Assessing Drone Performance and Probability of Detection for Search and Rescue Operation in Northern Canada

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ABSTRACT

Drones are increasingly valuable in Search and Rescue (SAR) operations, offering rapid aerial coverage and improved situational awareness in remote environments. However, environmental constraints and operational limitations affect their effectiveness. This study evaluates drone deployability and operation in SAR missions across Northern Canada through statistical analysis of SAR operability in various weather conditions, accounting for seasonal variations, and Probability of Detection (PoD) in different search scenarios. The first research question classifies operability categories based on historical weather data, identifying periods and locations for reliable drone deployment, considering factors like temperature, wind speed, and seasonal changes. The second research question estimates PoD, assessing the likelihood of detecting Persons in Distress (PiDs) with drones under varying conditions, including terrain, sensor capabilities, and target visibility. This research aims to evaluate drone usefulness in SAR operations by identifying constraints, informing deployment planning, and supporting technological advancements to improve search effectiveness in remote, high-risk areas.

Keywords

Emergency Management, Search and Rescue, Unmanned Aerial Vehicles (UAVs), Probability of Detection (PoD), Canadian Arctic

INTRODUCTION

Search and Rescue (SAR) encompasses a wide range of actions aimed at locating and assisting Persons in Distress (PiDs) in remote or challenging environments or who are trapped in disaster zones. The ultimate goal of SAR operations is to maximize the likelihood of survival for those in distress (Karamanou et al. 2018). In Northern Canada, ground SAR operations are governed by the legal authority of each territory, which delegates responsibility to local police services. Parks Canada oversees SAR efforts within national parks, while the Canadian Rangers often provide vital support for ground SAR missions when requested (Defence 2018).

The harsh conditions of Northern Canada present significant challenges to SAR operations. Extremely low temperatures and severe weather reduce the time available to save lives, as exposure to such environments can be fatal. Additionally, the sparsely populated Arctic and northern regions lack the infrastructure needed for effective emergency response, further complicating SAR missions (Lauta et al. 2018).

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In recent years, SAR operations in Northern Canada have become more challenging due to climate change and the erosion of traditional survival skills, particularly among younger generations. This shift has left many communities less prepared for emergencies. Additionally, the increasing number of visitors and some travelers' lack of preparedness, such as inadequate fuel and equipment, has significantly heightened the demand for SAR services (Kikkert, Lackenbauer, et al. 2021).

Environmental factors further exacerbate these challenges. Seasonal ice dynamics, particularly in the spring and fall, increase the likelihood of incidents involving mechanical breakdowns, overheating, and immobilized vehicles in mud. Rising temperatures during these seasons contribute to thinner and less stable ice, leading to hazardous travel conditions. Winter offers more predictable conditions with thicker ice and snow cover, highlighting the link between environmental factors and SAR incidents (Clark et al. 2016). However, extreme cold still presents significant challenges for SAR operations and survival time.

Given the evolving pressures and unique challenges of SAR operations in Northern Canada, innovative solutions are urgently needed. Unmanned Aerial Vehicles (UAVs), commonly known as drones, have emerged as transformative tools in this domain. These advanced technologies offer enhanced efficiency, improved safety, and greater endurance, making them highly promising for SAR missions in remote and harsh environments. (Messmer et al. 2024).

UAVs, or drones, are aircraft operated remotely or autonomously without an onboard pilot or passengers (Aabid et al. 2022). They are also known as Unmanned Aerial Systems (UAS), Remotely Piloted Vehicles (RPV), and Remotely Piloted Aircraft Systems (RPAS). While "drone" is the most commonly used term, formal and regulatory contexts often use UAV, UAS, RPAS, and RPA (Mohd Daud et al. 2022).

UAVs with real-time imaging and GPS offer rescuers vital insights into terrain, victim status, and hazards, helping teams make informed decisions on equipment, route planning, and personnel deployment (McRae et al. 2019). This is especially crucial in Northern Canada's challenging landscapes, where accurate information enhances SAR mission effectiveness and safety.

