# An Assessment of Weather Impacts on Domestic MALE UAV Operations

Michael Laska
*Directorate of Air Staff Operational Research*

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**Defence R&D Canada**
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**Defence R&D Canada – CORA**

Technical Report

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Principal Author

Michael Laska

Approved by

Denis Bergeron
Head Air Operational Research Section

Approved for release by

Jocelyn Tremblay
Chief Scientist, Chair DRP

# Abstract (U)

This report documents a high-level statistical investigation of the frequency and persistence characteristics of historical cloud cover and weather observations recorded in five operating areas of interest (AOIs) located in Canada. In this study, frequency characteristics are used to provide a quantitative measure of the relative occurrences of specific weather events considered limiting to medium altitude long endurance (MALE) unmanned aerial vehicle (UAV) takeoff, recovery and flight operations, as well as those weather events considered to adversely affect electro-optic and infrared (EO/IR) sensor image quality or interpretability.

Low cloud ceilings present the most significant constraint to domestic UAV intelligence, surveillance and reconnaissance (ISR) operations during the summer months, while potential icing conditions present the most significant constraint to UAV ISR operations during the rest of the year. Significant benefits in terms of the percent of time possible for UAV flight operations may be achieved by operating UAVs that incorporate anti-icing systems, particularly in the Northwest Passage and Atlantic regions; however, the utility and performance of a UAV ISR platform depends on the combined utility and performance of both the platform and the sensor. This analysis indicates that the sensor would be the critical limiting factor affecting the success of a domestic UAV ISR mission requiring EO/IR imaging at the identification and classification tasking level.

# Résumé (U)

Le rapport décrit une étude de haut niveau sur les caractéristiques de fréquence et de persistance des nuages et des données météorologiques historiques provenant de cinq régions canadiennes d’intérêt. Dans l’étude, les caractéristiques de fréquence servent à obtenir une mesure quantitative des occurrences de certains événements météorologiques dont on considère qu’ils limitent les vols d’engins télépilotés à moyenne altitude et grande autonomie, et d’autres dont on estime qu’ils nuisent à la qualité des images électro-optiques et infrarouges ou à la possibilité d’interpréter ces images.

Pendant les mois d’été, les nuages présentent la plus importante contrainte pour les opérations domestiques de vol d’engins télépilotés. Des conditions de givrage présentent le plus important obstacle aux opérations de vol d’engins télépilotés domestiques le reste de l’année. Il serait possible d’augmenter sensiblement le pourcentage du temps où les opérations de vol d’engins télépilotés sont possibles en exploitant un engin télépiloté qui intègre un système antigivrage, en particulier dans le passage du Nord-Ouest et les régions atlantiques. Cette analyse indique que le capteur serait le facteur limitant critique affectant le succès des opérations domestiques de renseignement, surveillance et reconnaissance quand des images électro-optiques et infrarouge doivent être d’une qualité suffisante pour des tâches d’identification et la classification.

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# Executive summary (U)

## An Assessment of Weather Impacts on Domestic MALE UAV Operations

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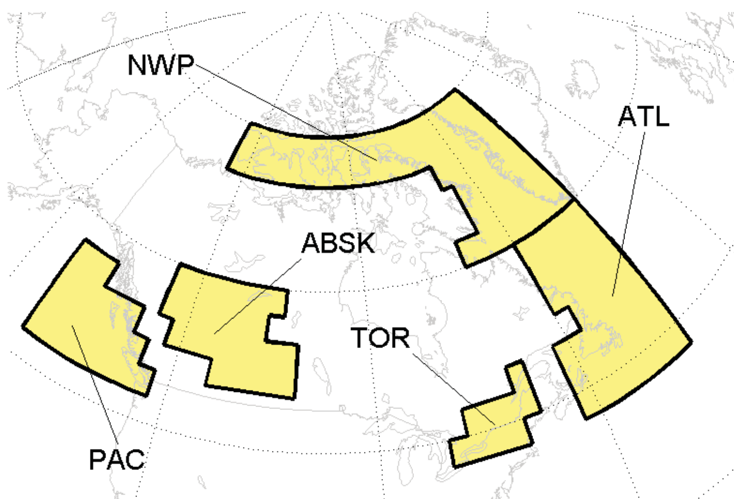
### Background

ES.1. This technical report documents an analysis performed by the Director of Air Staff Operational Research (DASOR) for the Director Air Requirements, Unmanned Aerial Vehicles section (DAR 8) to assess the amount of time that electro-optical and infrared (EO/IR) surveillance of the ground surface could be undertaken by a medium altitude long endurance unmanned aerial vehicle (MALE UAV) in 5 domestic operating areas of interest (AOIs). Figure ES.1 shows the general locations of the 5 AOIs considered in this analysis.




| | |
|---|---|
| PAC | Pacific region |
| ABSK | Oil-producing regions of Alberta & Saskatchewan |
| NWP | The Northwest Passage and Baffin Bay regions of the Canadian Arctic |
| TOR | The Toronto-Quebec City Corridor of the St. Lawrence and Lake Ontario |
| ATL | Atlantic region |

***Figure ES.1 (U):*** *Domestic operating area boundaries*

### Materiel and Operational Assumptions

ES.2. For the purpose of this study, a generic MALE UAV of similar size and exhibiting similar operating characteristics to the General Atomics RQ-1 Predator is assumed. It is also assumed that the generic UAV platform supports a generic EO/IR sensor ball similar to the WESCAM MX-20 system, and that the UAV does not possess an anti-icing capability.

ES.3. As the CF has yet to establish a set of aircraft operating instructions for MALE UAVs, it is assumed that UAV flight operations will follow the operating instructions established for the CU 161 Sperwer tactical UAV. Specifically, it is assumed that UAV flight into forecast or known icing conditions is prohibited, that visual flight rules (VFR) are required for UAV takeoff and recovery operations, and that the maximum permissible cross wind speed during takeoff and recovery is 20 kts.

## Analysis Methodology

ES.4. The study has three components:

1. a regional cloud climatology assessment, where cloud cover data is used to assess the general cloud climate to estimate the expected percent of time that a UAV operating at 21,000 ft could successfully employ an EO/IR sensor;

2. a local assessment of the frequency of occurrence and persistence of the various weather conditions considered to adversely affect EO/IR sensor image quality; and

3. a local assessment of the frequency of occurrence and the persistence of potential icing conditions, as well as other weather conditions considered to adversely affect UAV takeoff and recovery operations.

In both local assessments, meteorological records from 21 locations of interest (LOIs), spread across all 5 AOIs, are used to quantify the occurrence frequency of various weather events considered to adversely affect EO/IR sensor image quality or to adversely affect UAV takeoff and recovery operations.

ES.5. In the takeoff, recovery and icing conditions assessment, cloud ceiling, visibility and wind speed observations are used to assess the expected impacts of local climate on vehicle takeoff and recovery operations. Operational threshold limits meeting the minimim requirements for visual flight are defined, and records reporting observations outside of the assumed thresholds are identified as exceedence events. Exceedence event populations are then used to quantify the expected amount of time that UAV takeoff and recovery operations would be affected by adverse weather.

ES.6. In the icing conditions assessment, three test conditions, the Appleman criteria, the critical temperature and precipitation criteria and the freezing precipitation criteria, are used to assess the impacts of potential icing conditions on UAV flight operations. Records reporting observations that meet each test criterion are identified, and are used to quantify the expected amount of time that UAV flight conditions are affected by icing conditions.

ES.7. In the sensor visibility assessment, individual weather observations are assigned a hierarchical ISR tasking designation according to the following criteria descriptions:

1. *Identification* tasks possible – the observed weather event has very little negative effect on EO/IR image quality;

2. *Classification* tasks possible – the observed weather event has some negative effect on EO/IR image quality;

3. *Detection* tasks possible – the observed weather event has a strong negative effect on EO/IR image quality; and

4. No Imaging tasks possible – the observed weather event prevents the creation of an EO/IR image that is useful for any task.

Historical meteorological records are then parsed to identify individual records reporting conditions where specific ISR tasks could potentially be undertaken.

## Results

ES.8. The results of the regional cloud climatology assessment are summarized in Table ES.1. This table presents the expected %-cloud cover, averaged over all months and years, for all clouds located between the earth's surface and 21,000 ft. Assuming that the EO/IR sensor requires a clear optical path for imaging, the expected percent of time that a UAV platform operating at 21,000 ft could complete a domestic ISR mission ranges from 30% in the Atlantic region to 57% in the Northwest Passage region.

***Table ES.1 (U):*** *Expected percent cloud cover across all AOI regions for clouds located between the Earth's surface and 21,000 ft. Tabulated values represent %-cloud cover, averaged over all months and years.*

| Region | % Cloud Cover |
|---|---|
| Pacific region | 53% |
| Alberta/Saskatchewan region | 51% |
| Northwest Passage region | 43% |
| Toronto-Quebec City corridor | 50% |
| Atlantic region | 60% |

ES.9. Results of the sensor visibility assessment are summarized in Table ES.2. Tabulated values represent the expected percent of time that an EO/IR sensor would be operating in weather conditions potentially suitable for performing a given ISR task, averaged over all months and years, and over all LOIs within the region.

***Table ES.2 (U):*** *Percent of time that an EO/IR sensor could perform a given ISR task. Tabulated values represent a combined average of all LOI values within the region, averaged over all months.*

| Region | Detection Tasks Possible | Classification Tasks Possible | Identification Tasks Possible |
|---|---|---|---|
| PAC | 93% | 84% | 31% |
| ABSK | 95% | 84% | 38% |
| NWP | 87% | 57% | 20% |
| TOR | 90% | 82% | 37% |
| ATL | 82% | 72% | 29% |

ES.10. Across all regions, weather conditions considered potentially suitable for identification tasks are observed on average 29% of the time, while weather conditions considered potentially suitable

for classification tasks are observed on average 76% of the time and conditions considered potentially suitable for detection tasks are observed on average 88% of the time.

ES.11. Table ES.3 shows the percent of time that critical cloud ceiling, visibility, wind speed and icing conditions are expected to occur in each of the five areas of interest. Tabulated values represent a combined average of all LOI values within the region, averaged over all months and years.

***Table ES.3 (U):*** *Percent of time that critical takeoff, recovery and icing conditions are expected to occur in each of the 5 Canadian AOIs. Tabulated values represent a combined average of all LOI values within the region, averaged over all months and years.*

| | PAC | ABSK | NWP | TOR | ATL |
|---|---|---|---|---|---|
| Appleman test | - | 17% | 51% | 4% | 7% |
| Critical temp. & precip. test | 1% | 21% | 40% | 17% | 19% |
| Freezing precip. condition | - | - | 1% | 1% | 2% |
| Visibility < 3 nm | 3% | 4% | 10% | 5% | 14% |
| Wind speed > 20 kts | 1% | 2% | 7% | 2% | 4% |
| Cloud ceiling < 1,500 ft | 8% | 9% | 16% | 10% | 31% |

ES.12. Across all regions, potential icing conditions present the most significant constraint to UAV operations during the autumn and winter months, while critical cloud ceiling and visibility conditions present the most significant constraints during the summer months.

ES.13. Table ES.4 compares the percent of time possible for UAV flight operations under the assumed operating conditions of:

1. VFR requirements and no anti-icing equipment;
2. instrument flight capabilities and no anti-icing equipment;
3. VFR requirements and anti-icing equipment; and
4. instrument flight capabilities and anti-icing equipment.

In the fourth case, wind speed is the limiting factor. The values presented in the table represent a combined average of all LOIs within that region, averaged over all months.

ES.14. UAV platforms possessing both instrument flight and anti-icing capabilities should be considered for domestic UAV ISR operations, as they offer a significant incremental benefit in utility over more basic UAV platforms, particularly in the NWP and PAC regions. By employing both capabilities, it is expected that a UAV platform could operate at least 93% of the time across all of the AOI regions, compared to 69% of the time with anti-icing capabilities alone and 43% of the time with instrument flight capabilities alone. From the perspective of utility, the vehicle component of a UAV surveillance system appears quite resilient – the overall utility of a UAV ISR system is largely constrained by the performance and imaging characteristics of the sensor. This analysis indicates that the sensor would be the limiting factor affecting the success of a UAV ISR mission requiring EO/IR imaging at the identification and classification tasking levels across each of the 5 AOI regions.

***Table ES.4 (U):*** *Percent of time that UAV flight operations would be possible under various combinations of anti-icing and instrument flight capabilities. Tabulated values represent a combined average of all LOI values within the region, averaged over all months and years.*

| Region | VFR & No Ice | Inst. Flt. & No Ice | VFR & Ice | Inst. Flt. & Ice |
|---|---|---|---|---|
| PAC | 92% | 99% | 92% | 99% |
| ABSK | 76% | 78% | 91% | 98% |
| NWP | 64% | 81% | 69% | 93% |
| TOR | 80% | 82% | 89% | 98% |
| ATL | 40% | 43% | 85% | 96% |

1) Ice – Anti-icing capability

2) Inst. Flt. – Instrument flight capability

ES.15. It is recommended that further investigations focused on quantitatively assessing the performance of different UAV imaging systems under representative cloud conditions be undertaken. Specifically, it is recommended that a simulation-type modeling study be undertaken to better quantify the operational utility of employing UAV systems for domestic ISR operations. Such a study would be beneficial in quantifying the operational and financial impacts of employing different types of sensors and platforms, both manned and unmanned.

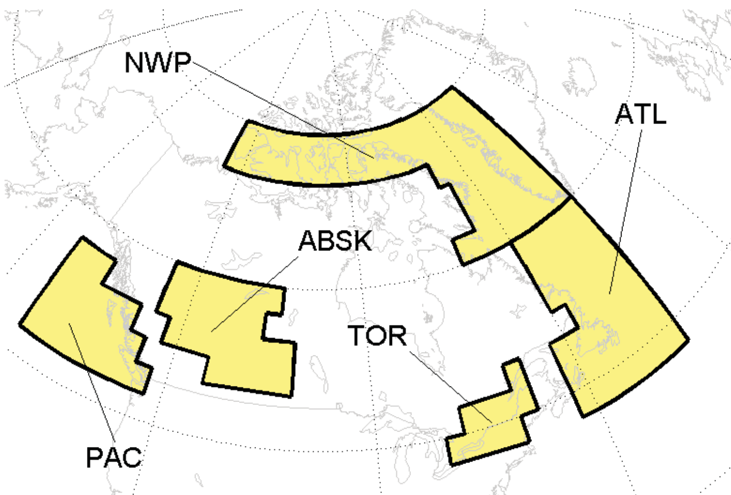
# Sommaire (U)

## An Assessment of Weather Impacts on Domestic MALE UAV Operations

Michael Laska ; DRDC CORA TR 2007-22 ; R & D pour la défense Canada – CARO ; décembre 2007 ; , UNCLASSIFIED.


### Contexte

S.1. Ce rapport documente une analyse effectuée par la Direction de la recherche opérationnelle de la Force aérienne (DROFA) pour évaluer le nombre de jours qui se prêteraient à la surveillance du sol à partir d'une altitude de moyenne à élevée (15 000 à 40 000 pi) par un engin télépiloté de moyenne altitude et de grande autonomie (MALE - medium altitude long endurance) avec une au capteur l'électro-optique et infrarouge (EO/IR), dans diverses zones d'opérations au Canada. La figure S.1 montre l'emplacement des zones d'operations retenues pour l'étude (ZI).




| | |
|---|---|
| PAC | région du Pacifique |
| ABSK | régions productrices de pétrole de l'Alberta et de la Saskatchewan |
| NWP | passage du Nord-Ouest et baie de Baffin |
| TOR | Corridor Toronto-Québec bordant le Saint-Laurent et le lac Ontario |
| ATL | région de l'Atlantique |

***Figure S.1 (U):*** *Limites des zones d'intérêt*

### Hypothèses relatives au matériel et aux opérations

S.2. Aux fins de l'étude, on retient un engin télépiloté MALE générique ayant la taille et les caractéristiques de fonctionnement du RQ-1 Predator de General Atomics. On suppose que l'engin n'a pas de système antigivrage. On suppose aussi que cette plateforme générique est équipée d'un système de captation EO/IR générique semblable au système MX-20 de WESCAM.

S.3. Comme les Forces canadiennes n'ont pas encore établi les instructions d'exploitation des engins télépilotés MALE, on considère que les vols obéiront aux instructions établies à l'égard de l'engin télépiloté tactique CU 161 Sperwer . Précisément, on suppose que le vol dans des conditions connues ou prévues de givrage est interdit et que les règles de vol à vue (VFR - visual flight rules) s'appliquent au lancement et à la récupération de l'engin télépiloté. La vitesse maximale d'un vent de travers au moment du décollage et de la récupération est fixée à 20 kts.

## Méthodologie

S.4. Pour remplir la mission, on a entrepris une étude en trois volets : analyse climatologique des nuages par région, évaluation de la visibilité des capteurs et évaluation des conditions de décollage, de récupération et de givrage.

S.5. Dans l'analyse climatologique des nuages par région, on évaluer les caractéristiques climatiques des nuages entre la surface de la Terre et une altitude de 21 000 pi, de façon à estimer le pourcentage du temps où un engin télépiloté volant à 21 000 pi peut utiliser avec succès un capteur EO/IR.

S.6. Pour évaluer la visibilité du capteur, on utilise des observations météorologiques de quantifier la fréquence et la persistance de divers événements météorologiques qui nuiraient à la qualité de l'imagerie EO/IR. Dans l'analyse, on sélectionnez 21 lieux d'intérêt (LI), qui sont situés sur les 5 ZI. Aux fins de l'analyse, on a fourni aux spécialistes en la matière une liste de toutes les observations météo uniques contenues dans les ensembles de données des LI. Les spécialistes ont classé chaque observation selon son impact sur la qualité des images EO/IR en appliquant la taxonomie RSR suivante : tâches de détection possibles, tâches de classification possibles et tâches d'identification possibles . Selon cette taxonomie, les observations météo des LI ont été analysées pour trouver celles rendant possibles des tâches particulières de RSR. On utilisent ces observations pour quantifier le temps où les conditions météo permettraient de réaliser un type de tâche de RSR dans une ZI donnée.

S.7. Pour évaluer les effets du givrage sur les opérations de vol de l'engin télépiloté, on applique trois conditions de vérification : le critère d'Appleman, le critère dit des température et précipitations critiques et le critère des précipitations verglaçantes. Dans chaque cas, les observations consignées qui répondent au critère de vérification sont considérées indiquer des dépassements, et servent à quantifier le temps durant lequel les intempéries compromettraient les opérations de vol de l'engin télépiloté.

S.8. Comme elles sont importantes pour définir les conditions de vol à vue, les observations sur le plafond nuageux et la visibilité servent à évaluer les effets à attendre du climat local sur le décollage et la récupération de l'engin. Pour chaque variable, on suppose que les seuils opérationnels correspondent aux conditions minimales requises pour le vol à vue (c. à d. plafond > 1500 pi et visibilité > 3 mi). Les observations qui débordent les seuils hypothétiques signalent des dépassements, et servent à quantifier le temps durant lequel les intempéries compromettraient le décollage et la récupération de l'engin télépiloté. On évalue les conditions de vent de manière analogue, en posant un seuil de 20 kts – la vitesse maximale présumée de vent de travers pour le décollage et la récupération de l'engin télépiloté MALE.

## Résultats

S.9. Le tableau S.1 résume le pourcentage prévu de couverture nuageuse, moyenné sur tous les mois et toutes les années, et compte tenu de tous les nuages situés entre la surface de la Terre et 21 000 pi. Exception faite du PNO, ce pourcentage dépasse 50% dans toutes les régions. En supposant que le capteur EO/IR exige un trajet optique sans obstacle pour produire des images, le pourcentage prévu de temps où une plateforme télépilotée volant à 21 000 pi pourrait remplir une mission de renseignement, surveillance et reconnaissance (RSR) dans l'espace national va de 30% dans la région Atlantique à 57% dans la région du passage du Nord-Ouest.

***Tableau S.1 (U):*** *Couverture nuageuse prévue en pourcentage sur toutes les ZI entre la surface de la Terre et 21 000 pi. Les valeurs indiquées représentent le % de couverture moyenné sur l'ensemble des mois et des années.*

| Région | % Couverture nuageuse moyenne |
|---|---|
| Pacifique | 53% |
| Alberta et Saskatchewan | 51% |
| Passage du Nord-Ouest | 43% |
| Corridor Toronto-Québec | 50% |
| Atlantique | 60% |

S.10. Le tableau S.2 montre le pourcentage du temps où les conditions météo seraient propices à la réalisation d'une tâche donnée de RSR par un capteur EO/IR. Les valeurs indiquées font la moyenne de toutes les valeurs des LI dans la région, sur tous les mois.

***Tableau S.2 (U):*** *Pourcentage du temps (moyenné sur tous les LI) où un capteur EO/IR pourrait réaliser une tâche donnée de RSR.*

| Region | Tâches de détection possibles | Tâches de classification possibles | Tâches d'identification possibles |
|---|---|---|---|
| PAC | 93% | 84% | 31% |
| ABSK | 95% | 84% | 38% |
| PNO | 87% | 57% | 20% |
| TOR | 90% | 82% | 37% |
| ATL | 82% | 72% | 29% |

S.11. Le pourcentage du temps où les conditions météo seraient propices aux tâches d'identification est plutôt faible dans les régions de l'Atlantique et du Pacifique, ainsi que dans celle du passage du Nord-Ouest. Dans les régions de l'Atlantique et du Pacifique, les conditions météo éventuellement propices sont observées 30 % du temps si on fait la moyenne sur tous les mois ; toutefois, en novembre, décembre et janvier, ces conditions s'observent en moyenne 12 % du temps dans la région du Pacifique et 24 % du temps dans la région de l'Atlantique. Pareillement, dans la région du passage du Nord-Ouest, les conditions météo éventuellement propices aux tâches d'identification sont réunies 20 % du temps, en moyenne ; cependant, en août, septembre et octobre, elles s'observent en moyenne 13 % du temps. Dans toutes les régions, les conditions météo éventuellement propices aux tâches à la classification sont réunies 76 % du temps, en moyenne, et les conditions météo éventuellement propices aux tâches à la détection sont réunies 88 % du temps.

S.12. Le tableau S.3 montre le pourcentage du temps où les conditions critiques de plafond, de visibilité, de vitesse du vent et de givrage sont prévisibles dans chaque LI. Les valeurs indiquées constituent la moyenne de toutes les valeurs des LI dans la région, sur tous les mois. Dans toutes les régions, la règle de vol à vue relative au plafond nuageux impose la contrainte la plus importante à l'exploitation de l'engin télépiloté au cours des mois d'été (juin, juillet et août) ; elle est remplacée par les conditions propices au givrage le reste de l'année.

***Tableau S.3 (U):*** *Pourcentage du temps (moyenné sur tous les mois) où les conditions critiques pour le décollage, la récupération et le givrage de l'engin sont à prévoir.*

| | PAC | ABSK | PNO | TOR | ATL |
|---|---|---|---|---|---|
| Critère d'Appleman | - | 17% | 51% | 4% | 7% |
| Critère des tempér. et précip. critiques | 1% | 21% | 40% | 17% | 19% |
| Critère des précip. verglaçantes | - | - | 1% | 1% | 2% |
| Visibilité < 3 mi | 3% | 4% | 10% | 5% | 14% |
| Vitesse du vent > 20 kts | 1% | 2% | 7% | 2% | 4% |
| Plafond nuageux < 1500 ft | 8% | 9% | 16% | 10% | 31% |

S.13. Le tableau S.4 compare le pourcentage du temps où les opérations de vol de l'engin télépiloté sont possibles : 1) vol à vue (VFR) et aucun équipement antigivrage ; 2) capacité de vol aux instruments (IFR) et aucun équipement antigivrage ; 3) vol à vue et équipement antigivrage ; 4) capacité de vol aux instruments et équipement antigivrage. Dans le quatrième cas, la vitesse du vent est le facteur limitant. Les valeurs indiquées font la moyenne de toutes les valeurs des LI dans la région, sur tous les mois.

***Tableau S.4 (U):*** *Pourcentage du temps (moyenné sur tous les mois) où les opérations de vol de l'engin télépiloté seraient possibles.*

| Region | VFR sans antigivrage | IFR sans antigivrage | VFR avec antigivrage | IFR avec antigivrage |
|---|---|---|---|---|
| PAC | 92% | 99% | 92% | 99% |
| ABSK | 76% | 78% | 91% | 98% |
| PNO | 64% | 81% | 69% | 93% |
| TOR | 80% | 82% | 89% | 98% |
| ATL | 40% | 43% | 85% | 96% |

S.14. Il serait possible d'augmenter sensiblement le pourcentage du temps où les opérations de vol de l'engin télépiloté sont possibles soit en relaxant les règles de vol à vue pour ces opérations, soit en exploitant un engin télépiloté qui intègre un système antigivrage. En adoptant ces deux moyens, on s'attend à ce qu'une plateforme télépilotée pourrait fonctionner au moins 93 % du temps dans toutes les ZI. Comparativement, on s'attend à ce qu'une plateforme télépilotée en possédant équipement antigivrage pourrait fonctionner à 69 % du temps, et une plateforme télépilotée en possédant la capacité de vol aux instruments à 43 % du temps. Cette analyse indique que la réussite à l'emploi un engin télépiloté MALE d'une mission RSR impliquant des tâches à la classification ou des tâches d'identification serait le plus influant par le capteur.

S.15. Il est recommandé que des enquêtes plus poussées axées sur l'évaluation quantitative de la performance des différents systèmes d'imagerie soient entreprises. Plus précisément, il est recommandé que d'une étude sous la forme d'une simulation soit entreprise afin de mieux quantifier l'utilité opérationnelle d'un système RCR comprenant des engins télépilotés dans des conditions nuageuses représentées dans les 5 ZI. Une telle étude serait utile pour quantifier les impacts opérationnels et financiers à l'emploi des différents types de capteurs et des différents types de plateformes de surveillance.

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# 1 INTRODUCTION

## 1.1 Statement of problem

1. Meteorological conditions such as cloud cover, winds, precipitation and icing conditions commonly experienced in Canada's domestic operational environment are quite different from those of regions where unmanned aerial vehicle (UAV) intelligence, surveillance and reconnaissance (ISR) systems have historically been employed. Extreme temperatures, high winds, precipitation and icing conditions can impact UAV takeoff, recovery and flight operations, and the performance of electro-optical (EO) and infrared (IR) sensor payloads can be affected by weather conditions like fog, snow and low cloud ceiling, which can act to obscure targets, and to increase path losses and reduce image quality and interpretability [1].

2. In August of 2006, the Directorate of Air Requirements, Unmanned Aerial Vehicles section (DAR 8), requested that the Directorate of Air Staff Operational Research (DASOR) perform an assessment to determine the number of days which would be suitable for EO/IR surveillance of the ground surface from medium-to-high altitude (15,000 ft to 40,000 ft) by a Medium Altitude Long Endurance (MALE) UAV, for various operating areas within Canada. The operating areas to be investigated include:

- the Pacific (PAC) and Atlantic (ATL) littoral areas, out to and including the limit of Canada's exclusive economic zone (EEZ) [1];
- the major urban areas of the Toronto-Quebec City corridor (TOR);
- significant oil-producing areas of Alberta and Saskatchewan (ABSK); and
- the Northwest Passage portions of the Canadian Arctic (NWP).

## 1.2 Scope

3. The principal objective of this study is to assess the expected percentage of time suitable for domestic UAV flight operations in support of ISR missions. Specifically, a historical assessment of the frequency and persistence characteristics of cloud cover, precipitation and aircraft icing conditions for five general operating areas within Canada is required.

1. The notion of an EEZ was given binding international recognition by the Third United Nations Convention on the Law of the Sea in 1982. The EEZ represents an area beyond and adjacent to the territorial sea, not exceeding 200 nautical miles, under which the rights and jurisdiction of the coastal State and the rights and freedoms of other States are governed by the relevant provisions of the Convention on the Law of the Sea.[2]

# 2 CONTEXT

## 2.1 The Canadian Forces and Canada's national security policy

4. The CF is a key enabler of Canada's domestic security policy. It supports other departments in dealing with such issues as fisheries and environmental protection enforcement, border control and immigration, and counter terrorism, and remains ready to help civilian authorities respond to natural disasters and other incidents, including floods, ice storms, forest fires, hurricanes and plane crashes. The CF holds primary responsibility for wide area surveillance and sovereignty protection in the more remote and isolated regions of the country, and is a key supporter of domestic security initiatives for events of international interest [2] through their provision of aerial surveillance assets and an anti-terrorist response capability. In addition, the CF holds responsibility for maintaining an updated recognized maritime picture (RMP) of marine traffic in Canada's EEZ. Through the North American Aerospace Defence Command (NORAD), the CF holds responsibility for surveillance, control and protection of Canadian airspace, and has operational command and control of all air defence forces in the Canadian NORAD Region (CANR). Under the 2006 renewal of the NORAD agreement, the CF's maritime surveillance mandate was officially expanded to include a maritime warning mission aimed at maintaining situational awareness of all activities conducted in American and Canadian maritime approaches, maritime areas and inland waterways [3].

## 2.2 Situational awareness and Canada's common operational picture

5. Maintaining complete and accurate situational awareness of Canada's air, land and maritime jurisdiction presents no small task. Canada has a total area of responsibility (AOR) in excess of 20 million $km^2$ and a coastline in excess of 243,000 km that fronts three oceans and the Great Lakes [4]. More than 800,000 legal ship movements are recorded annually within Canadian territorial waters. Furthermore, Canada's common operational picture is becoming increasingly complex as the northern economy develops and as air and marine traffic through Canadian airspace and waters increase. This complexity could be further exacerbated by the potential impacts of climate change, leading to more commercial vessel traffic in the Northwest Passage and Canada's other northern territorial waters. Improving situational awareness, particularly in Canada's marine and Arctic jurisdictions, has emerged as a critical strategic issue facing Canada.

6. Over the past number of years, the Department of National Defence (DND) has pursued several strategic policy initiatives aimed at improving situational awareness and obtaining a more timely and informative common operational picture. Many of these initiatives have focused on advancing their ISR capabilities, to enhance not only the operational capabilities of the CF and its contributions to multinational operations, but also its ability to support other national institutions and levels of government in domestic defence and security missions.

2. Domestic events of international interest include meetings such as the G-8 and APEC Summits, and sporting events such as Olympics. They are domestic events in that Canada is the host nation; however, a significantly lower level of security risk is required for these international events due to their diplomatic and political sensitivities.

7. The CF relies on a variety of space, aerial, maritime and land-based surveillance assets to synthesise Canada's common operational picture. While each type of asset provides specific advantages, the advantages offered by aerial sensor platforms over other environmental (i.e. land, space and maritime) platforms in terms of speed, range, elevation, stealth, precision and mobility have made them an invaluable component of Canada's ISR architecture.

8. Aerial surveillance platforms enjoy a broader field of view (FOV) and can cover a significantly larger area than surface-based systems, allowing them to dominate activities on the surface and below the sea. Furthermore, the size, speed and manoeuverability of many aerial vehicles makes their detection difficult, thus improving their chances of surprising non-cooperative targets. Due to their superior mobility, aerial sensors can offer significant advantages over most space and ground sensors for identifying targets and truthing their locations. Due in large part to their operational utility, aerial sensor platforms have been an integral component of the CF's domestic ISR initiatives since the early 1950s [5].

9. Currently, the CF's prime aerial surveillance asset is the CP 140 Aurora [3] [5]. The CF fleet of 21 Aurora aircraft was purchased between 1980 and 1991 largely to support Canada's anti-submarine warfare mission obligations under the North Atlantic Treaty Organization (NATO) agreements; however, since the end of the Cold War, the Aurora has been used primarily for coastal surveillance and sovereignty patrols. In 1998, faced with an aging Aurora fleet and an impending wide area surveillance capability gap, DND initiated the Aurora Incremental Modernization Plan (AIMP) to upgrade the Aurora's avionics and sensors and extend the life of the aircraft [7]. Concurrent with the Aurora fleet planning initiatives of the late 1990's, DND initiated strategic investigations aimed at identifying alternative wide area ISR solutions to supplement Aurora operations, particularly in the maritime and Arctic regions, to improve the CF's domestic operational picture. These investigations identified a number of promising ISR technology alternatives, key among these being long endurance UAVs.

## 2.3 The role of unmanned aerial vehicles in wide area surveillance

10. From a tactical perspective, long endurance UAVs present the advantages of being faster than helicopters and being able to spend more time on station than conventional manned aerial surveillance assets. These apparent performance advantages, coupled with the perceived fiscal benefits offered by UAVs – namely smaller unit procurement costs and smaller flight crew requirements compared to manned aircraft – have led a number of allied countries including Canada to investigate using high altitude long endurance (HALE) and medium altitude long endurance (MALE) UAVs in a variety of roles ranging from maritime and overland surveillance, to communications relays to hunter-killer missions [4] [8] [9] [10].

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3. In 1991, CP 140A Arcturus aircraft were purchased by the Department of National Defence to bolster the existing CP 140 fleet. The Arcturus shares the same airframe as the Aurora, but is not equipped for anti-submarine warfare (ASW)[6]. For the purpose of this report, both the CP 140A and the CP 140 are considered to be Aurora aircraft.

4. The class of MALE UAV systems are generally defined as having a maximum operating ceiling of around 9,000 m (30,000 ft) and an operating range in excess of 200 km. In comparison, the HALE class of UAV systems are generally defined as having a maximum operating altitude of 18,000 m (60,000 ft), 24 hour time-on-station capability and an

11. Canada’s Joint Unmanned Aerial Vehicle Surveillance and Target Acquisition System (JUSTAS) program was initiated in 2000, when it was incorporated as a development project under the stewardship of the Director General Joint Force Development (DGJFD). In May 2005, the Vice Chief of Defence Staff (VCDS) directed that the Chief of Air Staff (CAS) would assume lead for the project, and JUSTAS became the main focus of the Directorate Air Requirements - Unmanned Aerial Vehicles section (DAR 8), with technical, scientific and operational research support being provided by several Defence Research and Development Canada (DRDC) centres, including the Centre for Operational Research and Analysis (CORA).

12. JUSTAS is a long term, multi-phased capability development program. Initial work for JUSTAS focused on identifying the preferred category of long endurance UAV for patrolling Canada’s maritime approaches and Arctic territory. In support of this objective, starting in 2000, the CF tested several MALE UAV systems in operational trials and in simulated and live experiments covering a range of overland and maritime missions.

13. One of the CF’s first widely reported domestic UAV ISR trials occurred in June 2002, when a General Atomics I-GNAT UAV was used to provide real-time information for security forces during the G-8 Summit held in Kananaskis, Alberta [11]. The following year, in July 2003, the Canadian Forces Experimentation Centre (CFEC) conducted the Pacific Littoral ISR Experiment (PLIX), a live experiment designed to test UAV connectivity in a multi-sensor Line of Sight operation (LOS) [12]. The PLIX experiment used an Israeli Aircraft Industries Eagle-1 MALE UAV fitted with an Elta M-2022 maritime search radar. The Eagle-1 was flown out of Tofino, British Columbia, and was used to characterize surface-vessel contacts in Canadian waters. Following PLIX, in August 2004, CFEC conducted the Atlantic Littoral ISR Experiment (ALIX) to test Beyond Line of Sight (BLOS) UAV operations in deconflicted civil airspace [13] [14] [15]. The ALIX trials operated out of Goose Bay, Laborador, and used a General Atomics Altair UAV equipped with a Telephonics maritime surveillance radar and an L-3 Wescam sensor turret. Missions undertaken during the ALIX trials were intended to test maritime and overland surveillance, reconnaissance and targeting capabilities over the Grand Banks and the Gulf of St. Lawrence and over Baffin Island in the vicinity of Iqualuit, Nunavut and Pangnirtung, Nunavut and to test reconnaissance and targeting capabilities during an army exercise in the Land Forces Atlantic Area.

14. The CF’s domestic UAV trials proved beneficial, not only in helping to identify the true operational advantages offered by a dedicated UAV ISR capability, but also in bringing to light the real operational constraints presented by these systems in the demanding and varied Canadian operational environment. As a result of the PLIX and ALIX experiments, three major constraints, namely the lack of bandwidth in the North, altitude fluctuations in the UAV’s flight path due to strong winds aloft and a general inability to operate in icing conditions, were identified as critical factors limiting the operational effectiveness of employing MALE UAV ISR systems for missions in Canada’s maritime and Arctic regions [16].

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operating range in excess of 5,500 kilometers. The General Atomics MQ-1 Predator and the Israel Aircraft Industries (IAI) Heron are typical MALE-class UAVs, while the Northrop Grumman RQ-4 Global Hawk is the most recognized HALE UAV.

## 2.4 Weather as a constraint to domestic ISR operations

15. Weather is generally acknowledged as one of the key factors affecting ISR mission success, as it can impact both the sensor and the sensor platform with equal consequence. Weather conditions like fog, snow and low cloud ceiling act to obscure targets, and to increase path losses and reduce image quality and interpretability. This is of particular concern for EO sensors operating in the visual and IR spectral ranges, as they are very sensitive to scattering and absorption by atmospheric water and other suspended particles. Similarly, extreme temperatures, high winds, precipitation and icing can ground aerial platforms, and render maritime and land platforms inoperable.

16. The sensitivity of aerial ISR platforms to adverse weather conditions is well documented. In the 1990-1991 Gulf War, nearly half the air sorties conducted by Coalition forces were affected by weather [17]. The effects of adverse weather conditions were also felt during the 78-day NATO air offensive in the Balkans War, when cloud cover exceeded 50% more than 70% of the time. During the Balkans campaign, the need to minimize civilian casualties demanded visual identification of targets prior to engagement; however, without a reasonably clear optical path, laser-guided bombs could not be employed. Furthermore, reports on American Hunter UAV operations in Kosovo indicate that 25% of all scheduled UAV flight missions were adversely affected by icing conditions or rainfall, even during the relatively warm months of April through October [18].

17. Like the American experience with Hunter operations in Kosovo, Canada's domestic trials and operational experience have shown MALE UAVs to be particularly sensitive to adverse weather conditions. MALE UAVs are smaller, lighter, and generally less powerful than conventional fixed-wing aircraft. While such minimalist design characteristics greatly benefit vehicle endurance and persistence capabilities, they also present significant operational constraints, particularly under icing and strong wind conditions [19].

18. In general, UAVs have a slower cruise speed and rate of climb and descent than traditional fixed-wing aircraft [5], thus exposing them to extended periods of icing, and making them more susceptible to the formation of ice layers during the two most aerodynamically critical phases of flight [22]. Ice build-up acts to disrupt laminar flow over wings, increase drag and weight, and in severe cases can initiate disruptive vibrations in propellers or otherwise destabilize control during vehicle flight [23]. Furthermore, the low weight and power characteristics typical of many MALE UAVs makes them particularly susceptible to cross-winds during takeoff and landing, and difficult to control during flight in strong wind conditions. Compromised controllability presents a significant concern, particularly when operating in civil airspace. Furthermore, while some UAV platforms incorporate fully automated takeoff and landing flight systems, many current MALE UAVs require human (pilot) control during takeoff and recovery. As a consequence, many UAV operating procedures stipulate visual flight rules (VFR) [6] as a minimum requirement for initiating a UAV mission.

5. The reported patrol speed of the CP 140 Aurora at 1,500 ft (457 m) is 206 kt (381 km/h), with a service ceiling of 35,000 ft (10,668 m) and a range of 5,000 nm (9,266 km) [20]. In comparison, the reported loiter speed of the Predator A is 73 kt (135 km/h), with a service ceiling of 25,000 ft (7,620 m) and an operational radius of 400 nm (740 km) [21].

6. CF regulations governing VFR and VFR conditions are stipulated in [24].

## 2.5 Weather and climate studies

19. The earth's atmosphere forms a complex, dynamic system, making accurate predictions of future atmospheric states extremely difficult. Atmospheric states are generally described by weather and climate; however, the terms weather and climate are not synonymous, and the level of predictability of each is comparably different. Weather refers to the extant phenomena in a given atmosphere, at a given location and time, whereas climate defines a statistical description of those relevant weather quantities such as temperature, precipitation, and wind, averaged over longer periods of time [25]. Due to the complex nature of the atmospheric system, weather exhibits poor predictability characteristics that degrade as the range of the forecast increases. Time-averaging has the effect of removing randomness from the weather record, which in turn makes climate forecasting much more predictable than weather forecasting.

20. Satellite and terrestrial meteorological station records are widely used in climate forecasting studies, as they form two of the most complete and accessible sources of historical weather information. Weather satellites primarily function as remote sensing platforms. They typically carry EO (visible and IR) or radio frequency sensors, and are capable of producing images from which analysts can determine such atmospheric state variables as cloud height, wind direction, and surface temperature, though the type of data collected depends primarily on the type of sensors supported by the satellite. Many satellite data products represent inferred quantities, derived from measurements of a surrogate variable such as solar reflectance.

21. In comparison, terrestrial meteorological station records typically contain data produced from direct measurements and observations of actual atmospheric state variables at a specific location on the ground, or near the ground surface. Satellite data products tend to offer greater spatial coverage than terrestrial meteorological station records; however, due to their comparatively large field of view and low sampling (revisit) rate, they tend to exhibit much lower spatial and temporal resolutions than terrestrial meteorological station data products.

# 3 METHODOLOGY

22. This study represents a high-level statistical investigation of the frequency and persistence characteristics of historical weather observations from five Canadian AOIs. The study has three main components:

1. a regional cloud climatology assessment, where cloud cover data is used to assess the general cloud climate to estimate the expected percent of time that an EO/IR sensor could operate;
2. a local assessment of the frequency of occurrence and persistence of the various weather conditions considered to adversely affect EO/IR sensor image quality; and
3. a local assessment of the frequency of occurrence and the persistence of potential icing conditions, as well as other weather conditions considered to adversely affect UAV take-off and recovery operations.

23. The term *utility* is used in this study to represent the expected amount of time that UAV ISR operations could be undertaken when needed, without being affected by weather. This definition considers the utility of the UAV platform to be separate from the utility of the EO/IR sensor: UAV utility is measured in terms of being able to launch, recover and to operate free of icing conditions, while sensor utility is measured in terms of being able to achieve an acceptable quality of image to meet a given operational objective (i.e. *detecting*, *classifying* or *identifying* a specified target)[7]. While sensor and platform are assessed independently in this study, it is noted that the utility and performance of a UAV ISR platform depends on the combined utility and performance of both the platform and the sensor.

24. Specific ISR mission scenarios (i.e. identifying a given target in a given physical environment, using a specific sensor package under specific weather conditions) are not considered in this study; rather, the frequencies of occurrence of specific weather conditions which are known to cause path loss effects for sensors operating in the EO/IR spectral range are examined.

## 3.1 Materiel and operational assumptions

25. For the purposes of this study, a generic MALE UAV of similar size and exhibiting similar operating characteristics to the General Atomics RQ-1 Predator is assumed. It is assumed that the UAV does not possess an anti-icing capability. It is also assumed that the generic UAV platform supports a generic EO/IR sensor ball similar to the WESCAM MX-20 system that is currently used on the CP 140 Aurora [20].

26. At the time that this study was initiated, the CF had not yet established a set of aircraft operating instructions for MALE UAVs. Consequently, for analysis purposes it is assumed that MALE UAV operations would follow the operating instructions established for the CU 161 Sperwer

7. In this study, *sensor utility* is not considered to be a measure of sensor resolution or sensor imaging performance, as resolution and performance depend on a number of target and sensor-specific variables in addition to numerous environmental factors.

tactical UAV, particularly with respect to air vehicle flight limitations [8]. Specifically, in this study it is assumed that UAV flight into forecast or knowing icing conditions is prohibited, and that VFR conditions are required for UAV takeoff and recovery operations [26]. It is also assumed that the maximum permissible cross wind speed during takeoff and recovery is 20 kt (37 km/h) [27].

