out prior to flight. The following basic checklist will summarize the previous sections and focus on details that are specifically useful for any planning of drone flight missions in cold climate and the Arctic region:

- Pay extra attention to possible compass deviation and inclination and any related error messages displayed. Consider to always do a compass calibration according to instructions in manual prior to flight.
- If flying with GNSS support, make sure satellites are available and signal strength is sufficient which should be indicated in the hand controller and/or the additional software.
- Prepare to fly without GNSS support in case of sudden interference or interruption.
- Monitor weather regarding possible icing. Icing on propellers may occur within a few minutes in bad weather conditions.
- Ensure batteries have the correct temperature, preferably above 20 degrees Celsius.
- Hover the drone for a while at a low altitude immediately after take-off. Monitor battery status.
- Avoid large control inputs as this requires high current output from the batteries.
- Consider not flying in temperatures around or below freezing point when humidity is high. Risk of icing.
- Pay attention to vibrations, deviations or difficulties in manoeuvring the aircraft as this may indicate icing. Prepare to land immediately.
- Use a landing pad if snow is present to avoid whirling snow from propellers.

4. Batteries

Batteries are in the closest future expected to be the predominant power source for a majority of the drone missions carried out by Arctic researchers. A more in-deep description of battery technology for drones can be found in section 3.3.4 and in (Gustafsson, Bendz, Ader, Axelsson, & Isacsson, 2018).

4.1. *General notes on the transportation of batteries on commercial airlines*

Usually commercial airline will not have any restrictions against bringing a drone itself on an aircraft. Consider sending the drone, well packaged, with the check in luggage. At the same time, as the drone uses batteries, there are several rules to comply with in these situations.

International Air Transport Association (IATA) have issued specific rules and regulations on how to handle lithium batteries on commercial flights. Table 8 summarizes the most relevant cases when travelling with batteries and is important to study and comply with prior to boarding a commercial airline flight with a UAV. Table 8 should be used to determine if portable electronic devices (PED) and spare battery(ies) can be carried onboard the aircraft.

Table 8. IATA Dangerous Goods Regulation for lithium batteries in personal electronic devices (PED).

Wh rating or lithium metal content	Configuration	Carry-on baggage	Checked baggage	Operator approval
≤ 100 Wh / 2g	In equipment	Yes max 15[1]	Yes	No[1]
	Spare battery(ies)	Yes (max 20 spare batteries[2])	No	No[2]
>100 to ≤160Wh	In equipment	Yes	Yes	Yes
	Spare battery(ies)	Yes (max 2 spare batteries)	No	Yes
>160Wh	Must be prepared and carried as cargo in accordance with the IATA Dangerous Goods Regulations			

1. Each person is limited to a maximum of 15 PED. The operator may approve the carriage of more than 15 PED.
2. Each person is limited to a maximum of 20 spare batteries of any type. The operator may approve the carriage of more than 20 batteries.

A complete guide can be found at (IATA, Passengers travelling with lithium batteries, 2018).

This section excludes methods for shipping batteries with cargo flights, since the assumption for this general document is that batteries are brought in personal for any scientific mission. There are more details to be found in the (IATA, 2018 Lithium Battery Shipping Guidance Document, 2018).

5. Sensor types and drone applications

There is a large number of applications of drones and sensors for arctic research. The identified opportunities and needs are so many that it is not possible to specify any particular measurement sensor or method to collect data. There are however ways to group the applications and from the conclusions of these identified applications different useful types of sensors could be listed as well as potential ways on how to use drones for scientific purposes.

5.1. *Identified sensor types*

There are INTERACT documents that describes useful sensors suitable for drones and arctic research (Gustafsson, Bendz, Ader, Axelsson, & Isacsson, 2018), (Gustafsson, o.a., 2018) . A summary of these sensors with a comment of *examples of applications is shown in Table 9.*

Table 9. Summary of sensors and applications for arctic research.

Sensor	*Application*
Gas, pressure, temperature	Measure greenhouse gases, measure atmospheric variation as a function of height
Camera	Documentation, observations, surveillance, build 3D models, count populations
Stereo camera	Identification of animals or vegetation
Normalized Difference Vegetation Index (NDVI)	Measure vegetation
Infrared cameras	Observations, surveillance, count populations
Radar	All weather, day and night observations, build 3D models, snow/land/ice/sea measurements
Lidar	Build 3D models

5.2. *Ways to exploit drones*

Drones can also be useful for performing different types of missions in order to alleviate tedious repetitive work or open up possibilities to reach inaccessible areas. Identified possibilities have been described in detail in other INTERACT documents (Axelsson & Ader, 2017) (Gustafsson, o.a., 2018). A summary of some of these possibilities is shown Table 10.

Table 10. Summary of opportunities on ways to make use of drones

Opportunity	Application
Collect samples	Air, water, soil/mud/gravel from trees
Collect data	Collect sensor data from stationary sensors in remote areas or from underwater sensors
Follow tagged animals	Sensor or transponder reading/acquiring/data collecting from animals.
Delivery	Send or receive goods to teams out in the field

6. References

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