This research explores the potential of UAV technology to enhance SAR operations in Northern Canada by addressing two key questions. The first research question (RQ1) evaluates drone operability throughout the year, considering environmental factors like wind speed and temperature for effective deployment. The second research question (RQ2) examines the Probability of Detection (PoD) in various SAR scenarios, assessing how drones locate PiDs under different conditions. Understanding PoD is critical for evaluating drone effectiveness in challenging environments and operational constraints. With increasing SAR cases and challenges for traditional methods, drones offer a promising alternative to improve response times and success rates. The findings will provide SAR teams with data-driven insights for effective drone deployment, helping determine if drones can reliably support operations in Northern Canada and guide their integration into life-saving SAR strategies.

This study includes a literature review on UAV applications in Arctic SAR, a methodology for assessing drone operability, results from the analysis, and a discussion on implications and future work. The conclusion highlights key insights and their relevance to SAR operations.

LITERATURE REVIEW

Search and Rescue in Northern Canada

Canada's SAR operations encompass one of the most expansive and challenging regions in the world, marked by rugged terrain, extreme weather conditions, and sparsely populated areas. The SAR system relies on collaboration between various levels of government, Indigenous communities, volunteers, and private sector partners to assist PiDs. Public Safety Canada, a federal agency responsible for coordinating national safety and security efforts, plays a pivotal role in ensuring the safety and security of citizens, reflecting the government's core responsibility to protect its population (P. S. Canada 2018).

Indigenous and community responders play a crucial role in SAR efforts, often being the first to act due to their proximity and deep knowledge of local landscapes (Kikkert, Lackenbauer, et al. 2021). Meanwhile, the Canadian Armed Forces (CAF) oversee aeronautical and maritime SAR, with the Canadian Coast Guard (CCG) managing maritime rescues. Ground SAR falls under provincial and territorial jurisdiction, with specialized teams for national parks. Despite this structure, SAR operations in remote Arctic regions remain complex and resource-intensive, challenged by vast distances, extreme weather, limited infrastructure, and jurisdictional constraints, which hinder timely federal responses (Kikkert, Quigley, et al. 2023).

SAR demand in the Arctic has risen due to increased maritime traffic, resource exploration, aviation, and climate change risks. The ability to deploy efficient SAR resources is essential for maintaining sovereignty and ensuring the safety of individuals in distress(Kikkert, Lackenbauer, et al. 2021).

The Role of Drones in SAR Operations

The development of UAVs, commonly known as drones, has significantly improved SAR operations by enabling rapid deployment, cost-effective solutions, and enhanced mobility in hazardous or remote areas (Lyu et al. 2023). Even if a small UAV crashes in harsh conditions, the financial loss is minimal. Furthermore, UAVs enhance SAR operations by improving rescuer safety, reducing their exposure to hazardous areas. They allow teams to assess difficult or inaccessible terrain without risking accidents or injuries. (Karamanou et al. 2018). In addition, UAVs are immune to the psychological pressures that often lead to errors in human rescuers. Compared to manned aircraft, UAVs can operate at lower altitudes and speeds, enabling them to capture higher-resolution data. (Romanova 2020). Their ability to navigate difficult terrains and provide real-time aerial data makes them essential tools for locating missing persons and supporting rescue efforts. Drones require minimal maintenance and can be quickly deployed, allowing responders to cover large areas efficiently. Moreover, their capability to hover in place provides a stable platform for gathering critical imagery and sensor data (Lyu et al. 2023).

Drones' maneuverability makes them highly effective in urban and mountainous SAR missions, accessing areas unreachable by ground teams. Integrated with ground control stations (GCS), UAVs enhance coordination by providing real-time imaging and communication. Field studies show that UAV-assisted imaging significantly reduces response times, improving the chances of locating individuals before they face severe risks like hypothermia or dehydration (Tuśnio and Wróblewski 2021).

Drones have been successfully utilized in various SAR operations, demonstrating their efficiency in real-life scenarios. For instance, a study documented the successful rescue of a 65-year-old man in Beskid Niski, southeastern Poland, using UAVs , which enabled the identification of the lost individual within hours (Niedzielski et al. 2021). The British Broadcasting Corporation (BBC) reported a case in Norfolk, UK, where a 75-year-old missing man was located through drone imagery analyzed by a police expert (BBC 2018). In another case, UAV technology was critical in a high-altitude mountain rescue. A 65-year-old Scottish climber became stranded on Broad Peak in the Himalayas at 7,600 meters after falling from an ice cliff. Two Polish mountaineers used a DJI Mavic Pro drone to locate him, surpassing the drone's specified operational limit.(McRae et al. 2019). Another example is Norway's largest landslide disaster on December 30, 2020, in Ask, Gjerdrum. In temperatures as low as -23°C, Norwegian emergency services used DJI Matrice 300 RTK drones to map the area, locate survivors, and identify hazardous zones, improving rescue coordination and reducing risks for ground teams. (DJI 2021).