27. The UAV platform is generally assumed to have an operating altitude of between 15,000 ft and 40,000 ft (4,500 m – 12,200 m).

## 3.2 Data sets

### 3.2.1 ISCCP reduced radiance satellite data archive

28. The majority of the observation stations in Canada's national meteorological station network are land-based and are located in the more populated regions of the country; consequently, archival meteorological station records are generally unavailable for most of Canada's Atlantic and Pacific EEZ, as well as large portions of Canada's northern territory [28]. To overcome some of the analytical constraints presented by the limited spatial coverage of archival meteorological station data, 21 years [9] (1983 to 2005 inclusive) of low resolution monthly averaged cloud cover data is referenced from the International Satellite Cloud Climatology Project (ISSCP) data archive[29].

29. The ISCCP was established in 1982 as part of the World Climate Research Program to collect weather satellite radiance measurements and to analyze them to infer the global distribution of clouds, their properties, and their diurnal, seasonal and inter-annual variations [30] [31]. Though the ISCCP produces several data products, due to its completeness and availability, the D2 reduced radiance data set is used in this study.

30. The ISCCP D2 data set reports mean monthly values for several atmospheric variables including:

- high level cloud cover – clouds located between 21,000 ft and 61,000 ft (6,500 m – 18,600 m);
- middle level cloud cover – clouds located between 10,500 ft and 21,000 ft (3,200 m – 6,500 m); and
- low level cloud cover – clouds located between the earth's surface and 10,500 ft (3,200 m).

8. It is noted that the CU 161 is a tactical UAV, and is significantly different from a Predator-type air vehicle in terms of vehicle size and endurance, as well as the methods employed for vehicle launch and recovery. Nevertheless, the visibility, cloud ceiling and icing condition restrictions contained in the CU 161 aircraft operating instructions are considered applicable for the purpose of this study, as the assumed MALE UAV does not have an anti-icing capability, and under current CF policy UAVs are not authorized to conduct VFR or VFR Over the Top flight outside of Military Class F special use airspace unless specifically approved by Commander 1 Canadian Air Division [24].

9. The El Nino/El Nina cycle has an expected period of between 2 and 7 years. Consequently, a 21-year period of record is assumed sufficiently long to capture at least one El Nino/El Nina cycle.

The various cloud cover variables contained in the D2 data set represent the fraction of pixels in the satellite FOV [10] reporting a cloudy condition, as determined by the ISCCP's cloud detection algorithm [30].

31. Though distinctions are made between the various cloud elevation data sets, these populations are not independent in the statistical sense – because the ISCCP datasets are obtained from passive measurements of radiation reflected and emitted by clouds, they cannot provide direct information about the vertical distribution of cloud mass [31]. As a consequence, the high, middle and low level cloud populations in the D2 set exhibit an additive property such that, for each gridbox, the cloud climate below 21,000 ft (i.e. between the earth's surface and the top of the middle cloud layer) can be described as the summation of the low level and middle level cloud amounts. From an analysis perspective, this additive definition of middle level cloud amount is preferred, as it is assumed that an intended surveillance target would be located near or on the earth's surface, rather than at the top of the next lowest cloud layer. Consequently, for this study, the term middle level cloud amount is used to represent the population of clouds located between the earth's surface and 21,000 ft (6,500 m), and the term high level cloud amount is used to represent the population of clouds located between the earth's surface and 61,000 ft (18,600 m). These definitions of cloud height are are illustrated in Figure 1.

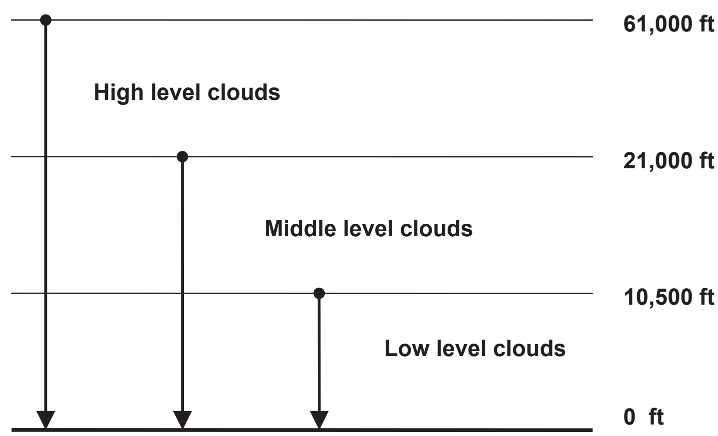



***Figure 1 (U):*** *Cloud elevation definitions used in the regional cloud climate assessment*

32. Because of the averaging processes used in producing the D2 cloud cover data (i.e. for each grid cell record, spatially averaged pixel counts are averaged over a time period of one month), within a given grid cell, differences in cloud cover cannot be determined for time intervals of less than 1 month, nor can geographic differences in cloud cover within a gridbox be detected. As a result, each variable reported in the D2 data set can be interpreted as representing either the expected amount of time that a grid box is completely covered by clouds (monthly averaging), or

10. Each ISCCP grid cell is represented by 88 pixels, the equivalent of 1 satellite FOV. Each pixel represents an area of approximately 900 $km^2$.

the expected grid cell area fraction that is covered by clouds over a given monthly interval (pixel averaging).

33. The D2 data products are geo-located to an equal-area grid developed specifically for the ISCCP. To enable using the MatLab Mapping Toolbox functions [32] for analysis, the equal-area grid was mapped to an equal angle grid [11], using an algorithm developed by the ISCCP [29]. In this report, subsequent references to the ISCCP grid refer to the equal angle grid, unless otherwise indicated.

### 3.2.2 The national climate data and information archive

34. While the D2 data set provides complete geographic coverage of all five AOIs, the data sets document inferred cloud products, and are not of sufficient temporal resolution to characterize the frequency and persistence distributions of potential aircraft icing conditions, or weather conditions considered limiting to MALE UAV flight operations. Consequently, to supplement the D2 cloud cover data, single station meteorological records drawn from the National Climate Data and Information Archive (NCDIA)[33] are referenced for 21 locations of interest (LOIs) across Canada.

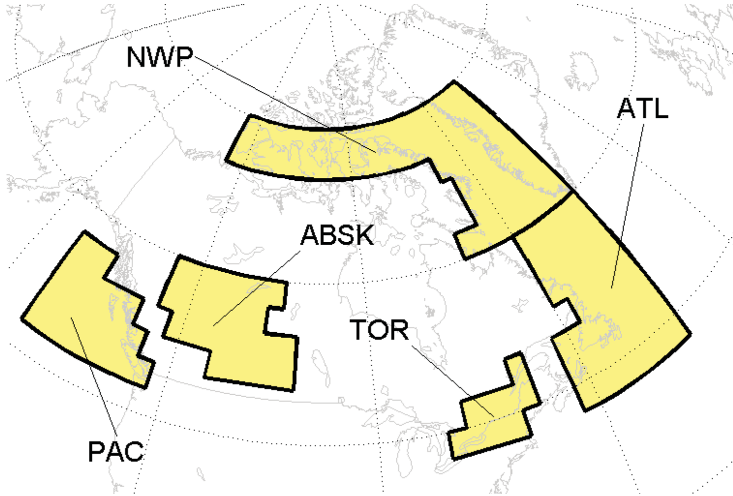
35. The NCDIA is operated and maintained by Environment Canada. It contains official climate and weather observation records from more than 1,150 active and inactive meteorological stations within Canada's national meteorological station network [33]. The single station data sets held in the NCDIA are of varying temporal resolution (i.e. hourly observations; monthly and yearly means) and have varying periods of record. While the specific meteorological parameters recorded in the archive vary between data sets, all of the LOI data sets referenced in this study contain consistent observation records of temperature, relative humidity, wind speed, cloud ceiling and weather.

## 3.3 Designating areas of interest and locations of interest

36. From the general area descriptions provided in the study terms of reference, specific geographic boundaries are defined for each of the 5 AOIs by first identifying prominent population centres, distinguishing land forms and other characteristic features located within the AOI, and then identifying the specific ISCCP grid cells within which the identified population centres, characteristic features, etc. are located. Regularly shaped boundaries are then defined for each AOI by grouping those grid cells containing the characteristic regional features so as to form one continuous AOI region. Once a continuous AOI region is defined, its constituent grid cells are given unique numeric identifiers to permit subsequent evaluations of geographic cloud climate trends within the AOI. With the exception of the ATL and NWP areas, each of the AOIs is geographically separated and is situated in a different climatic region from all others. Figure 2 shows the locations and boundaries of the 5 AOIs considered in this study, while Figure 3 shows the indexing convention used to uniquely identify the constituent gridboxes of each AOI.

37. For each of the 5 AOIs, the data records for at least 3 locations of interest (LOIs) are selected from the NCDIA. For consideration as an LOI, a candidate location's NCDIA record is required to

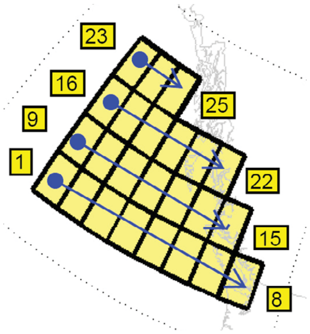
11. The ISCCP equal area grid consists of 6,596 cells, with each grid cell covering an area of approximately 78,400 $km^2$ (280 km × 280 km). In comparison, the ISCCP equal angle grid is consists of 10,368 cells, with each cell covering an area of 2.5° × 2.5° (latitude × longitude).



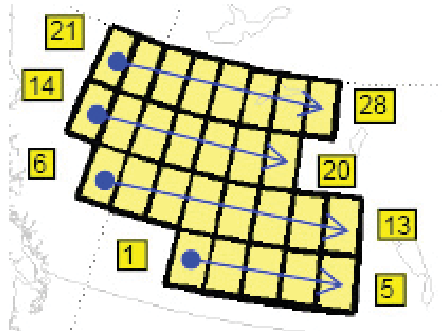

| | |
|---|---|
| PAC | Pacific region |
| ABSK | Oil-producing regions of Alberta & Saskatchewan |
| NWP | The Northwest Passage and Baffin Bay regions of the Canadian Arctic |
| TOR | The Toronto-Quebec City Corridor of the St. Lawrence and Lake Ontario |
| ATL | Atlantic region |

***Figure 2 (U):*** *Area of interest (AOI) boundaries defined for the regional cloud climatology assessment*

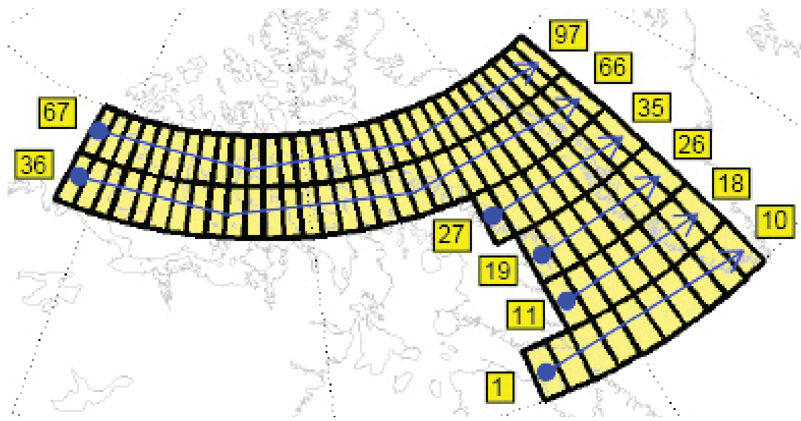
cover a minimum period of 11 years (1995 to 2005 inclusive) and to have a minimum sampling rate of 1 observation per hour. Where multiple candidate LOIs are identified within a given AOI, LOIs are selected so as to cover important population centres and to be geographically distributed within the AOI. Figure 4 shows the locations of the 21 LOIs selected for this study.



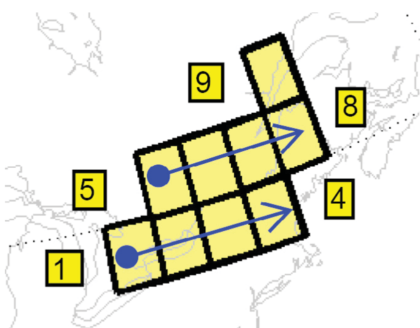

(a) PAC region local gridbox index



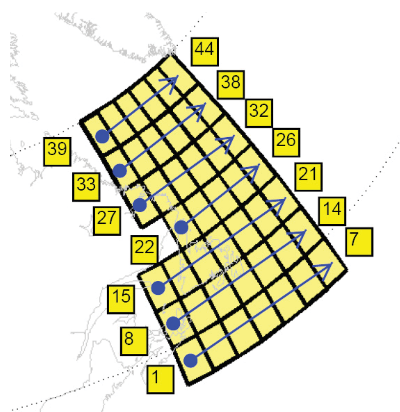

(b) ABSK region local gridbox index




(c) NWP region local gridbox index

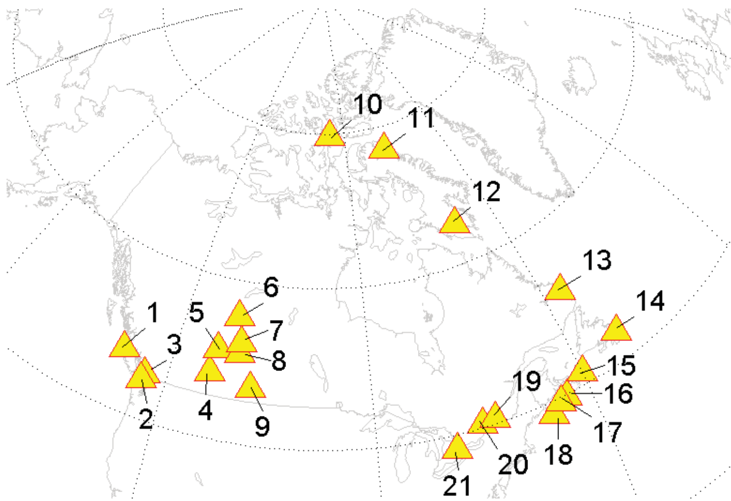



(d) TOR region local gridbox index




(e) ATL region local gridbox index

***Figure 3 (U):*** *Summary of the indexing convention used to identify individual gridboxes within each of the five areas of interest (AOIs) defined for the study.*




| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1 | Port Hardy, BC | 6 | Fort McMurray, AB | 11 | Pond Inlet, NU | 16 | Halifax, NS |
| 2 | Victoria, BC | 7 | Cold Lake, AB | 12 | Iqualuit, NU | 17 | Greenwood, NS |
| 3 | Vancouver, BC | 8 | Lloydminister, AB/SK | 13 | Cartwright, NFLD | 18 | Yarmouth, NS |
| 4 | Calgary, AB | 9 | Swift Current, SK | 14 | St. John's, NFLD | 19 | Montreal, PQ |
| 5 | Edmonton, AB | 10 | Resolute, NU | 15 | Sydney, NS | 20 | Ottawa, ON |
| | | | | | | 21 | Toronto, ON |

***Figure 4 (U):*** *Locations of interest (LOIs) defined for the frequency and persistence assessment studies*

## 3.4 Regional cloud climatology assessment procedure

38. In the regional cloud climatology assessment, cloud cover data from the ISCCP D2 archive is used to assess the general cloud climate of high, middle and low level clouds, to estimate the expected percent of time that an EO/IR sensor could operate in each of the 5 AOIs established for this study. Cloud cover fraction (%-cloud cover) is the metric used in this assessment, as it is assumed that the EO/IR sensor requires a clear optical path for imaging.

39. In the analysis, records from the low, middle and high level cloud data sets are indexed into multi-dimensional data arrays using the indexing convention $D_{X,Y,Z}$, where $D$ represents the variable (i.e. high level cloud amount), $X$ represents an ISCCP grid box identifier (the size of $X$ is AOI-specific – refer to Figure 3), $Y$ represents a month identifier ranging from 1 to 12 (January to December), and $Z$ represents a year identifier ranging from 1 to 21 (representing 1983 to 2005 inclusive). Sets of *monthly* arrays are derived by taking means along the $Z$ dimension, and the resulting data products are plotted to permit a visual assessment of the seasonal and geographic variability in cloud climates within the various AOI regions.

40. Where significant seasonal and/or geographic differences in cloud climate are perceived within an AOI, a clustering technique based on the quality threshold (QT) clustering algorithm presented in [34] is used to quantitatively assess the significance of any observed differences in cloud climate. The clustering algorithm employs the following procedure:

1. For a given AOI, cloud cover data is grouped twice: once according to its month index ($Y$), and a second time according to its gridbox index number ($X$).

2. Arithmetic means and standard deviations are calculated for each month (e.g. the January data set) in the *monthly* data array and for each gridbox in the *gridbox* data array, and are saved in vectors.

3. The elements of each *mean* vector (i.e *monthly mean* and *gridbox mean*) are sorted in ascending order, and cluster memberships are determined by comparing the differences in magnitude between subsequent vector elements. The element of smallest value ($e_1$) is compared to the element of second smallest value ($e_2$): if the value of $|e_2 - e_1|$ is less than a defined maximum cluster diameter, $d$, then both elements $e_1$ and $e_2$ are clustered together, and a subsequent comparison between element $e_1$ and $e_3$ is made.

41. According to this procedure, elements are added to a cluster until the quality threshold condition of $|e_n - e_1| < d$ ceases to be met. When no additional elements can be added to the cluster (i.e. $|e_n - e_1| > d$), a new cluster is defined using the test condition of $|e_{(n+1)} - e_n| < d$. It is a requirement that all data elements be included in a cluster, and that each element be counted in only one cluster.

42. A maximum cluster diameter of 5% is used in the clustering analysis.

## 3.5 Local area sensor visibility assessment procedure

43. Two tests are used to assess the impacts of local weather conditions on EO/IR sensor utility in this study. In the first instance, weather observation records are used to quantify the frequency and persistence of various weather events considered to adversely affect EO/IR sensor image quality, while in the second test, cloud ceiling elevation measurements are used to quantify the utility of an EO/IR sensor operating at an elevation of at least 15,000 ft.

44. For the analysis, a list of all unique weather observations contained in the LOI weather observation fields was compiled and provided to EO/IR imaging subject matter experts (SMEs) from Director General Aerospace Equipment Program Management - Radar & Communications Systems (DGAEPM - R&CS). The SMEs classified each weather observation according to its relative impact on EO/IR sensor image quality by assigning each weather observation to one of 4 general ISR taxonomic groups:

1. Identification tasks possible – the observed weather event has very little negative effect on EO/IR image quality;
2. Classification tasks possible – the observed weather event has some negative effect on EO/IR image quality;
3. Detection tasks possible – the observed weather event has a strong negative effect on EO/IR image quality; and
4. No Image – the observed weather event prevents the creation of an EO/IR image that is useful for any task.

45. Table 1 shows the ISR tasking designations assigned by the SMEs the various weather observations contained in the LOI data sets. Though precipitation events are generally associated with clouds, in this study it is assumed that the UAV is operating at an altitude below the cloud ceiling. Under this simplifying assumption, only the observed weather event (e.g. rain, snow, fog) is considered to contribute to path loss.

46. For each LOI, the occurrence frequency of those weather conditions considered suitable for undertaking a given ISR task is determined by counting the number of records in which weather observations considered suitable for undertaking the given task are reported, and then dividing by the total number of reported observation records contained in the data set. A hierarchical counting process is applied to the *detection tasks possible* and *classification tasks possible* weather conditions, whereby if an observation is classified as an *identification tasks possible* condition, it is also considered a *classification tasks possible* event and a *detection tasks possible* event. Similarly, if a weather event is classified as a *classification tasks possible* event, it is also considered a *detection tasks possible* event. Where a given data record contains multiple weather observation fields, the relative ranking of each weather observation is assessed, and the lowest ranking task description is assigned to the record [12].

12. As an example, consider the case where three weather observations, $OBS_1$, $OBS_2$, and $OBS_3$, are listed for a given record. $OBS_1$ has a rank of *detection possible*; while $OBS_2$ holds an *identification possible* rank and $OBS_3$ holds a *classification possible* rank. This record would be assigned an overall rank of *detection possible*, as $OBS_1$ represents the lowest rank (i.e. the critical case).

***Table 1 (U):*** *Summary of SME assessment as to the effects of specific weather observations on EO/IR image quality tasking designation*

(a) No imaging tasks possible

| | | |
|---|---|---|
| Blowing Dust | Heavy Drizzle | Heavy Hail |
| Blowing Sand | Heavy Rain | Moderate Ice Pellets |
| Blowing Snow | Heavy Rain Showers | Heavy Ice Pellets |
| Fog | Heavy Thunderstorms | Heavy Snow |
| Freezing Fog | Moderate Freezing Drizzle | Moderate Snow Showers |
| Ice Fog | Heavy Freezing Drizzle | Heavy Snow Showers |
| Haze | Moderate Freezing Rain | Moderate Snow Grains |
| Smoke | Moderate Hail | Moderate Snow Pellets |

(b) Detection imaging tasks possible

| | | |
|---|---|---|
| Moderate Drizzle | Freezing Drizzle | Snow Showers |
| Moderate Rain | Freezing Rain | Snow Grains |
| Rain Showers | Hail | Snow Pellets |
| Moderate Rain Showers | Snow | Ice Pellet Showers |
| Thunderstorms | Moderate Snow | Ice Pellets |
| | | Ice Crystals |

(c) Classification imaging tasks possible

| | |
|---|---|
| Mostly Cloudy | Drizzle |
| Cloudy | Rain |

(d) Identification imaging tasks possible

| | |
|---|---|
| Clear | Mainly Clear |

47. The persistence characteristics associated with those weather conditions considered limiting to specific ISR tasks are determined by comparing the similarity of an observation's ISR ranking taken at time $t$ with subsequent observation rankings taken at time $(t+\Delta t)$: if successive ISR ranks are similar, then a persistence counter is indexed; however, if successive ranks are dissimilar, then the current counter value is recorded, and the counter is reset.

48. In the second test, hourly cloud ceiling observation fields are parsed to identify those records reporting cloud ceilings below 15,000 ft (4,500 m). While not all of the LOIs selected for this study report cloud ceiling observations, cloud ceiling records were obtained for at least one LOI for each of the AOIs investigated the study. As it is assumed that the sensor cannot image through cloud, the occurrence frequency of cloud-limiting imaging conditions is determined by counting the number of records in which cloud ceilings below 15,000 ft are reported, and then dividing by the total number of reported cloud ceiling observation records contained in the data set. As in the first test, persistence characteristics of cloud-limiting imaging conditions are calculated by comparing the similarity of an observation's designation (i.e. as a critical event) at time $t$ with subsequent observation designations taken at time $(t+\Delta t)$: if successive event designations are similar, then a persistence counter is indexed; however, if successive designations are dissimilar, then the current counter value is recorded, and the counter is reset.

49. In the local area sensor visibility assessment, the correlation of records reporting cloud ceiling elevations below 15,000 ft and records reporting critical task-specific weather conditions was not analyzed.

## 3.6 Local area takeoff, recovery and flight conditions assessment procedure

### 3.6.1 Critical takeoff and recovery conditions

50. Due to their importance in defining visual flight conditions (VFR), the 3 weather parameters of cloud ceiling ($H_c$), wind speed ($v_w$) and visibility (VIS), are used to assess the expected impacts of local climate on vehicle takeoff and recovery operations.

51. For the analysis, sets of single station meteorological records are drawn from the NCDIA for each of the 21 LOIs identified for the study. Each LOI data set is sorted into 12 subsets according to a monthly data grouping. Each monthly data subset is then parsed to identify those data records containing specific event observations that exceed the assumed operational threshold limits for takeoff and recovery under VFR, as summarized in Table 2. Observations found to exceed the assumed operational threshold limits are flagged as exceedence events.

***Table 2 (U):*** *Assumed threshold weather conditions for MALE UAV takeoff and recovery operations*

| Weather Observation | Threshold Condition for VFR |
|---|---|
| Wind Speed, $v_w$ | $v_w > 20$ kt (37 km/h) |
| Visibility, VIS | VIS < 3 nm (4.8 km) |
| Cloud Ceiling, $H_c$ | $H_c < 1{,}500$ ft (450 m) |

52. The occurrence frequency of an exceedence event is calculated by dividing the total number of exceedence event observations reported in the data set (or subset) by the total number of observation records contained in the set (or subset). The persistence characteristics associated with each exceedence event population are determined by comparing the similarity of an observation taken at time $t$ with subsequent observations taken at time $(t + \Delta t)$: if successive exceedence events are observed, then a persistence counter is indexed; however, if successive events are dissimilar, then the current counter value is recorded, and the counter is reset.

### 3.6.2 Icing conditions

53. Three separate tests are used to assess the impacts of icing conditions on UAV takeoff, recovery and flight operations.

54. The first test is based on work presented in [35], where dew point depression, a relationship between the spread of ambient temperature ($T_{amb}$) and dew point temperature ($T_{dp}$), was used to predict the presence of clouds containing supercooled water droplets. When $T_{amb}$ was plotted against $T_{dp}$, clouds lying between the lines $\left(T_{amb} = T_{dp}\right)$ and $\left(T_{amb} = 0.8 \times T_{dp}\right)$ were found to

hold supercooled liquid water when the ambient temperature was below freezing. Subsequent experiments found that the probability of experiencing aircraft icing conditions in clouds when these atmospheric conditions were met was 95%. This relationship between dew point and ambient air temperature is commonly referred to as the Appleman condition.

55. In the first test, for each LOI, the variables of ambient temperature and dew point temperature are drawn from the NCDIA, and are sorted into 12 subsets according to a monthly data grouping. Within each subset, individual records reporting ambient temperatures below freezing are identified, and tested against the Appleman icing condition, as defined in Equation 1. Records meeting the Appleman icing condition are considered to represent potential icing conditions, and are subject to the same statistical determinations of occurrence frequency and persistence as the exceedence event populations described in Section 3.6.1.

$$T_{dp} \leq T \leq 0.8 \times T_{dp} \tag{1}$$

56. The second and third tests are based on the work presented in [36], where ground-based weather observations were used as an indicator of icing conditions aloft. In addition to characterizing the frequency of occurrence of freezing precipitation events, the study quantified the amount of various types of precipitation associated with many aviation hazards, including dry snow, wet snow, ice pellets, snow pellets, freezing rain and freezing drizzle, received in different regions of Canada.

57. In the second test, the so-called *critical temperature and precipitation test*, records in which ambient temperatures below freezing are reported in combination with any precipitation event are considered to represent icing conditions. First, the weather observation fields of each LOI data set are parsed to identify all unique weather observations reported over the study period of record. From this set of unique weather observations, a subset of critical precipitation observations containing all unique precipitation event observations is defined. Specific weather observations identified as belonging to the precipitation [13] observation set are shown in Table 3(a). Each monthly subset of LOI data is then parsed to identify those records reporting ambient temperatures below freezing and critical precipitation observations in their weather observation fields. Where records contain multiple weather observation fields, each observation is individually assessed for membership in the critical precipitation observation set: if 1 or more of the observations belongs to the critical precipitation observation list, then the record is considered to meet the critical precipitation criterion. Records meeting the critical temperature and critical precipitation criterion are considered to represent potential icing conditions, and are subject to the same statistical determinations of occurrence frequency and persistence as the exceedence event populations described in Section 3.6.1.

58. In the third test, only those records reporting freezing precipitation observations are considered to represent icing conditions. From the set of unique weather observations, a sub-set of critical freezing precipitation observations containing all unique freezing precipitation event observations is defined. Each monthly sub-set of LOI data is then parsed to identify records reporting observations defined as critical freezing precipitation events. As in the *critical temperature and precipitation*

13. Due to the icing potential presented by clouds, the terms *Mostly Cloudy* and *Cloudy* are included in the precipitation event set.

test, where records contain multiple weather observation fields, each observation is individually assessed for membership in the freezing precipitation event set. As in the other tests, records meeting the freezing precipitation criterion are considered to represent potential icing conditions, and are subject to the same statistical determinations of occurrence frequency and persistence as the exceedence event populations described in Section 3.6.1.

59. Specific weather observations identified as belonging to the freezing precipitation observation set are shown in Table 3(b).

***Table 3 (U):*** *Precipitation and freezing precipitation event set designations. A glossary of meteorological terms is presented in Annex A.*

(a) Precipitation events

| | | |
|---|---|---|
| Snow | Moderate Rain Showers | Moderate Ice Pellets |
| Mostly Cloudy | Heavy Rain Showers | Heavy Ice Pellets |
| Cloudy | Thunderstorms | Ice Pellet Showers |
| Fog | Heavy Thunderstorms | Moderate Snow |
| Freezing Fog | Freezing Drizzle | Heavy Snow |
| Ice Fog | Moderate Freezing Drizzle | Snow Showers |
| Drizzle | Heavy Freezing Drizzle | Moderate Snow Showers |
| Moderate Drizzle | Freezing Rain | Heavy Snow Showers |
| Heavy Drizzle | Moderate Freezing Rain | Snow Grains |
| Rain | Hail | Moderate Snow Grains |
| Moderate Rain | Moderate Hail | Snow Pellets |
| Heavy Rain | Heavy Hail | Moderate Snow Pellets |
| Rain Showers | Ice Pellets | |

(b) Freezing precipitation events

| | |
|---|---|
| Heavy Freezing Drizzle | Moderate Freezing Rain |
| Freezing Rain | Moderate Freezing Drizzle |
| Freezing Drizzle | |

# 4 RESULTS & DISCUSSION

## 4.1 Regional cloud climatology assessment

60. General results of the regional cloud climatology assessment are summarized in the following sections. A more detailed description of the regional cloud climate analysis results are presented in Annex B.

### 4.1.1 Spatial distributions in cloud cover

61. Figure 5 shows mean cloud amounts, averaged over all months and years, for high, medium and low level clouds across all gridboxes in each of the AOI regions. At all elevations, regional differences in cloud cover amount are observed between AOIs. In general, greater cloud cover amounts are observed in the maritime environment compared to inland locations. Across all AOIs, cloud amounts increase with elevation. Mean amounts of low level clouds ($H_c < 10,500ft$) range from 10% in central Canada to 35% in the Atlantic and Pacific bluewater regions, while the incidence of middle level cloudiness ($H_c < 21,000ft$) ranges from 45% in central Canada to 75% in the Atlantic and Pacific bluewater regions. The incidence of high level cloudiness ($H_c < 61,000ft$) ranges from 70% in central Canada to 95% in the Atlantic and Pacific bluewater regions respectively.

### 4.1.2 Temporal distributions in cloud cover

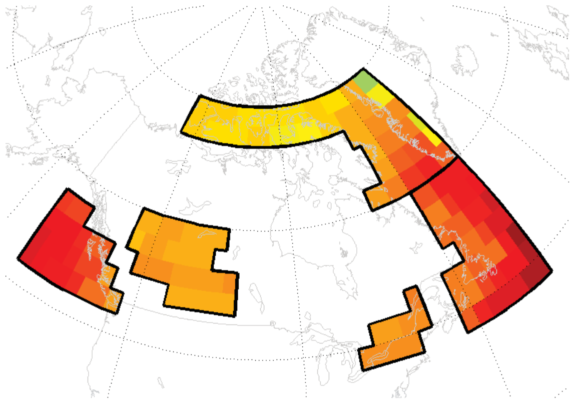
62. The temporal distributions of high, middle and low level cloud amounts vary across the different AOI regions. In the PAC region, negligible seasonal variability is observed in the amount of middle level clouds, while the greatest amounts of high and low level clouds are observed in June through August inclusive. In the ABSK, TOR and ATL regions, the greatest amounts of low level clouds are observed in April through August inclusive, while the greatest amounts of middle and high level clouds are observed in November through February inclusive.

63. The high level cloud climate of the NWP region exhibits significant geographic trends in temporal variability. In the Davis Strait, high level cloud amounts are smallest in March, April and October, while little seasonal variability is observed in the more northerly areas of the NWP region (i.e. over the Canadian Arctic Archipelago and the Perry Channel). Across the NWP region, little seasonal variability is observed in the middle level cloud population, with the smallest amounts of middle level clouds occurring in May through August inclusive.

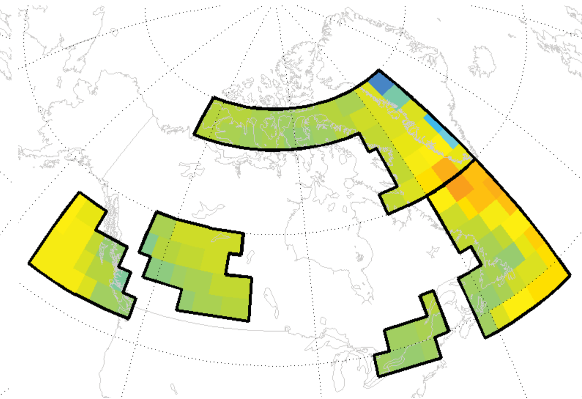
### 4.1.3 Homogeneity of regional cloud climates

#### Geographic variability

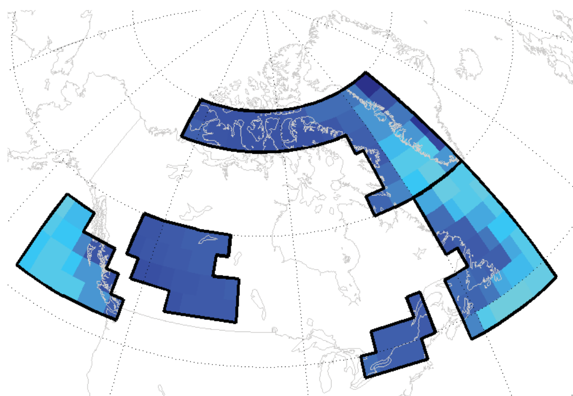
64. Results of the gridbox clustering analysis (see Section 3.4) shows the high, middle and low level cloud climates of both the TOR and ABSK regions to be geographically homogeneous. At all cloud elevations in the TOR region, differences in mean cloud cover (averaged over all months and



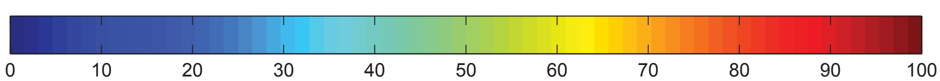
(a) Mean high level cloud amount ($H_c < 61,000 ft$)



(b) Mean middle level cloud amount ($H_c < 21,000 ft$)



(c) Mean low level cloud amount ($H_c < 10,500 ft$)




(d) %-Cloudiness

***Figure 5 (U):*** *Mean high level, middle level and low level cloud amounts (averaged over all months) expressed as %-cloudiness across all AOIs* years) between gridboxes vary by less than 5%. In the ABSK region, all gridboxes are contained in 1 cluster group for the high level cloud data, while gridboxes are clustered into 2 groups for the middle level cloud data and 3 groups for the low level cloud data. In the ABSK middle and low level cloud data sets, grid cells located over the Canadian Rockies form distinct clusters from those grid cells located in the prairie regions of Alberta and Saskatchewan. Results of the ABSK gridbox clustering analysis are summarized in Figure 6.

65. Results of the PAC gridbox clustering analyses are summarized in Figure 7. In the PAC region, gridboxes are clustered into 4 geographically distinct groups for the high and low level cloud data sets, and 3 groups for the middle level cloud data set. The cluster groupings generally follow the same geographic trends, with gridboxes in the lower mainland forming a distinct cluster, gridboxes covering Vancouver Island and the Queen Charlotte Islands forming a second distinct cluster and gridboxes in the Pacific forming a third distinct cluster.

66. Of the 5 AOIs investigated, the NWP and ATL regions show the greatest geographic variability in cloud climate. In the ATL region, 5 distinct cluster groups are formed in both the high and low level cloud data sets and 6 cluster groups are formed in the middle level data set, while in the NWP region 6 distinct cluster groups are formed in both the high and low level cloud data sets and 8 groups are formed in the middle level data set. Results of the ATL and NWP gridbox clustering analyses are summarized in Figures 8 and 9 respectively.

67. In the ATL region high and low level cloud data sets, cluster groupings follow similar geographic trends, with gridboxes located over land forming a distinct cluster, gridboxes located over the littoral area forming a second cluster and additional clusters being formed as the gridbox location progresses further away from land, into the Atlantic. Similar west-east cloud climate variability trends are also observed in the middle level cloud data set; however, the middle cloud data set also shows distinct south-north cloud climate variability trends.

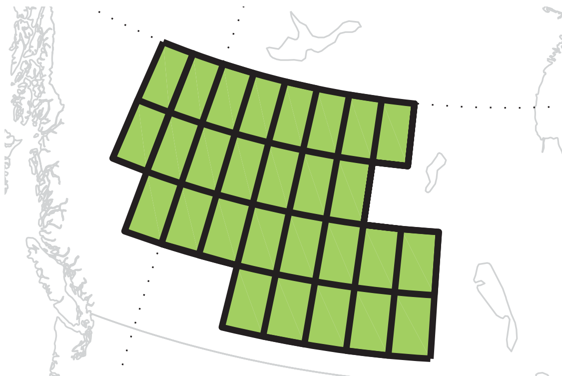
68. In the NWP region, cluster groupings generally follow the same geographic trends across all elevation data sets, with gridboxes located over the Archipelago and Baffin Island forming one cluster, gridboxes located in Baffin Bay forming a second cluster and gridboxes in the North Atlantic forming several clusters, depending on their relative proximity to land.

#### Temporal variability

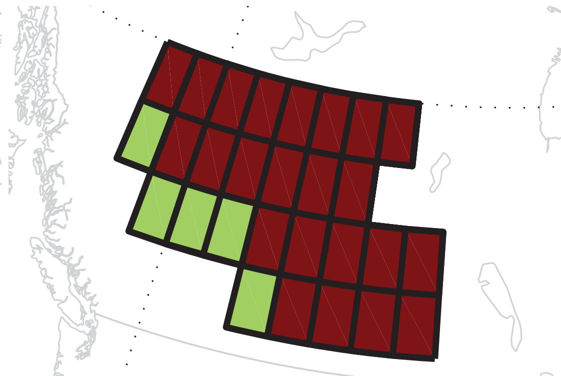
69. At all cloud elevations across each of the AOIs, mean monthly cloud amount data is generally found to cluster into either 3 or 4 groups. Where 4 monthly clusters are formed, the monthly groupings generally correspond to the 4 seasons – spring, summer, autumn and winter – traditionally associated with the northern hemisphere. In the instances where three clusters are formed, the monthly groupings tend to consist of a traditional summer group, a traditional winter group and a combined spring and autumn group.

### 4.1.4 Discussion

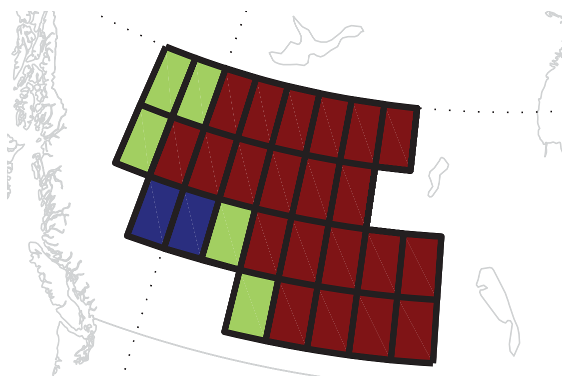
70. The regional cloud climatology assessment shows significant geographic, seasonal and elevation trends in mean cloud amounts across the various Canadian AOI regions. In general, more



(a) Gridbox clusters for high level ($H_c < 61,000 ft$) cloud cover trends exhibiting similar cloud climates (averaged over all years). Gridboxes of similar colour belong to the same cluster group.

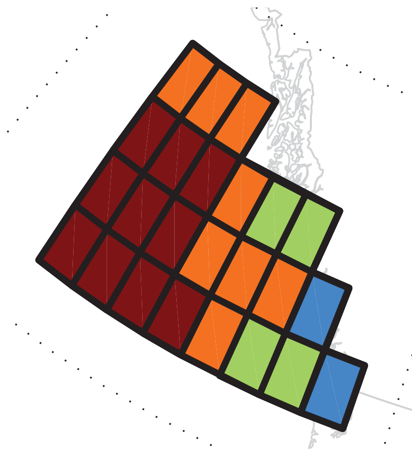


(b) Gridbox clusters for middle level ($H_c < 21,000 ft$) cloud cover trends exhibiting similar cloud climates (averaged over all years). Gridboxes of similar colour belong to the same cluster group.

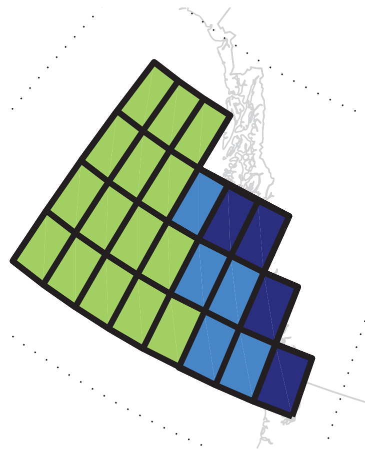


(c) Gridbox clusters for low level ($H_c < 10,500 ft$) cloud cover trends exhibiting similar cloud climates (averaged over all years). Gridboxes of similar colour belong to the same cluster group.

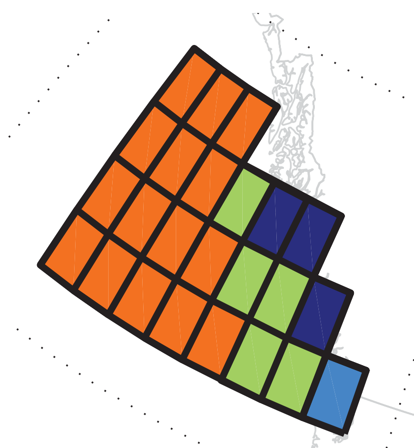
***Figure 6 (U):*** *Summary of the ABSK region high, middle and low level cloud data clustering analysis. Cluster groups represent a maximum cluster diameter (quality threshold) of 5%.*



(a) Gridbox clusters for high level ($H_c < 61,000ft$) cloud cover trends exhibiting similar cloud climates (averaged over all years). Gridboxes of similar colour belong to the same cluster group.

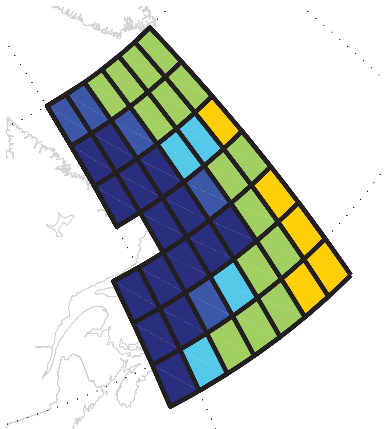


(b) Gridbox clusters for middle level ($H_c < 21,000ft$) cloud cover trends exhibiting similar cloud climates (averaged over all years). Gridboxes of similar colour belong to the same cluster group.

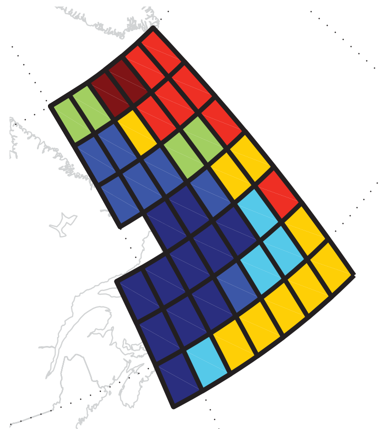


(c) Gridbox clusters for low level ($H_c < 10,500ft$) cloud cover trends exhibiting similar cloud climates (averaged over all years). Gridboxes of similar colour belong to the same cluster group.

