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Major Cold-Season Precipitation Events at Iqaluit, Nunavut

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ABSTRACT. This study focuses on cold-season (October–April) precipitation events at Iqaluit, Nunavut, that exceed the 97th percentile of daily corrected precipitation accumulation. This corresponds to a threshold of 9.5 mm. The characteristics of 194 major precipitation events are described for the 1955–96 period. On the basis of NCEP-NCAR and NARR reanalysis data, these events were classified into four storm tracks: south, west, Atlantic, and other. South- and Atlantic-originating systems tended to be associated with the most severe events. The duration and precipitation rate of the events, rather than the speed of motion, were critical factors influencing precipitation accumulation. Snow was the dominant precipitation type. Surface warm frontal passage was a common tropospheric feature, and the topography was important in terms of altering surface wind direction during the events. No significant trend in the occurrence of major precipitation is evident.

Key words: Canadian Arctic, autumn storms, extreme events, Iqaluit, precipitation, snow

RÉSUMÉ. Ce travail traite des événements de précipitations qui sont supérieurs au 97e rang centile des précipitations quotidiennes à Iqaluit, Nunavut, durant la saison froide, soit d'octobre à avril. Cela correspond à un seuil de précipitation de 9,5 mm. Nous décrivons les caractéristiques de 194 événements de précipitations majeures qui se sont déroulés entre 1955 et 1996. Selon les données traitées par NCEP-NCAR et NARR, les systèmes dépressionnaires responsables de ces événements ont été classés en quatre catégories : sud, ouest, Atlantique et autre. Les systèmes provenant du sud et de l'Atlantique ont eu tendance à être associés aux événements les plus sévères. Plus que la vitesse des systèmes dépressionnaires, la durée et le niveau des précipitations ont été des facteurs déterminants sur les accumulations. La neige a été le principal type de précipitation. La présence de fronts chauds en surface a représenté une caractéristique troposphérique commune de ces événements et la topographie a influencé de manière importante la direction du vent à la surface. Aucune tendance de la fréquence des événements de précipitations majeures n'est évidente.

Mots clés : Arctique canadien, tempêtes automnales, événements extrêmes, Iqaluit, précipitation, neige

INTRODUCTION

Autumn and winter storms in the eastern Canadian Arctic are typically characterized by heavy precipitation and strong winds. When produced in large quantities or at high rates, precipitation can have major effects on the human population and infrastructures, as well as paralyzing transport. The combination of heavy snowfall and strong winds causes blowing snow, which leads to a reduction of low-level visibility, dangerous flying conditions, and hazardous surface conditions, especially for Inuit involved in travel and hunting activities (Ford et al., 2006a, b; Henshaw, 2006; Laidler, 2006). Blowing snow may also block roads and access to buildings. Freezing rain and mixed-phase precipitation increase the impact of a storm. Inuit have reported higher occurrences of hazardous weather and unanticipated changes, which increase northern communities' vulnerability and limit their capacity to adapt to environmental change (Ford et al., 2006a, b; Henshaw, 2006; Laidler, 2006). It is normally very difficult to predict such events, and concerns about how storm frequency and intensity may change in the future only add to their impact on northern communities.

Studies reported an increase in heavy precipitation (Zhang et al., 2001; Groisman et al., 2003) and hazardous weather (Hanesiak et al., 1997; Hanesiak and Wang, 2005) in the Arctic. In contrast, Curtis et al. (1998) observed a decrease in precipitation in the western Arctic as a result in the shift of the Aleutian low and Arctic high. Several studies (Serreze et al., 1993; Serreze, 1995; Chang and Fu, 2002; Zhang et al., 2004) reported an increase in cyclonic activity in the Arctic since the mid 20th century, a finding in accord with the suggested tendency of a northward shift of storm tracks in the Arctic (McCabe et al., 2001; Wang et al., 2004; Yin, 2005).

Previous studies (Stewart et al., 1995; Hudson et al., 2001; Intihar and Stewart, 2005) have identified the main storm tracks of systems affecting the Canadian Archipelago. These storms typically originate from the Gulf of Alaska and Beaufort Sea, the Midwest of the United States and Great Lakes region, the Atlantic Ocean (New England), the Canadian Prairies, or northern Greenland. More recently,

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Roberts et al. (2008) analyzed six storms passing over Iqaluit. Half of them originated from Great Lakes cyclones and moved through northern Quebec and into Foxe Basin; two were initiated over the Atlantic Ocean; and one developed over the Northwest Territories.