Drone Operability in Northern Conditions

While UAVs offer significant advantages in SAR operations, they also face notable operational and regulatory challenges. One of the primary limitations is their reliance on battery power, which restricts flight duration. Carrying heavier payloads, such as specialized sensors or medical supplies, further reduces operational time. In addition, adverse weather conditions, especially strong winds and extreme temperatures, can significantly impact UAV performance, making them less reliable in Arctic and other harsh environments (Lyu et al. 2023).

Regulatory constraints limit UAV effectiveness in SAR missions, with flight height restrictions such as the 122-meter (400-foot) limit (T. Canada 2023). Visual line-of-sight requirements further reduce the usefulness of drones in large-scale searches. Privacy concerns add another layer of complexity, as UAVs risk infringing on personal privacy and capturing sensitive infrastructure data (Kang et al. 2024).

The extreme Arctic environment presents challenges for drone operability. Research conducted in Eureka, Nunavut, tested the performance of DJI Matrice drones in temperatures as low as -46°C. The study found that while advanced navigation systems enabled stable flights, battery performance significantly declined in extreme cold, requiring modifications such as insulated enclosures to maintain optimal functionality (Tikhomirov et al. 2021).

In addition to battery challenges, icing on UAV components presents a major operational risk in Arctic SAR missions. Ice accumulation on propellers and sensors can degrade flight stability and disrupt data collection, necessitating the development of anti-icing technologies and de-icing protocols to ensure reliable drone operations (Hasan et al. 2022).

Building on these advancements, additional mitigation strategies have been explored to further enhance UAV reliability in harsh environments. Some fixed-wing UAVs incorporate anti-icing systems, such as pinhole mechanisms in the wing surface that release glycol solutions to prevent ice accumulation. Practical low-tech solutions have also been employed to maintain battery performance in cold conditions. For instance, the Alaska UAS Test Site Program utilizes HotHands, air-activated warming pouches, to keep drone batteries warm until deployment, offering a simple yet effective method to counteract temperature-related battery degradation (FAA Safety Briefing 2023).

Probability of Detection Using Drones

The probability of detecting lost individuals is a critical factor in SAR operations. UAVs enhance detection capabilities by providing aerial coverage and real-time imaging, but their effectiveness depends on several factors, including environmental conditions, sensor technology, and search strategies. A study conducted in Tanzania assessed the use of different imaging technologies for detecting subjects under varying canopy densities. The results highlighted that altitude, subject contrast, and analyst expertise significantly influenced detection rates (Hambrecht et al. 2019).

As a key challenge in SAR missions is balancing rapid area coverage with effective victim detection. Fast aerial mapping allows for broad coverage but may lack the detail needed to identify individuals, whereas slower, high-resolution imaging improves detection but extends mission duration. Ongoing research seeks to optimize this trade-off to enhance UAV-assisted SAR efficiency (Karamanou et al. 2018).

The concept of Effective Sweep Width (ESW) is instrumental in estimating detection probabilities, as field experiments in real SAR scenarios provide data-driven insights to refine search techniques. Integrating UAV technology with probability distribution models further improves search efficiency by prioritizing the most likely locations for finding missing persons (Potomac Management Group 2006).

METHODOLOGY

This section outlines the research methodology, detailing the conceptual framework and processes used to investigate the study's objectives. A mixed-methods approach is employed, combining qualitative insights from semi-structured interviews with SAR professionals and quantitative analysis of historical weather data to evaluate drone operability and effectiveness in Northern Canadian SAR operations.

The study focuses on two key research questions. RQ1 examines drone operability in extreme weather conditions, addressing the impact of the northern climate on performance and the feasibility of drone deployment in SAR missions. Semi-structured interviews provide qualitative insights into environmental constraints and operational considerations, while historical weather data are analyzed to define performance thresholds.

Although RQ2 concerns the Probability of Detection (PoD) of persons in distres, its methodology is still being refined and will be further discussed in the discussion section, allowing for refinement as the study progresses. The following sections elaborate on data sources, preprocessing steps, and analytical procedures used to derive insights.