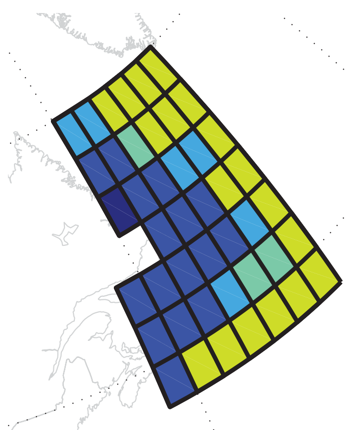
***Figure 7 (U):*** *Summary of the PAC region high, middle and low level cloud data clustering analysis. Cluster groups represent a maximum cluster diameter (quality threshold) of 5%.*



(a) Gridbox clusters for high level ($H_c < 61,000 ft$) cloud cover trends exhibiting similar cloud climates (averaged over all years). Gridboxes of similar colour belong to the same cluster group.

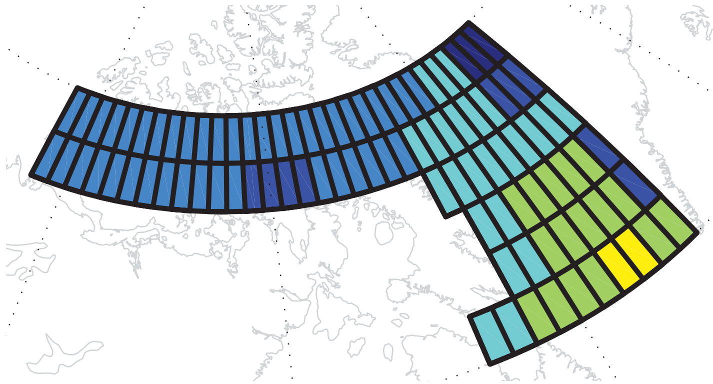


(b) Gridbox clusters for middle level ($H_c < 21,000 ft$) cloud cover trends exhibiting similar cloud climates (averaged over all years). Gridboxes of similar colour belong to the same cluster group.

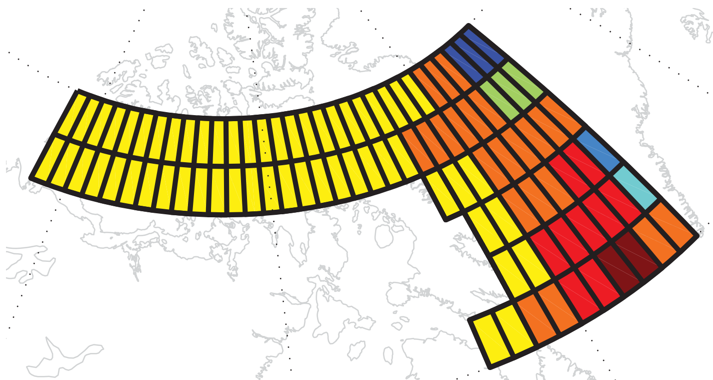


(c) Gridbox clusters for low level ($H_c < 10,500 ft$) cloud cover trends exhibiting similar cloud climates (averaged over all years). Gridboxes of similar colour belong to the same cluster group.

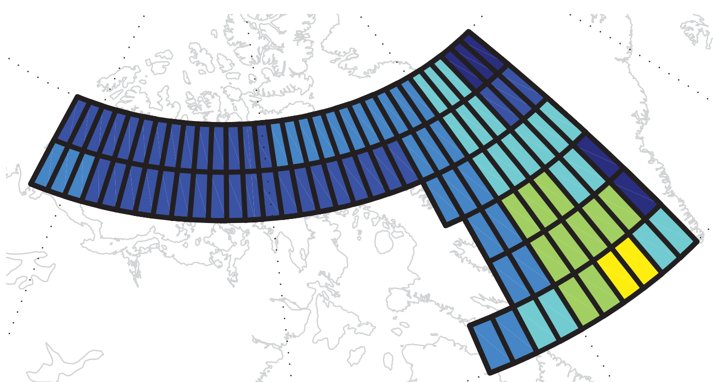
***Figure 8 (U):*** *Summary of the ATL region high, middle and low level cloud data clustering analysis. Cluster groups represent a maximum cluster diameter (quality threshold) of 5%.*



(a) Gridbox clusters for high level ($H_c < 61,000 ft$) cloud cover trends exhibiting similar cloud climates (averaged over all years). Gridboxes of similar colour belong to the same cluster group.



(b) Gridbox clusters for middle level ($H_c < 21,000 ft$) cloud cover trends exhibiting similar cloud climates (averaged over all years). Gridboxes of similar colour belong to the same cluster group.



(c) Gridbox clusters for low level ($H_c < 10,500 ft$) cloud cover trends exhibiting similar cloud climates (averaged over all years). Gridboxes of similar colour belong to the same cluster group.

***Figure 9 (U):*** *Summary of the NWP region high, middle and low level cloud data clustering analysis. Cluster groups represent a maximum cluster diameter (quality threshold) of 5%.*

severe cloud climates are experienced in the PAC and ATL maritime regions, in the mountainous regions of ABSK and in the Arctic than are experienced in Canada's overland regions. Seasonally, across all regions, the autumn and winter months present the most severe cloud climates. These results suggest that the cloud climates experienced in Canada's maritime and arctic regions will negatively affect UAV ISR mission success when EO/IR imaging is mission-critical.

71. Assuming that the UAV is required to operate free of cloud, Table 4 summarizes the expected amount of time, averaged over all months and years, that UAV ISR operations could be conducted from medium altitude (15,000 ft to 40,000 ft) in each of the 5 AOI regions investigated in this study. With the exception of the NWP region, the expected amount of time that cloud-free UAV ISR operations could be undertaken is 50% or less across all regions.

***Table 4 (U):*** *Expected percent of time that UAV ISR operations could be undertaken across all AOI regions for middle level clouds (clouds located between the earth's surface and 21,000 ft). Tabulated values represent the % of time that cloud-free conditions exist, averaged over all months and years.*

| **Region** | **% of time cloud-free** |
|---|---|
| Pacific region | 47% |
| Alberta/Saskatchewan region | 49% |
| Northwest Passage region | 57% |
| Toronto-Quebec City corridor | 50% |
| Atlantic region | 40% |

72. For a number of reasons, it is not easy to remotely assess cloud clover. Specific issues relating to the remote sensing of clouds is discussed in [37], along with sources of error in the ISCCP D2 data set. Overall, error in the D2 data set is estimated to be in the order of 10% to 15%, with cloud detection representing the largest source of error. Consequently, the values presented in the preceeding regional cloud climate assessment section should be considered as non-conservative, but representative measures of UAV ISR performance – actual cloud cover may be greater than the results suggest.

## 4.2 Sensor visibility assessment

73. In the following sections, average results (i.e. results averaged over all LOIs) of the EO/IR sensor visibility assessment are presented for each of the AOI regions considered in the study. More detailed descriptions of the assessment results for individual LOIs are presented in Annex C.

### 4.2.1 Results

74. Considering an operational demand of 24 hours per day, 365 days per year (24/365), Table 5 presents a summary of the expected utility of an EO/IR sensor operating in each of the 5 AOI regions. The tabulated values represent the percent of time, averaged over all months, years and LOIs, that a given type of mission could be undertaken in a particular AOI region. It is noted that the cloud ceiling values reported in Table 5 represent cloud ceiling observations from land-based meteorological stations – operations in the ATL, PAC and NWP maritime areas are expected to be

***Table 5 (U):*** *Summary comparison of the expected utility of an EO/IR sensor tasked for undertaking detection, classification and identification type ISR missions in the PAC, ABSK, NWP, TOR and ATL regions. Tabulated cloud ceiling values represent the expected % of time that a UAV operating at 15,000 ft would be flying below the cloud ceiling.*

| | PAC | ABSK | NWP | TOR | ATL |
|---|---|---|---|---|---|
| Identification | 0.31 | 0.38 | 0.20 | 0.37 | 0.29 |
| Classification | 0.84 | 0.84 | 0.57 | 0.82 | 0.72 |
| Detection | 0.93 | 0.95 | 0.87 | 0.90 | 0.82 |
| No Image | 0.06 | 0.05 | 0.13 | 0.10 | 0.18 |
| Cloud ceiling < 15,000 ft | 0.38 | 0.65 | 0.55 | 0.53 | 0.65 |

more constrained by cloud cover than the results suggest.

75. Table 6 presents a comparison of the expected utility of an EO/IR sensor tasked with undertaking various types of ISR missions for different months across each AOI region. The tabulated values represent the percent of time, averaged over all years and LOIs, that a given type of mission could be undertaken during a particular month, in a particular AOI region. As in Table 5, the cloud ceiling values reported in Table 6 are expected to be more constrained by cloud cover than the results suggest.

76. As in the regional cloud climate assessment, geographic and seasonal variability in sensor utility is observed across each of the AOI regions. In general, for a given type of ISR tasking, the utility rate of an EO/IR sensor is expected to be greatest in the ABSK and TOR regions, and smallest in the ATL and NWP regions. Across all regions, identification tasks are most impaired by local weather climates, with inclement weather occurring most frequently in November through January inclusive in the ABSK, TOR and ATL regions, and in August through October inclusive in the NWP region. Significant seasonal variability in the utility rate of an EO/IR sensor employed for classification tasks is observed in the ABSK and NWP regions, with inclement weather occurring most frequently in October through March inclusive. Across all of the AOI regions, little variability is observed in the utility rate of an EO/IR sensor employed for detection tasks.

***Table 6 (U):*** *Summary comparison of the expected % of time, averaged over all years, that an EO/IR sensor could successfully conduct detection, classification and identification type ISR missions in each AOI region. Tabulated cloud ceiling values represent the expected % of time that a UAV operating between 15,000 ft and 30,000 ft would be flying below the cloud ceiling.*

(a) PAC Region

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Identification | 0.12 | 0.21 | 0.14 | 0.20 | 0.20 | 0.23 | 0.30 | 0.30 | 0.27 | 0.17 | 0.15 | 0.12 |
| Classification | 0.76 | 0.81 | 0.79 | 0.83 | 0.79 | 0.83 | 0.73 | 0.78 | 0.80 | 0.73 | 0.74 | 0.74 |
| Detection | 0.91 | 0.96 | 0.97 | 0.98 | 0.98 | 0.98 | 0.96 | 0.95 | 0.93 | 0.88 | 0.90 | 0.92 |
| No Image | 0.09 | 0.04 | 0.03 | 0.02 | 0.02 | 0.02 | 0.04 | 0.05 | 0.07 | 0.12 | 0.10 | 0.08 |
| Cloud ceiling < 15k ft | 0.25 | 0.38 | 0.31 | 0.43 | 0.42 | 0.40 | 0.51 | 0.52 | 0.50 | 0.32 | 0.27 | 0.25 |

(b) ABSK Region

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Identification | 0.36 | 0.39 | 0.38 | 0.37 | 0.36 | 0.32 | 0.43 | 0.46 | 0.42 | 0.37 | 0.33 | 0.39 |
| Classification | 0.59 | 0.66 | 0.69 | 0.77 | 0.86 | 0.89 | 0.89 | 0.90 | 0.90 | 0.81 | 0.64 | 0.65 |
| Detection | 0.95 | 0.94 | 0.96 | 0.97 | 0.97 | 0.96 | 0.97 | 0.96 | 0.96 | 0.96 | 0.94 | 0.95 |
| No Image | 0.05 | 0.06 | 0.04 | 0.03 | 0.03 | 0.04 | 0.03 | 0.04 | 0.04 | 0.04 | 0.06 | 0.05 |
| Cloud ceiling < 15k ft | 0.53 | 0.56 | 0.59 | 0.56 | 0.54 | 0.55 | 0.62 | 0.63 | 0.57 | 0.50 | 0.46 | 0.52 |

(c) NWP region

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Identification | 0.21 | 0.20 | 0.24 | 0.28 | 0.21 | 0.21 | 0.22 | 0.15 | 0.12 | 0.12 | 0.18 | 0.20 |
| Classification | 0.43 | 0.41 | 0.47 | 0.59 | 0.62 | 0.82 | 0.86 | 0.81 | 0.70 | 0.47 | 0.46 | 0.40 |
| Detection | 0.89 | 0.89 | 0.89 | 0.94 | 0.95 | 0.92 | 0.90 | 0.88 | 0.90 | 0.91 | 0.92 | 0.91 |
| No Image | 0.11 | 0.11 | 0.11 | 0.06 | 0.05 | 0.08 | 0.10 | 0.12 | 0.10 | 0.09 | 0.08 | 0.09 |
| Cloud ceiling < 15k ft | 0.32 | 0.29 | 0.32 | 0.42 | 0.64 | 0.65 | 0.63 | 0.74 | 0.79 | 0.74 | 0.60 | 0.43 |

(d) TOR region

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Identification | 0.28 | 0.36 | 0.36 | 0.39 | 0.37 | 0.39 | 0.43 | 0.47 | 0.47 | 0.36 | 0.23 | 0.28 |
| Classification | 0.67 | 0.75 | 0.79 | 0.86 | 0.87 | 0.85 | 0.87 | 0.88 | 0.88 | 0.87 | 0.77 | 0.71 |
| Detection | 0.89 | 0.89 | 0.92 | 0.92 | 0.92 | 0.88 | 0.91 | 0.90 | 0.91 | 0.90 | 0.87 | 0.88 |
| No Image | 0.11 | 0.11 | 0.08 | 0.08 | 0.08 | 0.12 | 0.09 | 0.10 | 0.09 | 0.10 | 0.13 | 0.12 |
| Cloud ceiling < 15k ft | 0.70 | 0.60 | 0.56 | 0.52 | 0.51 | 0.44 | 0.40 | 0.39 | 0.38 | 0.54 | 0.69 | 0.67 |

(e) ATL region

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Identification | 0.24 | 0.30 | 0.30 | 0.28 | 0.30 | 0.30 | 0.30 | 0.34 | 0.37 | 0.33 | 0.23 | 0.24 |
| Classification | 0.60 | 0.66 | 0.67 | 0.70 | 0.74 | 0.75 | 0.74 | 0.78 | 0.80 | 0.80 | 0.73 | 0.66 |
| Detection | 0.86 | 0.85 | 0.84 | 0.80 | 0.78 | 0.78 | 0.76 | 0.80 | 0.83 | 0.85 | 0.84 | 0.85 |
| No Image | 0.14 | 0.15 | 0.16 | 0.20 | 0.22 | 0.22 | 0.24 | 0.20 | 0.17 | 0.15 | 0.16 | 0.15 |
| Cloud ceiling < 15k ft | 0.76 | 0.69 | 0.67 | 0.68 | 0.63 | 0.59 | 0.57 | 0.53 | 0.55 | 0.62 | 0.75 | 0.76 |

### 4.2.2 Discussion

77. Assessing the general utility of a sensor is difficult, as utility is defined by the operational context of mission success. For all ISR taskings, mission success requires that the sensor platform be able to mobilize the sensor; however, the sensor requirements can vary, depending on the mission, from visually identifying a specific target, to target detection, to target tracking. While one of primary objectives of this study is to provide a qualitative assessment of EO/IR sensor utility, the value of such a general assessment is limited without context of the expected performance requirements of such a system. Not withstanding, the results of this study do provide some quantification of EO/IR sensor limitations: this analysis indicates that the sensor would be the critical limiting factor affecting the success of a UAV ISR mission requiring EO/IR imaging at the *identification* and *classification* tasking level across each of the 5 AOI regions.

78. The impacts of weather on EO/IR sensor system utility is not unique to UAV ISR operations. As with manned aircraft, improvements in sensor performance may be achieved by operating the sensor at a lower elevation, below cloud and other weather layers, or by performing flight maneuvers to position the sensor to look through openings in the clouds; however, such operations will negatively impact the overall utility of the UAV sensor system. As with manned aircraft, flight operations at lower altitudes will have a significant impact on UAV endurance. Furthermore, low-level operations will likely require that dynamic (operator controlled) flight maneuvers be undertaken in conflicted civil airspace. This type of operation necessitates having robust real-time control of the UAV, and can have significant cost implications, particularly if satellite data links are required.

79. As improving Canada's domestic maritime and Arctic ISR capabilities has been identified as a strategic priority, it is recommended that further investigations focused on quantitatively assessing the quality of images that would be produced by various sensor options (i.e. EO/IR, SAR) under representative cloud conditions be undertaken as part of the JUSTAS program. By providing a more quantitative assessment of sensor utility, such studies could significantly reduce risk during a capability acquisition phase, particularly when evaluating the operational performance claims of different ISR systems.

## 4.3 UAV takeoff, recovery and flight conditions assessment

80. In the following sections, average results (i.e. results averaged over all LOIs) of the takeoff, recovery and flight conditions assessment are presented for each of the AOI regions considered in the study. More detailed descriptions of the assessment results for individual LOIs are presented in Annex D.

### 4.3.1 PAC region

81. UAV flight operations in the PAC region are most affected by adverse cloud ceiling conditions. These conditions are encountered most frequently in the autumn months of October and November, and in the winter months of December and January. Results from the takeoff, recovery and icing conditions assessment averaged over all LOIs in the PAC region are presented in Table 7.

***Table 7 (U):*** *Summary comparison of PAC region takeoff, recovery and icing conditions assessment results. Tabulated values represent the expected % of time that UAV operations could be undertaken free of a given critical condition. Values expressed in* ***bold*** *represent the limiting critical condition affecting UAV flight conditions for that month.*

| Critical Condition | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Appleman test | 0.99 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0.99 |
| Temp. & precip. | 0.96 | 0.99 | 0.99 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0.99 | 0.98 |
| Freez. precip. | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Visib. < 3 nm | 0.94 | 0.98 | 0.99 | 0.99 | 0.99 | 0.99 | 0.99 | 0.98 | 0.97 | 0.93 | 0.94 | 0.95 |
| Wind spd > 20 kt | 0.98 | 0.99 | 0.99 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0.99 | 0.98 |
| Clouds < 1,500 ft | **0.88** | **0.92** | **0.95** | **0.97** | **0.95** | **0.95** | **0.93** | **0.92** | **0.90** | **0.89** | **0.89** | **0.87** |

1) Temp. & precip. – critical temperature and precipitation test for icing

2) Freez. precip. – freezing precipitation test for icing

In this table, the limiting weather condition for a given month is highlighted in bold text.

82. Considering an operational demand of 24 hours per day, 365 days per year (24/365), the expected utility of a UAV performing flight operations in the PAC region is approximately 92%, assuming that flight operations require VFR conditions, and that flight into forecast or known icing conditions is prohibited.

### 4.3.2 ABSK region

83. General results from the takeoff, recovery and icing conditions assessment averaged over all LOIs in the ABSK region are presented in Table 8. In this table, the limiting critical weather condition for a given month is highlighted in bold text.

***Table 8 (U):*** *Summary comparison of ABSK region takeoff, recovery and icing conditions assessment results. Tabulated values represent the expected % of time that UAV operations could be undertaken free of a given critical condition. Values expressed in* ***bold*** *represent the limiting critical condition affecting UAV flight conditions for that month.*

| Critical Condition | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Appleman test | **0.41** | 0.62 | 0.88 | 0.96 | 0.99 | 1 | 1 | 1 | 1 | 0.95 | 0.70 | **0.52** |
| Temp. & precip. | 0.49 | **0.54** | **0.53** | **0.84** | 0.97 | 1 | 1 | 1 | 0.99 | **0.84** | **0.56** | 0.53 |
| Freez. precip. | 0.99 | 0.99 | 0.99 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0.99 | 0.99 |
| Visib. < 3 nm | 0.92 | 0.93 | 0.94 | 0.96 | 0.98 | 0.97 | 0.99 | 0.98 | 0.98 | 0.96 | 0.93 | 0.93 |
| Wind spd > 20 kt | 0.98 | 0.98 | 0.98 | 0.98 | 0.97 | 0.99 | 0.99 | 0.99 | 0.99 | 0.98 | 0.99 | 0.98 |
| Clouds < 1,500 ft | 0.86 | 0.86 | 0.92 | 0.94 | **0.94** | **0.94** | **0.94** | **0.95** | **0.94** | 0.90 | 0.83 | 0.83 |

1) Temp. & precip. – critical temperature and precipitation test for icing

2) Freez. precip. – freezing precipitation test for icing

84. UAV flight conditions in the ABSK region are most affected by icing conditions from October through April, and most affected by adverse cloud ceiling conditions from April though October. Considering a 24/365 operational demand, the expected utility of a UAV performing flight operations in the ABSK region is 76%, assuming that flight operations require VFR conditions, and that flight into forecast or known icing conditions is prohibited.

### 4.3.3 NWP region

85. UAV flight conditions in the NWP region are most affected by icing conditions from December through March inclusive, and most affected by adverse cloud ceiling conditions from April though November inclusive. Considering a 24/365 operational demand, the expected utility of a UAV performing flight operations in the NWP region is approximately 64%, assuming that flight operations require VFR conditions, and that flight into forecast or known icing conditions is prohibited.

86. Table 9 presents the general results from the takeoff, recovery and icing conditions assessment averaged over all LOIs in the NWP region. In this table, the limiting critical weather condition for a given month is highlighted in bold text.

***Table 9 (U):*** *Summary comparison of NWP region takeoff, recovery and icing conditions assessment results. Tabulated values represent the expected % of time that UAV operations could be undertaken free of a given critical condition. Values expressed in* ***bold*** *represent the limiting critical condition affecting UAV flight conditions for that month.*

| Critical Condition | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Appleman test | 0.72 | 0.78 | 0.87 | 0.96 | 1 | 1 | 1 | 1 | 1 | 1 | 0.98 | 0.89 |
| Temp. & precip. | **0.42** | **0.50** | **0.59** | 0.81 | 0.98 | 1 | 1 | 1 | 1 | 0.99 | 0.84 | **0.59** |
| Freez. precip. | 0.98 | 0.97 | 0.97 | 0.98 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0.99 |
| Visib. < 3 nm | 0.83 | 0.84 | 0.84 | 0.84 | 0.84 | 0.85 | 0.84 | 0.88 | 0.90 | 0.91 | 0.88 | 0.85 |
| Wind spd > 20 kt | 0.93 | 0.93 | 0.94 | 0.96 | 0.98 | 0.98 | 0.99 | 1 | 0.98 | 0.97 | 0.95 | 0.93 |
| Clouds < 1,500 ft | 0.67 | 0.68 | 0.65 | **0.63** | **0.67** | **0.71** | **0.72** | **0.75** | **0.74** | **0.73** | **0.69** | 0.67 |

1) Temp. & precip. – critical temperature and precipitation test for icing

2) Freez. precip. – freezing precipitation test for icing

87. It is noted that flight operations in the NWP region are subject to potential icing conditions year round, particularly in more northern operating areas over the Davis Strait and the Archipelago.

### 4.3.4 TOR region

88. General results from the takeoff, recovery and icing conditions assessment averaged over all LOIs in the TOR region are presented in Table 10. In this table, the limiting critical weather condition for a given month is highlighted in bold text.

89. In general, UAV flight conditions in the TOR region are most affected by icing conditions from November through March inclusive, and most affected by adverse cloud ceiling conditions from April though October inclusive. Considering a 24/365 operational demand, the expected utility of a UAV performing flight operations in the TOR region is approximately 80%, assuming that flight operations require VFR conditions, and that flight into forecast or known icing conditions is prohibited.

### 4.3.5 ATL region

90. UAV flight conditions in the ATL region are most affected by icing conditions from November through March inclusive, and most affected by adverse cloud ceiling conditions from April

***Table 10 (U):*** *Summary comparison of TOR region takeoff, recovery and icing conditions assessment results. Tabulated values represent the expected % of time that UAV operations could be undertaken free of a given critical condition. Values expressed in* ***bold*** *represent the limiting critical condition affecting UAV flight conditions for that month.*

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Appleman test | 0.82 | 0.90 | 0.97 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0.98 | 0.88 |
| Temp. & precip. | **0.43** | **0.56** | **0.69** | 0.94 | 1 | 1 | 1 | 1 | 1 | 0.99 | **0.81** | **0.54** |
| Freez. precip. | 0.98 | 0.99 | 0.99 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0.99 | 0.99 |
| Visib. < 3 nm km | 0.88 | 0.91 | 0.92 | 0.96 | 0.98 | 0.97 | 0.98 | 0.98 | 0.98 | 0.97 | 0.94 | 0.90 |
| Wind spd > 20 kt | 0.97 | 0.97 | 0.97 | 0.97 | 0.99 | 0.99 | 0.99 | 1 | 0.99 | 0.98 | 0.96 | 0.96 |
| Clouds < 1,500 ft | 0.78 | 0.85 | 0.89 | **0.89** | **0.92** | **0.92** | **0.94** | **0.96** | **0.95** | **0.91** | 0.87 | 0.84 |

1) Temp. & precip. – critical temperature and precipitation test for icing

2) Freez. precip. – freezing precipitation test for icing

though October inclusive. Considering a 24/365 operational demand, the expected utility of a UAV performing flight operations in the ATL region is approximately 40%, assuming that flight operations require VFR conditions, and that flight into forecast or known icing conditions is prohibited.

91. Table 11 summarizes general results from the takeoff, recovery and icing conditions assessment averaged over all LOIs in the ATL region. In this table, the limiting critical weather condition for a given month is highlighted in bold text. It is noted that the amalgamated results may exhibit bias toward the extreme weather climate of the North Atlantic, and that based on flight conditions, UAV utility over the land and littoral areas of the ATL region may greater than is reported in this study.

***Table 11 (U):*** *Summary comparison of ATL region takeoff, recovery and icing conditions assessment results. Tabulated values represent the expected % of time that UAV operations could be undertaken free of a given critical condition. Values expressed in* ***bold*** *represent the limiting critical condition affecting UAV flight conditions for that month.*

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Appleman test | **0.06** | **0.05** | **0.11** | **0.32** | 0.64 | 0.95 | 0.99 | 0.97 | 0.86 | 0.53 | **0.29** | **0.11** |
| Temp. & precip. | 0.48 | 0.47 | 0.51 | 0.54 | **0.50** | 0.85 | 0.98 | 0.87 | **0.68** | **0.41** | 0.42 | 0.45 |
| Freez. precip. | 1 | 1 | 1 | 1 | 0.99 | 0.99 | 1 | 0.99 | 0.98 | 0.99 | 1 | 1 |
| Visib. < 3 nm | 0.88 | 0.88 | 0.88 | 0.91 | 0.91 | 0.93 | 0.93 | 0.90 | 0.91 | 0.89 | 0.89 | 0.90 |
| Wind spd > 20 kt | 0.92 | 0.93 | 0.93 | 0.93 | 0.94 | 0.97 | 0.97 | 0.95 | 0.93 | 0.91 | 0.91 | 0.92 |
| Clouds < 1,500 ft | 0.93 | 0.94 | 0.94 | 0.91 | 0.79 | **0.77** | **0.79** | **0.71** | 0.71 | 0.78 | 0.86 | 0.90 |

1) Temp. & precip. – critical temperature and precipitation test for icing

2) Freez. precip – freezing precipitation test for icing

### 4.3.6 Discussion

92. With the exception of the PAC region, across all of the AOI regions, UAV flight operations are most affected by critical icing conditions during the late autumn, winter and early spring months, and by critical cloud cover conditions the remainder of the time. Adverse cloud cover conditions are expected to have the greatest impact during takeoff and recovery operations, while icing conditions are expected to impact all aspects of UAV takeoff, recovery and flight operations.

93. Significant benefits in terms of the percent of time possible for UAV flight operations may be achieved either by relaxing VFR requirements for UAV flight operations, or by operating a UAV that incorporates an anti-icing system. Table 12 compares the percent of time possible for UAV flight operations under:

1. the assumed operating conditions of VFR requirements and no anti-icing equipment;
2. instrument flight capabilities and no anti-icing equipment;
3. VFR requirements and anti-icing equipment; and
4. instrument flight capabilities and anti-icing equipment.

In the fourth case, wind speed is the limiting factor. The values presented in the table represent a combined average of all LOIs within an AOI region, averaged over all months.

***Table 12 (U):*** *Comparison of the expected percent of time (averaged over all months and all LOIs) that UAV flight operations would be possible under the different permission constrains of VFR, instrument flight and flight into icing conditions.*

| Region | VFR & No Ice | Inst. Flt. & No Ice | VFR & Ice | Inst. Flt. & Ice |
|---|---|---|---|---|
| PAC | 92% | 99% | 92% | 99% |
| ABSK | 76% | 78% | 91% | 98% |
| NWP | 64% | 81% | 69% | 93% |
| TOR | 80% | 82% | 89% | 98% |
| ATL | 40% | 43% | 85% | 96% |

1) Ice – Anti-icing capability

2) Inst. Flt. – Instrument flight capability

94. For domestic UAV operations, the benefits of employing UAVs with anti-icing capabilities cannot be understated, as in several regions potential icing conditions are reported even during the summer months. The operational benefits of anti-icing capabilities are particularly evident in the ATL region, where a UAV employing an anti-icing system is expected to have twice the utilization rate of a similar UAV operating without anti-icing capabilities.

95. UAV platforms possessing both instrument flight and anti-icing capabilities should be considered for domestic UAV ISR operations, as they offer a significant incremental benefit in utility over platforms possessing anti-icing capabilities alone, particularly in the NWP and PAC regions. By employing both capabilities, it is expected that a UAV platform could operate at least 93% of the time across all of the AOI regions, compared to 69% of the time with anti-icing capabilities alone and 43% of the time with instrument flight capabilties alone.

96. From the perspective of utility, the vehicle component of a UAV surveillance system appears quite resilient – the overall utility of a UAV ISR system is largely constrained by the performance and imaging characteristics of the sensor.

# 5 SUMMARY & CONCLUSIONS

## 5.1 EO/IR sensor visibility assessment

97. Geographic and seasonal variability in sensor utility is observed across each of the AOI regions. Across all AOIs, mean cloud amount is observed to increase with increasing elevation, and in both the PAC and ATL regions, cloud amount is observed to increase with increasing distance (seaward) from the littoral zone.

98. In general, for a given type of ISR tasking, the utility rate of an EO/IR sensor is expected to be greatest in the ABSK and TOR regions, and smallest in the ATL and NWP regions. In the NWP region, weather conditions considered potentially suitable for *identification* tasks are observed on average 20% of the time over all months, and on average 13% of the time in August, September and October. In the PAC and ATL regions, weather conditions considered potentially suitable for *identification* type tasks are experienced on average 30% of the time over all months. Significant seasonal variability in the utility rate of an EO/IR sensor employed for classification tasks is observed in the ABSK and NWP regions, with inclement weather occurring most frequently in October through March inclusive. Across all of the AOI regions, little variability is observed in the utility rate of an EO/IR sensor employed for detection tasks.

99. The results of the regional cloud climate assessment show that, with the exception of the NWP, the expected percent cloud cover between the earth's surface and 21,000 ft exceeds 50% across all regions. The results of the regional assessment are corroborated by local cloud ceiling observations, where across all AOIs, between 45% and 62% of observation records report cloud ceilings below 15,000 ft. Assuming that the EO/IR sensor requires a clear optical path for imaging, the expected percent of time that a UAV platform operating at medium altitude (between 15,000 ft and 40,000 ft) could complete a domestic ISR mission ranges from approximately 30% in the ATL region to approximately 55% in the NWP region. These values should be considered as non-conservative, but representative measures of UAV performance, as actual cloud cover may be greater than the results suggest.

## 5.2 Takeoff, recovery and icing conditions assessment

100. Across all regions, the VFR cloud ceiling requirement presents the most significant constraint to UAV operations during the summer months (i.e. June, July and August), while potential icing conditions present the most significant constraint to flight operations during the remaining months, particularly during the winter months of December through February inclusive.

101. Significant benefits in terms of the percent of time possible for UAV flight operations may be achieved either by relaxing VFR requirements, or by operating a UAV that incorporates an anti-icing system. Anti-icing capabilities would particularly benefit operations in the NWP and ATL regions, as in both of these regions, potential icing conditions are reported even during the summer months.

102. UAV platforms possessing both instrument flight and anti-icing capabilities should be considered for domestic UAV ISR operations, as they offer a significant incremental benefit in utility over platforms possessing anti-icing capabilities alone, particularly in the NWP and PAC regions. By employing both capabilities, it is expected that a UAV platform could operate at least 93% of the time across all of the AOI regions, compared to 69% of the time with anti-icing capabilities alone and 43% of the time with instrument flight capabilities alone.

## 5.3 Study limitations

103. In this study, UAV utility is defined as exhibiting an ability to launch, recover and operate. This definition of utility does not permit making a quantitative assessment of UAV performance, as upper atmospheric weather phenomena such as winds aloft are not explicitly considered in this study. Such weather conditions may have a significant impact on UAV performance by means of increasing transit times, and reducing vehicle controllability and endurance.

104. The National Image Interpretability Rating Scale (NIIRS) was not used in this study. Though simple relationships exist for converting sensor resolution to an NIIRS rating, these relationships generally cannot account for obscurants in the optical path, let alone the effects of different obscurants on optical path loss. Radiative transfer models such as the Moderate Resolution Atmospheric Transmission program (MODTRAN) are not used to quantify sensor operational effectiveness.

105. While sensor and platform are assessed independently in this study, it is noted that the utility and performance of a UAV ISR platform depends on the combined utility and performance of both the platform and the sensor.

106. Other than the ISCCP D2 radiance data, no upper atmospheric data is considered in this study. Consequently, single station meteorological records are assumed to represent uni-form weather columns, extending from the earth's surface to the upper boundary of the atmosphere, in which the weather characteristics of temperature, humidity and wind conditions are assumed to remain relatively constant. This limiting assumption of a uniform weather column implies that specific weather state combinations such as those that contribute to icing conditions will only be experienced at altitude when they are experienced on the ground.

## 5.4 Study extensions

107. As the implementation of a domestic maritime and Arctic ISR capability has been identified as a strategic priority, it is recommended that further investigations focused on quantitatively assessing the performance of different imaging systems under representative cloud conditions be undertaken. Specifically, it is recommended that a simulation-type modeling study be undertaken to better quantify the operational utility of employing UAV systems for domestic ISR operations. Such a study would be beneficial in quantifying the operational and financial impacts of employing different types of sensors and platforms, both manned and unmanned, and could significantly reduce risk during a subsequent ISR capability acquisition program. The statistical products presented in this study provide insight into the expected weather climates in Canada's PAC, ATL, TOR, ABSK and NWP regions, and should be used to calibrate the simulation model.

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# Annex A: Glossary of meteorological terms

The following glossary is a compilation of meteorological terms referenced from [38], [39], [40] and [41].

| | |
|---|---|
| Cloud | A visible aggregate of minute water droplets and/or ice particles in the atmosphere above the earth's surface. |
| Clear | After U.S. weather observing practice, the state of the sky when it is cloudless or when the sky cover is less than 0.1 (to the nearest tenth). In weather forecast terminology, the maximum cloudiness considered is about 0.2. |
| Mainly Clear | By inference, the character of a day's weather when the average cloudiness is greater than 0.1 and less than 0.4 (to the nearest tenth). |
| Mainly Cloudy | (Mostly Cloudy/Partly Cloudy) In U.S. climatological practice, the character of a day's weather when the average cloudiness, as determined from frequent observations, has been from 0.4 to 0.7 for the 24-hour period. |
| Cloudy | In popular usage, the state of the weather when clouds predominate at the expense of sunlight, or obscure the stars at night. In weather forecast terminology, expected cloud cover of about 0.7 (to the nearest tenth) or more warrants the use of this term. |
| Drizzle | Very small, numerous, and uniformly distributed water drops that may appear to float while following air currents. By convention, drizzle drops are taken to be less than 0.5 mm in diameter. |
| Light Drizzle | Rate of fall being from a trace to 0.3 mm per hour. |
| Moderate Drizzle | Rate of fall being from 0.3 to 0.5 mm per hour. |
| Heavy Drizzle | Rate of fall being greater than 0.5 mm per hour. |
| Freezing Drizzle | Drizzle that falls in liquid form but freezes upon impact to form a coating of glaze. |
| Ice Crystals | Precipitation in the form of slowly falling, singular or unbranched ice needles, columns, or plates. They make up cirriform clouds, frost, and ice fog. |

| | |
|---|---|
| Ice Fog | Water droplets suspended in the atmosphere in the vicinity the earth's surface that affect visibility. Fog reduces visibility below 1 km. When composed of ice crystals, it is termed ice fog. |
| Ice Pellets | Precipitation in the form of balls or irregular lumps of ice, always produced by convective clouds, nearly always cumulonimbus. Hail of particles smaller than 5 mm are classed as either ice pellets or snow pellets. |
| Rain | Precipitation in the form of liquid water drops that have diameters greater than 0.5 mm, or, if widely scattered, the drops may be smaller. |
| Light Rain | Rate of fall varying between a trace and 0.25 cm per hour, the maximum rate of fall being no more than 0.025 cm in six minutes. |
| Moderate Rain | Rate of fall varying between 0.26 and 0.76 cm per hour, the maximum rate of fall being no more than 0.076 cm in six minutes. |
| Heavy Rain | Rate of fall in excess of 0.76 cm per hour or more than 0.076 cm in six minutes. |
| Freezing Rain | Rain that falls in liquid form but freezes upon impact to form a coating of glaze upon the ground and on exposed objects. |
| Rain Showers | Rain events characterized by the suddenness with which they start and stop, by the rapid changes of intensity, and usually by rapid changes in the appearance of the sky. |
| Light Rain Showers | A rain shower event with light rain intensity. |
| Moderate Rain Showers | A rain shower event of moderate rain intensity. |
| Heavy Rain Showers | A rain shower event of heavy rain intensity. |
| Snow | Precipitation composed of white or translucent ice crystals, chiefly in complex branch hexagonal form and often agglomerated into snowflakes. |
| Light Snow | Visibility is 1 km or more. |
| Moderate Snow | Visibility is less than 1 km but more than 1/2 km. |
| Heavy Snow | Visibility is less than 1/2 km. |

| | |
|---|---|
| Snow Grains | Precipitation in the form of very small, white opaque particles of ice; the solid equivalent of drizzle. They resemble snow pellets in external appearance, but are more flattened and elongated, and generally have diameters of less than 1 mm; they neither shatter nor bounce when they hit a hard surface. |
| Snow Pellets | Precipitation in the form of balls or irregular lumps of ice, always produced by convective clouds, nearly always cumulonimbus. Hail of particles smaller than 5 mm are classed as either ice pellets or snow pellets. |
| Snow Showers | Snow events characterized by the suddenness with which they start and stop, by the rapid changes of intensity, and usually by rapid changes in the appearance of the sky. |
| Thunderstorms | In general, a local storm, invariably produced by a cumulonimbus cloud and always accompanied by lightning and thunder, usually with strong gusts of wind, heavy rain, and sometimes with hail. In U.S. weather observing procedure, a thunderstorm is reported whenever thunder is heard at the station; it is reported on regularly scheduled observations if thunder is heard within 15 minutes preceding the observation. Classified as light, medium and heavy. |
| Blowing Snow | Snow lifted from the surface of the earth by the wind to a height of 2 m or more above the surface (higher than drifting snow), and blown about in such quantities that horizontal visibility is reduced to less than 11 km. |
| Fog | Water droplets suspended in the atmosphere in the vicinity the earth's surface that affect visibility. Fog reduces visibility below 1 km. Fog differs from cloud only in that the base of fog is at the earth's surface while clouds are above the surface. |
| Frost | The fuzzy layer of ice crystals on a cold object, such as a window or bridge, that forms by direct deposition of water vapor to solid ice. Frost is the condition that exists when the temperature of the earth's surface and earthbound objects fall below freezing. |
| Hail | Precipitation in the form of balls or irregular lumps of ice, always produced by convective clouds, nearly always cumulonimbus. Hail has a diameter of 5 mm or more. |
| Haze | Particles suspended in air, reducing visibility by scattering light. Haze is often a mixture of aerosols and photochemical smog. |

| | |
|---|---|
| Visibility | The greatest distance in a given direction at which it is just possible to see and identify with the unaided eye 1) in the daytime, a prominent dark object against the sky at the horizon, and 2) at night, a known, preferably unfocused, moderately intense light source. |

# Annex B: Regional Cloud Climatology – Detailed Assessment Results

## B.1 Regional Cloud Climates

### B.1.1 PAC region

108. High, middle and low level cloud cover observations for the PAC region are summarized in Figures B.1, B.2 and B.3 respectively. In the PAC region, the high level cloud climate shows slight geographic and monthly trends in mean cloud amount, with the littoral grid cells showing reduced cloud amounts compared to the Pacific bluewater grid cells. Both the middle and low level cloud amounts exhibit similar geographic trends, with increased cloud amounts observed in the bluewater grid cells compared to the littoral grid cells. Negligible seasonal variability is observed in the middle level cloud cover observations, while slight seasonal variability is observed in the PAC low level cloud data. In the low level cloud data set, the greatest cloud cover amounts are observed during the months of June to August inclusive.

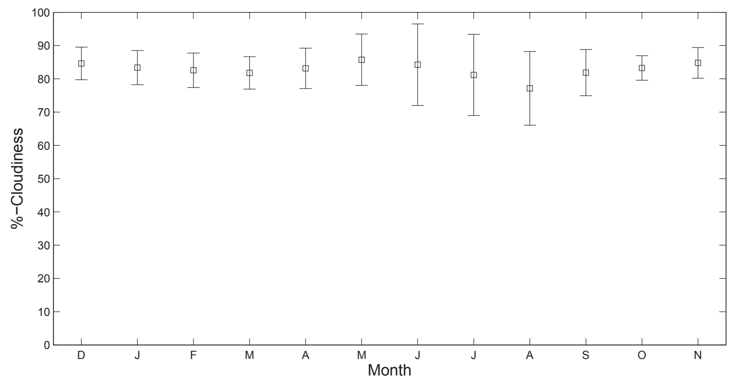
### B.1.2 ABSK region

109. Figure B.4 shows the high level cloud cover climate for the ABSK region. High level clouds show some seasonal variability. Geographic trends are not detected. In the ABSK region, the smallest high level cloud amounts are observed during the months of July and August.

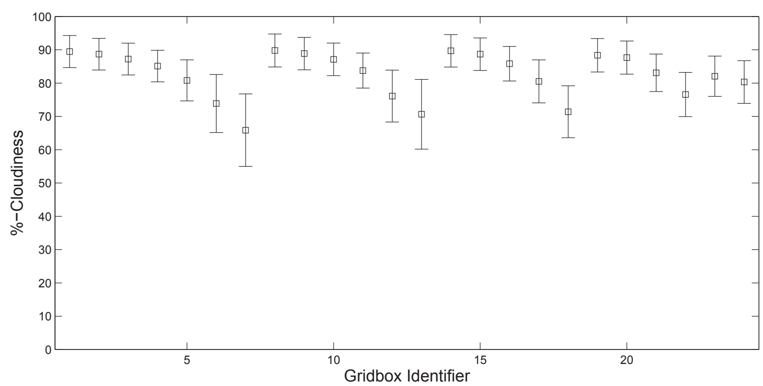
110. The middle level cloud cover climate for the ABSK region is summarized in Figure B.5, and the low level cloud cover climate is summarized in Figure B.6. The ABSK middle level cloud climate shows slight seasonal variability, with the smallest amounts of middle cloud cover occurring in March to September inclusive. In comparison, the low level cloud cover climate shows some geographic variability, with gridboxes in the more mountainous (western) areas of the ABSK region showing reduced low level cloud cover compared to the more easterly gridboxes. Slight seasonal variability is also noted in the low cloud climate, with the smallest low level cloud amounts being observed in December and January, and the largest amounts being observed during the months of April to August inclusive.