Data and Information Sources

Semi-Structured Interviews

The selection of data and information sources is carefully considered to ensure the robustness and reliability of the study. Semi-structured interviews are conducted with SAR professionals, drone operators, and community representatives to capture the practical realities of drone use in the North. This study has received Research Ethics Board (REB) approval for conducting these interviews. Their insights directly inform the criteria for evaluating drone operability. These interviews offer critical insights into the practical challenges of using drones in extreme weather conditions and inform the selection of variables, such as temperature, wind speed, and precipitation, which influence drone operability. Key themes include operational constraints, such as limited battery life in sub-zero temperatures, wind tolerance thresholds, and challenges in integrating drones with existing SAR protocols.

Historical Weather Data

The quantitative analysis described in Section [Statistical Analysis] utilizes Spire's nanosatellite-based weather data due to its high-resolution, granular, hourly observations (*Spire Weather* 2025) that cover remote regions of Northern Canada. Spire's dataset provides precise and localized weather patterns essential for understanding how environmental factors influence drone operability across different regions and seasons. Table 1 presents sample weather data illustrating some of the parameters such as temperature, wind speed, and cloud cover at different hours of the day.

The dataset spans 2018 and 2019 for all of North America and includes parameters such as Temperature (°k), Wind speed (m/s), Wind gusts (m/s), Precipitation (kg/m^2), and Snowfall (m). Additionally, geographic and temporal fields such as longitude, latitude, year, month, day, and time periods are available, enabling location- and time-specific analyses. While these fields are relevant for mapping weather patterns, the selection of specific variables for analysis is informed by insights from the semi-structured interviews. A more detailed discussion on the data analysis approach is provided in Section [RQ1: Analyzing Drone Operability].

Table 1. Example Spire Weather Data Fields

Date	Time	Latitude	Longitude	Temperature (°C)	Wind Speed (km/h)	Cloud Cover(%)
2018-01-01	0:00	62.80	-92.09	-29.73	13.48	100
2018-01-01	1:00	62.80	-92.09	-29.12	13.79	100
2018-01-01	2:00	62.80	-92.09	-28.11	14.90	100
2018-01-01	3:00	62.80	-92.09	-27.90	15.67	100
2018-01-01	4:00	62.80	-92.09	-27.80	16.44	100
2018-01-01	0:00	63.75	-68.52	-29.67	6.43	82.70
2018-01-01	1:00	63.75	-68.52	-29.73	5.92	87.84
2018-01-01	2:00	63.75	-68.52	-30.00	5.46	88.64
2018-01-01	3:00	63.75	-68.52	-30.06	5.58	82.52
2018-01-01	4:00	63.75	-68.52	-30.29	5.52	72.24

RQ1: Analyzing Drone Operability

Establishing Operational Thresholds

To evaluate drone operability under different weather conditions, environmental data are categorized into three distinct categories: Favorable, Unfavorable, and No-Go. These zones correspond to specific weather thresholds, beyond which drones either perform optimally, face some operational limitations, or become entirely unsuitable for deployment. Table 2 summarizes the thresholds used.

These thresholds for drone operability are derived from a combination of drone manufacturer specifications, input from SAR experts interviewed for this study, and real-world operational constraints. They specifically apply to the DJI Mavic 3 Enterprise, which is the drone considered in this study for use in the Canadian Arctic. These thresholds reflect the critical environmental conditions under which this drone can operate effectively in Northern Canada's challenging climate. For instance, the Mavic 3 Enterprise typically struggles to function in temperatures lower than -20°C due to battery limitations, while wind speeds exceeding 40 km/h compromise stability and flight control. By categorizing weather conditions into favorable, unfavorable, and no-go zones, a clear framework is established to assess drone operability for real-time missions and strategic SAR planning.

Table 2. Operational Thresholds for Drone Operability in Northern Canada

Environmental Factor	Favorable	Unfavorable	No-Go
Temperature (°C)	≥ -10	$-20 \leq$ Temperature < -10	< -20
Wind Speed (km/h)	≤ 30	$30 <$ Wind Speed ≤ 40	> 40

Data Processing

The data pre-processing includes critical steps to ensure its quality and alignment with the study's geographical scope. Weather data for Northern Canada is sourced from Spire's GRIB files, which contain hourly meteorological measurements for various regions. The data processing and analysis are primarily conducted using Python-based tools, ensuring a comprehensive and systematic approach. The pre-processing steps includes extracting key geographic and temporal factors, such as latitude, longitude, year, month, day, and time, to associate each weather observation with specific locations and times. To standardize the data, longitudes in the GRIB files, which are reported in the 0–360° system, are converted to the standard -180 to 180° format, ensuring compatibility with common geographic coordinates. The next step involves cleaning the dataset by removing missing or erroneous data points, thus ensuring the accuracy and reliability of the data for further analysis. Once cleaned, the weather variables are transformed to align with the operational thresholds. For instance, temperature values, initially recorded in Kelvin, are converted to Celsius, and wind speed values, provided in meters per second, are converted to kilometers per hour to ensure uniformity in the analysis. Subsequent analyses focus on categorizing each weather observation at a given location and time, based on predefined thresholds for temperature and wind speed. These classifications identify favorable, unfavorable, or no-go conditions for drone operability across different times and locations, using the criteria and thresholds outlined in Table 2. The processed data is spatially queried to identify the nearest weather observations to community coordinates in Nunavut, ensuring the data's relevance to specific regions. The data processing workflow is illustrated in Figure 1, outlining the key steps from raw data acquisition to final analysis.

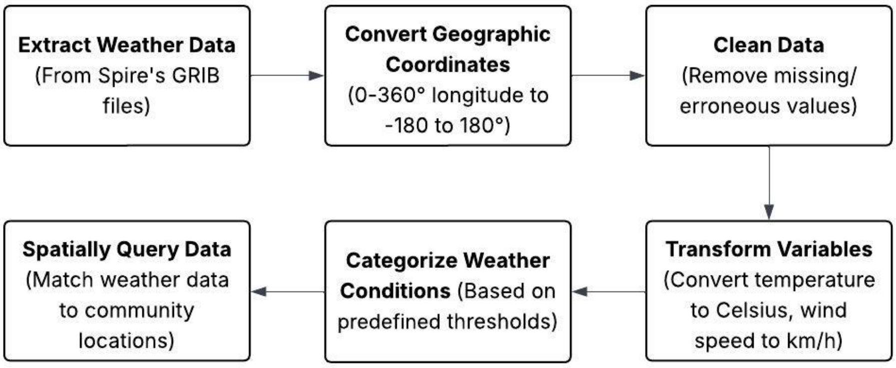

Figure 1. Steps of Data Processing

Statistical Analysis

The statistical analysis is conducted to identify patterns in weather data and drone operability for specific communities in Nunavut. This process involves analyzing weather conditions over time and across different locations to assess their impact on drone operability. Summary statistics, such as mean and median temperatures, and wind speeds are also computed to assess the overall operability across different time periods and locations. Temporal patterns are then analyzed to determine periods when drones are more or less deployable, with a focus on specific Arctic communities (see Figure 2 for locations).

Figure 2. Selected Communities in Northern Canada

The analysis relies on several essential Python libraries. Pandas is used to facilitate efficient data manipulation, organization, and filtering of weather data by community, allowing for the computation of aggregate statistics such as the frequency and duration of favorable, unfavorable, and no-go conditions (pandas 2025). NumPy is used for numerical operations, including unit conversions (e.g., temperature from Kelvin to Celsius and wind speed from meters per second to kilometers per hour) to ensure consistency in the dataset (NumPy 2025). Matplotlib enables visualization of trends, aiding in the identification of temporal and regional patterns in drone operability (Matplotlib 2025). Additionally, Geopy's Nominatim Geocoder converted community names (e.g., "Arctic Bay", "Iqaluit") into geographic coordinates (latitude and longitude) (GeoPy 2025), which were then used to extract precise weather data from GRIB files, ensuring accurate assessments of drone operability conditions. QGIS is employed to visualize spatial patterns and generate maps that illustrate variations in drone operability across different Arctic regions, enhancing the interpretability of results.

Operability Analysis

To assess the impact of weather on UAVs functionality, weather data is classified into three operability categories based on predefined thresholds for temperature and wind speed, as outlined in Section [Establishing Operational Thresholds]:

- Favorable Conditions – Suitable for drone operation without significant limitations.
- Unfavorable Conditions – Present challenges but may still allow limited operation.
- No-Go Conditions – Prohibit drone deployment due to extreme weather.