### B.1.3 NWP region

111. In the NWP region, the high level cloud climate shows some geographic and temporal variability. In the Davis Strait, high level cloud amount is smallest in March, April and October though little seasonal variability is observed in the more northerly areas of the NWP region, over the Canadian Arctic Archipelago (Archipelago) and the Perry Channel. In general, the amount of high level cloud cover in the NWP region decreases with increasing latitude. Geographically, the greatest variability is observed over the Archipelago, while relatively little variability is observed in high level cloud amount data over the Davis Strait. Figure B.7 summarizes the NWP high level cloud climate.




(a) Seasonal variability in high level cloud cover. Reported values represent %-cloud cover, averaged over all gridboxes and years for given month.




(b) Geographic variability in high level cloud cover. Reported values represent %-cloud cover, averaged over all months and years for given gridbox.

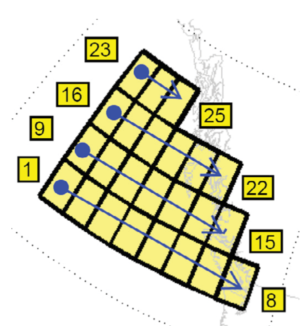
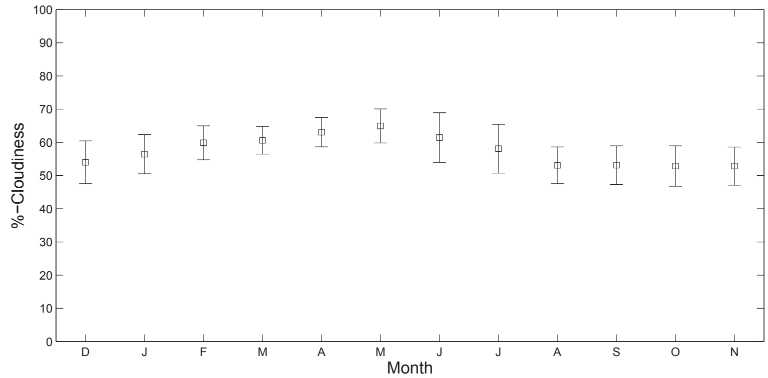
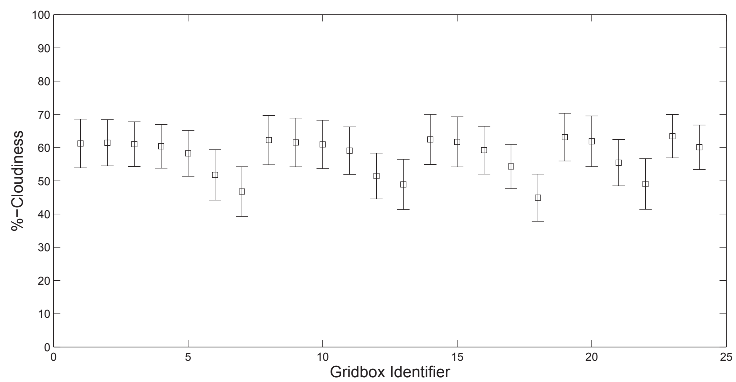



***Figure B.1 (U):*** *Geographic and seasonal trends in high level cloud cover ($H_c$ < 61,000 ft) for the PAC Region.*




(a) Seasonal variability in middle level cloud cover. Reported values represent %-cloud cover, averaged over all gridboxes and years for given month.




(b) Geographic variability in middle level cloud cover. Reported values represent %-cloud cover, averaged over all months and years for given gridbox.

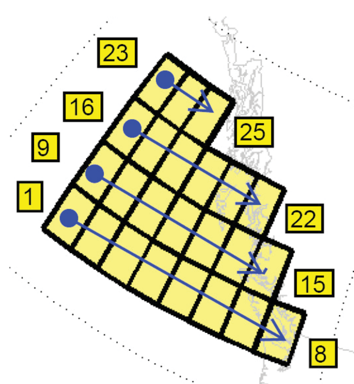
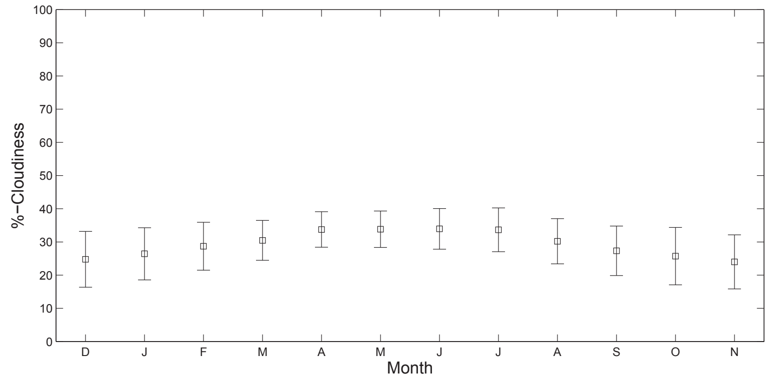
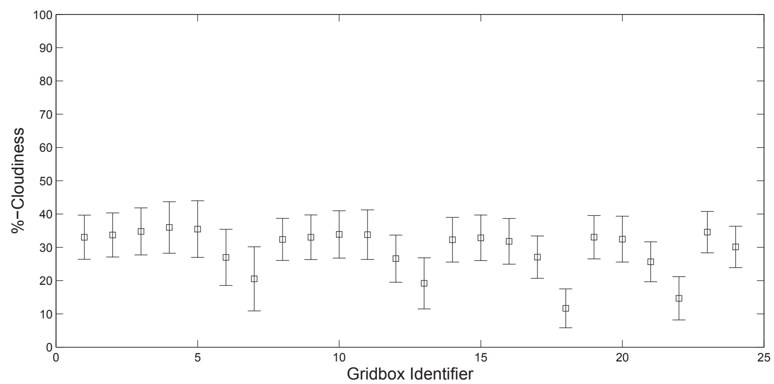



***Figure B.2 (U):*** *Geographic and seasonal trends in middle level cloud cover ($H_c$ < 21,000 ft) for the PAC Region.*




(a) Seasonal variability in low level cloud cover. Reported values represent %-cloud cover, averaged over all gridboxes and years for given month.




(b) Geographic variability in low level cloud cover. Reported values represent %-cloud cover, averaged over all months and years for given gridbox.

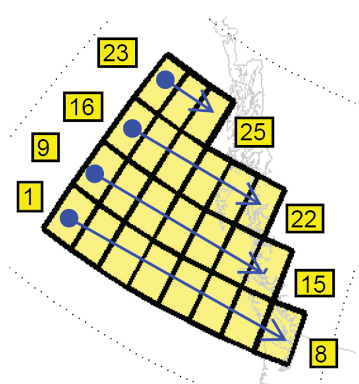
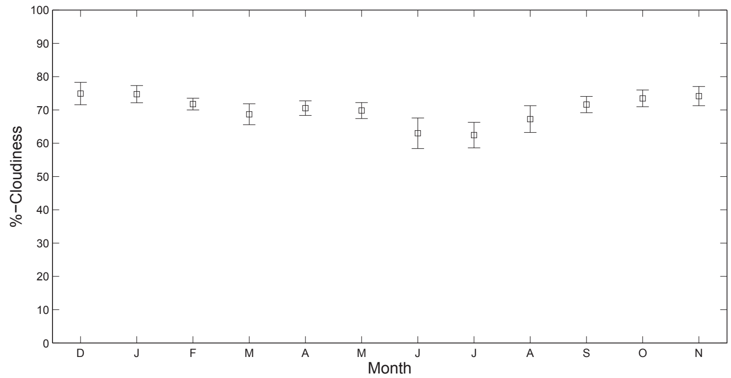
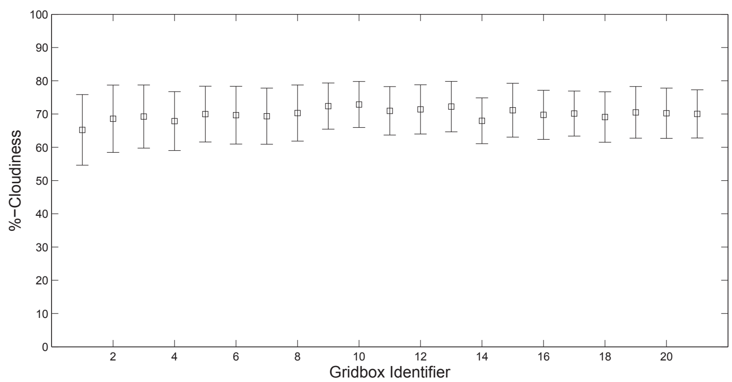



***Figure B.3 (U):*** *Geographic and seasonal trends in low level cloud cover ($H_c$ < 10,500 ft) for the PAC Region.*




(a) Seasonal variability in high level cloud cover. Reported values represent %-cloud cover, averaged over all gridboxes and years for given month.




(b) Geographic variability in high level cloud cover. Reported values represent %-cloud cover, averaged over all months and years for given gridbox.

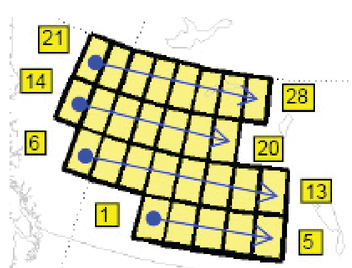
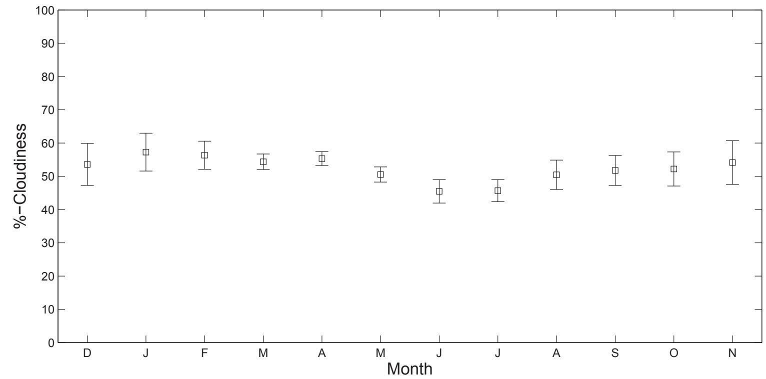
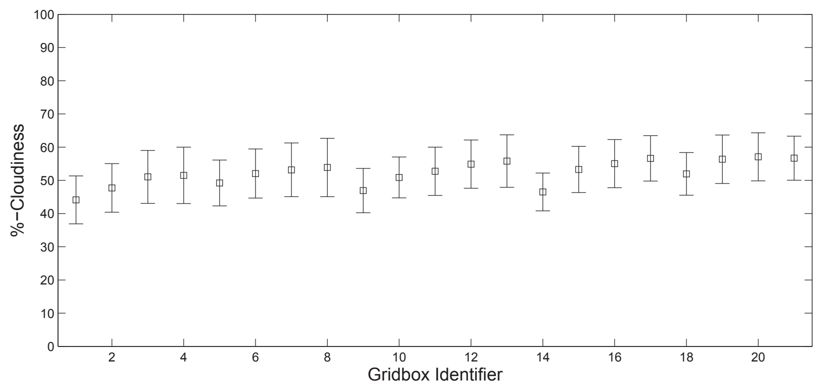



***Figure B.4 (U):*** *Geographic and seasonal trends in high level cloud cover ($H_c$ < 61,000 ft) for the ABSK Region.*




(a) Seasonal variability in middle level cloud cover. Reported values represent %-cloud cover, averaged over all gridboxes and years for given month.




(b) Geographic variability in middle level cloud cover. Reported values represent %-cloud cover, averaged over all months and years for given gridbox.

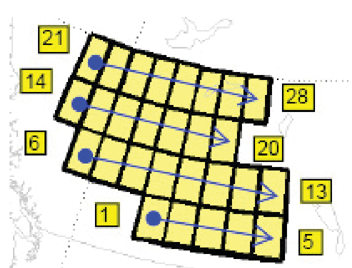
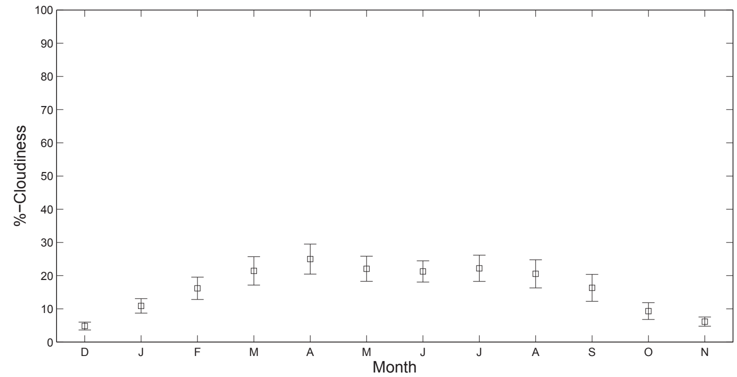
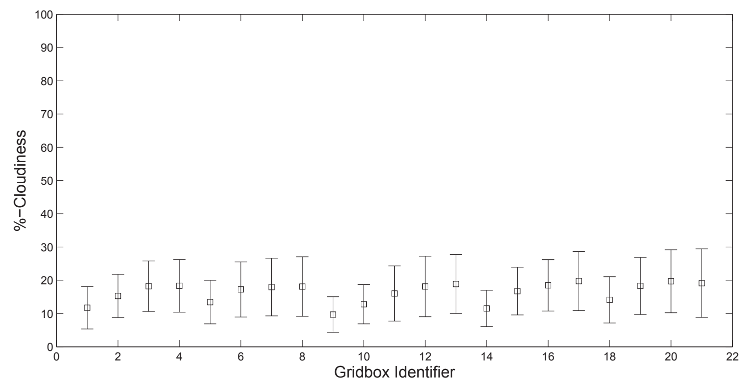



***Figure B.5 (U):*** *Geographic and seasonal trends in middle level cloud cover ($H_c$ < 21,000 ft) for the ABSK Region.*




(a) Seasonal variability in low level cloud cover. Reported values represent %-cloud cover, averaged over all gridboxes and years for given month.




(b) Geographic variability in low level cloud cover. Reported values represent %-cloud cover, averaged over all months and years for given gridbox.

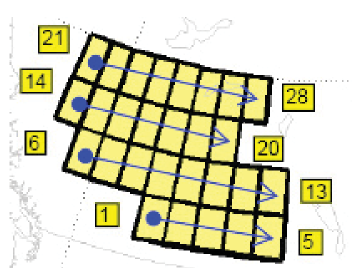



***Figure B.6 (U):*** *Geographic and seasonal trends in low level cloud cover ($H_c$ < 10,500 ft) for the ABSK Region.*

112. The NWP middle level cloud climate is summarized in Figure B.8. In the NWP region, strong geographic variability in middle level cloud amount is noted, with less cloud cover being recorded over Greenland and Labrador compared to the Davis Strait and the Archipelago. Small seasonal variability in middle level cloud cover is also observed, with the smallest amounts of middle level clouds occurring in May to August inclusive.

113. Like the high level cloud climate, the low level cloud climate shows some geographic variability. In general, in the NWP region, low level cloud amounts decrease with increasing latitude. The largest amounts of low level cloud are observed over the Davis Strait and Baffin Bay, with comparatively smaller amounts being observed over Greenland, Labrador and the Archipelago. Figure B.9 summarizes the NWP low level cloud climate.

114. Cloud amount observations appear to be under-reported in several areas of the NWP region, specifically over parts of Greenland, and in other northern land areas. One possible explanation for these apparent outliers, is that the ISCCP data products are inferred from solar reflectance measurements – in areas were different surface coverings exist (i.e. rocks, ice, snow and water), misrepresentation or misinterpretation of the true surface albedo (reflectance properties) may produce anomalous or otherwise suspicious results [14].

### B.1.4 TOR region

115. In the TOR region, the high level cloud climate shows negligible seasonal or geographic variability, while the middle and low level cloud climates shows small seasonal variations. The smallest amounts of middle level clouds are observed in June and July, while the greatest amounts are observed in November and December. In contrast, the smallest amounts of low level clouds are observed in November and December, while the greatest amounts occur in March, April, August and September. Figure B.10 summarizes the TOR high level cloud climate, while Figure B.11 summarizes the TOR middle level cloud climate and Figure B.12 summarizes the low level cloud climate.

### B.1.5 ATL region

116. In the ATL region, both geographic and seasonal variations are observed in high and middle level cloud climates. Both high and middle level cloud covers are greatest in the blue water regions of the Labrador Sea and Atlantic Ocean, and smallest in the Atlantic littoral areas and in the Gulf of St. Lawrence. In both instances, slight seasonal variations in cloud amount are observed in the Atlantic littoral area, with smallest cloud amounts being observed in July and August, and the largest amounts being observed in November, December and January. Figure B.13 summarizes the high level cloud climate in the ATL region, while Figure B.14 summarizes the middle level cloud climate.

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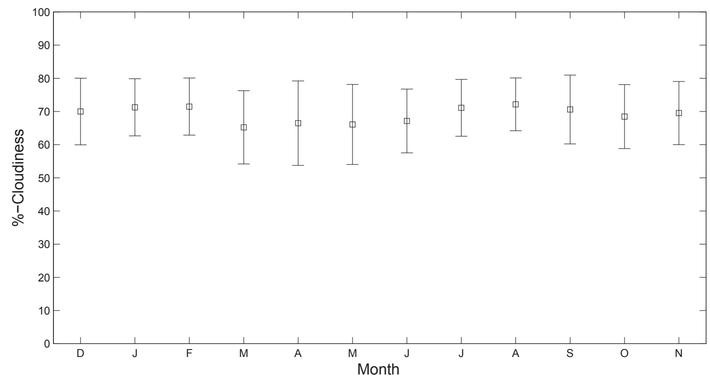
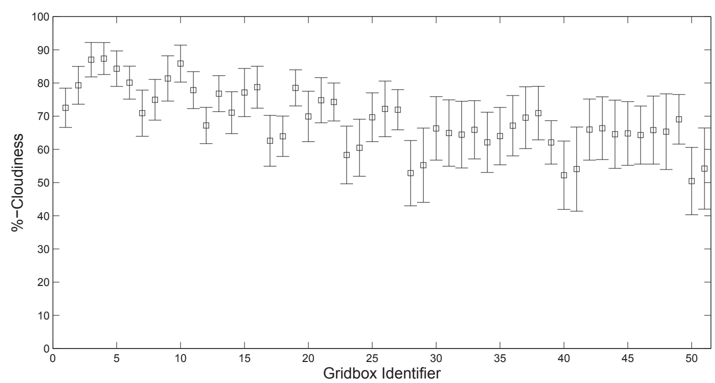
14. As an example, consider that the albedo of ice is greater than that of a grass-covered surface. Supposing for a given gridbox the ISCCP radiance measurements were correlated with an albedo representative of a grass-covered surface when the actual reflecting surface was ice-covered, then the data product for that gridbox would underestimate the cloud amount.




(a) Seasonal variability in high level cloud cover. Reported values represent %-cloud cover, averaged over all gridboxes and years for given month.




(b) Geographic variability in high level cloud cover. Reported values represent %-cloud cover, averaged over all months and years for given gridbox.

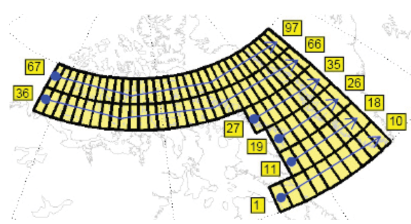
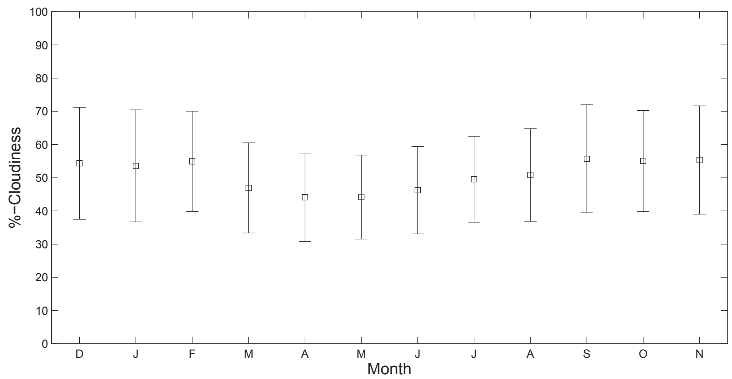
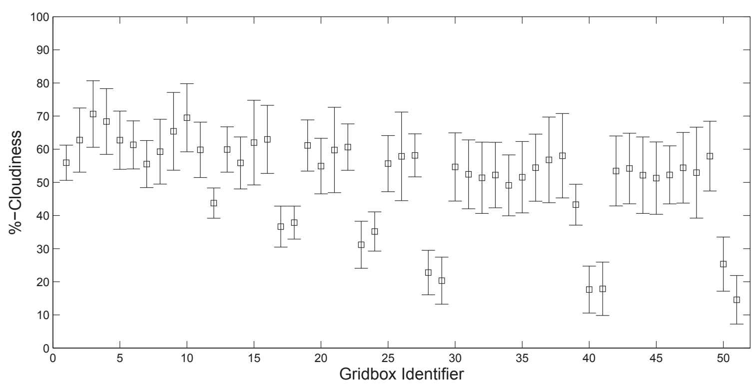



***Figure B.7 (U):*** *Geographic and seasonal trends in high level cloud cover ($H_c < 61{,}000$ ft) for the NWP Region.*




(a) Seasonal variability in middle level cloud cover. Reported values represent %-cloud cover, averaged over all gridboxes and years for given month.




(b) Geographic variability in middle level cloud cover. Reported values represent %-cloud cover, averaged over all months and years for given gridbox.

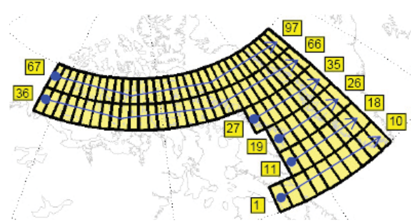
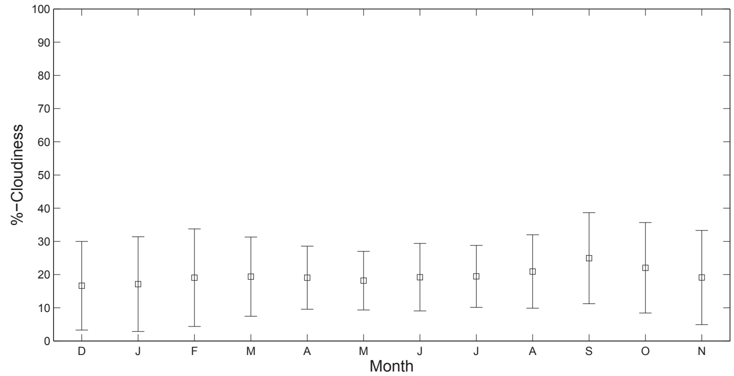
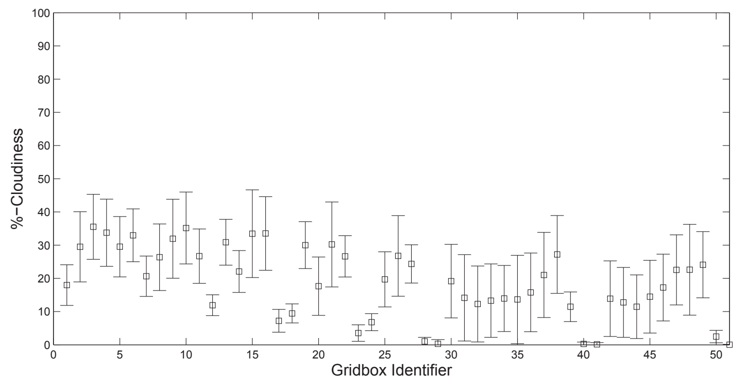



***Figure B.8 (U):*** *Geographic and seasonal trends in middle level cloud cover ($H_c$ < 21,000 ft) for the NWP Region.*




(a) Seasonal variability in middle level cloud cover. Reported values represent %-cloud cover, averaged over all gridboxes and years for given month.




(b) Geographic variability in low level cloud cover. Reported values represent %-cloud cover, averaged over all months and years for given gridbox.

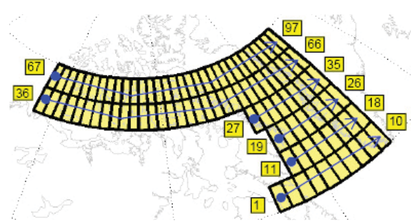
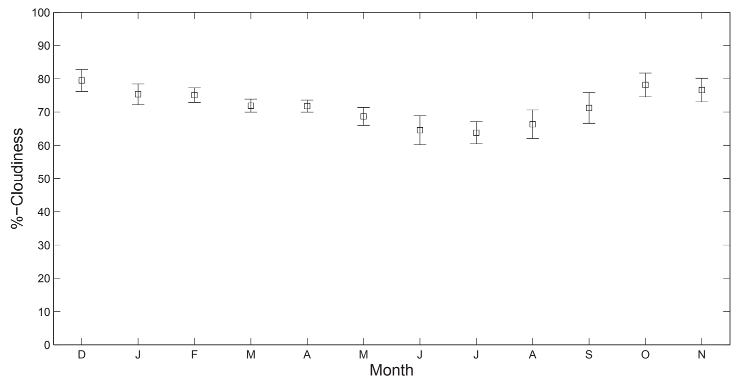
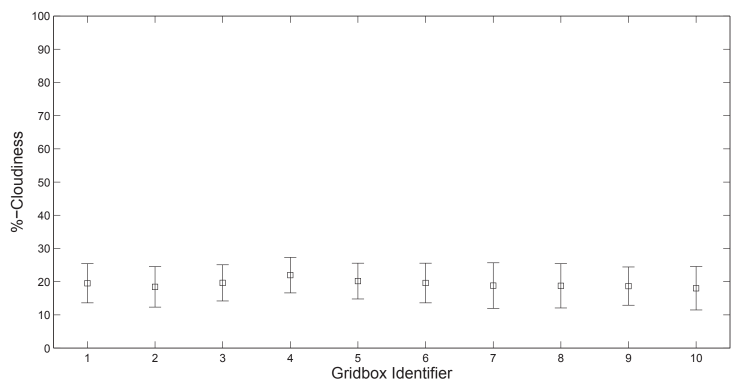



***Figure B.9 (U):*** *Geographic and seasonal trends in low level cloud cover ($H_c$ < 10,500 ft) for the NWP Region.*




(a) Seasonal variability in middle level cloud cover. Reported values represent %-cloud cover, averaged over all gridboxes and years for given month.




(b) Geographic variability in high level cloud cover. Reported values represent %-cloud cover, averaged over all months and years for given gridbox.

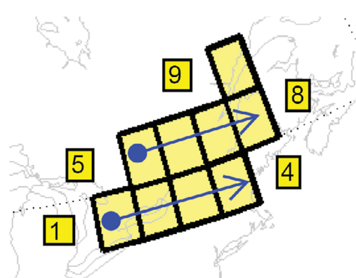
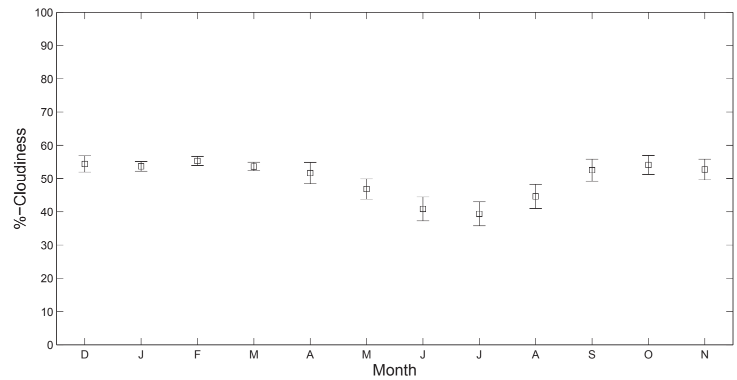
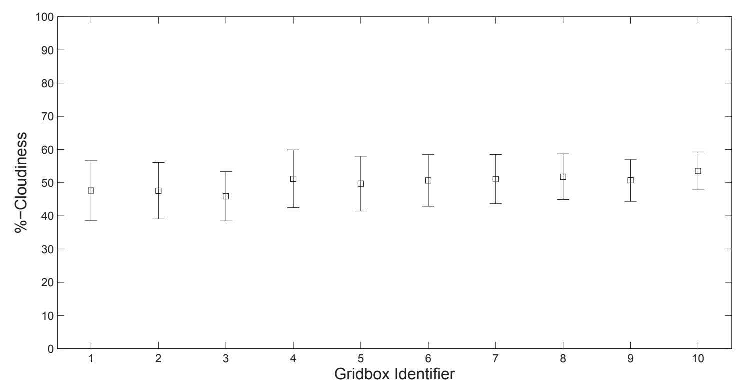



***Figure B.10 (U):*** *Geographic and seasonal trends in high level cloud cover ($H_c$ < 61,000 ft) for the TOR Region.*




(a) Seasonal variability in middle level cloud cover. Reported values represent %-cloud cover, averaged over all gridboxes and years for given month.




(b) Geographic variability in middle level cloud cover. Reported values represent %-cloud cover, averaged over all months and years for given gridbox.

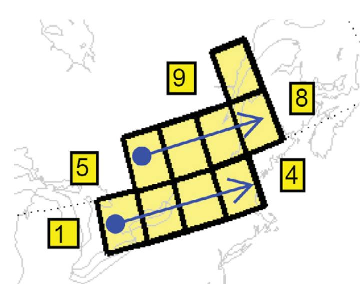
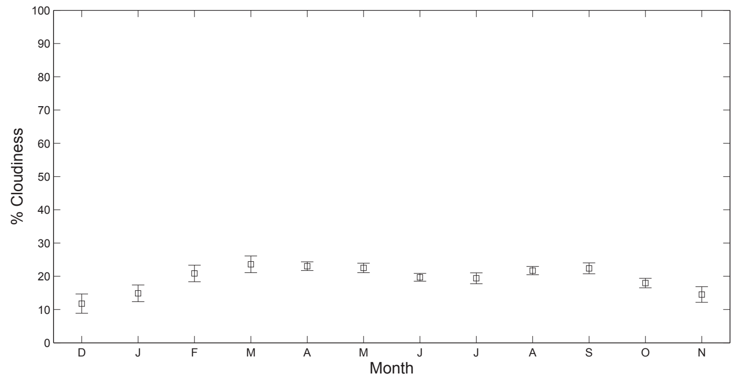
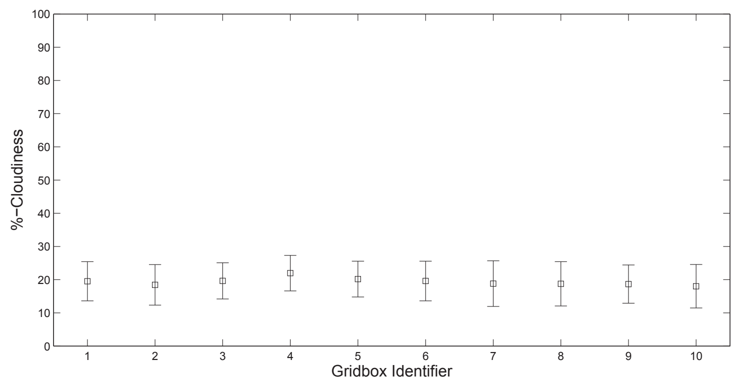



***Figure B.11 (U):*** *Geographic and seasonal trends in middle level cloud cover ($H_c$ < 21,000 ft) for the TOR Region.*




(a) Seasonal variability in low level cloud cover. Reported values represent %-cloud cover, averaged over all gridboxes and years for given month.




(b) Geographic variability in low level cloud cover. Reported values represent %-cloud cover, averaged over all months and years for given gridbox.

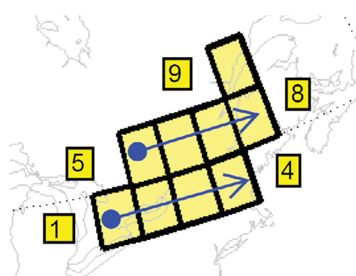
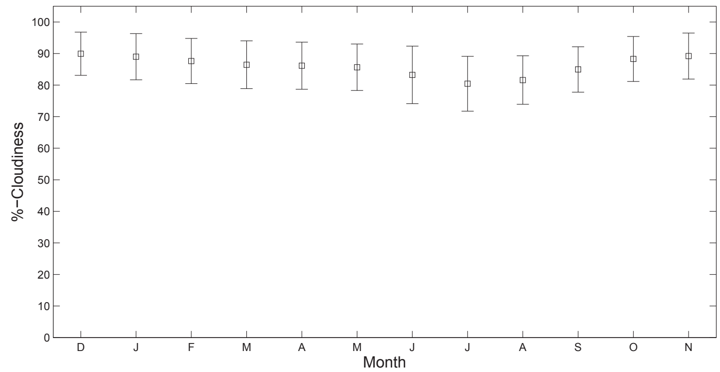
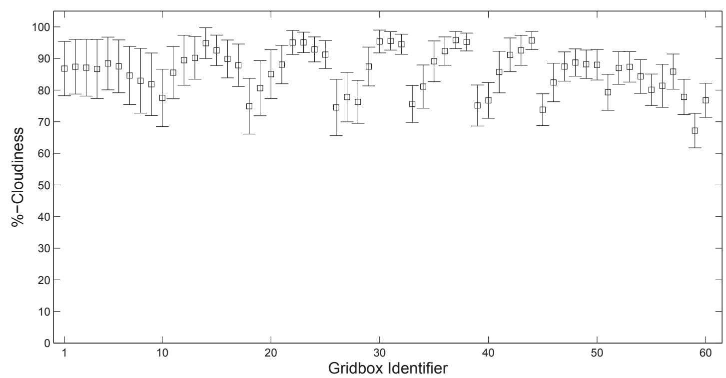



***Figure B.12 (U):*** *Geographic and seasonal trends in low level cloud cover ($H_c$ < 10,500 ft) for the TOR Region.*

117. Seasonal and geographic variability is also observed in the ATL low level cloud climate data. In contrast to the high and middle level seasonal cloud climate trends, the smallest amounts of low level clouds are observed in December and January, while greatest amounts are observed in March, April and September. Geographic variability in low cloud amount is smaller in the littoral areas compared to the blue water regions of the Atlantic. Figure B.15 summarizes the low level cloud climate in the ATL region.




(a) Seasonal variability in high level cloud cover. Reported values represent %-cloud cover, averaged over all gridboxes and years for given month.




(b) Geographic variability in high level cloud cover. Reported values represent %-cloud cover, averaged over all months and years for given gridbox.

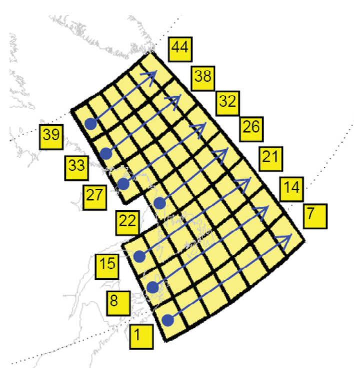
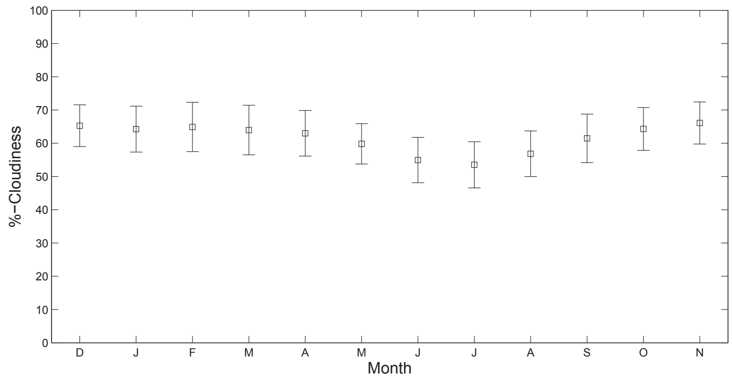
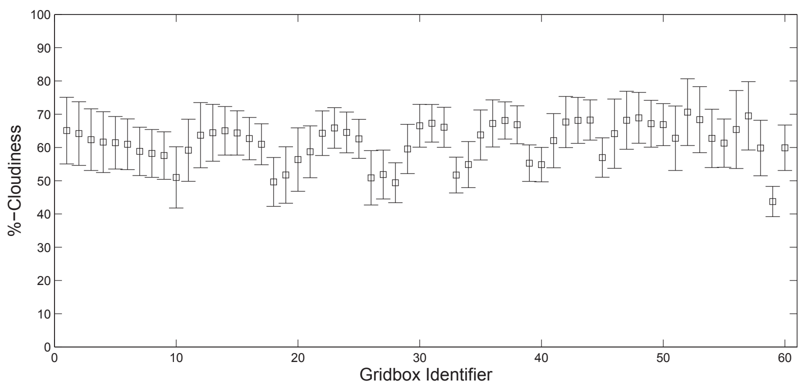



***Figure B.13 (U):*** *Geographic and seasonal trends in high level cloud cover ($H_c$ < 61,000 ft) for the ATL Region.*




(a) Seasonal variability in middle level cloud cover. Reported values represent %-cloud cover, averaged over all gridboxes and years for given month.




(b) Geographic variability in middle level cloud cover. Reported values represent %-cloud cover, averaged over all months and years for given gridbox.

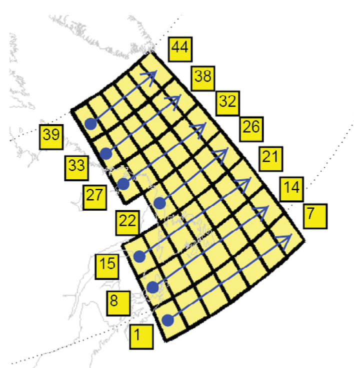
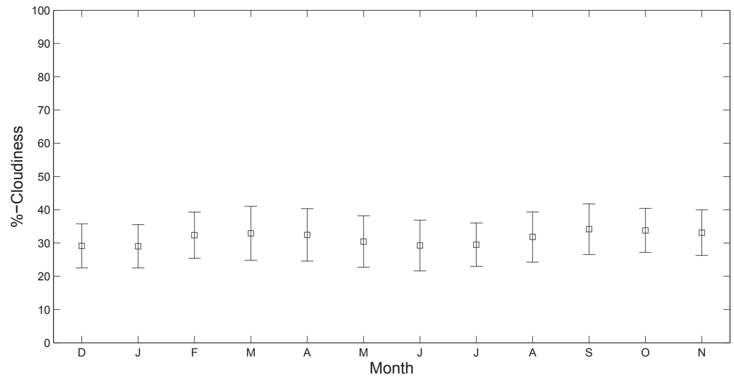
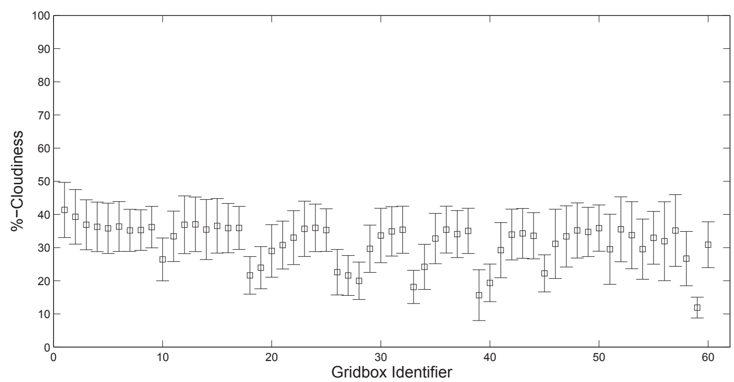



***Figure B.14 (U):*** *Geographic and seasonal trends in middle level cloud cover ($H_c$ < 21,000 ft) for the ATL Region.*




(a) Seasonal variability in middle level cloud cover. Reported values represent %-cloud cover, averaged over all gridboxes and years for given month.




(b) Geographic variability in low level cloud cover. Reported values represent %-cloud cover, averaged over all months and years for given gridbox.

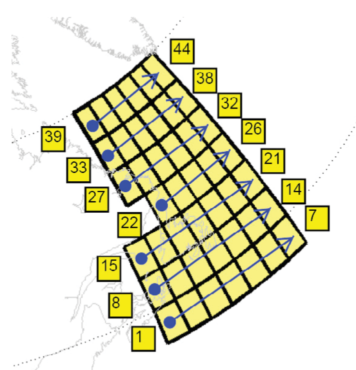



***Figure B.15 (U):*** *Geographic and seasonal trends in low level cloud cover ($H_c$ < 10,500 ft) for the ATL Region.*

## B.2 Cluster Analysis Results

### B.2.1 Geographic cluster results

***Table B.1 (U):*** *Summary of geographic cluster statistics for the PAC region. Tabulated values represent % cloud cover, averaged over all months and years.*

(a) High level cloud cover clusters ($H_c$ < 61,000 ft)

| Cluster | Mean | Maximum | Standard Deviation |
|---|---|---|---|
| 1 | 72.0 | 89 | 9.2 |
| 2 | 76.3 | 92 | 7.2 |
| 3 | 82.7 | 97.5 | 6.1 |
| 4 | 88.6 | 99 | 4.9 |

(b) Middle level cloud cover clusters ($H_c$ < 21,000 ft)

| Cluster | Mean | Maximum | Standard Deviation |
|---|---|---|---|
| 1 | 47.4 | 68.0 | 7.6 |
| 2 | 53.3 | 71.5 | 7.2 |
| 3 | 61.1 | 85.5 | 7.2 |

(c) Low level cloud cover clusters ($H_c$ < 10,500 ft)

| Cluster | Mean | Maximum | Standard Deviation |
|---|---|---|---|
| 1 | 13.2 | 32.0 | 6.4 |
| 2 | 19.9 | 43.5 | 8.7 |
| 3 | 26.6 | 51.5 | 7.0 |
| 4 | 33.3 | 60 | 7.0 |

***Table B.2 (U):*** *Summary of geographic cluster statistics for the ABSK region. Tabulated values represent % cloud cover, averaged over all months and years.*

(a) High level cloud cover clusters ($H_c$ < 61,000 ft)

| Cluster | Mean | Maximum | Standard Deviation |
|---|---|---|---|
| 1 | 70.2 | 91.5 | 8.0 |

(b) Middle level cloud cover clusters ($H_c$ < 21,000 ft)

| Cluster | Mean | Maximum | Standard Deviation |
|---|---|---|---|
| 1 | 48.2 | 69.5 | 6.8 |
| 2 | 54.1 | 77.5 | 7.7 |

(c) Low level cloud cover clusters ($H_c$ < 10,500 ft)

| Cluster | Mean | Maximum | Standard Deviation |
|---|---|---|---|
| 1 | 9.7 | 25.0 | 5.4 |
| 2 | 12.7 | 31.5 | 6.3 |
| 3 | 18.0 | 42 | 8.5 |

***Table B.3 (U):*** *Summary of geographic cluster statistics for the NWP region. Tabulated values represent % cloud cover, averaged over all months and years.*

(a) High level cloud cover clusters ($H_c$ < 61,000 ft)

| Cluster | Mean | Maximum | Standard Deviation |
|---|---|---|---|
| 1 | 53.2 | 85.0 | 11.2 |
| 2 | 61.1 | 82.5 | 8.3 |
| 3 | 65.4 | 89.5 | 9.2 |
| 4 | 70.8 | 90 | 7.5 |
| 5 | 77.6 | 97.5 | 6.4 |

(b) Middle level cloud cover clusters ($H_c$ < 21,000 ft)

| Cluster | Mean | Maximum | Standard Deviation |
|---|---|---|---|
| 1 | 16.7 | 42.0 | 7.6 |
| 2 | 22.9 | 55.5 | 7.6 |
| 3 | 31.2 | 56 | 7.1 |
| 4 | 36.6 | 56.5 | 5.8 |
| 5 | 43.5 | 61 | 5.4 |
| 6 | 53.4 | 82.5 | 10.0 |
| 7 | 58.6 | 86 | 10.8 |
| 8 | 62.4 | 88.5 | 9.6 |
| 9 | 69.5 | 90 | 10.1 |

(c) Low level cloud cover clusters ($H_c$ < 10,500 ft)

| Cluster | Mean | Maximum | Standard Deviation |
|---|---|---|---|
| 1 | 3.2 | 19.0 | 3.9 |
| 2 | 13.2 | 54 | 10.5 |
| 3 | 20.1 | 60.5 | 9.8 |
| 4 | 26.0 | 63.5 | 9.5 |
| 5 | 31.6 | 69 | 10.4 |
| 6 | 35.3 | 60.5 | 10.3 |

***Table B.4 (U):*** *Summary of geographic cluster statistics for the TOR region. Tabulated values represent % cloud cover, averaged over all months and years.*

(a) High level cloud cover clusters ($H_c$ < 61,000 ft)

| Cluster | Mean | Maximum | Standard Deviation |
|---|---|---|---|
| 1 | 68.2 | 87.0 | 7.5 |

(b) Middle level cloud cover clusters ($H_c$ < 21,000 ft)

| Cluster | Mean | Maximum | Standard Deviation |
|---|---|---|---|
| 1 | 50.8 | 71.5 | 7.7 |

(c) Low level cloud cover clusters ($H_c$ < 10,500 ft)

| Cluster | Mean | Maximum | Standard Deviation |
|---|---|---|---|
| 1 | 22.0 | 37.5 | 5.3 |

***Table B.5 (U):*** *Summary of geographic cluster statistics for the ATL region. Tabulated values represent % cloud cover, averaged over all months and years.*

(a) High level cloud cover clusters ($H_c$ < 61,000 ft)

| Cluster | Mean | Maximum | Standard Deviation |
|---|---|---|---|
| 1 | 67.2 | 80.5 | 5.5 |
| 2 | 76.1 | 97.5 | 7.1 |
| 3 | 81.2 | 99.5 | 7.7 |
| 4 | 85.0 | 100 | 7.5 |
| 5 | 87.9 | 100 | 6.8 |
| 6 | 94.0 | 100 | 4.2 |

(b) Middle level cloud cover clusters ($H_c$ < 21,000 ft)

| Cluster | Mean | Maximum | Standard Deviation |
|---|---|---|---|
| 1 | 50.9 | 75.5 | 7.6 |
| 2 | 55.7 | 78 | 6.8 |
| 3 | 59.0 | 79 | 7.7 |
| 4 | 61.9 | 83.5 | 7.9 |
| 5 | 64.4 | 87.5 | 8.8 |
| 6 | 67.4 | 89 | 7.0 |
| 7 | 70.1 | 90 | 10.2 |

(c) Low level cloud cover clusters ($H_c$ < 10,500 ft)

| Cluster | Mean | Maximum | Standard Deviation |
|---|---|---|---|
| 1 | 22.0 | 48 | 6.4 |
| 2 | 28.9 | 58.5 | 8.6 |
| 3 | 31.2 | 69 | 9.4 |
| 4 | 35.1 | 66.5 | 7.8 |
| 5 | 40.3 | 67 | 8.3 |

### B.2.2 Monthly cluster results

***Table B.6 (U):*** *Summary of monthly cluster statistics for the PAC region. Tabulated values represent % cloud cover, averaged over all grid cells and all years.*

(a) High level cloud cover clusters ($H_c$ < 61,000 ft)

| Cluster | Mean | Maximum | Standard Deviation |
|---|---|---|---|
| Aug | 76.9 | 96.5 | 12.6 |
| Jul | 80.9 | 99.0 | 13.0 |
| Mar,Sep | 81.6 | 98.5 | 7.8 |
| Jan,Feb,Apr,Oct | 82.8 | 98.5 | 7.1 |
| Dec,May,Jun,Nov | 84.6 | 99.0 | 9.1 |

(b) Middle level cloud cover clusters ($H_c$ < 21,000 ft)

| Cluster | Mean | Maximum | Standard Deviation |
|---|---|---|---|
| Dec,Aug,Sep,Oct,Nov, | 53.2 | 74.5 | 8.2 |
| Jan,Jul | 57.3 | 77.0 | 9.0 |
| Feb,Mar,Jun | 60.6 | 79.5 | 7.8 |
| Apr,May | 64.0 | 85.5 | 7.1 |

(c) Low level cloud cover clusters ($H_c$ < 10,500 ft)

| Cluster | Mean | Maximum | Standard Deviation |
|---|---|---|---|
| Dec,Jan,Oct,Nov | 25.2 | 52.0 | 9.9 |
| Feb,Sep | 28.0 | 50.0 | 8.7 |
| Mar,Aug | 30.3 | 52.5 | 8.2 |
| Apr,May,Jun,Jul | 33.8 | 60.0 | 8.4 |

***Table B.7 (U):*** *Summary of monthly cluster statistics for the ABSK region. Tabulated values represent % cloud cover, averaged over all grid cells and all years.*

(a) High level cloud cover clusters ($H_c$ < 61,000 ft)

| Cluster | Mean | Maximum | Standard Deviation |
|---|---|---|---|
| Jun,Jul | 62.5 | 82.5 | 7.66 |
| Feb,Mar,Apr,May,Aug,Sep | 69.7 | 91.5 | 7.10 |
| Dec,Jan,Oct,Nov | 74.1 | 89.5 | 7.4 |

(b) Middle level cloud cover clusters ($H_c$ < 21,000 ft)

| Cluster | Mean | Maximum | Standard Deviation |
|---|---|---|---|
| Jun,Jul | 45.6 | 63.5 | 6.0 |
| May,Aug,Sep,Oct | 51.2 | 75.0 | 7.1 |
| Dec,Mar,Apr,Nov | 54.3 | 73.0 | 7.5 |
| Jan,Feb | 56.8 | 77.5 | 8.1 |

(c) Low level cloud cover clusters ($H_c$ < 10,500 ft)

| Cluster | Mean | Maximum | Standard Deviation |
|---|---|---|---|
| Dec,Nov | 5.5 | 20.5 | 3.0 |
| Jan,Oct | 10.1 | 33.0 | 4.9 |
| Feb,Sep | 16.3 | 34.5 | 5.5 |
| Mar,May,Jun,Jul,Aug | 21.5 | 39.5 | 5.5 |
| Apr | 25.0 | 42.0 | 6.4 |

***Table B.8 (U):*** *Summary of monthly cluster statistics for the NWP region. Tabulated values represent % cloud cover, averaged over all grid cells and all years.*

(a) High level cloud cover clusters ($H_c$ < 61,000 ft)

| Cluster | Mean | Maximum | Standard Deviation |
|---|---|---|---|
| Mar,Apr,May,Jun | 66.0 | 96.0 | 13.1 |
| Dec,Sep,Oct,Nov | 69.4 | 96.5 | 12.0 |
| Jan,Feb,Jul,Aug | 71.2 | 99.0 | 10.6 |

(b) Middle level cloud cover clusters ($H_c$ < 21,000 ft)

| Cluster | Mean | Maximum | Standard Deviation |
|---|---|---|---|
| Mar,Apr,May,Jun | 45.4 | 83.5 | 14.7 |
| Jul,Aug | 50.2 | 80.0 | 14.6 |
| Dec,Jan,Feb,Sep,Oct,Nov | 55.4 | 90.0 | 17.1 |

(c) Low level cloud cover clusters ($H_c$ < 10,500 ft)

| Cluster | Mean | Maximum | Standard Deviation |
|---|---|---|---|
| Dec,Jan | 15.4 | 64.5 | 15.3 |
| Feb,Mar,Apr,May,Jun,Jul,Nov | 18.6 | 69.0 | 12.7 |
| Aug,Oct | 21.0 | 60.0 | 13.8 |
| Sep | 24.4 | 63.5 | 15.4 |

***Table B.9 (U):*** *Summary of monthly cluster statistics for the TOR region. Tabulated values represent % cloud cover, averaged over all grid cells and all years.*

(a) High level cloud cover clusters ($H_c$ < 61,000 ft)

| Cluster | Mean | Maximum | Standard Deviation |
|---|---|---|---|
| Jun,Jul,Aug | 64.6 | 80.5 | 7.2 |
| Mar,Apr,May,Sep | 70.7 | 90.5 | 6.9 |
| Jan,Feb,Nov | 75.4 | 93.5 | 6.9 |
| Dec,Oct | 78.6 | 93.0 | 7.5 |

(b) Middle level cloud cover clusters ($H_c$ < 21,000 ft)

| Cluster | Mean | Maximum | Standard Deviation |
|---|---|---|---|
| Jun,Jul | 40.1 | 55.0 | 5.3 |
| May,Aug | 45.7 | 62.5 | 5.8 |
| Dec,Jan,Feb,Mar,Apr,Sep,Oct,Nov | 53.5 | 71.5 | 6.2 |

(c) Low level cloud cover clusters ($H_c$ < 10,500 ft)

| Cluster | Mean | Maximum | Standard Deviation |
|---|---|---|---|
| Dec | 11.8 | 28.0 | 4.8 |
| Jan,Nov | 14.7 | 30.5 | 5.6 |
| Jun,Jul,Oct | 19.0 | 34.5 | 4.0 |
| Feb,Mar,Apr,May,Aug,Sep | 22.4 | 41.5 | 5.2 |

***Table B.10 (U):*** *Summary of monthly cluster statistics for the ATL region. Tabulated values represent % cloud cover, averaged over all grid cells and all years.*

(a) High level cloud cover clusters ($H_c$ < 61,000 ft

| Cluster | Mean | Maximum | Standard Deviation |
|---|---|---|---|
| Jun,Jul,Aug | 81.5 | 100.0 | 10.2 |
| Mar,Apr,May,Sep | 85.5 | 100.0 | 8.7 |
| Dec,Jan,Feb,Oct,Nov | 88.6 | 100.0 | 8.1 |

(b) Middle level cloud cover clusters ($H_c$ < 21,000 ft)

| Cluster | Mean | Maximum | Standard Deviation |
|---|---|---|---|
| Jun,Jul,Aug | 55.1 | 79.5 | 8.9 |
| Apr,May,Sep | 61.4 | 87.5 | 8.9 |
| Dec,Jan,Feb,Mar,Oct,Nov | 64.8 | 90.0 | 9.0 |

(c) Low level cloud cover clusters ($H_c$ < 10,500 ft)

| Cluster | Mean | Maximum | Standard Deviation |
|---|---|---|---|
| Dec,Jan,May,Jun,Jul | 29.5 | 67.0 | 9.6 |
| Feb,Mar,Apr,Aug,Nov | 32.5 | 69.0 | 9.9 |
| Sep,Oct | 34.0 | 60.0 | 9.4 |

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# Annex C: Sensor Visibility Assessment – Detailed Assessment Results

## C.1 PAC region

### No Image and Detection potential

In Port Hardy, approximately 7% of records report weather conditions that are unsuitable for EO/IR sensor operation. NI conditions are reported most frequently in July through December inclusive, when 10% of records meet critical conditions. NI events are reported with the lowest frequency in February through May, when approximately 3% of records report critical weather condions. Of the NI events reported in Port Hardy, 33% last less than 1 h, 75% last less than 5 h and 92% last less than 10 h.

On average, 9% of Victoria records report NI weather conditions. NI conditions are reported with the greatest frequency in October through January inclusive, when 19.5% of records report weather conditions unsuitable for EO/IR sensor operation. In comparison, on average 1.5% of records in May through August report NI conditions. In Victoria, 30% of critical NI events less than 1 h, 66% of events less than 5 h and 96% of events less than 20 h.

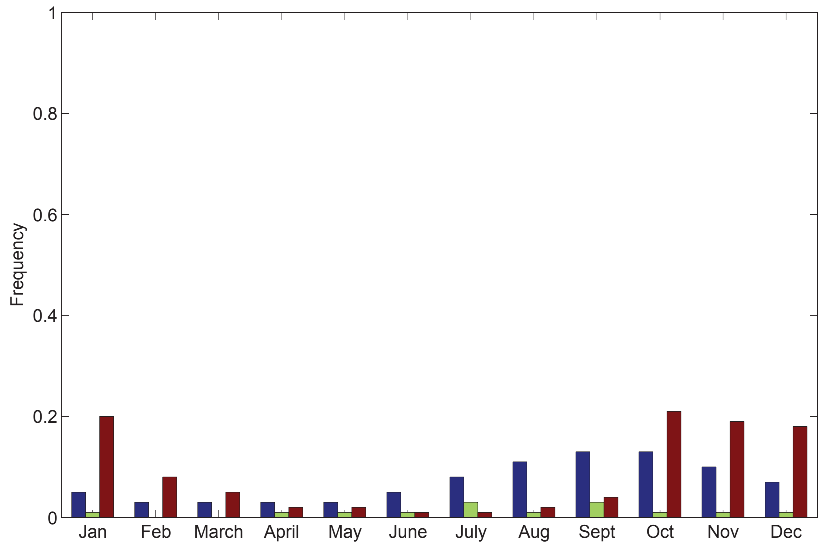
In Vancouver, 2% of records report NI weather conditions. In October to December inclusive, 6% of records report weather conditions unsuitable for EO/IR sensor operation, while in April through August, less than 0.1% of records report NI conditions. In Vancouver, 45% of NI events last less than 1 h, 83% of events last less than 5 h and 93% of events last less than 10 h.

Weather conditions suitable for detection tasks are reported in approximately 94% of Vancouver records, 93% of Port Hardy records and 91% of Victoria Records. Of the detection events reported in Port Hardy, 6% last less than 1 h, 24% last less than 10 h, 46% last less than 20 h and 95% of events last less than 214 h. In Victoria, 7% of detection events last less than 1 h, 32% last less than 10 h and 95% of events last less than 239 h. In Vancouver, 18% of critical events last less than 1 h, 46% of events last less than 10 h and 95% of detection events last less than 275 h.

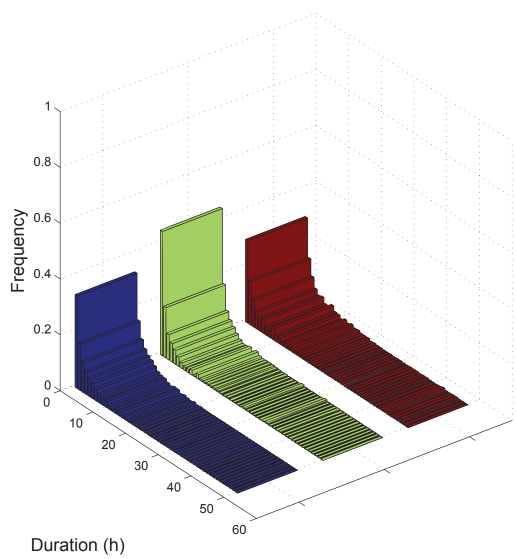
Frequency and persistence characteristics of NI conditions and events for the PAC region are shown in Figure C.1, while frequency and persistence characteristics of detection conditions and events are shown in Figure C.2.

### Classification potential

In Port Hardy and Victoria, weather conditions suitable for classification tasks are reported in 77% and 88% of records respectively. Classification conditions are reported with the greatest frequency in April through September. Over this period, 81% and 96% of records in Port Hardy and Victoria respectively report classification conditions. Conversely, critical conditions are reported with lowest frequency in October through March, when 73% and 81% of Port Hardy and Victoria records respectively report classification conditions. In Victoria, 12% of classification events last less than




(a) Monthly distribution of records reporting *no image* conditions




(b) Persistence of reported *no image* events in the PAC region


***Figure C.1 (U):*** *Summary of the frequency and persistence characteristics of reported* no image *events in the PAC region. Weather conditions defined as* no image *events are assumed to prevent the creation of an EO/IR image that is useful for any task.*

1h, 47% of events last less than 5 h and 95% of events last less than 126 h. In Port Hardy, 21% of events last less than 1h, 70% of events last less than 10 h and 95% of events last less than 56 h.

Weather conditions suitable for classification are reported in 87% of Vancouver records. In October through January inclusive, 79% of records report critical conditions, while in April through September inclusive, critical conditions are reported in 93% of records. Of the classification events reported in Vancouver, 20% of events last less than 1 h, 48% of events last less than 5 h and 95% of events last less than 94 h.

Frequency and persistence characteristics of classification conditions and events for the PAC region are shown in Figure C.3.

### Identification potential

Weather conditions suitable for identification tasks are reported in 35% of Victoria records. Critical conditions are reported with the greatest frequency in June through September inclusive, when on average 53% of records report identification conditions. In October through May, critical conditions are reported in 27% of records. Identificaton conditions are reported with the lowest frequency in January, when 16% of records show critical conditions. In Victoria, 30% of identification events last less than 1 h, 80% of events last less than 10 h, and 92% of events last less than 20 h.

In Port Hardy, 25% of records report identification conditions. Critical conditions are reported with the greatest frequency in August and September, when 32% records report identification conditions, and with the lowest frequency in December, when 18% of records report weather conditions suitable for identification tasks. In Port Hardy, 31% of identification events less than 1 h, 68% of events last less than 5 h and 90% of events last less than 15 h.

In Vancouver, weather conditions suitable for identification tasks are reported in 34% of records. Critical conditions are reported with greatest frequency in June through September inclusive, when 53% of records report identification conditions, and with the lowest frequency in November, December, January and March, when 21% of records report weather conditions suitable for identification tasks. In Vancouver, 28% of identification events last less than 1 h, 64% of events last less than 5 h and 79% of identification events last less than 10 h.

Frequency and persistence characteristics of identification conditions and events for the PAC region are shown in Figure C.4.

### Cloud ceiling

In Vancouver and in Port Hardy, 57% and 67% of records respectively report cloud ceiling elevations below the UAV's assumed operating elevation of 4,500 m. In Vancouver, critical cloud ceiling conditions are reported with the lowest frequency in July through September inclusive, when on average 37% of records report cloud ceiling conditions below 15,000 ft. Critical cloud ceiling conditions are reported with greatest frequency in November through January inclusive, when 74% of records report ceilings below 15,000 ft. In Port Hardy, critical ceiling conditions are reported with lowest frequency in September, when 60% of records report critical conditions, and with the highest frequency in December through January inclusive, when 75% of records report cloud ceilings below 15,000 ft.

## C.2 ABSK region

### No Image and Detection potential

In Edmonton, Lloydminister and Cold Lake, weather conditions unsuitable for EO/IR sensor operation are reported most frequently in February, when 10%, 11% and 6% of records respectively report NI conditions. In Calgary, NI conditions are reported most frequency in November, when 11% of records report conditions unsuitable for EO/IR sensor operation. In Cold lake, 34% of NI events last less than 1 h, 79% of events last less than 5 h and 93% of events last less than 10 h. In Calgary, 31% of NI events last less than 1 h, 71% of events last less than 5 h and and 87% of events last less than 10 h, and in Edmonton, 28% of NI events last less than 1 h, 73% of events last less than 5 h and 91% of events last less than 10 h.

Systematic reporting tendencies whereby only precipitation events are recorded are observed in the Swift Current data records. As a result of this apparent reporting methodology, approximately 90% of records in the Swift Current data set do not report weather observations. Due to the poor resolution of the Swift Current weather observation records, the Swift Current data set was not used in the sensor visibility assessment.

In Fort McMurray, NI conditions are reported most frequently in June through September inclusive. Over this period, 5.75% of records report weather conditions unsuitable for EO/IR sensor operation. In Fort McMurray, 32% of NI events last less than 1 h, 78% of events last less than 5 h and 93% of events last less than 10 h.

Frequency and persistence characteristics of NI conditions and events for the ABSK region are shown in Figure C.5.

Across the ABSK region, on average 95% of records meet the detection tasking criteria. On average, 7% of detection events across the region last less than 1 h, 31% of events last less than 10 h, at least 46% of events last less than 20 h and at least 95% of events last less than 423 h.

Frequency and persistence characteristics of ABSK detection conditions and events are shown in Figure C.6.

### Classification potential

Similar temporal trends are observed in the frequency of weather conditions considered suitable for classification tasks across all ABSK LOIs. On average, 84% of records report classification conditions. Classification conditions are reported most frequently in April through October inclusive, when, on average, 90% of records report classification conditions. In comparision, 77% of records in November through March inclusive report classification conditions. Across all ABSK LOIs, classification conditions are most persistent in Lloydminister, and least persistent in Cold Lake, with between 9% and 17% of classification events lasting less than 1 h, between 43% and 58% of events lasting less than 10 h, between 62% and 72% of events lasting less than 10 h and 95% of events lasting less than 133 h.

Frequency and persistence characteristics of ABSK classification conditions and events are shown in Figure C.7.

### Identification potential

Across all ABSK LOIs, weather conditions considered suitable for identification tasks are reported in 38% of records. Identification conditions are reported with slightly greater frequency in July through September inclusive, when 44% of records report identification conditions. Across all ABSK LOIs, approximatley 30% of reported identification events last less than 1 h, 65% of events last less than 5 h and 80% of events last less than 10 h.

Frequency and persistence characteristics of ABSK identification conditions and events are shown in Figure C.8.

### Cloud ceiling

In Cold Lake, 45% of records report cloud ceiling elevations below 4,500 m. Critical cloud ceiling conditions are observed most frequently in November, when 54% records report critical conditions, and least frequently in August, when 37% of records report cloud ceiling elevations below 15,000 ft.

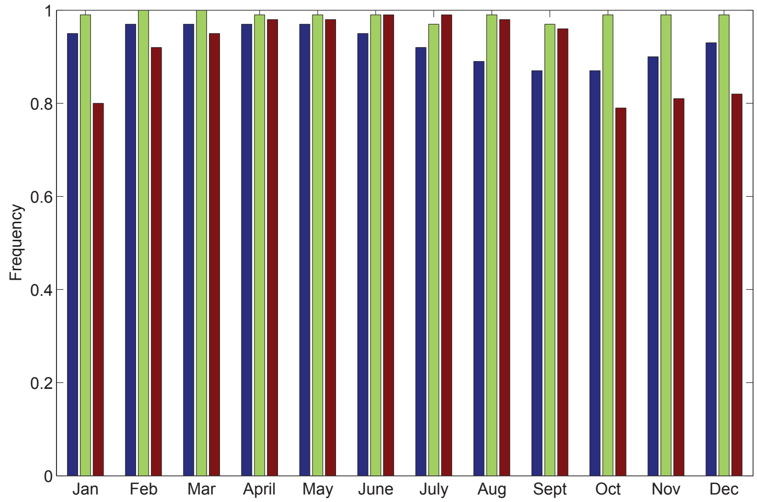
## C.3 NWP region

### No Image and Detection potential

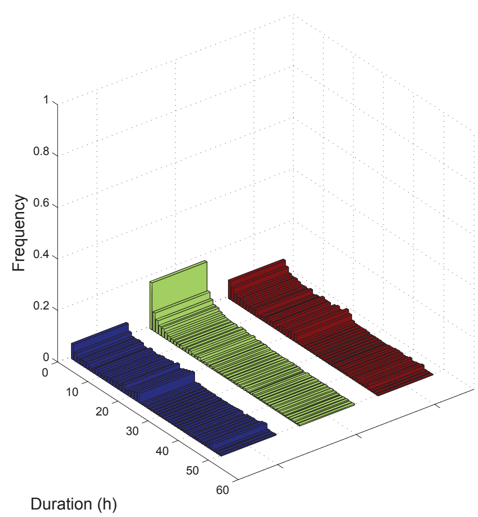
In Resolute and Iqualuit, weather conditions unsuitable for EO/IR sensor operation are reported in 18% and 7% of records respectively, while conditions suitable for detection tasks are reported in 82% of Resolute records and 93% of Iqualuit records.

In the Pond Inlet data, systematic reporting tendencies are noted whereby weather observations are recorded over an 8 h period, followed by a period of 16 h over which weather observations are not recorded. As a consequence of this reporting methodology, approximately 66% of records in the Pond Inlet data set do not report weather observations. Due to the poor resolution of the Pond Inlet weather observation records, the Pond Inlet data set was not used in the sensor visibility assessment.

In Resolute, NI conditions are observed in 12% of records in April, May, June and December, and in 21% of records over the remaining months. Of the reported NI events, 26% last less than 1 h, 66% last less than 5 h and 81% last less than 10 h. Detection conditions are reported with greatest frequency in May, when 91% of records report detection conditions, and with lowest frequency in August, when 77% of records report critical detection conditions. In Resolute, 11% of detection events last less than 1 h, 44% of events last less than 10 h, 66% of events last less than 20 h and 95% of records last less than 115 h.

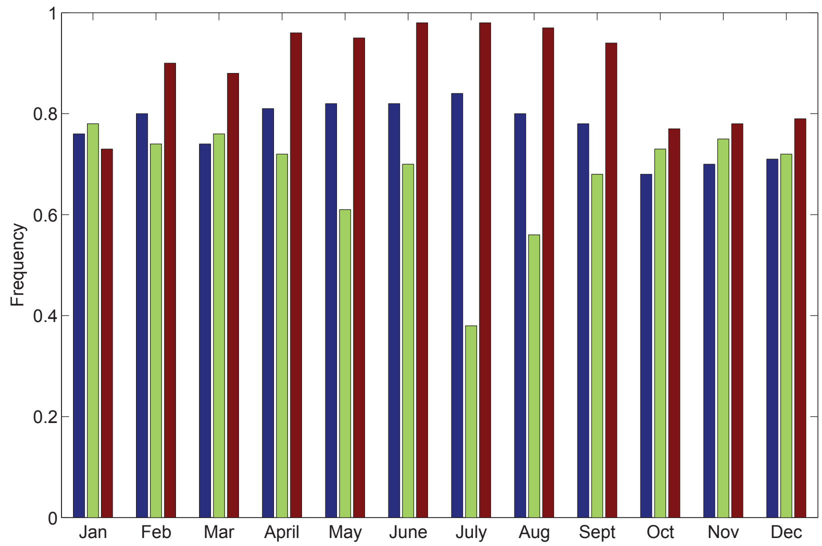



(a) Monthly distribution of records reporting *detection* conditions

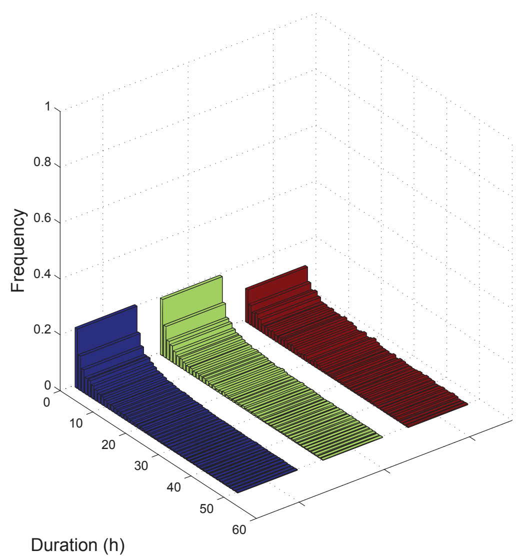



(b) Persistence of reported *detection* events in the PAC region


***Figure C.2 (U):*** *Summary of the frequency and persistence characteristics of reported detection events in the PAC region. Weather conditions defined as detection events are assumed to have a strong negative effect on EO/IR image quality.*



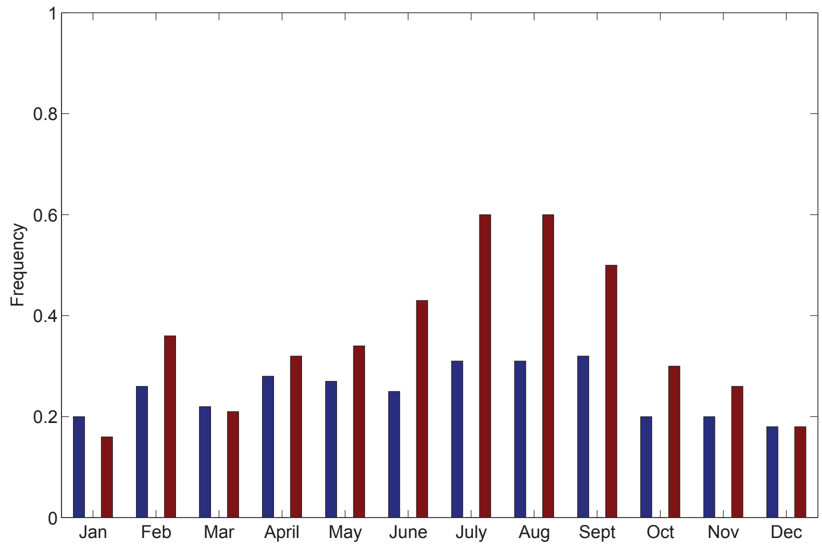

(a) Monthly distribution of records reporting *classification* conditions



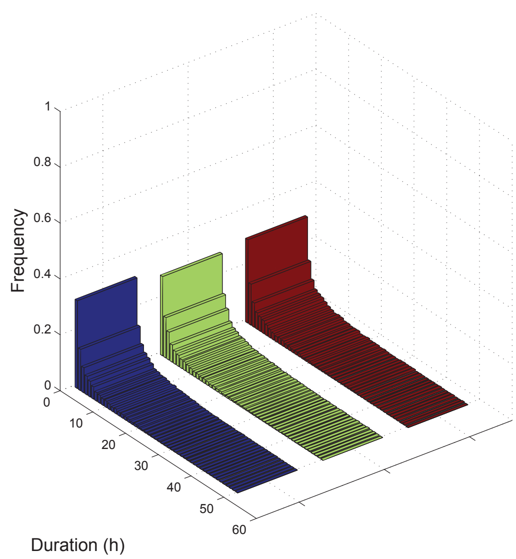

(b) [Persistence of reported *classification* events in the PAC region

Port Hardy, BC   Vancouver, BC   Victoria, BC

***Figure C.3 (U):*** *Summary of the frequency and persistence characteristics of reported classification events in the PAC region. Weather conditions defined as classification events are assumed to have some negative effect on EO/IR image quality.*



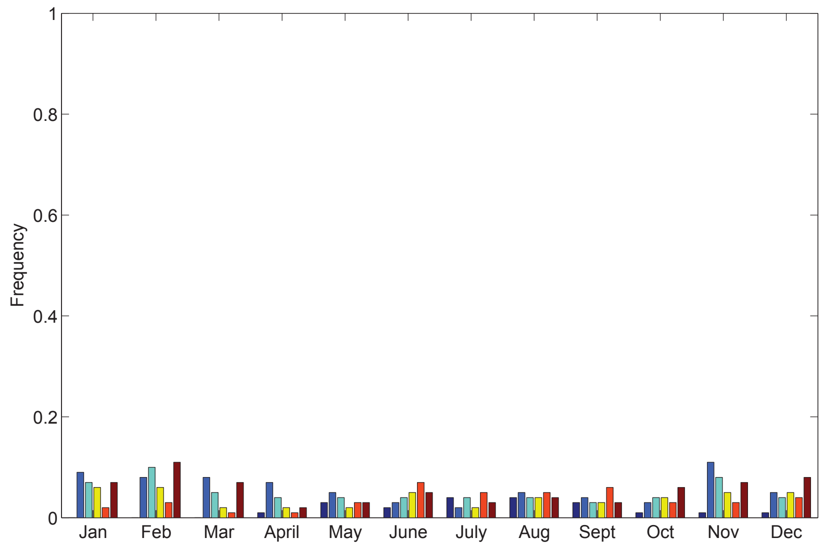

(a) Monthly distribution of records reporting *identification* conditions



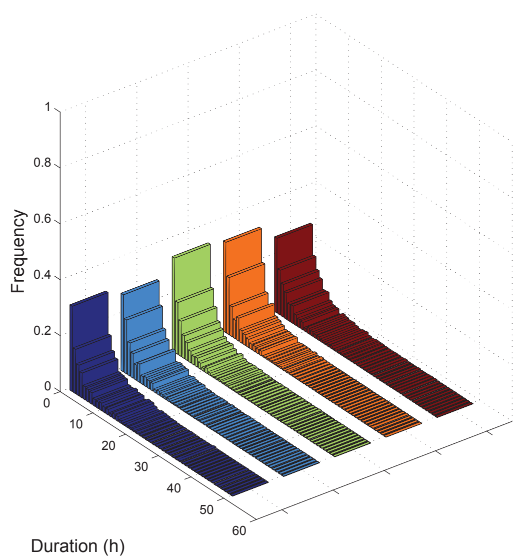

(b) Persistence of reported *identification* events in the PAC region

Port Hardy, BC   Vancouver, BC   Victoria, BC

***Figure C.4 (U):*** *Summary of the frequency and persistence characteristics of reported identification events in the PAC region. Weather conditions defined as identification events are assumed to have very little negative effect on EO/IR image quality.*

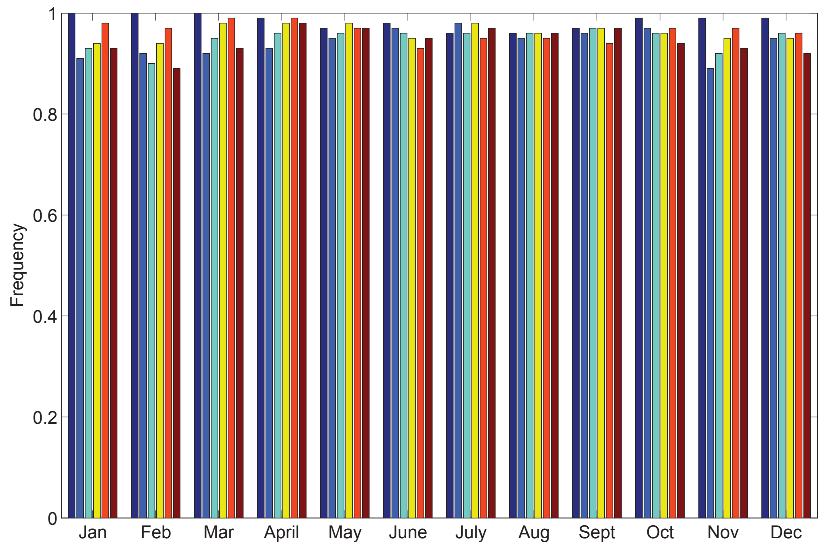



(a) Monthly distribution of records reporting *no image* conditions

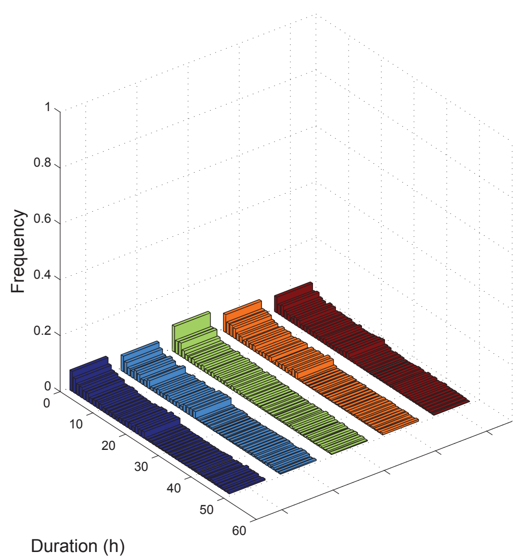



(b) Persistence of reported *no image* events in the ABSK region


***Figure C.5 (U):*** *Summary of the frequency and persistence characteristics of reported* no image *events in the ABSK region. Weather conditions defined as* no image *events are assumed to prevent the creation of an EO/IR image that is useful for any task.*

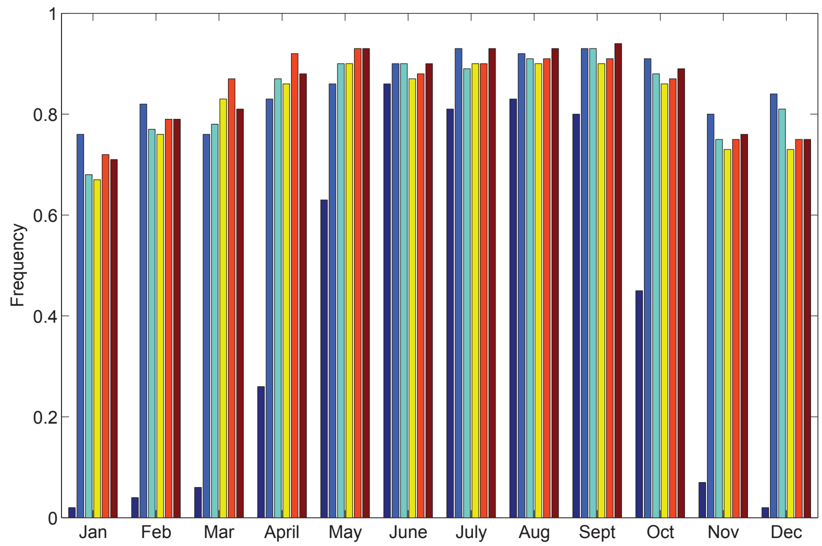



(a) Monthly distribution of records reporting *detection* conditions

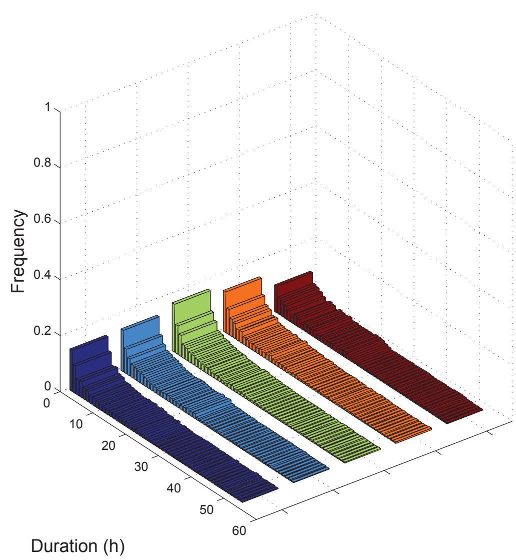



(b) Persistence of reported *detection* events in the ABSK region


***Figure C.6 (U):*** *Summary of the frequency and persistence characteristics of reported* detection *events in the ABSK region. Weather conditions defined as* detection *events are assumed to have a strong negative effect on EO/IR image quality.*

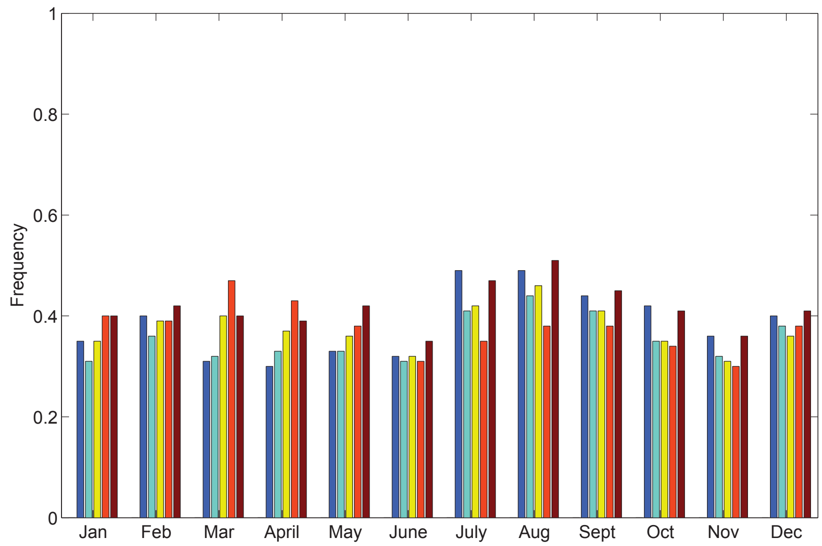



(a) Monthly distribution of records reporting *classification* conditions

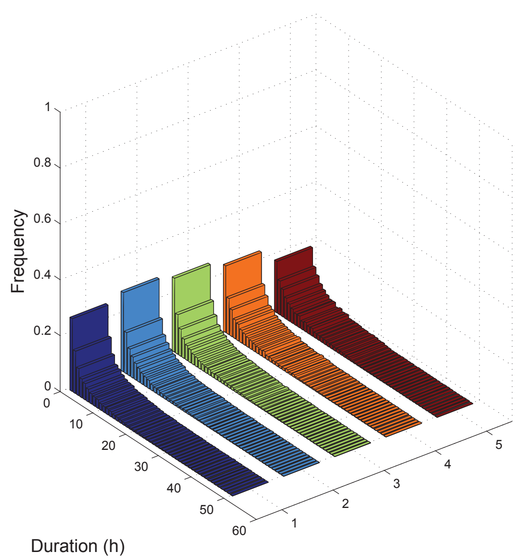



(b) Persistence of reported *classification* events in the ABSK region


***Figure C.7 (U):*** *Summary of the frequency and persistence characteristics of reported classification events in the ABSK region. Weather conditions defined as classification events are assumed to have some negative effect on EO/IR image quality.*




(a) Monthly distribution of records reporting *identification* conditions




(b) Persistence of reported *identification* events in the ABSK region

Swift Current, SK | Calgary, AB | Edmonton, AB | Cold Lake, AB | Fort McMurray, AB | Lloydminiser, AB/SK

***Figure C.8 (U):*** *Summary of the frequency and persistence characteristics of reported identification events in the ABSK region. Weather conditions defined as identification events are assumed to have very little negative effect on EO/IR image quality.*

In Iqualuit, weather conditions unsuitable for EO/IR sensor operation are reported with the lowest frequency in April, May, June, July, October and November. On average, 5% of records report NI conditions over this period, while 10% of records in December through March inclusive report critical conditions. In Iqualuit, 24% of NI events last less than 1 h, 63% of NI events last less than 5 h and 84% of NI events last less than 10 h. Of the reported detection events, 2% last less than 1 h, 23% last less than 10 h, 43% last less than 20 h and 95% last less than 285 h.

Frequency and persistence characteristics of NI conditions and events for the NWP region are shown in Figure C.9, while frequency and persistence characteristics of detection conditions and events are shown in Figure C.10.

### Classification potential

In Resolute, significant temporal trends are observed in the frequency of weather conditions suitable for classification tasks. In June through August inclusive, 74% of records report classification conditions. In comparison, 22% of records in December through February report classification conditions. Critical conditions are reported with increasing frequency in March through May and decreasing frequency in September through November inclusive. On average, 41% of records in March through May, and 48% of records in September through November report classification conditions. In Resolute, 21% of classification events last less than 1 h, 57% of events last less than 5 h, 73% of events last less than 10 h and 95% of events last less than 43 h.

Similar temporal trends are observed in reported classification weather conditions in Iqualuit as are observed in Resolute. Critical conditions are reported with greatest frequency in June through September inclusive, and with lowest frequency in December through February, when 86% and 68% of records respectively report classification conditions. On average, 68% of records in Resolute report classification conditions, with 5% of classification events lasting less than 1 h, 43% of events lasting less than 10 h, 74% of events lasting less than 20 h and 95% of events lasting less than 67 h.