This classification enables calculating the percentage of observations in each category across different communities and months, providing insights into how often drones are deployable in various regions. A monthly breakdown of favorable, unfavorable, and no-go conditions helps identify seasonal variations in drone operability. For example, communities experiencing more favorable conditions in summer may see increased drone usage, whereas winter months, with extended no-go periods due to extreme cold and high wind speeds, may require alternative operational strategies.

By analyzing temporal variations in operability, key operational windows can be identified, aiding SAR teams in determining when drone deployment is most viable. Additionally, regions with frequent unfavorable or no-go conditions highlight the need for additional resources, such as more robust drone models or adaptive operational strategies to enhance deployment efficiency.

Duration and Frequency Analysis

Beyond category classification, the analysis also examines the duration and frequency of each operability category. Specifically, it assesses continuous periods of ”No-Go” conditions to identify extended intervals when drones were unable to operate in a given location. This aspect of the study is critical for quantifying the impact of adverse weather on SAR operations relying on UAVs.

The seasonal aspect of this analysis highlights prolonged disruptions due to extreme weather, such as extended no-go periods in winter months. Understanding these patterns aids operational and strategic planning by ensuring SAR teams and planners are aware of potential prolonged inoperability and can develop contingency measures accordingly.

RESULTS

Monthly Operability

To assess how drone operability fluctuates throughout the year, the percentage of each operability category—Favorable, Unfavorable, and No-Go—was calculated for every month in Iqaluit and Rankin Inlet for the years 2018 and 2019. Figures 3 and 4 provide a visual representation of these trends, showing the monthly distribution of each category in both communities. These results are based on the defined restricted thresholds for drone operation, using the DJI Mavic 3 Enterprise as the reference model.

The results indicate a strong seasonal pattern in drone operability. In both Iqaluit and Rankin Inlet, the winter months were characterized by a high percentage of No-Go conditions, with values reaching over 95% in January for Rankin Inlet in 2018 and 2019, and Iqaluit in 2018. This highlights the challenging environmental conditions that severely restrict drone deployment during the colder months.

As temperatures rise in the spring and summer months, the proportion of Favorable conditions increases significantly. For example, in June and July, both communities experienced over 90% Favorable conditions, with minimal No-Go periods. This seasonal shift suggests that drone operations are most viable during the warmer months when environmental factors are less restrictive.

Comparing the two years, there is a noticeable improvement in operability conditions in 2019 compared to 2018, particularly in the spring and fall months. For instance, in October 2018, Iqaluit had only 64.38% Favorable

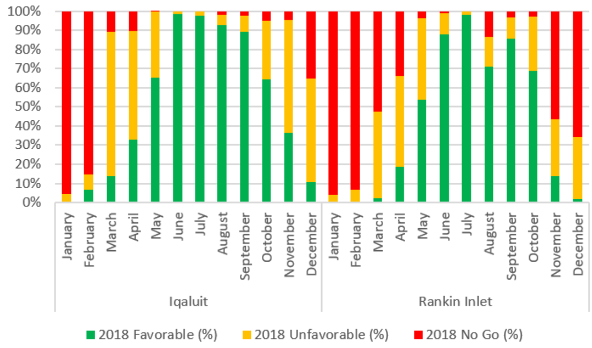

Figure 3. Percentage Distribution of Categories in Iqaluit and Rankin Inlet for 2018

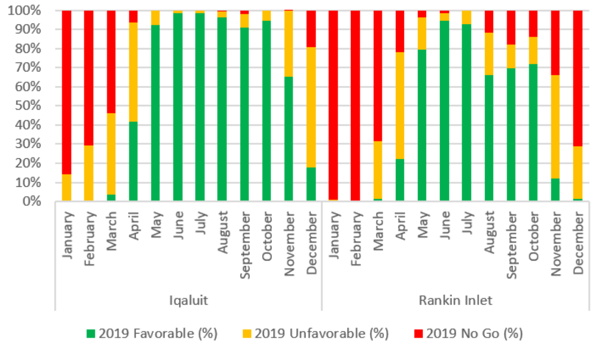

Figure 4. Percentage Distribution of Categories in Iqaluit and Rankin Inlet for 2019

conditions, whereas in October 2019, this increased to 94.62%. Similarly, Rankin Inlet showed a reduction in No-Go periods for several months, indicating slightly more stable conditions in 2019. However, winter constraints remained consistently severe in both years.