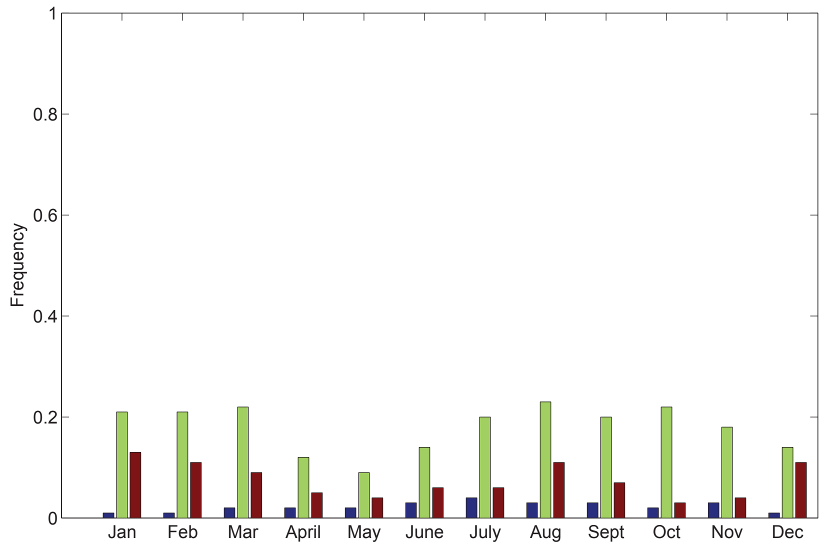
Frequency and persistence characteristics of classification conditions and events for the NWP region are shown in Figure C.11.

### Identification potential

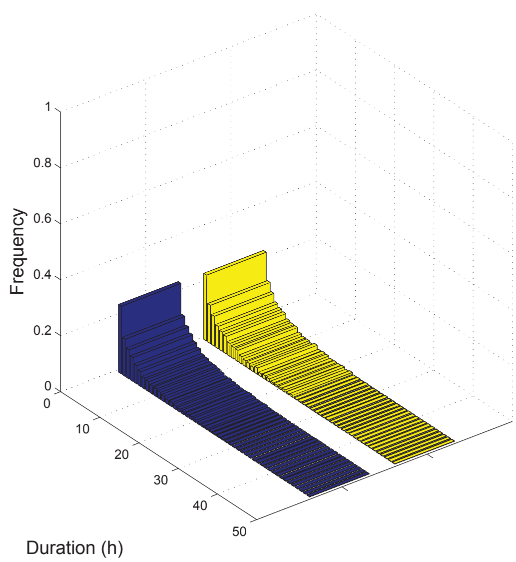
In Iqualuit, 27% of records report identification weather conditions. Identification conditions are observed with lowest frequently in May, September and October, when 21%, 18% and 17% respectively of records report critical conditions. In Iqualuit, 15% of identification events last less than 1 h, 78% of events last less than 10 h and 93% less than 20 h.

Identification conditions are reported in 22% of records in Resolute. In August and September, 13% of records report identification conditions, while 37% of records in April report identification conditions. In Resolute, 27% of identification events last less than 1 h, 80% of events last less than 10 h and 92% of events last less than 20 h.

Frequency and persistence characteristics of identification conditions and events for the NWP region are shown in Figure C.12.



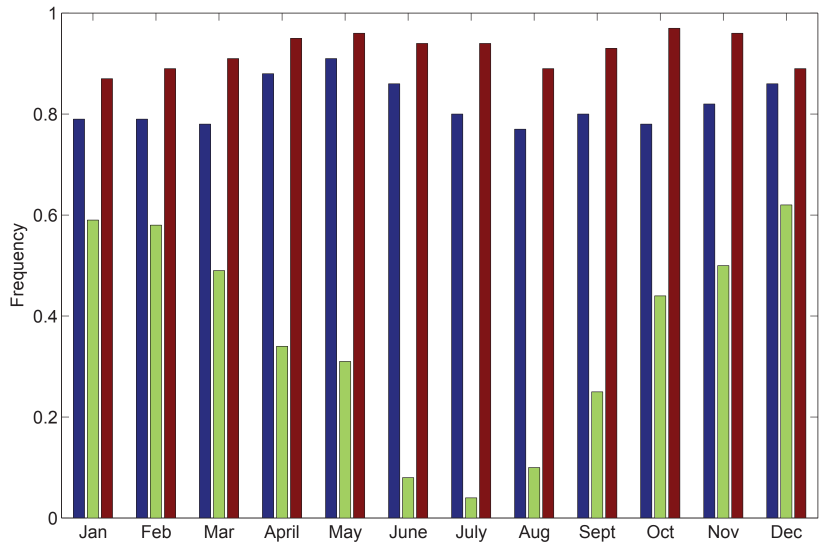

(a) Monthly distribution of records reporting *no image* conditions



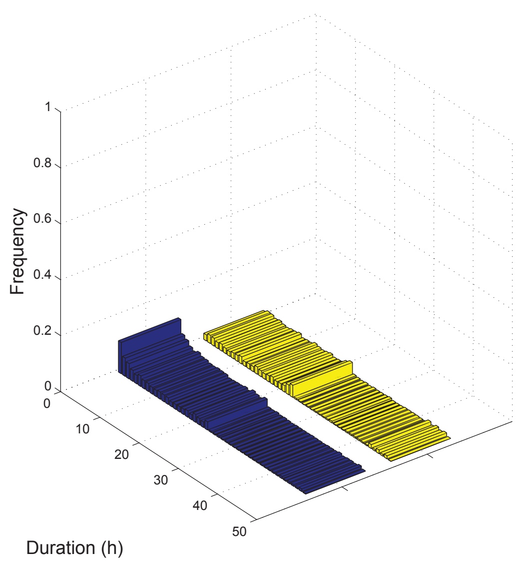

(b) Persistence of reported *no image* events in the NWP region

Pond Inlet, NU   Resolute, NU   Iqaluit, NU

***Figure C.9 (U):*** *Summary of the frequency and persistence characteristics of reported* no image *events in the NWP region. Weather conditions defined as* no image *events are assumed to prevent the creation of an EO/IR image that is useful for any task.*



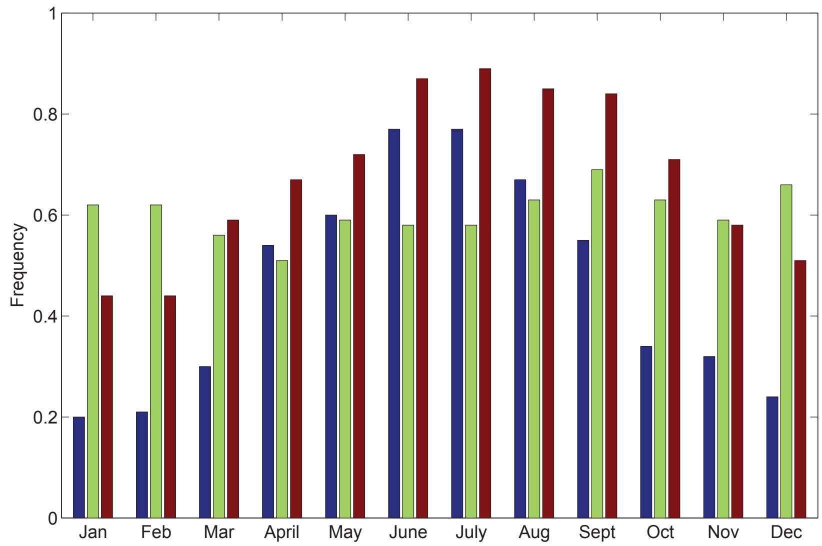

(a) Monthly distribution of records reporting *detection* conditions



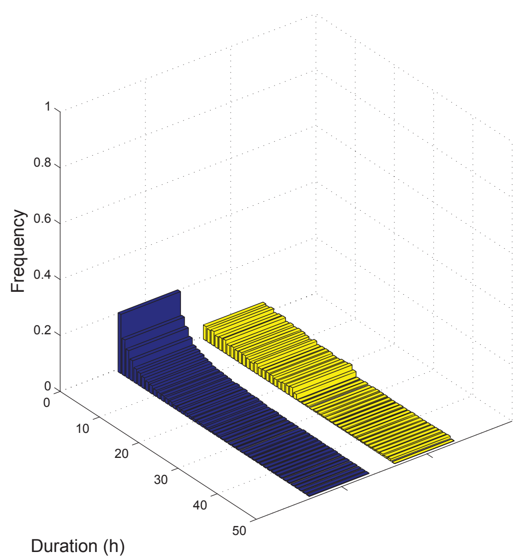

(b) Persistence of reported *detection* events in the NWP region

Pond Inlet, NU　Resolute, NU　Iqualuit, NU

***Figure C.10 (U):*** *Summary of the frequency and persistence characteristics of reported detection events in the NWP region. Weather conditions defined as detection events are assumed to have a strong negative effect on EO/IR image quality.*

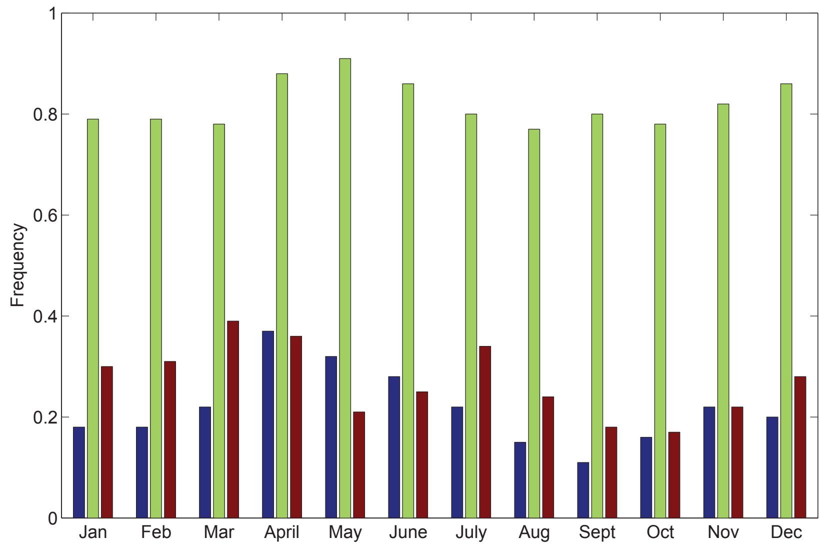



(a) Monthly distribution of records reporting *classification* conditions

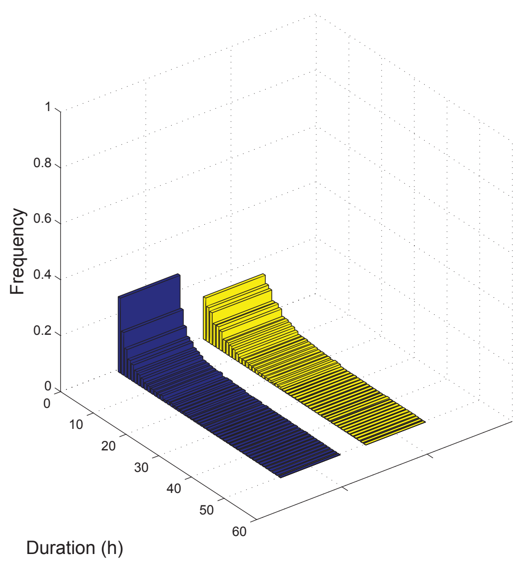



(b) Persistence of reported *classification* events in the NWP region


***Figure C.11 (U):*** *Summary of the frequency and persistence characteristics of reported* classification *events in the NWP region. Weather conditions defined as* classification *events are assumed to have some negative effect on EO/IR image quality.*




(a) Monthly distribution of records reporting *identification* conditions




(b) Persistence of reported *identification* events in the PAC region

Pond Inlet, NU   Resolute, NU   Iqualuit, NU

***Figure C.12 (U):*** *Summary of the frequency and persistence characteristics of reported identification events in the NWP region. Weather conditions defined as identification events are assumed to have very little negative effect on EO/IR image quality.*

### Cloud ceiling

In Resolute, cloud ceiling elevations below 15,000 ft are reported in 58% of records in May through June inclusive and in October and November. In July through September inclusive, 74% of records report critical cloud ceiling conditions, and in December through April inclusive, critical conditions are reported in 27% of records. Similar temporal trends are observed in Iqualuit, where 75% of records in May and in August through November inclusive report cloud ceiling elevations below 15,000 ft. In December through April inclusive, 44% of records report critical cloud conditions.

## C.4 TOR region

### No Image and Detection potential

Weather conditions considered unsuitable for EO/IR sensor operation are reported in 10% of records across all TOR LOIs, while between 88% and 91% of records report weather conditions suitable for detection tasks. Across the TOR region, very little temporal variation is observed in the frequencies of either NI or classification events. In Toronto, Ottawa and Montreal, on average 27% of reported NI events last less than 1 h, while between 7% and 9% of detection events last less than 1 h. In Montreal, 71% of NI events last less than 5 h and 89% of events last less than 10 h. In Ottawa, 67% of NI events last less than 5 h, and 88% of events last less than 10 h, while in Toronto, 75% of NI events last less than 5 h and 91% of events last less than 10 h. Across all LOIs, between 23% and 28% of detection events last less than 5 h, and between 52%, 60% of detection events last less than 20 h and 95% of detection events last less than 181 h.

Frequency and persistence characteristics of NI conditions and events for the TOR region are shown in Figure C.13, while frequency and persistence characteristics of detection conditions and events are shown in Figure C.14.

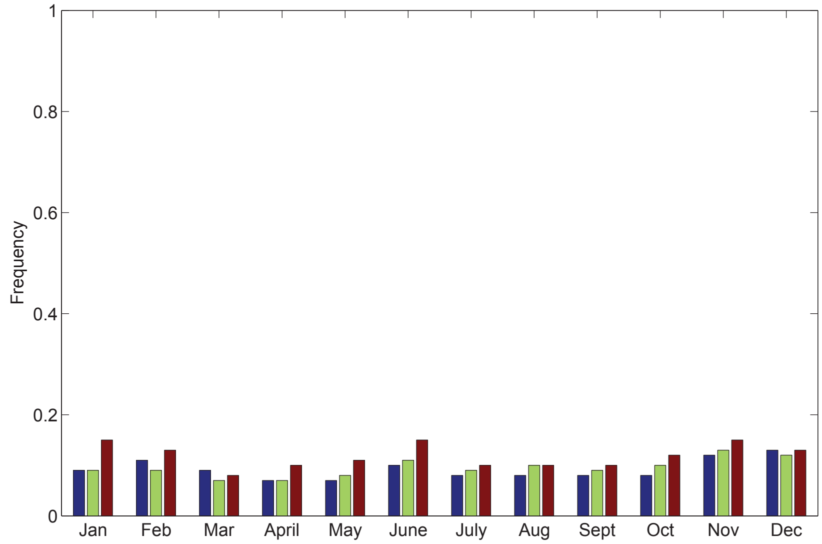
### Classification potential

Weather conditions suitable for classification tasks are reported in 82% of records in Toronto, Montreal and Ottawa. Across the TOR region, classification conditions are reported with greatest frequency in April through October inclusive, when 87% of records report classification conditions. Classification conditions are observed with with lowest frequency in January, when 64% of Toronto records, 67% of Ottawa records and 69% of Montreal records report classification conditions. Across all TOR LOIs, 15% of classification events last less than 1h, between 41% and 44% of events last less than 5 h and between 73% and 75% of events last less than 20 h. At least 95% of events last less than 87 h.

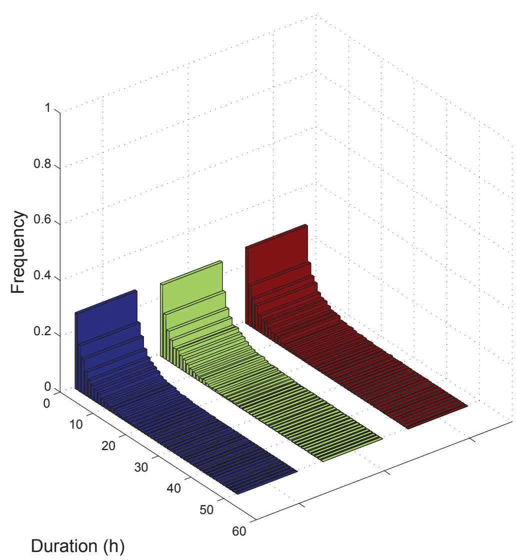
Frequency and persistence characteristics of classification conditions and events for the TOR region are shown in Figure C.15.

### Identification potential

Weather conditions suitable for identification tasks are reported in 36% of Montreal and Toronto records and 38% of Ottawa records. Identification conditions are observed with greatest frequency

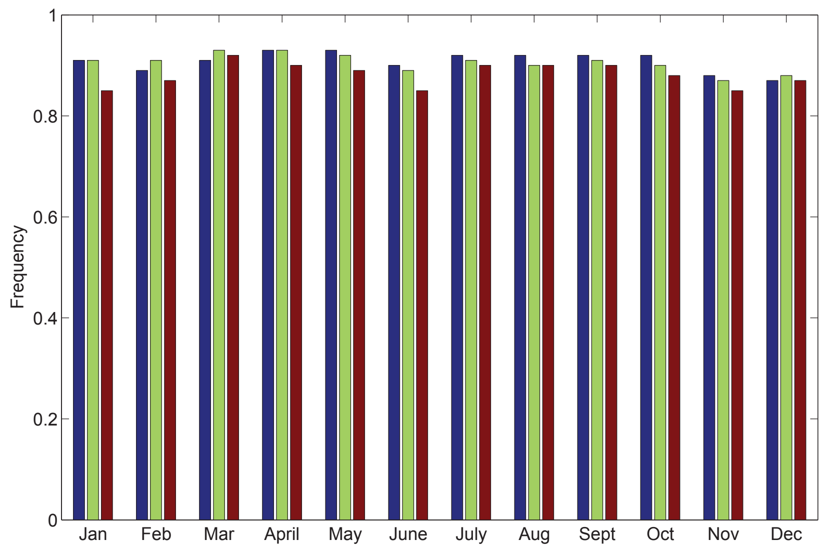



(a) Monthly distribution of records reporting *no image* conditions

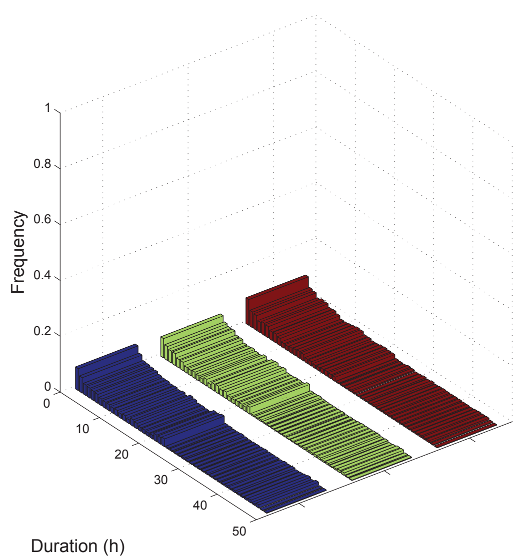



(b) Persistence of reported *no image* events in the TOR region


***Figure C.13 (U):*** *Summary of the frequency and persistence characteristics of reported* no image *events in the TOR region. Weather conditions defined as* no image *events are assumed to prevent the creation of an EO/IR image that is useful for any task.*

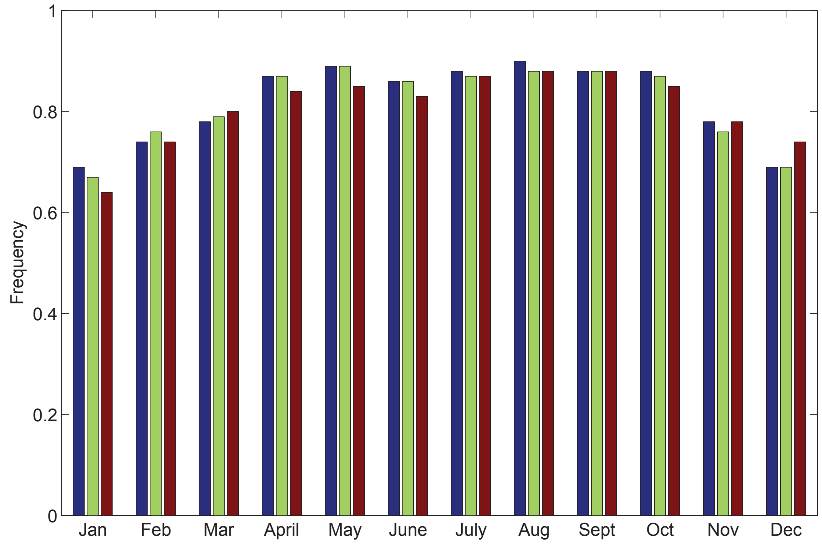



(a) Monthly distribution of records reporting *detection* conditions

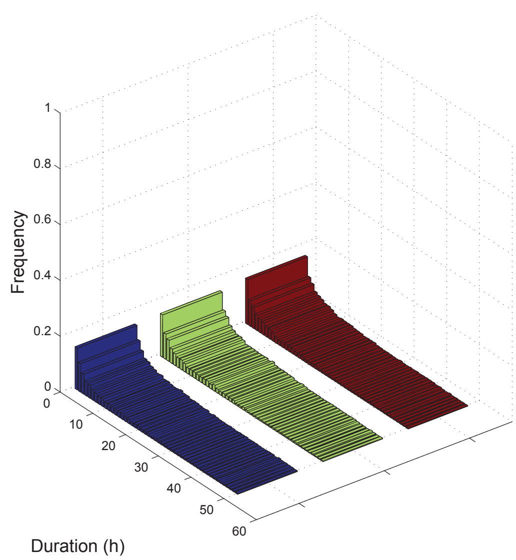



(b) Persistence of reported *detection* events in the TOR region


***Figure C.14 (U):*** *Summary of the frequency and persistence characteristics of reported* detection *events in the TOR region. Weather conditions defined as* detection *events are assumed to have a strong negative effect on EO/IR image quality.*




(a) Monthly distribution of records reporting *classification* conditions




(b) Persistence of reported *classification* events in the TOR region

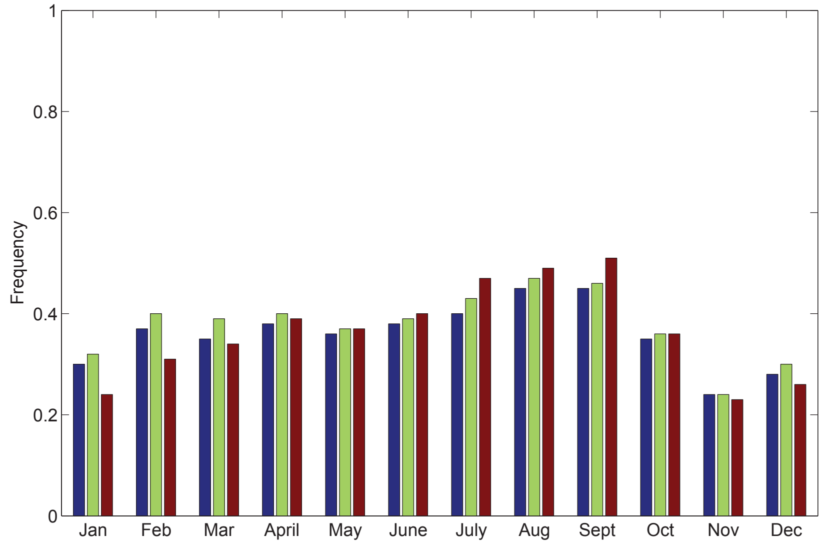

***Figure C.15 (U):*** *Summary of the frequency and persistence characteristics of reported classification events in the TOR region. Weather conditions defined as classification events are assumed to have some negative effect on EO/IR image quality.*

in July through September inclusive, and with lowest frequency in November and December. In July through September inclusive, 49%, 45% and 43% of records from Toronto, Ottawa and Montreal respectively report weather conditions suitable for identification tasks. In November and December, 24% of Toronto records, 27% of Ottawa records and 26% of Montreal records report identification conditions. Of the identification conditions reported in the TOR LOI records, between 29% and 32% of the events last less than 1 h and between 79% and 82% of the events last less than 10 h.

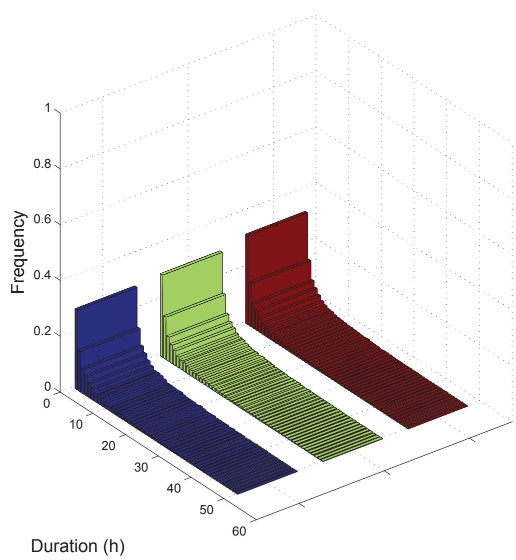
Frequency and persistence characteristics of identification conditions and events for the TOR region are shown in Figure C.16.

### Cloud ceiling

In Toronto, cloud ceiling elevations below 4,500 m are reported in 53% of records. Critical cloud ceiling elevations are observed with greatest frequency in November through February inclusive, when 67% of records report cloud ceilings below 15,000 ft. Critical conditions are met with lowest frequency in July, August and September, when 39% of records report cloud ceiling elevations below 15,000 ft.




(a) Monthly distribution of records reporting *identification* conditions




(b) Persistence of reported *identification* events in the TOR region


***Figure C.16 (U):*** *Summary of the frequency and persistence characteristics of reported identification events in the TOR region. Weather conditions defined as identification events are assumed to have very little negative effect on EO/IR image quality.*

## C.5 ATL region

### No Image and Detection potential

Weather conditions considered unsuitable for EO/IR sensor operations are reported in 21% of Yarmouth records, while weather conditions suitable for detection tasks are reported in 88% of Yarmouth records. NI conditions are reported in 35% of records in June through August, and in 14% of records in November, December, February and March. In comparison, 65% of records report detection conditions in June through August inclusive, and 86% of records report detection conditions in November through March inclusive. In Yarmouth, 21% of NI events last less than 1 h, 50% of events last less than 5 h and 88% of events last less than 20 h, while 12% of detection events last less than 1h, 44% of detection events last less than 10 h, 64% of detetection events last less than 20 h and 95% of events last less than 110 h.

In St. John's, 20% of records in August and September report NI conditions, while 30.5% of records in April and May report NI conditions. Over all, 25% of St. John's records report NI conditions, with 21% of NI events lasting less than 1 h, 58% of events lasting less than 5 h, 78% of events lasting less than 10 h and 95% of events lasting less than 22 h.

Detection conditions are reported in 75% of records in St. John's. Detection conditions are observed with lowest frequency in May, when 69% of records report detection conditions, and with greatest frequency in August and September, when 80% of records report detection conditions. In St. John's, 12% of detection events last less than 1 h, 45% of events last less than 10 h, 69% of events last less than 10 h and 95% of events lasting less than 91 h.

In Cartwright, NI conditions are reported in 11% of records. The highest frequency of NI observations are recorded in April through July inclusive, when 18% of observations report NI conditions. Detection conditions are reported in 89% of Cartwright records. Detection conditions are observed least frequently in April though July inclusive, when 83% of records report detection conditions. Of the reported NI conditions, 22% of critical events last less than 1 h, 58% of events last less than 5 h, 78% of events last less than 10 h and 95% of events last less than 21 h. In comparison, 7% of detection events last less than 1 h, 30% of detection events last less than 10 h, 50% of detection events last less than 20 h and 95% of events last less than 214 h.

In Sydney, weather conditions considered unsuitable for EO/IR operation are reported in 17% of records, while 83% of records report detection conditions. In April through July inclusive, 21% of records report NI conditions, while 12% of records in January report NI conditions. In comparison, 86% of records in August through January report detection conditions, while 77% of May records report detection conditions. Of the NI conditions reported in Sydney, 21% of events last less than 1 h, 60% of events last less than 5 h and 91% of events last less than 15 h. In Sydney, 9% of detection conditions last less than 1 h, 42% of detection conditions last less than 10 h, 62% of detection conditions last less than 20 h and 95% of events last less than 130 h.

In Halifax, 21% of records report NI conditions, while in Greenwood, 12% of records report NI conditions. NI conditions are reported with greatest frequency in Halifax in May through August inclusive, when 25% of records report NI conditions, while in Greenwood, NI conditions are reported with greatest frequency in January, when 15% of records report critical conditions. NI conditions are reported with lowest frequency in February in both Greenwood and Halifax, when 10% and 16% of records respectively report detection conditions. Of the NI conditions reported in Greenwood, 35% of events last less than 1h, 74% of events last less than 5 h and 95% of events last less than 10 h. In Halifax, 18% of NI events last less than 1 h, 51% of NI events last less than 5 h, 87% of NI events last less than 15 h and 95% last less than 21 h.

Weather conditions suitable for detection tasks are reported in 79% of Halifax records and 88% of Greenwood records. In Halifax, detection events are reported with lowest frequency in July, when 71% of records report critical conditions, and with highest frequency in December through February inclusive, when 83% of records report detection events. In Greenwood, detection events are reported with lowest frequency in January, when 85% of records report detection conditions, and with highest frequency in February, when 90% of records report detection conditions. In Halifax and Greenwood, 9% and 15% respectively of detection events last less than 1 h, 27% of events last less than 5 h, 41% of events last less than 10 h and 95% of events last less than 126 h.

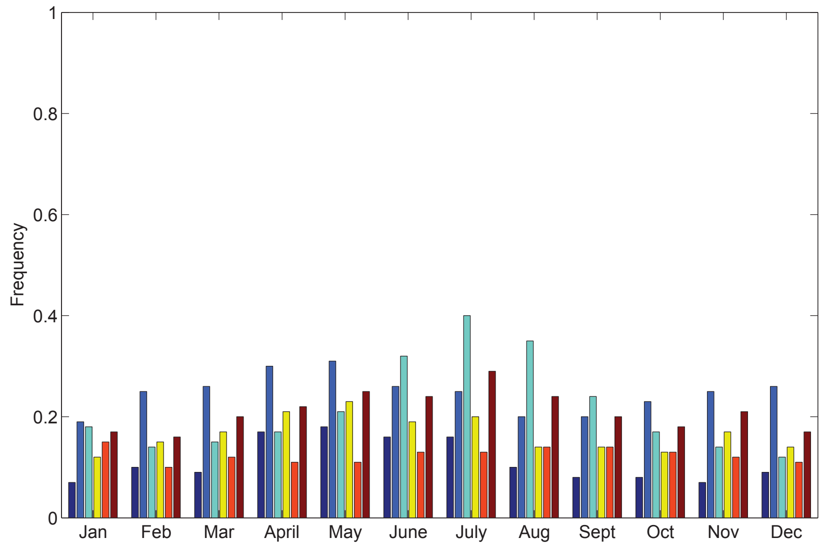
Frequency and persistence characteristics of NI conditions and events for the ATL region are shown in Figure C.17, while frequency and persistence characteristics of detection conditions and events are shown in Figure C.18.

### Classification potential

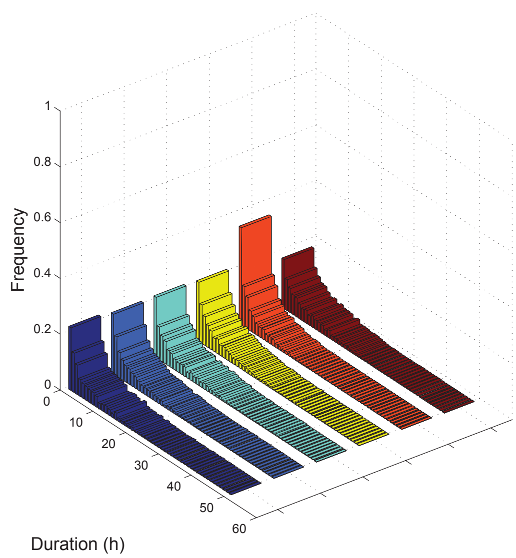
In Cartwright and Greenwood, weather conditions suitable for classification tasks are reported in 77% and 75% of records respectively. In Cartwright, classification conditions are observed with greatest frequency in August, September and October, when, on average, 88% of records report classification conditions. Critical conditions are reported with lowest frequency in December through April, when, on average 69% of records report classification conditions. In Greenwood, classification conditions are observed with greatest frequency in May through October, when 82% of records report critical conditions. In comparison, the lowest frequency of classification events are reported in January, when 57% of records report critical conditions. In Cartwright, 15% of classification events last less than 1 h, 53% of events last less than 10 h, 69% of events last less than 20 h and 95% of events last less than 85 h, while in Greenwood, 21% of classification events last less than 1 h, 63% of events last less than 10 h, 77% of events last less than 20 h and 95% of events last less than 66 h.

In Yarmouth and Halifax, classification conditions are reported in 70% and 69% of records respectively. In Yarmouth and Halifax, classification conditions are met with greatest frequency in October and November, when 80% of Yarmouth records and 79% of Halifax records report classification conditions. Similarly, conditions suitable for classification tasks are reported with lowest frequency in January and July, when 58% of Yarmouth records and 57% of Halifax records report critical conditions. In Yarmouth, 18% of classification events last less than 1 h, 62% of events last less than 10 h, 78% of events last less than 20 h and 95% of events last less than 65 h, while in Halifax, 17% of classification events last less than 1h, 60% of events last less than 10 h, 79% of events last less than 20 h and 95% of events last less than 62 h.

Classification conditions are reported in 73% of Sydney records, with the highest frequency of



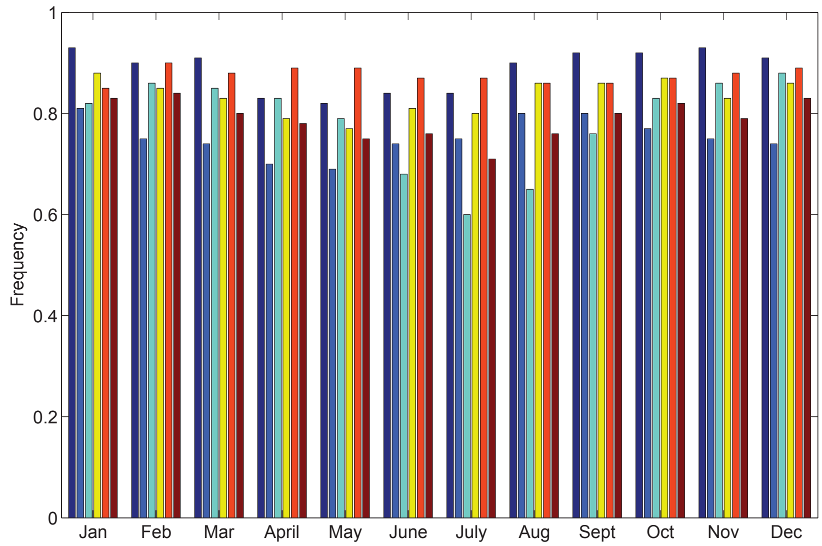

(a) Monthly distribution of records reporting *no image* conditions



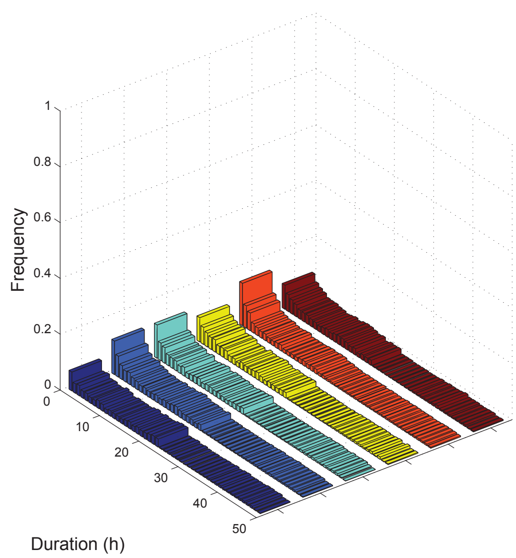

(b) Persistence of reported *no image* events in the ATL region

Cartwright, NFLD | St. John's, NFLD | Yarmouth, NS | Sydney, NS | Greenwood, NS | Halifax, NS

***Figure C.17 (U):*** *Summary of the frequency and persistence characteristics of reported* no image *events in the ATL region. Weather conditions defined as* no image *events are assumed to prevent the creation of an EO/IR image that is useful for any task.*




(a) Monthly distribution of records reporting *detection* conditions




(b) Persistence of reported *detection* events in the ATL region

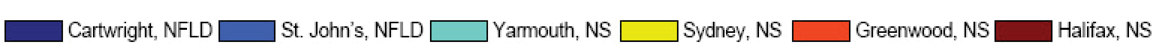



***Figure C.18 (U):*** *Summary of the frequency and persistence characteristics of reported detection events in the ATL region. Weather conditions defined as detection events are assumed to have a strong negative effect on EO/IR image quality.*

classification conditions being reported in June to October inclusive. Over this period, 80% of records report classification weather conditions. The lowest frequency of classification conditions being reported is in January, when 62% of records report critical conditions. In Sydney, 17% of classification events last less than 1 h, 61% of events last less than 10 h, 78% of events last less than 20 h and 95% of events last less than 62 h.

In St. John's, 65% of records report classification conditions. Conditions are reported with lowest frequency in January, when 57% of records report classification conditions, and with greatest frequency in August and September, when 77% of records report critical classification conditions. In St. John's, 19% of classification events last less than 1h, 65% of events last less than 10 h, 84% of events last less than 20 h and 95% of events last less than 47 h.

Frequency and persistence characteristics of classification conditions and events for the ATL region are shown in Figure C.19.

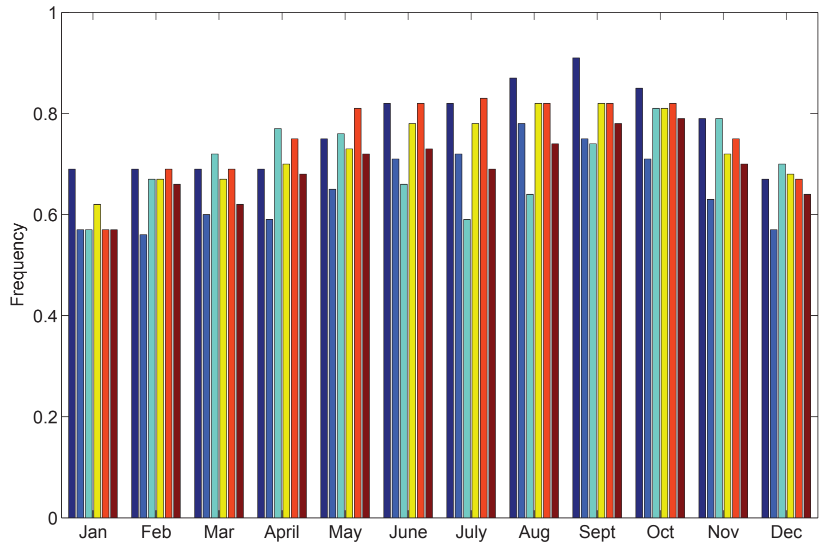
### Identification potential

Across all ATL LOIs, weather conditions suitable for identification tasks are reported in 29% of records. St. John's reports the lowest frequency of identification observations, with 25% of records reporting identification conditions. In contrast, the highest frequency of identification observations are reported in Halifax, Greenwood and Sydney, where 32% of records in Halifax and 31% of records in Greenwood and Sydney report identification conditions. In St. John's, identification conditions are reported with greatest frequency in May through October, when 29% of records report identification conditions. Over the remaining months, 21% of records report critical identification conditions. In Sydney, identification conditions are reported with greatest frequency in June through September inclusive, when 37% of records report identification conditions, and in Greenwood, 40% of records in August through October report identification conditions. Critical conditions are reported with lowest frequency in November through January in both Sydney and Greenwood. Over this period 21% of records report critical conditions. In St. John's, 31% of identification events last less than 1 h, 72% of events last less than 5 h and 87% of events last less than 10 h, while in Sydney, 28% of identification events last less than 1 h, 68% of events last less than 5 h and 84% of events last less than 10 h. In Greenwood, 27% of identification events last less than 1 h, 63% of events last less than 5 h and 80% of events last less than 10 h.

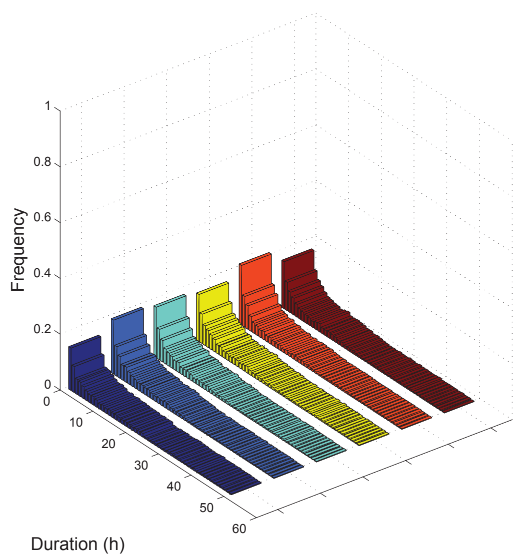
In Yarmouth, identification conditions are reported with greatest frequency in September through October, and in March through May inclusive, when 40% of records report identification conditions. Identification conditions are reported with lowest frequency in January, when 19% of records report identification conditions. In Yarmouth, 31% of identification events last less than 1 h, 68% of events last less than 5 h and 89% of events last less than 15 h.

In Halifax, 32% of records report identification conditions. In August though October inclusive, 39% of records report identification conditions, while in November, 26% of records report identification conditions. Of the identification events reported in Halifax, 26% of events last less than 1 h, 63% of events last less than 5 h and 80% of events last less than 10 h.

Weather conditions suitable for identification conditions are reported in 30% of Cartwright records.




(a) Monthly distribution of records reporting *classification* conditions




(b) Persistence of reported *classification* events in the ATL region

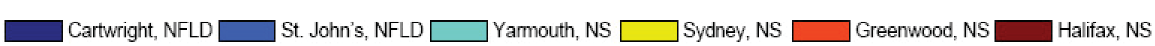



***Figure C.19 (U):*** *Summary of the frequency and persistence characteristics of reported classification events in the ATL region. Weather conditions defined as classification events are assumed to have some negative effect on EO/IR image quality.*

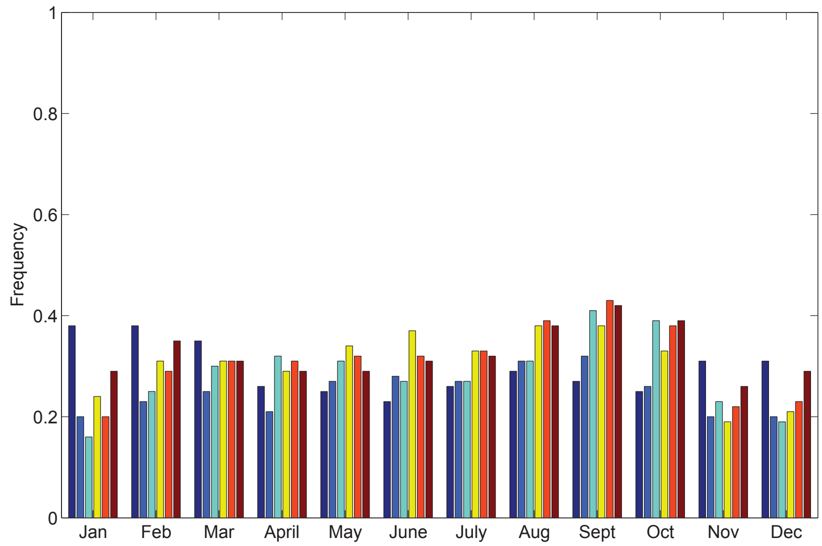
Conditions are reported with lowest frequency in April, June and October, when 25% of records report cricital conditions. In contrast, 37% of records in January through March inclusive report identification weather conditions. In Cartwright, 26% of identification events last less than 1 h, 62% of events last less than 5 h and 79% of events last less than 10 h.

Frequency and persistence characteristics of identification conditions and events for the ATL region are shown in Figure C.17.

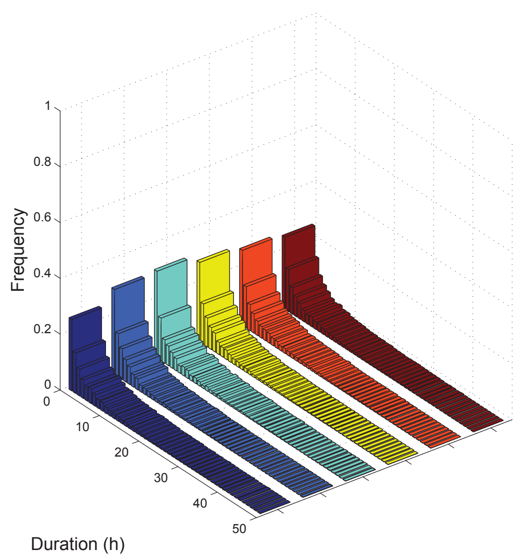
### Cloud ceiling

In St. John's, cloud ceiling elevation below 15,000 ft are reported in 70% of records. Critical cloud ceiling elevations are observed with greatest frequency in November through April inclusive, when 75% of records report cloud ceilings below 15,000 ft. Critical conditions are met with lowest frequency in August, when 61% of records report cloud ceiling elevations below 15,000 ft.

In Greenwood, critical cloud ceiling elevations are reported in 59% of records. Cloud ceiling elevations below 15,000 ft are observed with greatest frequency in November through January inclusive when 73% of records report critical conditions. Critical conditions are met with lowest frequency in August and September, when 46% of records report cloud ceiling elevations below 15,000 ft.




(a) Monthly distribution of records reporting *identification* conditions




(b) Persistence of reported *identification* events in the ATL region

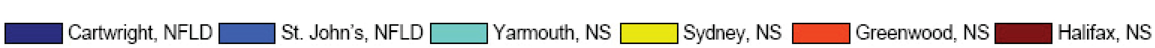



***Figure C.20 (U):*** *Summary of the frequency and persistence characteristics of reported identification events in the ATL region. Weather conditions defined as identification events are assumed to have very little negative effect on EO/IR image quality.*

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# Annex D: Takeoff, Recovery and Icing Conditions – Detailed Assessment Results

## D.1 PAC region

### Visibility

118. VFR-limiting visibility conditions (VIS < 3 nm) are experienced most frequently in the PAC LOIs in September to January inclusive. In Victoria, approximately 12% of all records from October and approximately 11% of all January and November records report visibility conditions of less than 3 nm. For Port Hardy, 7% of all September observations report adverse visibility conditions, while for Vancouver, 6% of all December observations report visibility measurements of less than 3nm. Across all three LOIs, visibility constraints to flight operations are lowest from April though August inclusive, with the mean frequency of adverse visibility conditions over this period being 0%, 2.2% and 0% respectively for Victoria, Port Hardy and Vancouver.

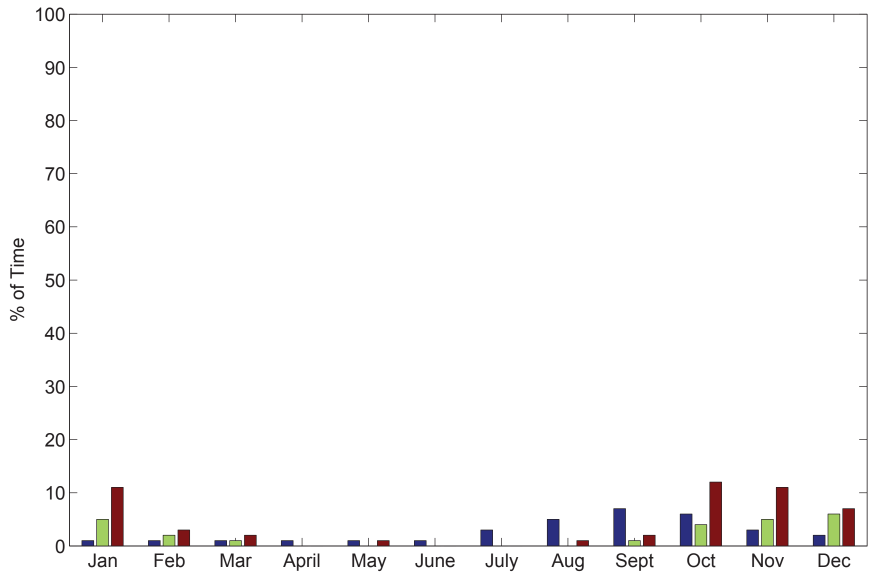
119. Approximately 36% of all adverse visibility events recorded for Victoria last less than 1 h, 80% of events last less than 5 h, and 92% of events last less than 10 h. For Port Hardy, approximately 45% of all recorded adverse events last less than 1 h, 84% last less than 5 h, and 96% last less than 10 h, and for Vancouver, approximately 50% of adverse events last less than 1 h, while 87% last less than 5 h, and 94% last less than 10 h. Results of the PAC visibility assessment are shown in Figure D.1.

### Wind speed

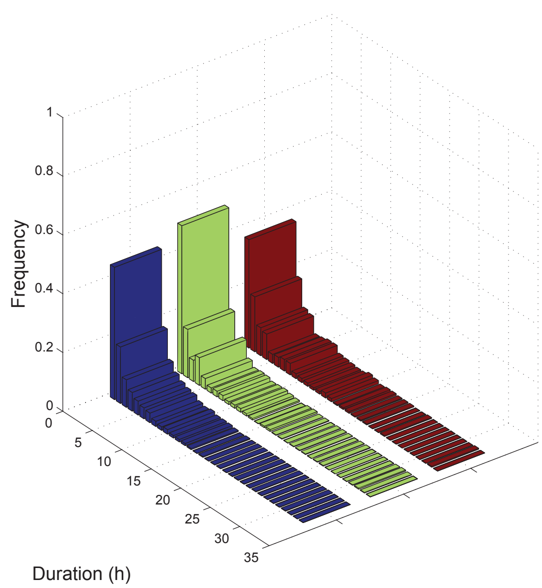
120. In Port Hardy, wind speed conditions exceeding the assumed maximum allowable cross wind speed for UAV launch and recovery ($v_w > 20$ kts) are experienced most frequently from November to March. On average, 3% of all wind speed observations exceed 20 kts during this period, with the highest frequency of exceedence events (4%) occuring in December and January. Of the adverse wind speed conditions observed in Port Hardy, 52% last less than 1h, and 90% last less than 5 h. For Victoria, December is the only month with reported adverse wind speed conditions. Approximatley 1% of all December wind speed observations exceed 20 kts in Victoria. Of these exceedance observations, 84% last less than 1 h, and 97% last less than 4 h. No adverse wind speed conditions are observed in the Vancouver data. The results of the PAC wind speed assessment are shown in Figure D.2.

### Cloud ceiling

121. On average, VFR-limiting cloud ceiling conditions of 1,500 ft or less are recorded in 10% and 7% of all Port Hardy and Vancouver records respectively. In Vancouver, cloud ceiling measurements are reported below 1,500 ft most frequently during December (14%), while in Port Hardy, the months of August (14%) and September (15%) are the most critical.




(a) Monthly distribution of records reporting critical visibility conditions in the PAC region. Values represent the % of time, averaged over all gridboxes and years, that critical visibility conditions are experienced.




(b) Persistence of critical visibility events in the PAC region where VIS < 3 nm.

Port Hardy, BC | Vancouver, BC | Victoria, BC

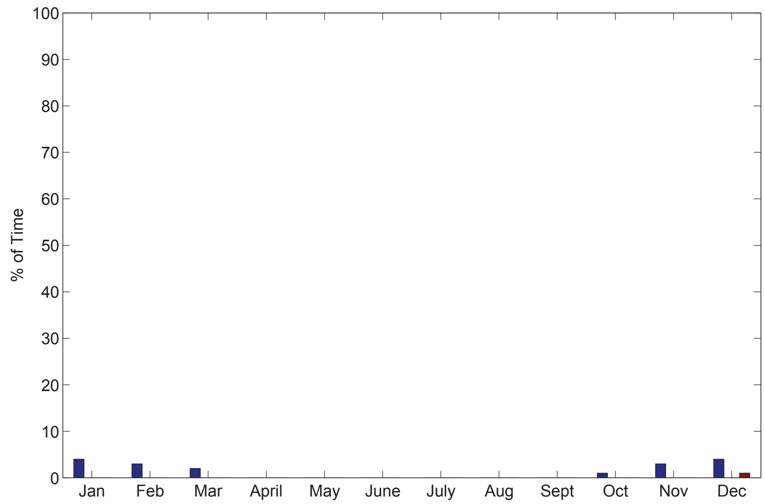
***Figure D.1 (U):*** *Summary of the frequency and persistence characteristics of reported critical visibility conditions in the PAC region. Critical visibility conditions are defined as a visibility measurement < 3 nm.*

## Icing conditions

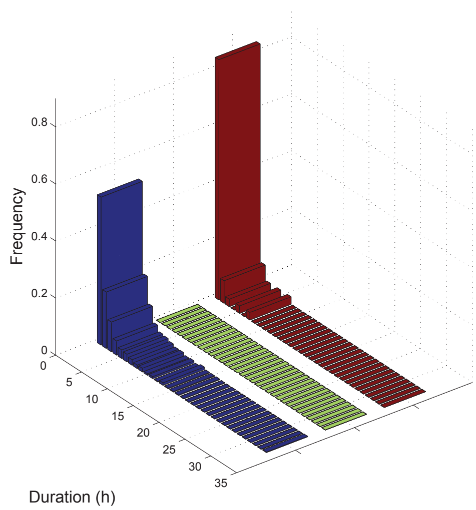
122. For all LOIs in the PAC region the Appleman condition is met most frequently in December and January. Over this period, icing conditions are experienced with a mean frequency of 1.5%, 1% and 1% respectively for Vancouver, Victoria and Port Hardy. In Vancouver, 79% of Appleman events last less than 1 h, while 95% of events last less than 5 h. In Victoria 68% of events last less than 1 h and 97% of events last less than 5 h. In Port Hardy, 61% of Appleman events last less than 1 h, while 94% of events last less than 5 h. The results of the PAC Appleman assessment are shown in Figure D.3.

123. In Victoria, the critical temperature and precipitation test condition for icing is met most frequently in January (8%), followed by March (2%) and December and February (1%). Of these events, 46% last less than 1 h, 82% last less than 5 h, and 97% last less than 10 h. In Port Hardy, the critical test conditions are met in approximately 4% of all January records, 3% of all December records, 2% of all February records and in 1% of all March records. Of these observations, 48% of critical events last less than 1 h, 86% last less than 5h and 96% less than 10 h. No Vancouver records meet the temperature and precipitation test condition over the period of record used in this study. The results of the critical temperature and precipitation test are shown in Figure D.4.

124. In Vancouver, freezing precipitation occurs most frequently during December and January. Over this period, freezing precipitation events have an average frequency of 0.1%. Of all observed freezing precipitation events, 88% last less than 2 h, while 100% of events last less than 4 h. No freezing precipitation events are recorded in Port Hardy or Victoria for the period of record used in this study.



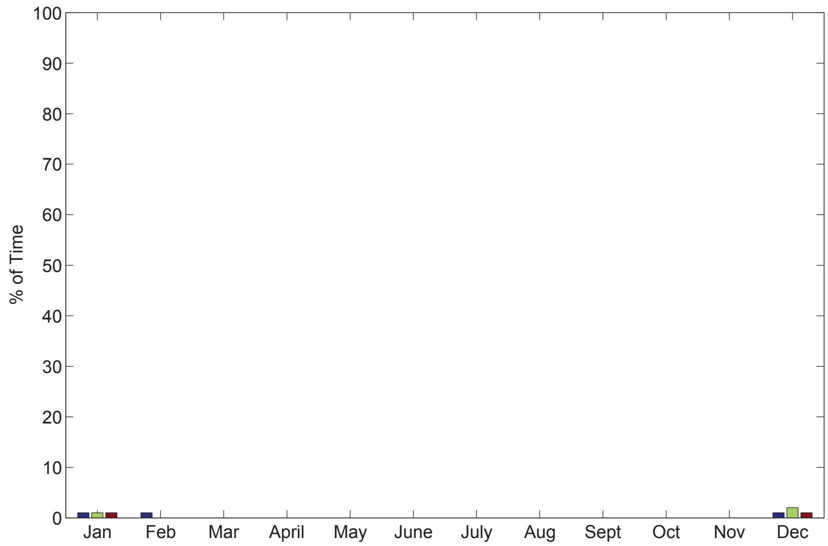

(a) Monthly distribution of records reporting critical wind speed conditions in the PAC region. Values represent the % of time, averaged over all gridboxes and years, that critical wind speed conditions are experienced.



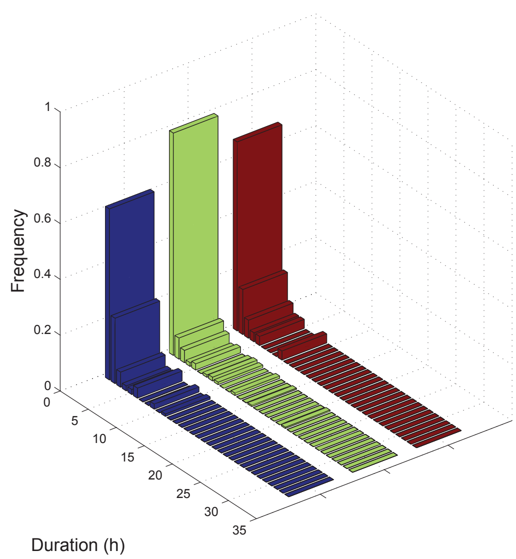

(b) Persistence of critical wind speed events in the PAC region where wind speed > 20 kts.

Port Hardy, BC | Vancouver, BC | Victoria, BC

***Figure D.2 (U):*** *Summary of the frequency and persistence characteristics of reported critical wind speed conditions in the PAC region. Critical wind speed conditions are defined as wind speed measurements > 20 kts.*

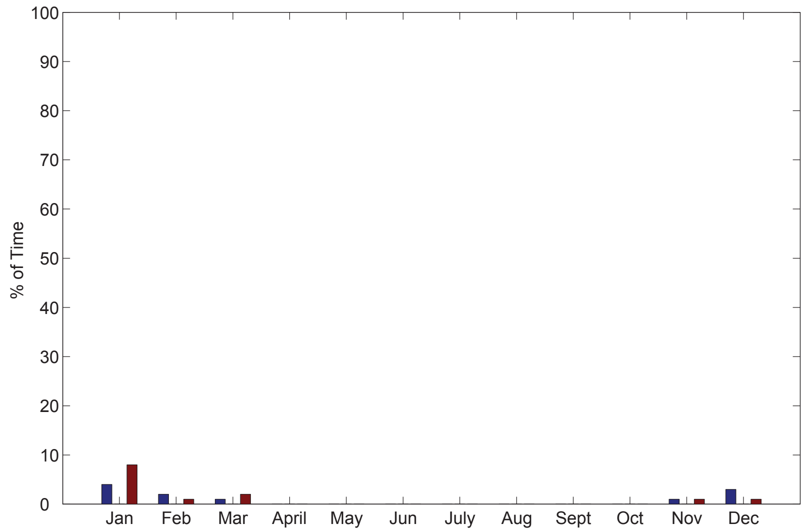



(a) Monthly distribution of records meeting the Appleman condition for icing in the PAC region. Values represent the % of time, averaged over all gridboxes and years, that the Appleman condition is experienced.

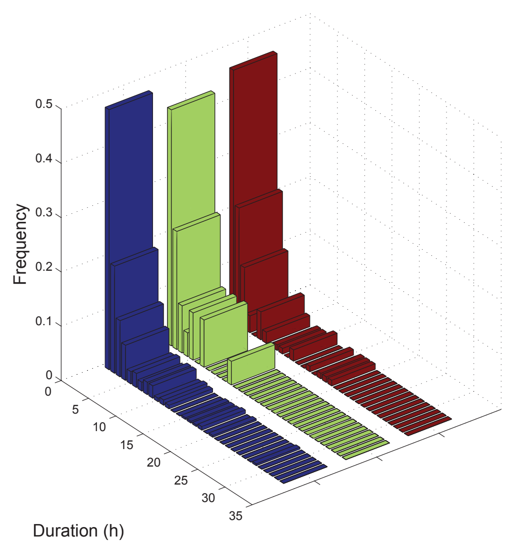



(b) Persistence of Appleman icing events in the PAC region.


***Figure D.3 (U):*** *Summary of the frequency and persistence characteristics of reported Appleman condition events in the PAC region. The Appleman condition defines temperature and humidity conditions under which potential icing conditions exist.*




(a) Monthly distribution of records meeting the critical temperature and precipitation condition for icing in the PAC region. Values represent the % of time, averaged over all gridboxes and years, that critical temperature and precipitation conditions are experienced.




(b) Persistence of critical temperature and precipitation conditions in the PAC region.

Port Hardy, BC   Vancouver, BC   Victoria, BC

***Figure D.4 (U):*** *Summary of the frequency and persistence characteristics of reported critical temperature and precipitation events in the PAC region. The critical temperature and precipitation condition defines icing potential if the ambient temperature is below freezing and any form of precipitation is observed.*

## D.2 ABSK region

### Visibility

125. For the ABSK region, adverse visibility conditions are experienced most frequently in November through February inclusive. With the exception of Swift Current, the frequency of adverse visibility conditions over this period ranges between 4% and 9% across all of the LOIs. In Swift Current, the frequency ranges between 9% and 15% over this same period. Across all LOIs, the frequency of adverse conditions is lowest in June through September inclusive, ranging from 0.1% to 3% over this period. An apparent anomoloy is noted in Swift Current, where 8% of all June observations report visibility conditions of less than 3 nm. Across all LOIs, between 37% and 44% of all adverse visibility events last less than 1 h, while between 83% and 88% of events last less than 5 h. For all ABSK LOIs, at least 95% of reported adverse visibility events last less than 10 h. The results of the ABSK visibili ty assessment are shown in Figure D.5.

### Wind speed

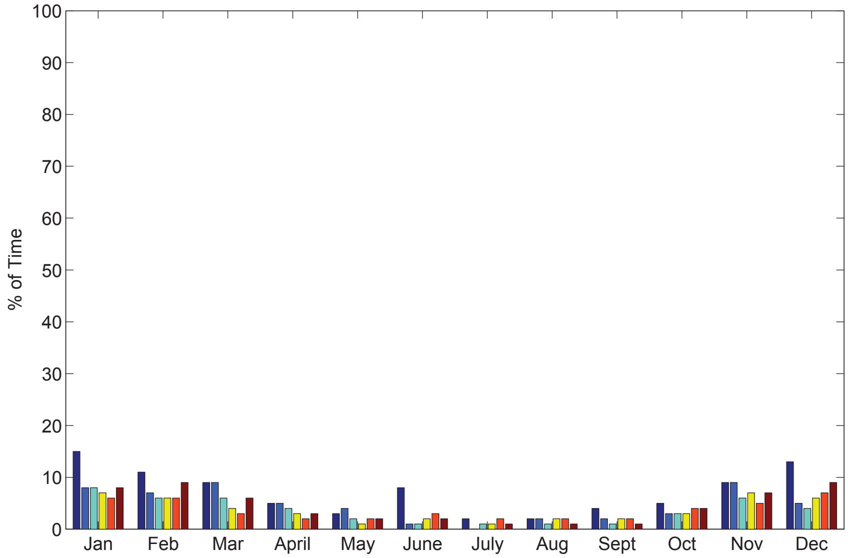
126. The LOIs in the ABSK region are generally unaffected by adverse wind speed conditions. Critical wind speed conditions are met with the greatest frequency in Swift Current, where 5% of all recorded observations exceed 37 km/h. In December to May inclusive, 7% of Swift Current wind speed observations exceed critical conditions. Overall, 52% of the critical wind speed events recorded in Swift Current last less than 1 h and 90% of events last less than 5 h. For the other LOIs, critical conditions are observed to occur with an average frequency of 1%, with 88% of all reported critical events lasting less than 3 h and at least 95% of events lasting less than 8 h. Within this group, critical wind conditions are met most frequently in Calgary, where, on average 2% of observations exceed 37 km/h. The results of the ABSK wind speed assessment are shown in Figure D.6.

### Cloud ceiling

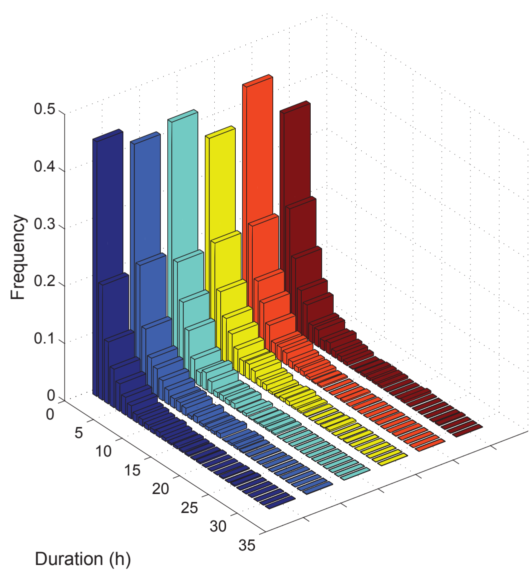
127. In Cold Lake, 9% of all cloud observations report cloud ceiling elevations below 1,500 ft. Event frequency is greatest in November and December, when 17% of records meet the critical cloud ceiling condition. Conversely, the lowest event frequency occurs in July and August, when 4% and 5% respectively of all records meet the critical cloud ceiling condition.

### Icing conditions

128. Figure D.7 shows results of Appleman condition assessment for the ABSK LOIs. In May through September inclusive, the Appleman condition is observed with a frequency of 1% or less across all LOIs in the ABSK region. Appleman conditions are reported with greatest frequency in November to February inclusive. Over this period, the Appleman condition is met on average 31% of the time in Calgary and Edmonton, compared with 50% of the time in the other LOIs. Across all ABSK LOIs, approximately 26% of critical events last less than 1h, while at least 68% of critical events last less than 10 h and 87% of critical events last less than 20 h. Across all ABSK LOIs, at



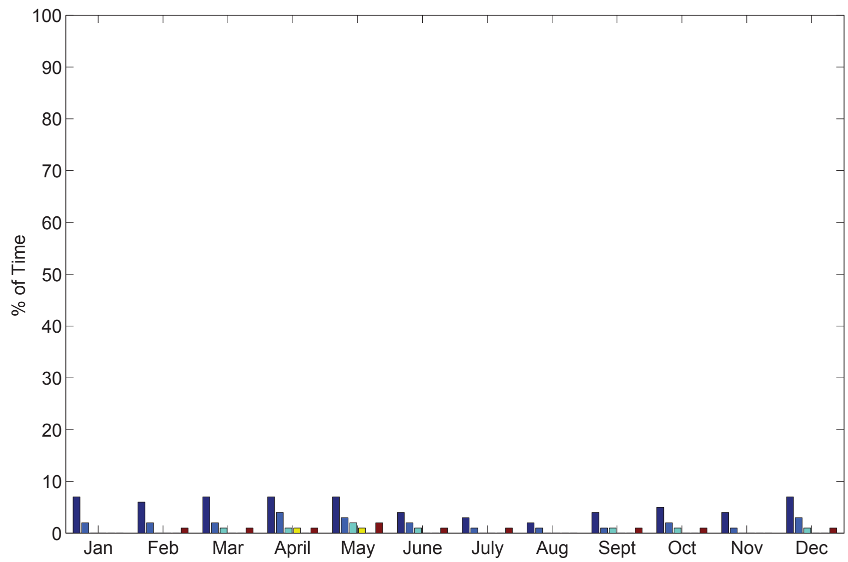

(a) Monthly distribution of records reporting critical visibility conditions in the ABSK region. Values represent the % of time, averaged over all gridboxes and years, that critical visibility conditions are experienced.



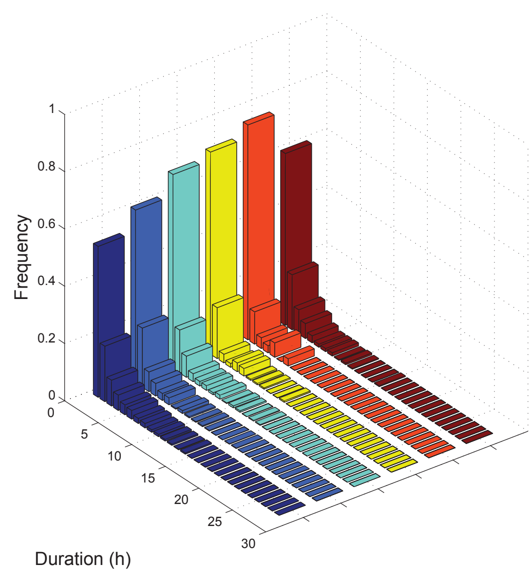

(b) Persistence of critical visibility events in the ABSK region where VIS < 3 nm.

Swift Current, SK | Calgary, AB | Edmonton, AB | Cold Lake, AB | Fort McMurray, AB | Lloydminiser, AB/SK

***Figure D.5 (U):*** *Summary of the frequency and persistence characteristics of reported critical visibility conditions in the ABSK region. Critical visibility conditions are defined as a visibility measurement < 43 nm.*



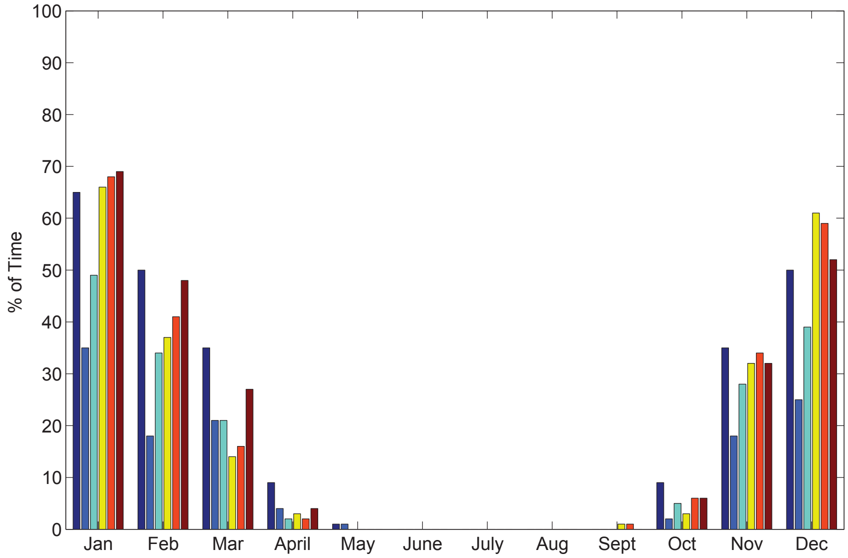

(a) Monthly distribution of records reporting critical wind speed conditions in the ABSK region. Values represent the % of time, averaged over all gridboxes and years, that critical wind speed conditions are experienced.



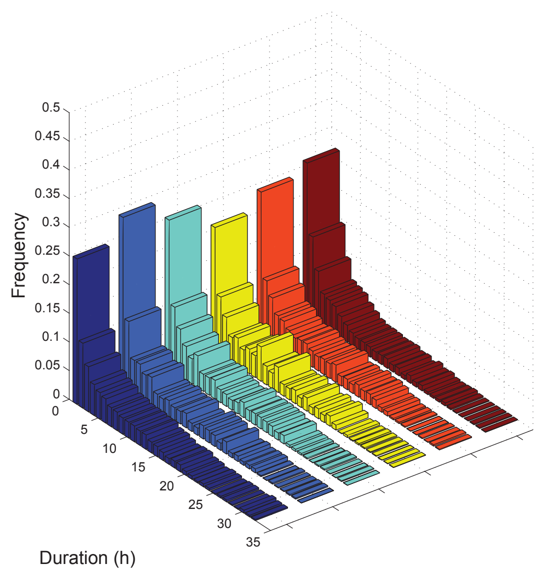

(b) Persistence of critical wind speed events in the ABSK region where wind speed > 20 kts.

Swift Current, SK | Calgary, AB | Edmonton, AB | Cold Lake, AB | Fort McMurray, AB | Lloydminiser, AB/SK

***Figure D.6 (U):*** *Summary of the frequency and persistence characteristics of reported critical wind speed conditions in the ABSK region. Critical wind speed conditions are defined as wind speed measurements > 20 kts.*




(a) Monthly distribution of records meeting the Appleman condition for icing in the ABSK region. Values represent the % of time, averaged over all gridboxes and years, that the Appleman condition is experienced.




(b) Persistence of Appleman icing events in the ABSK region.

Swift Current, SK | Calgary, AB | Edmonton, AB | Cold Lake, AB | Fort McMurray, AB | Lloydminiser, AB/SK

***Figure D.7 (U):*** *Summary of the frequency and persistence characteristics of reported Appleman condition events in the ABSK region. The Appleman condition defines temperature and humidity conditions under which potential icing conditions exist.*

least 95% of critical events last less than 55 h.

129. As in the Appleman assessment, temporal trends are observed in the critical temperature and precipitation test results across all of the ABSK LOIs. Critical conditions are met least frequently in May through September inclusive, when between 0% and 6% of records across all LOIs meet the critical temperature and precipitation criteria. Critical conditions are met with comparatively higher frequency in November through March inclusive, when between 37% and 64% of records across all LOIs indicate icing potential. Excluding Swift Current, on average 51% of records over this period meet the critical temperature and precipitation conditions for icing. Across all LOIs, on average 22% of critical events last less than 1 h, at least 72% of critical events last less than 10 h and at least 87% of critical events lasted less than 20 h. Across all ABSK LOIs, at least 95% of critical events last less than 44 h. The results of the critical temperature and precipitation assessment are shown in Figure D.8.

130. Freezing precipitation events are observed in less than 1% of records across all ABSK LOIs. Freezing precipitation events are most frequently reported in November through March inclusive. Over this period, freezing precipitation events are reported with a mean frequency of 1%. In Swift Current and Fort McMurray, 96% of reported freezing precipitation events last less than 5 h, while 90%, 88%, 85% and 80% of reported events last less than 5 h in Edmonton, Cold Lake, Calgary and Lloydminister respectively.

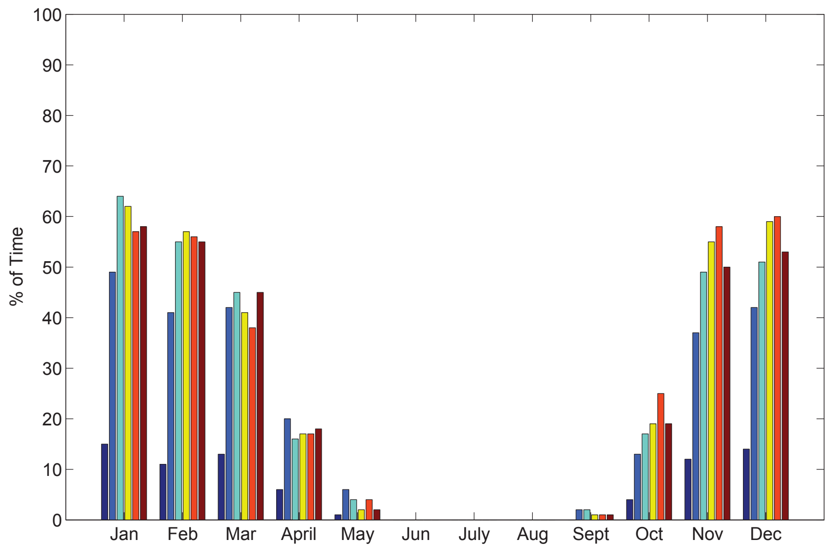
## D.3 NWP region

### Visibility

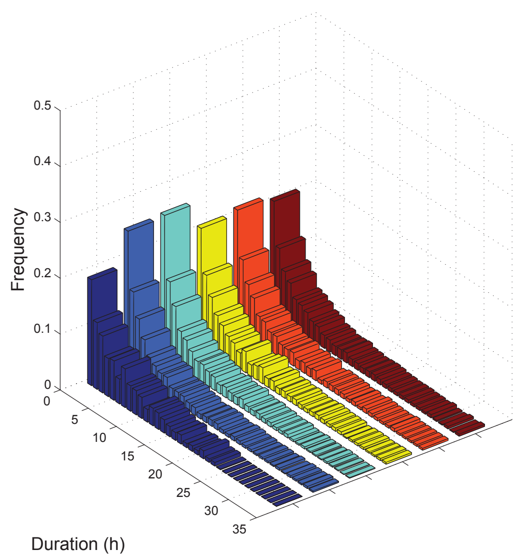
131. In Resolute, the frequency of adverse visibility conditions is quite homogeneous throughout the year. On average, 15% of all records report visibility conditions of less than 4.8 km. Overall, visibility conditions are best in April through to June, when critical conditions are met between 10% and 13% of the time. Critical conditions are encountered most frequently in August, September, October, February and March, 20%, 17%, 18%, 17% and 18% of records respectively report visibility conditions of less than 4.8 km.

132. In Resolute, 75% of the observed critical events last less than 5 h, while 90% last less than 10 h. In Pond Inlet, the mean annual frequency of critical visibility conditions is 7%. Critical visibility conditions are experienced with the lowest frequency in June, July, August and September, when between 3% and 5% of observations meet critical conditions. For the remaining months, on average 8% of observations meet critical conditions. In Pond Inlet, 52% of critical events last less than 1 h, and 90% of critical events last less than 5 h.

133. In Iqualuit, adverse visibility conditions are reported with a mean annual frequency of 8%. Between 3% and 5% of records in June through October inclusive report visibility conditions of less than 4.8 km, while in December through February inclusive, on average 12.6% of records meet critical visibility conditions. In Iqualuit, 84% of critical visibility events last less than 5 h, while



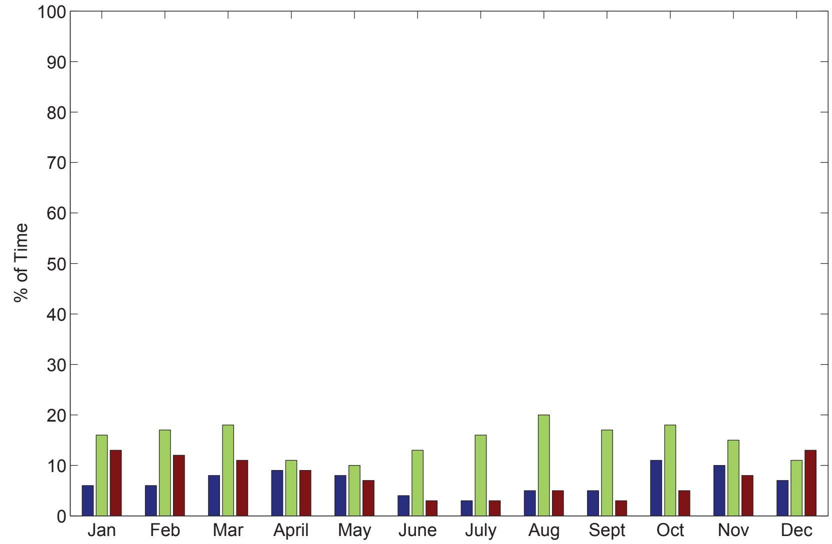

(a) Monthly distribution of records meeting the critical temperature and precipitation condition for icing in the ABSK region. Values represent the % of time, averaged over all gridboxes and years, that critical temperature and precipitation conditions are experienced.



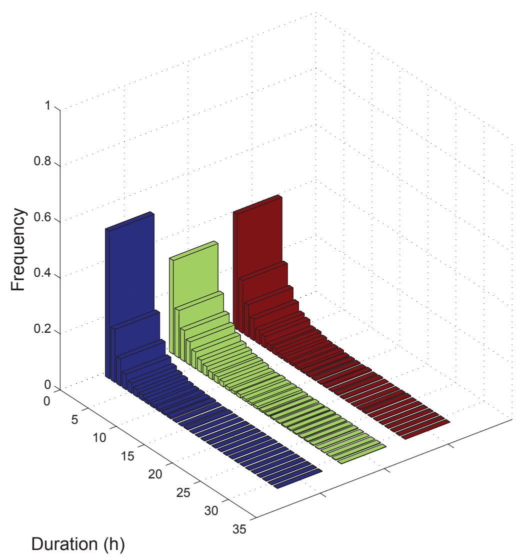

(b) Persistence of critical temperature and precipitation conditions in the ABSK region.

Swift Current, SK | Calgary, AB | Edmonton, AB | Cold Lake, AB | Fort McMurray, AB | Lloydminiser, AB/SK

***Figure D.8 (U):*** *Summary of the frequency and persistence characteristics of reported critical temperature and precipitation events in the ABSK region. The critical temperature and precipitation condition defines icing potential if ambient the temperature is below freezing and any form of precipitation is observed.*




(a) Monthly distribution of records reporting critical visibility conditions in the NWP region. Values represent the % of time, averaged over all gridboxes and years, that critical visibility conditions are experienced.




(b) Persistence of critical visibility events in the NWP region where VIS < 3 nm.


***Figure D.9 (U):*** *Summary of the frequency and persistence characteristics of reported critical visibility conditions in the NWP region. Critical visibility conditions are defined as a visibility measurement < 3 nm.*

95% of events last less than 10 h. The results of the visibility asssessment are shown in Figure D.9.

### Wind speed

134. In Pond Inlet, on average, 1.5% of all records report critical windspeed conditions. Of these critical events, 60% last less than 1 h, while 94% lasted less than 5 h.

135. In Resolute, critical wind speed conditions are met with an average frequency of 11%. In June and July, the frequency of critical events ranges between 5% and 6%, while the average frequency is 15.6% over the months of September to November inclusive. In Resolute, 48% of critical events last less than 1 h, 84% of events last less than 5 h and 94% of events last less than 10 h.

136. Compared to Resolute, wind speed measurements are more seasonally homogeneous in Iqualuit. Critical wind speed conditions are experienced on average 12% of the time in December, 11% of the time in November and January, and 3% of the time in June through September inclusive. In Iqualuit, 51% of critical events last less than 1 h, 89% last less than 5 h and 96% last less than 10 h. The results of the wind speed asssessment are shown in Figure D.10.

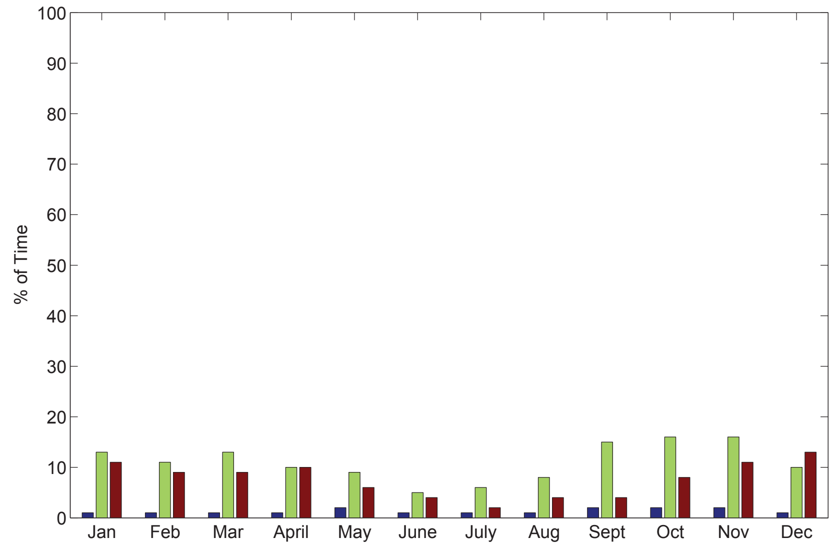
### Cloud ceiling

137. In Iqualuit and Resolute, on average 12% and 20% respectively of all cloud ceiling observations report cloud elevations at or below 1,500 ft. In Resolute, critical conditions are met most frequently during August and September, when 45% and 44% respectively of cloud observations report elevations below 450 m. In Iqualuit, 20% of cloud ceiling observations in May met critical conditions, as do 15% of September observations. Critical conditions were met with the lowest frequency in December through March, when approximately 5% of Resolute records and 9% of Iqualuit records meet critical conditions.

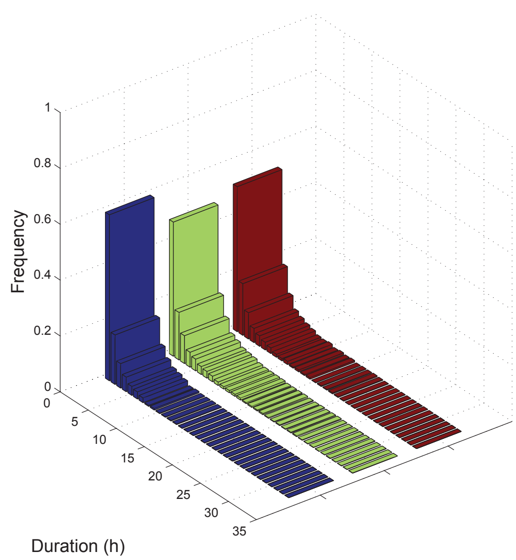
### Icing conditions

138. Figure D.11 shows the results of the Appleman condition assessment. Significant temporal trends are observed in icing potential at all NWP region LOIs. In Resolute, the Appleman condition is met in more than 50% of records from October through May inclusive, and in more than 90% of records for the months of November through March inclusive. Critical conditions were met with the lowest frequency in July and August, when 3% and 8% respectively of records met the Appleman condition for icing potential. In Resolute, 32% of Appleman events last less than 1 h, 75% of events last less than 10 h, 84% of events last less than 20 h and 95% of events last less than 204 h.

139. As in Resolute, in Pond Inlet the Appleman condition is met in more than 40% of records from October through May inclusive, and in more than 90% of records for the months of December through March. Critical conditions are recored with the lowest frequency in June through August inclusive, when, on average 1.6% of records met the Appleman condition. In Pond Inlet, 34% of Appleman events last less than 1 h, 81% last less than 10 h, 89% last less than 20 h and 95% last less than 139 h.




(a) Monthly distribution of records reporting critical wind speed conditions in the NWP region. Values represent the % of time, averaged over all gridboxes and years, that critical wind speed conditions are experienced.




(b) Persistence of critical wind speed events in the NWP region where wind speed > 20 kts.


***Figure D.10 (U):*** *Summary of the frequency and persistence characteristics of reported critical wind speed conditions in the NWP region. Critical wind speed conditions are defined as wind speed measurements > 20 kts.*

140. In Iqualuit, 91% of records in January and February, 78% of records in December and 77% of records in March meet the Appleman condition. In June through September inclusive less than 1% of records meet critical conditions, while 9% of records meet critical conditions in October. In Iqualuit, 30% of Appleman events last less than 1 h, 82% of events last less than 10 h and 95% of events last less than 41 h.