These findings suggest that drone operations in Northern Canada are highly seasonal, with peak operability occurring in the summer months, while winter conditions pose significant challenges. Future analysis will further investigate the meteorological variables contributing to these patterns.

Duration of Operability Conditions

In addition to the monthly percentages, an analysis of operability duration was conducted to understand the persistence of each condition before transitioning to another state. The results for Iqaluit in 2018 reveal that favorable conditions persisted for a total of 4,455 hours ($\approx$ 186 days), accounting for 50.89% of the year. Unfavorable conditions lasted 2,496 hours (104 days), representing 28.51%, while No-Go conditions were observed for 1,803 hours ($\approx$ 75 days), comprising 20.60% of the total duration. These findings indicate that while favorable conditions dominated, unfavorable and No-Go periods still represented a substantial portion of the year.

To further explore the persistence of each operability condition, the average duration of each period and the longest continuous occurrence of each category were analyzed. On average, favorable conditions lasted approximately 51.2 hours per period, while unfavorable conditions persisted for about 19.7 hours, and No-Go conditions endured for around 45.1 hours. The longest continuous periods recorded were 373 hours (15.5 days) for favorable conditions, 164 hours (6.8 days) for unfavorable conditions, and an extended 686 hours (28.6 days) for No-Go conditions.

These results suggest that while favorable conditions were typically sustained for longer durations, No-Go periods occasionally persisted for extended periods. Such prolonged No-Go conditions could present critical operational challenges for SAR missions dependent on drone deployment, necessitating contingency planning and resource allocation adjustments.

A further analysis calculated the probability of encountering each operability condition (No-Go, Unfavorable, and Favorable) over different time ranges. The histogram in Figure 5 shows that No-Go conditions, though less frequent, are more likely to last longer. Favorable conditions tend to last shorter periods, while Unfavorable conditions have moderate durations. This analysis helps SAR responders anticipate how long conditions may persist, aiding in operational planning and strategy adjustments.

Additional analyses and results will be explored in future work.

DISCUSSION AND FUTURE WORK

Discussion

The first research question (RQ1) focused on assessing the impact of environmental conditions on UAVs operability in SAR operations. By classifying weather conditions into favorable, unfavorable, and no-go categories, the findings highlight key temporal and regional patterns affecting UAVs deployment. These insights provide a foundational understanding of when and where drones can be effectively utilized, aiding SAR teams in strategic planning.

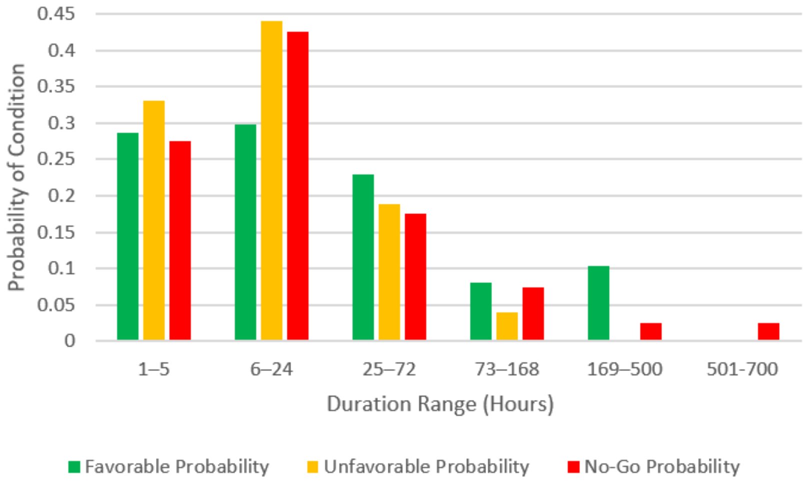

Figure 5. Probability Distribution of Operability Conditions Across Different Duration Ranges (Iqaluit, 2018)

However, the current analysis primarily addresses operability rather than search effectiveness. While determining when UAVs can fly is critical, their actual impact on search success remains an open question. Drones' ability to locate missing persons or objects depends not only on environmental conditions but also on sensor capabilities, visibility of the target, and flight altitudes. This gap leads directly into the next question of this research, which aims to evaluate the Probability of Detection (PoD) in drone-assisted SAR operations.

Future Work

Future Work for RQ1

Although RQ1 establishes an operability framework, further work is needed to refine and expand the analysis:

- Incorporating Additional Environmental Factors: Future research could integrate other meteorological variables, such as precipitation intensity (e.g., freezing rain and snowfall), visibility, and cloud cover.
- Expanding operability research to different drone models, including those with all-weather capabilities or AI-enhanced navigation.
- Using spatial statistics to identify geographic regions with similar operability patterns, that could highlight high-risk zones where extreme weather conditions frequently hinder UAV use, aiding in regional resource allocation and infrastructure planning for SAR teams.

Beyond the immediate scope of this thesis, Leveraging machine learning models to predict future operability windows based on historical weather trends could assist SAR teams in preemptive planning.

Future Work for RQ2: Probability of Detection (PoD)

The second research question of this research will focus on evaluating PoD in drone-assisted SAR operations. PoD is a critical metric that quantifies the likelihood of detecting a target under specific environmental and operational conditions. Unlike traditional SAR methods, drones introduce unique variables—such as aerial coverage, sensor resolution, and search algorithms—that influence detection success.

Key Areas of Investigation in RQ2:

- Environmental and Operational Constraints: How do weather conditions, terrain, and target visibility affect PoD?
- Sensor Performance: What role do camera specifications, thermal imaging, and other sensors play in PoD?
- Search Optimization Strategies: How can search patterns and automation enhance detection rates in various scenarios?

Preliminary Factors Identified:

Through a combination of early literature review and ongoing expert interviews with SAR personnel, we have begun mapping the key variables that likely influence PoD. These fall into three general categories:

Drone-Related Factors: Altitude (m), Camera Resolution (MP), Sensor Type (RGB, Thermal, Multispectral), Flight Time (minutes), Flight Speed (m/s)

Environmental Factors: Weather Conditions (Rain, Fog, Snow, Cloudy, Clear, etc.), Terrain Type (Open Field, Mountain, Snow, etc.)

Target Characteristics: Stationary vs. Moving Object, Clothing Color Contrast with Background (High/Low)

Human Factors: Target's Age/Experience, Searcher/Operator Fatigue, Searcher/Operator Training and Experience

These factors will be further examined through a detailed interview phase to assess their individual and combined effects on PoD under varying operational scenarios.

To address RQ2, the specific methods are yet to be finalized but may involve:

- Literature-Based PoD Modeling: Reviewing case studies and prior research to establish baseline PoD values and identify best practices and limitations..
- Analytical and Simulation-Based Approaches: Testing PoD in varying conditions through controlled simulations, factoring in elements like altitude, terrain, and sensor performance (e.g., Lee and Mason 2002 that applies computer simulation for computing PoD in the field of radar detection).
- Regression analysis and other data-driven approaches are widely used to model relationships between variables and make predictions based on observed data. These methods help identify key factors influencing an outcome and quantify their impact. Techniques such as multivariate regression, Bayesian modeling, and logistic regression are commonly applied across various fields to analyze complex systems and improve decision-making. Similar statistical approaches could be adapted to study factors affecting PoD in SAR operations (General explanations of these techniques can be found in, Cloud Software Group 2025, Pathan et al. 2018).

Future research could address additional challenges in SAR operations, such as analyzing lost person behavior to predict movement patterns and improve search efficiency. Another avenue is developing integrated search models that combine UAV data with other resources like ground teams, satellite imagery, and helicopters. Automation and AI could also optimize search patterns and decision-making, while multi-drone coordination may enhance coverage and efficiency in complex environments. Additionally, utilizing virtual reality (VR) or controlled physical targets, such as mannequins or brightly colored objects, in diverse terrains could help simulate lost individuals and further assess drone camera performance under varying environmental conditions, offering valuable insights into sensor and detection capabilities.

CONCLUSION

This study assessed UAV operability in Search and Rescue (SAR) operations in Northern Canada, focusing on environmental impacts on operability and the Probability of Detection (PoD) in different scenarios. The findings show that drone operations are highly seasonal, with favorable conditions mainly in warmer months, while winter presents significant operational challenges. Understanding these patterns helps SAR teams optimize drone deployment and resource allocation. Although the research offers insights into when drones can operate, further work is needed to evaluate their effectiveness in detecting Persons in Distress (PiDs) under varying conditions. Future research should refine the operability model by considering additional environmental factors and exploring different drone models. Furthermore, assessing PoD under various conditions will be key to improving search success and efficiency in challenging SAR missions. Ultimately, these advancements will enhance SAR operations in remote northern environments.

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