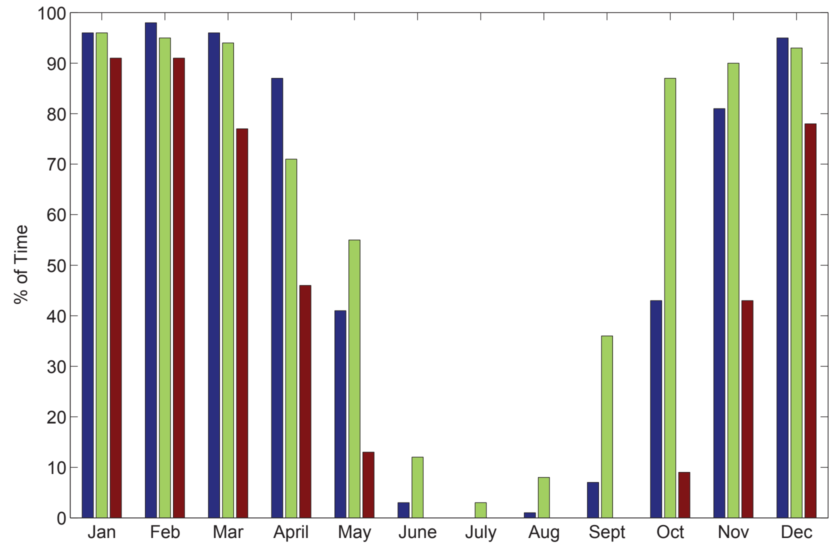
141. For the NWP LOIs, the critical temperature and precipitation test showed similar trends as the Appleman condition assessment. In Pond Inlet, critical temperature and precipitation conditions are met with a mean annual frequency of 18%. Critical conditions are met with the highest frequency in October, when 44% of records report temperatures below zero and precipitation. On average 2.3% of records in June, July and August report critical conditions, while, on average 21% of records for the remaining months report critical conditions. In Pond Inlet, 14.5% of critical temperature and precipitation events last less than 1h, 80% last less than 10 h, and 98% last less than 20 h.

142. In Resolute, critical conditions are met with the lowest frequency in July, when approximately 7% of records meet critical temperature and precipitation conditions. On average 75% of records from September to March inclusive meet critical conditions. In Resolute, 18% of critical temperature and precipitation events last less than 1 h, 67% last less than 10 h, 80% last less than 20 h and 95% last less than 77 h.

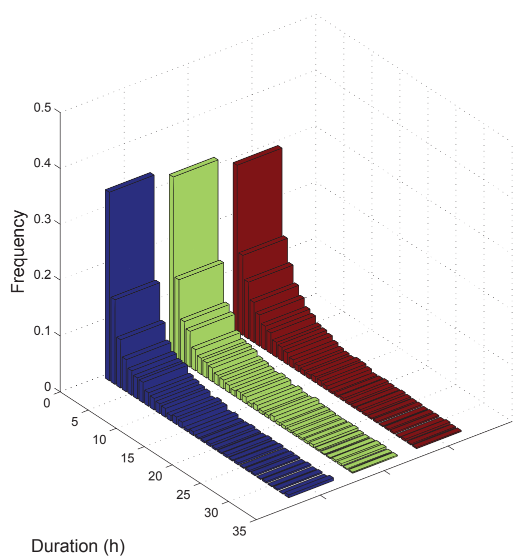
143. In Iqualuit, critical temperature and precipitation conditions are met with negligible frequency in July and August, and with the greatest frequency September through March inclusive, when on average 56% of records meet critical conditions. Of the critical events recorded in Iqualuit, 12% last less than 1h, 65% last less than 10 h, 84% last less than 20 h and 95% last less than 47 h. Results of the critical temperature and precipitation test for the NWP region are shown in Figure D.12.

144. Compared to the Appleman condition assessment results, the critical temperature and precipitation test results are more temporally homogeneous, with icing conditions being reported less frequently during the winter months, and more frequently during the spring and autumn months. This observation suggests that a conservative approach to estimating icing potential should consider the critical (i.e. highest frequency) case as representing icing risk.

145. In Resolute, freezing precipitation events are reported in June through October inclusive. Freezing precipitation events are reported in approximately 5% of August and September records, while in June, July and October, freezing precipitation is reported with an average frequency of 2%. In Iqualuit and Pond Inlet, freezing precipitation events are reported in March through June and in October through December. Over these periods, less than 1% of records from either location report freezing precipitation. In Iqualuit and in Pond Inlet, at least 40% of freezing precipitation events last less than 1h and at least 90% of events last less than 5 h.



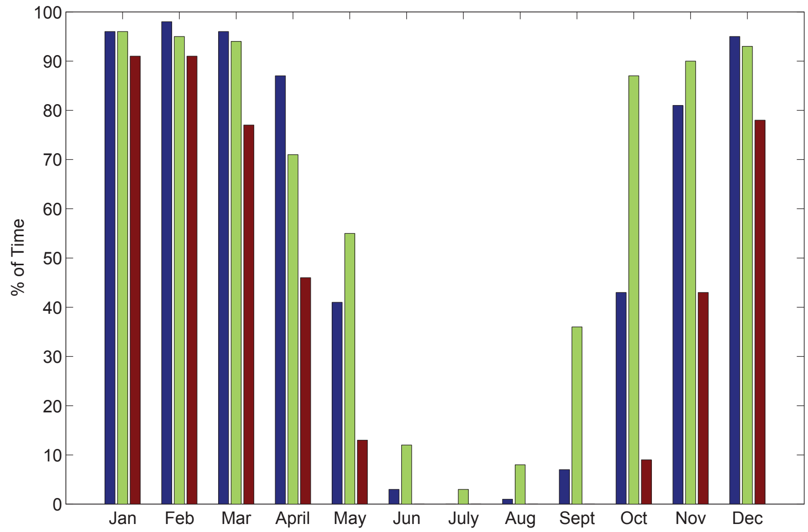

(a) Monthly distribution of records meeting the Appleman condition for icing in the NWP region. Values represent the % of time, averaged over all gridboxes and years, that the Appleman condition is experienced.



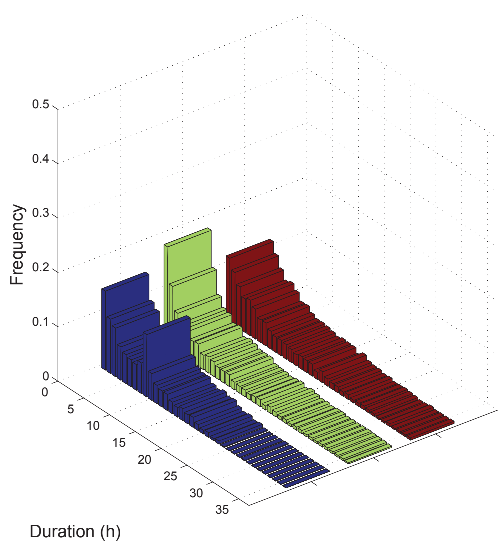

(b) Persistence of Appleman icing events in the ABSK region.



***Figure D.11 (U):*** *Summary of the frequency and persistence characteristics of reported Appleman condition events in the NWP region. The Appleman condition defines temperature and humidity conditions under which potential icing conditions exist.*




(a) Monthly distribution of records meeting the critical temperature and precipitation condition for icing in the NWP region. Values represent the % of time, averaged over all gridboxes and years, that critical temperature and precipitation conditions are experienced.




(b) Persistence of critical temperature and precipitation conditions in the NWP region.


***Figure D.12 (U):*** *Summary of the frequency and persistence characteristics of reported critical temperature and precipitation events in the NWP region. The critical temperature and precipitation condition defines icing potential if ambient temperature $< 0°$ and any form of precipitation is observed.*

## D.4 TOR region

### Visibility

146. Temporal trends in visibility conditions are geographically homogeneous across the TOR region LOIs, with, on average, 5%, 6% and 5% of all records for Toronto, Ottawa and Montreal respectively reporting visibility conditions of less than 3 nm. Across the region, critical visibility conditions are observed approximately 2% of the time in May through September inclusive, and between 8% and 13% of the time in December and January. For Montreal, 43% of critical visibility events last less than 1 h, while for Ottawa and Toronto, 42% of critical events last less than 1 h. At all locations, 85% of critical events last less than 5 h and 97% of critical events last less than 10 h. The results of the TOR region visiblity assessment are shown in Figure D.13.

### Wind speed

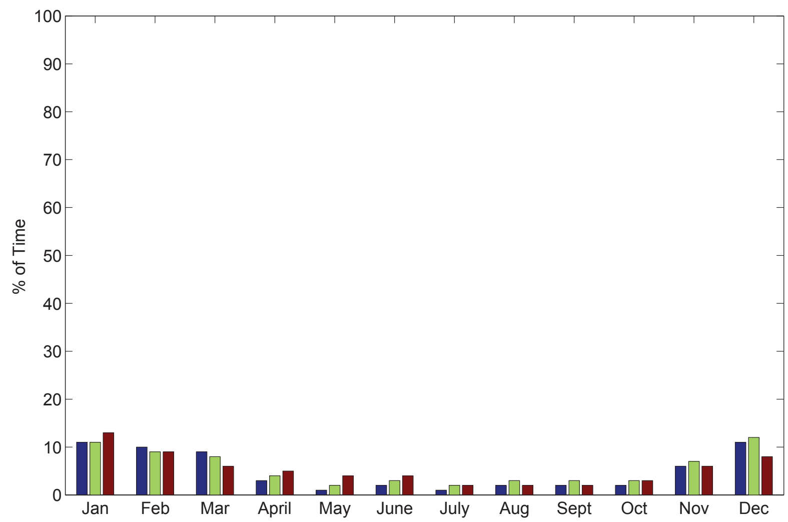
147. In the TOR region, critical wind speed conditions are reported with mean frequency of 2% across all LOIs. Critical conditions are reported with the highest frequency in Toronto in February and March, when 5% of records report wind speeds in excess of 20 kts, and in Montreal in February, when 4% of records report wind speeds in excess of 20 kts. In Ottawa, critical windspeed conditions are encountered most frequently in October through April, when 1% of monthly records report wind speeds in excess of 20 kts. In Toronto, 56% of critical wind speed events last less than 1 h and 91% lasted less than 5 h. In Ottawa, 70% of critical events last less than 1 h and 95% lasted less than 5 h, while in Montreal, 62% of critical events last less than 1 h and 93% last less than 5 h. The results of the TOR region critical windspeed assessment are shown in Figure D.14.

### Cloud ceiling

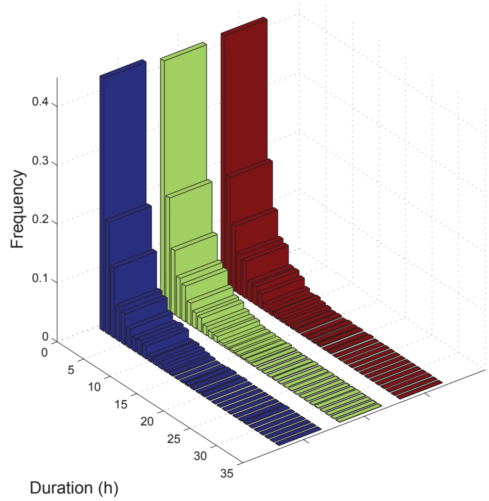
148. In Toronto, on average 10% of records report cloud ceiling measurements below 450 m. Approximately 20% of reports in January measure cloud ceiling below 450 m, while in December and February, approximately 16% and 15% of reports respectively meet the critical cloud ceiling condition. Less than 5% of records report critical cloud ceiling conditions during the months of July through September.

### Icing conditions

149. The TOR region shows seasonal trends with respect to the Appleman condition. Critical conditions are met most frequently in December through February inclusive for all TOR region LOIs. Overall, the Appleman condition is met most frequently in January. In Ottawa, 22% of January records meet the Appleman condition, while in Montreal and Toronto, 20% and 13% of records respectively show icing potential. Across all TOR LOIs, critical conditions are met in less than 1% of the records for April through October, and no critical conditions are observed in May through September. In Montreal, 32% of Appleman events last less than 1h, 69% of events last less than 5 h, and 95% of critical events last less than 14 h. In Ottawa, 29% of Appleman events last less than 1 h, 64% of events last less than 5 h and 95% of events last less than 16h. In Toronto, 42% of

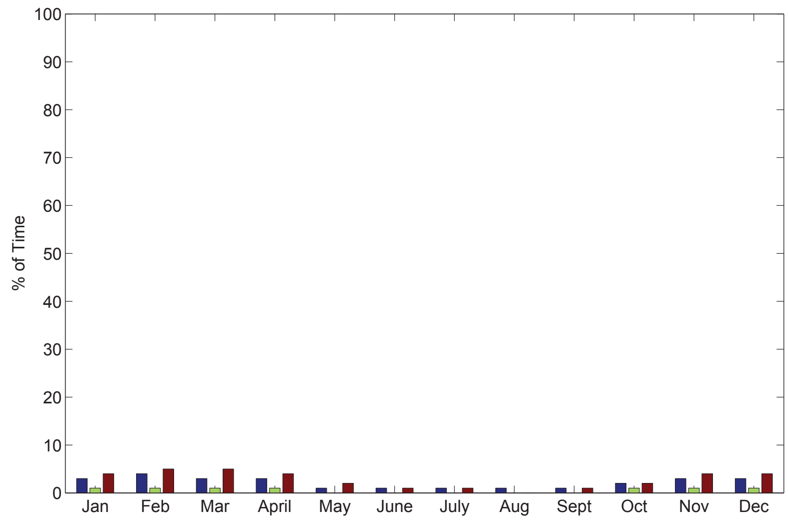



(a) Monthly distribution of records reporting critical visibility conditions in the TOR region. Values represent the % of time, averaged over all gridboxes and years, that critical visibility conditions are experienced.

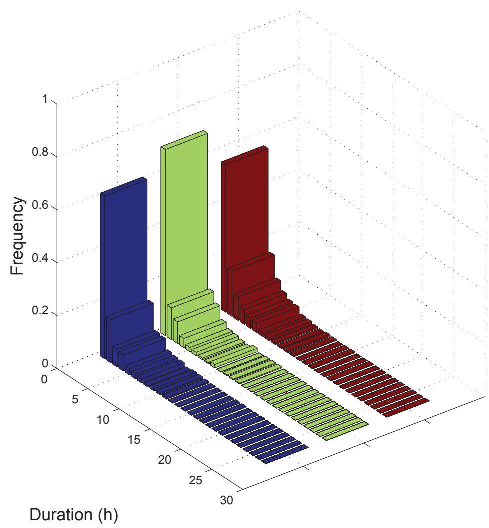



(b) Persistence of critical visibility events in the TOR region where VIS < 3 nm.


***Figure D.13 (U):*** *Summary of the frequency and persistence characteristics of reported critical visibility conditions in the TOR region. Critical visibility conditions are defined as a visibility measurement < 3 nm.*




(a) Monthly distribution of records reporting critical wind speed conditions in the TOR region. Values represent the % of time, averaged over all gridboxes and years, that critical wind speed conditions are experienced.




(b) Persistence of critical wind speed events in the TOR region where wind speed > 20 kts.

Montreal, PQ   Ottawa, ON   Toronto, ON

***Figure D.14 (U):*** *Summary of the frequency and persistence characteristics of reported critical wind speed conditions in the TOR region. Critical wind speed conditions are defined as wind speed measurements > 20 kts.*

critical events last less than 1h, 74% of events last less than 5 h, and 92% of events last less than 10 h. Results from the TOR region Appleman condition assessment are shown in Figure D.15.

150. Critical temperature and precipitation test results show similar trends to the Appleman condition assessment. Across all TOR region LOIs, critical conditions are met most frequently during November to March inclusive, with the highest frequency observed in January. In January, 59% of records in Ottawa and Montreal, and 53% of records in Toronto meet critical icing temperature and precipitation conditions. Over the November to March period, approximately 43% of records in Ottawa, 41% of records in Montreal and 34% of records in Toronto meet critical temperature and precipitation conditions. In Toronto, 25% of critical events last less than 1h, 81% of events last less than 10 h and 92% of events last less than 20 h. In Ottawa, 24% of events last less than 1 h, 75% of events last less than 10 h and 95% of events last less than 34 h, and in Montreal, 23% of events last less than 1 h, 74% of events last less than 10 h and 95% of events last less than 38 h. Figure D.16 shows the results of the critical temperature and precipitation test for the TOR region.

151. On average, freezing precipitation events are reported in approximately 1% records across each of the three TOR LOIs. In January, 3% of Ottawa records, 2% of Montreal records and 1% of Toronto records report freezing precipitation events. In April, the frequency of freezing precipitation events is less than 0.5% across each of the LOIs, and in May through September inlusive, the frequency of freezing precipitation events is less than 0.001% across each of the TOR LOIs. In Montreal and Ottawa, approximately 43% of freezing precipitation events last less than 1 h and at least 87% of events last less than 5 h, while in Toronto, 45% of freezing precipitation events last less than 1 h and 94% of events last less than 5 h.

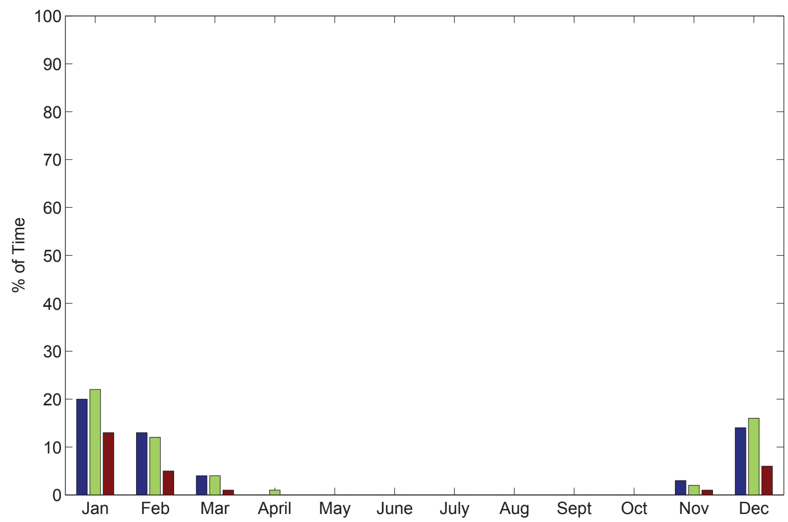
## D.5 ATL region

### Visibility

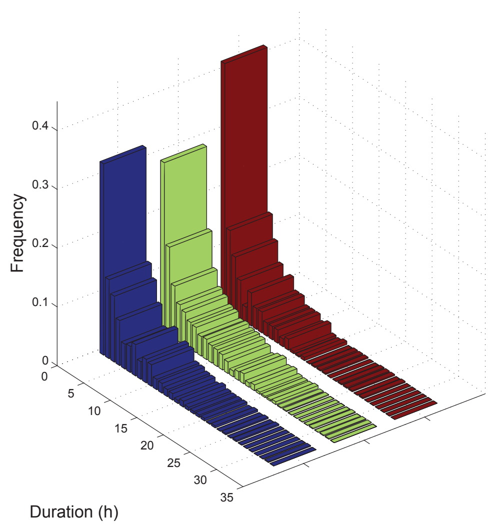
152. Both geographic and temporal trends in visibility conditions are observed across the 5 LOIs in the ATL region. Critical visibility conditions are experienced more frequently on the Atlantic coast compared to other coastal and inland areas, and more frequently during the autumn, winter and spring months compared to the summer months. On average, 19% of visibility records for Halifax and St. John's record visibility conditions of less than 4.8 km, while critical conditions are experienced least often in Grenwood and Cartwright, where, on average 8% and 12% respectively of records show visibility conditions of less than 3 nm.

153. For Halifax, the frequency of critical visibility conditions is relatively uniform from November to August, when approximately 20% of records report critical conditions. On average, 23% of January records report visibility conditions of less than 3 nm, while only 12% of October records report critical conditions. In Halifax, 28% of critical visibility events lasted less than 1 h, 67% of events lasted less than 5 h, and 95% of events lasted less than 16 h.

154. In St. John's, on average 22% of records from November to June report critical visibility conditions. Critical conditions are observed most frequently in April, when 26% of records report visibility conditions less than 3 nm. Conversely, 11% of August records report critical visibility



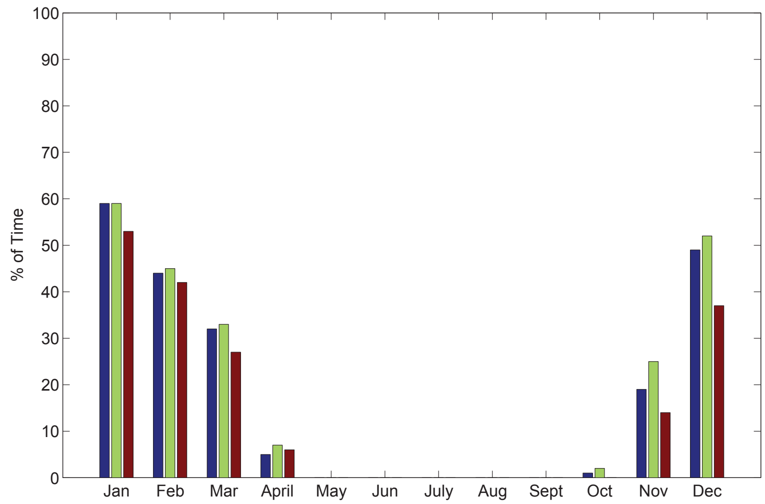

(a) Monthly distribution of records meeting the Appleman condition for icing in the TOR region. Values represent the % of time, averaged over all gridboxes and years, that the Appleman condition is experienced.



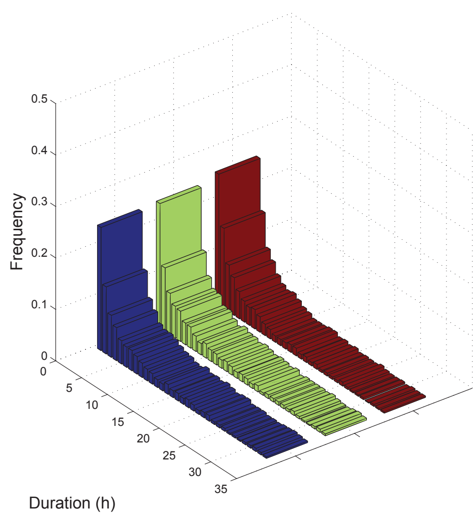

(b) Persistence of Appleman icing events in the TOR region.

Montreal, PQ  Ottawa, ON  Toronto, ON

***Figure D.15 (U):*** *Summary of the frequency and persistence characteristics of reported Appleman condition events in the TOR region. The Appleman condition defines temperature and humidity conditions under which potential icing conditions exist.*




(a) Monthly distribution of records meeting the critical temperature and precipitation condition for icing in the TOR region. Values represent the % of time, averaged over all gridboxes and years, that critical temperature and precipitation conditions are experienced.




(b) Persistence of critical temperature and precipitation conditions in the NWP region.


***Figure D.16 (U):*** *Summary of the frequency and persistence characteristics of reported critical temperature and precipitation events in the TOR region. The critical temperature and precipitation condition defines icing potential if the ambient temperature is below freezing and any form of precipitation is observed.*

conditions. In St.John's, 34% of critical events lasted less than 1 h, 74% lasted less than 5 h, and 95% lasted less than 16 h.

155. Cartwright, Sydney and Greenwood all exhibit similar temporal trends with respect to visibility conditions. From August to October, on average 6% of records from each LOI report visibility conditions less than 3 nm. In Cartwright and Sydney, critical conditions are observed in approximately 17% of April records, while in Greenwood, approximately 17% of January records report critical conditions. In Cartwright, 29% of critical events lasted less than 1 h, 72% of events lasted less than 5 h, and 95% of events lasted less than 16 h. In Sydney, 32% of critical visibility events lasted less than 1 h, 78% of events lasted less than 5 h, and 95% less than 12 h. In Greenwood, 40% of critical visibility events lasted less than 1 h, and 95% less than 10 h.

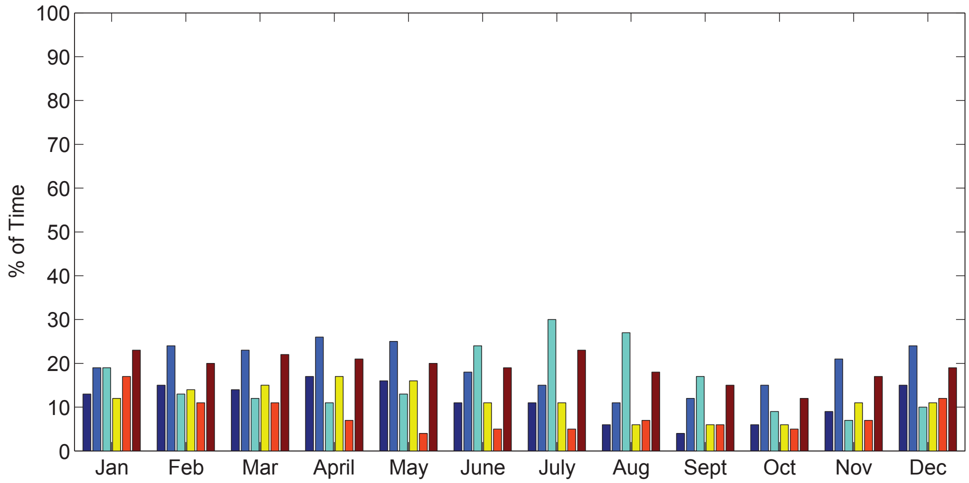
156. A distinct temporal pattern in visibility conditions is observed in Yarmouth, where approximately 30% of July records meet critical conditions, compared with only 7% of November records reporting visibility conditions of less than 3 nm. In Yarmouth, 32% of critical events lasted less than 1 h, 72% of events lasted less than 5 h, and 95% of events lasted less than 16 h. Results of the ATL visibility assessment are shown in Figure D.17.

### Wind speed

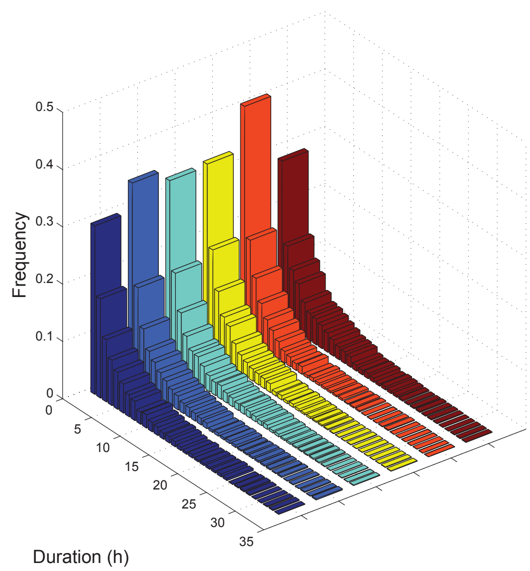
157. Of the ATL region LOIs, critical wind speed conditions are experienced with greatest frequency in Cartwright and St. John's. In Cartwright and St.John's, critical wind speed conditions in excess of 20 kts are recorded in approximately 10% of the records from October to March inclusive. In comparison, critical wind speed conditions are recorded in approximately 1% of July and August records. In Cartwright, 50% of critical events last less than 1 h, 84% of events last less than 5 h, and 93% of events last less than 10 h, while in St. John's, 52% of events last less than 1 h, 88% of events last less than 5 h, and 96% of events less than 10 h. Compared to Cartwright and St. John's, critical wind speed conditions are observed at much lower frequencies in the more southerly ATL LOIs. In Greenwood, Yarmouth, Sydney and Halifax, critical wind speed conditions exceeding 20 kts are reported in approximatley 2%, 3%, 4% and 3% of observations respectively, while across each location, approximately 1% of July and August records report wind speed conditions greater than 20 kts. Across these LOIs, at least 56% of critical visibility events lasted less than 1 h, while at least 91% of events lasted less than 5h. Results of the ATL wind speed assessment are shown in Figure D.18.

### Cloud ceiling

158. In St. John's, on average 41% of records report cloud ceiling elevations below 1,500 ft. Critical cloud ceiling conditions are encountered most frequently in April, when 50% of records reported conditions, and least frequently in August and September, when 34% of records report cloud ceiling elevations below 1,500 ft. Conditions are slightly improved in Greenwood, where, on average, 21% of observations report critical cloud ceiling conditions. Event frequencies range from a low of 16% in October to a high of 24% in January, March and April.




(a) Monthly distribution of records reporting critical visibility conditions in the ATL region. Values represent the % of time, averaged over all gridboxes and years, that critical visibility conditions are experienced.




(b) Persistence of critical visibility events in the ATL region where VIS < 3 nm.

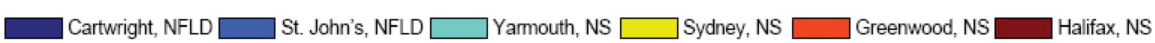
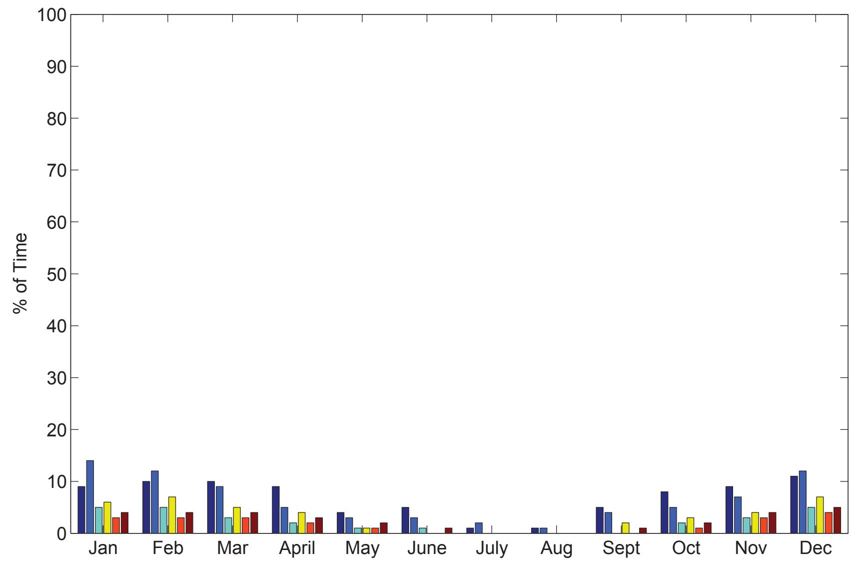
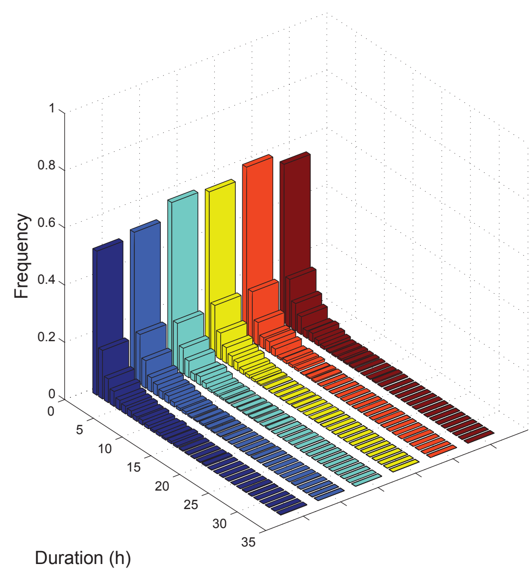



***Figure D.17 (U):*** *Summary of the frequency and persistence characteristics of reported critical visibility conditions in the ATL region. Critical visibility conditions are defined as a visibility measurement < 3 nm.*




(a) Monthly distribution of records reporting critical wind speed conditions in the ATL region. Values represent the % of time, averaged over all gridboxes and years, that critical wind speed conditions are experienced.



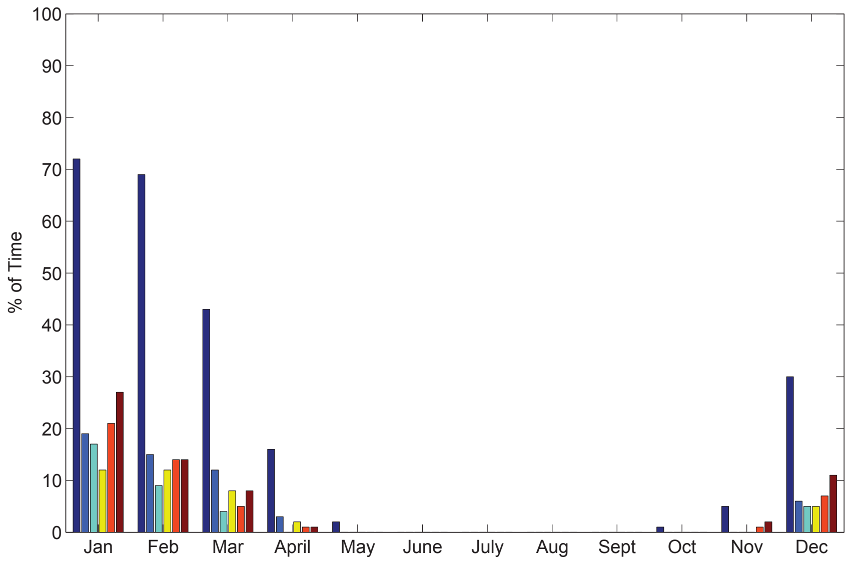

(b) Persistence of critical wind speed events in the ATL region where wind speed > 20 kts.

Cartwright, NFLD | St. John's, NFLD | Yarmouth, NS | Sydney, NS | Greenwood, NS | Halifax, NS

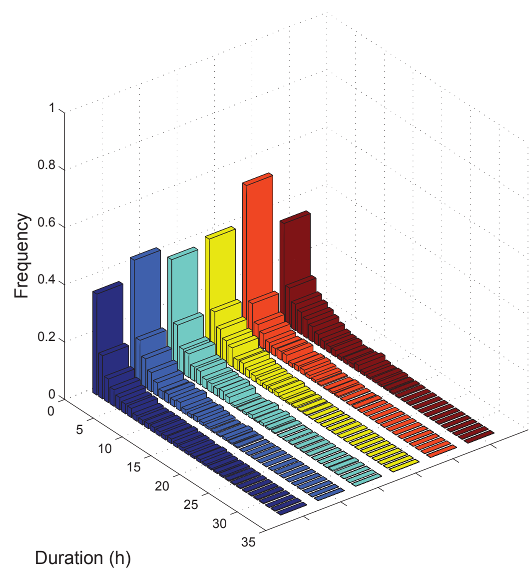
***Figure D.18 (U):*** *Summary of the frequency and persistence characteristics of reported critical wind speed conditions in the ATL region. Critical wind speed conditions are defined as wind speed measurements > 20 kts.*

### Icing conditions

159. Across all ATL LOIs the Appleman condition is met with increasing frequency from November to December, and decreasing frequency from February through to April. The Appleman condition is met most frequently in January, and least frequently in June through October inclusive. Between May and October the Appleman condition is met in fewer than 1% of records across all LOIs. In Cartwright, the Appleman icing condition is observed in approximately 20% of all records. In January, approximately 72% of records meet the Appleman condition for icing potential. In Cartwright, 35% of Appleman events lasted less than 1 h, 68% of events lasted less than 5 h, 80% of events lasted less than 10 h and 95% of events lasted less than 26 h. Compared to Cartwright, the Appleman condition is met less frequently in the other ATL LOIs. On average, 4% of records from Sydney, Greenwood, St. John's, Sydney and Halifax meet the Appleman condition. Among these LOIs, critical conditions are met most frequently in January, when between 12% (Sydney) and 27% (Halifax) of all records meet the Appleman condition. Between 35% and 52% of reported Appleman events lasted less than 1h, between 72% and 82% of events lasted less than 5 h and between 88% and 94% of events lasted less than 10 h. Results of the ATL Appleman assessment are shown in Figure D.19.




(a) Monthly distribution of records meeting the Appleman condition for icing in the ATL region. Values represent the % of time, averaged over all gridboxes and years, that the Appleman condition is experienced.




(b) Persistence of Appleman icing events in the ATL region.

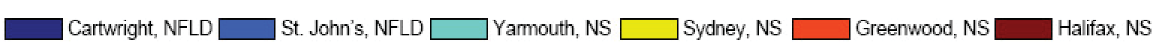
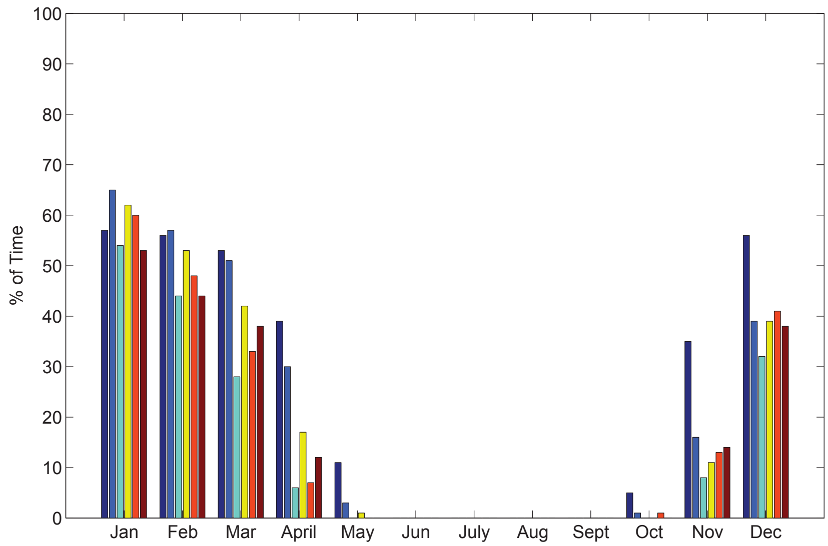


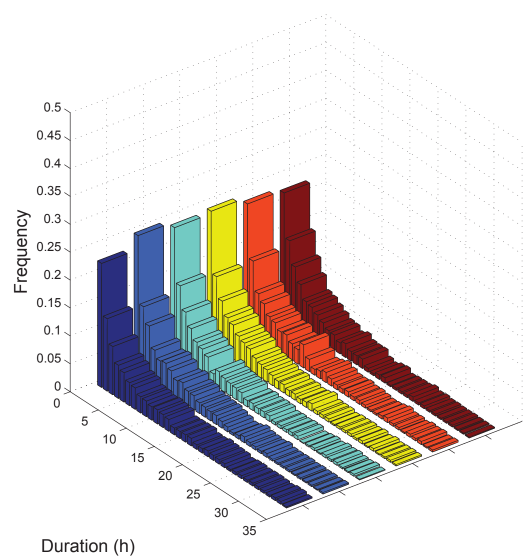

***Figure D.19 (U):*** *Summary of the frequency and persistence characteristics of reported Appleman condition events in the ATL region. The Appleman condition defines temperature and humidity conditions under which potential icing conditions exist.*

The critical temperature and precipitation test shows similar results to those of the Appleman test for the ATL LOIs. Across the ATL region the mean annual frequency of critical temperature and precipitation events ranges from 14% to 22% in Yarmouth and Cartwright respectively. Overall, critical conditions are met with increasing frequency from November to December and decreasing frequency from February to May. Across all LOIs, critical conditions are met with the greatest frequency in January, when 65% of St. John's records, 62% of Sydney records, 60% of Greenwood records, and 57%, 54% and 53% of records from Cartwright, Yarmouth and Halifax respectively report critical temperature and precipitation conditions. In June through September inclusive, critical conditions are reported in fewer than 0.1% records across the ATL region. Across all LOIs, between 22% and 25% of critical events lasted less than 1 h. With the exception of Cartwright, between 75% and 78% of critical events lasted less than 10 h, and approximately 91% of critical events lasted less than 20 h across the remaining 5 LOIs. In Cartwright, 71% critical events lasted less than 10 h, and 86% of events lasted less than 20 h. Results of the critical temperature and precipitation test are shown in Figure D.20

Across the ATL region, freezing precipitation is encountered most frequently in January through April, with the highest frequencies observed in February and March. In February, approximately 4% of Sydney records documented freezing precipitation observations, while in March, approximately 6% of St. John's records and 4% of Cartwright records showed freezing precipitation observations. Compared to St. John's, Sydney and Cartwright, freezing precipitation is reported less frequently in the other ATL LOIs, with on average 1% or fewer records reporting freezing precipitation observations. In Yarmouth, Greenwood and Halifax, at least 90% of freezing precipitation events lasted less than 5 h, while in Cartwright, St. John's and Sydney, at least 90% of freezing precipitation events lasted less than 7 h.




(a) Monthly distribution of records meeting the critical temperature and precipitation condition for icing in the ATL region. Values represent the % of time, averaged over all gridboxes and years, that critical temperature and precipitation conditions are experienced.




(b) Persistence of critical temperature and precipitation conditions in the NWP region.

Cartwright, NFLD St. John's, NFLD Yarmouth, NS Sydney, NS Greenwood, NS Halifax, NS

***Figure D.20 (U):*** *Summary of the frequency and persistence characteristics of reported critical temperature and precipitation events in the ATL region. The critical temperature and precipitation condition defines icing potential if the ambient temperature is below freezing and any form of precipitation is observed.*

# List of abbreviations/acronyms

| Anacronym | Meaning |
|---|---|
| ABSK | Alberta-Saskatchewan regional area |
| ALIX | Atlantic littoral ISR experiment |
| AOI | Area of interest |
| AOR | Area of responsibility |
| APEC | Asia Pacific Economic Cooperation |
| ASW | Anti-submarine warfare |
| ATL | Atlantic regional area |
| BLOS | Beyond line of sight |
| CANR | Canadian NORAD region |
| CAS | Chief of Air Staff |
| CF | Canadian Forces |
| CFEC | Canadian Forces Experimentation Centre |
| CORA | Centre for Operational Research and Analysis |
| DAR | Directorate of Air Requirements |
| DASOR | Directorate of Air Staff Operations Research |
| DGAEPM-R & CS | Director General Aerospace Equipment Program Management - Radar and Communications Systems |
| DND | Department of National Defence |
| DRDC | Defence Research and Development Canada |
| EEZ | Exclusive Economic Zone |
| EO | Electro-Optic |
| HALE | High Altitude Long Endurance |
| IR | Infrared |
| ISCCP | International Satellite Cloud Climatology Project |
| ISR | Intelligence, Surveillance and Reconnaissance |
| JUSTAS | Joint UAV Surveillance and Target Acquisition System |
| LI | Lieu d'intérêt |
| LOI | Location of Interest |
| LOS | Line of Sight |
| MALE | Medium Altitude Long Endurance |
| NATO | North Atlantic Treaty Organization |
| NCDIA | National Climate Data and Information Archive |
| NI | No Image |
| NORAD | North American Aerospace Defence Command |
| NWP | Northwest Passage Regional Area |
| PAC | Pacific Regional Area |
| PLIX | Pacific Littoral ISR Experiment |
| RMP | Recognized Maritime Picture |
| SME | Subject Matter Expert |
| TOR | Toronto-Quebec City Regional Area |

| | |
|---|---|
| UAV | Unmanned Aerial Vehicle |
| VFR | Visual Flight Rules |
| WMO | World Meteorological Organization |
| ZI | Zone d’intérêt |

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This report documents a high-level statistical investigation of the frequency and persistence characteristics of historical cloud cover and weather observations recorded in five operating areas of interest (AOIs) located in Canada. In this study, frequency characteristics are used to provide a quantitative measure of the relative occurrences of specific weather events considered limiting to medium altitude long endurance (MALE) unmanned aerial vehicle (UAV) takeoff, recovery and flight operations, as well as those weather events considered to adversely affect electro-optic and infrared (EO/IR) sensor image quality or interpretability.

Low cloud ceilings present the most significant constraint to domestic UAV intelligence, surveillance and reconnaissance (ISR) operations during the summer months, while potential icing conditions present the most significant constraint to UAV ISR operations during the rest of the year. Significant benefits in terms of the percent of time possible for UAV flight operations may be achieved by operating UAVs that incorporate anti-icing systems, particularly in the Northwest Passage and Atlantic regions; however, the utility and performance of a UAV ISR platform depends on the combined utility and performance of both the platform and the sensor. This analysis indicates that the sensor would be the critical limiting factor affecting the success of a domestic UAV ISR mission requiring EO/IR imaging at the identification and classification tasking level.

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UAV, ISR operations, weather effects

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