Several atmospheric field campaigns have been conducted to characterize the controlling mechanisms and microphysics of Arctic storms. The Beaufort and Arctic Storms Experiment (BASE), completed in the autumn of 1994, examined cloud systems and the evolution of mesoscale weather over the southern Beaufort Sea and the Mackenzie River delta (Hanesiak et al., 1997; Hudak and Young, 2002). The Arctic Water, Aerosol, Nuclei Transportation, and Snow experiment (WANTS) focused on the microphysics of snowstorms around Inuvik, Canada, in the winter of 1995 (Asuma et al., 1998, 2000). During the winter of 2007, the Storm Studies in the Arctic (STAR) project carried out a field campaign based at Iqaluit, which resulted in an extensive upper-air and surface dataset of snowstorm events (Hanesiak et al., 2009).

Despite their importance, storms in the Arctic producing snow and mixed-phase precipitation with significant accumulation have generally received little attention. Given the importance of these extreme forms of weather to Canadian Arctic communities, it is critical to understand the processes controlling them in order to eventually improve forecasting capabilities. To address this issue, this study concentrates on events at one site, Iqaluit, the capital of Nunavut. The community is located at latitude 63.75˚ N and longitude 68.55˚ W on the southeastern part of Baffin Island, in the northwestern end of Frobisher Bay (Fig. 1). Only cold-season (October–April) (e.g., Zhang et al., 2004; Intihar and Stewart, 2005) events are investigated, since snow, freezing rain, and mixed-phase precipitation are unlikely to be observed during the warm season.

The objective of this paper is to examine the characteristics and climatology of the 1955–96 major cold-season precipitation events at Iqaluit. Identifying these characteristics will provide a better understanding of the synoptic and surface features leading to, and associated with, major precipitation events at Iqaluit.

DATA SOURCES AND METHODS

Data

Environment Canada daily corrected water-equivalent precipitation data (Mekis and Hogg, 1999) at the Iqaluit meteorological weather station site were used to select major precipitation events. Corrections were made to account for gauge catchment errors due to wind effects, snow-water equivalence variations, and human error (manually retrieved precipitation). At the time of our study, continuous corrected precipitation data were available for Iqaluit only for the years from 1954 to 1996, so the analysis was not extended to the following years.

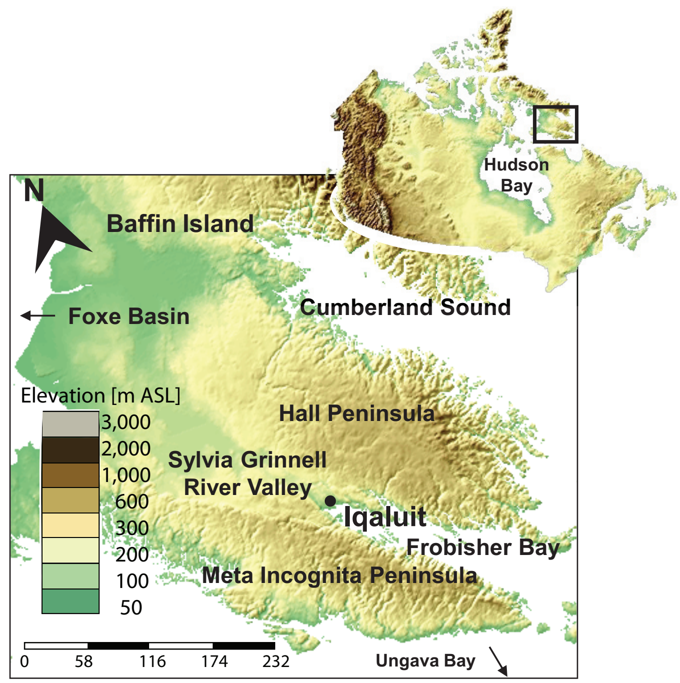

FIG. 1. Geographical location of Iqaluit, Nunavut (adapted from the Atlas of Canada, 2008).

Long-term hourly surface data for the period from 1954 through 1996 were obtained from the Environment Canada public archive (Environment Canada, 2007) for Iqaluit. The occurrence of precipitation and precipitation type were manually determined. Observations of surface temperature evolution used to detect frontal disturbances and surface wind were made by the automated operational meteorological station located at the Iqaluit airport at 34 m above sea level.

Cyclone tracks and synoptic evolution are described in this study using the National Centers for Environmental Prediction-National Center for Atmospheric Research (NCEP-NCAR) reanalysis data and the North American Regional Reanalysis (NARR) data. The NCEP-NCAR dataset provides six-hourly data for 28 layers of the atmosphere with a resolution of 208 km (205 km in the region of Iqaluit) since 1948 (Kalnay et al., 1996). NARR data, on the other hand, available from 1979, are a product of higher resolution (32 km), with outputs of three-hourly data for 29 distinct layers (Mesinger et al., 2006).

Identification of Major Events

Figure 2 shows the frequency distribution and cumulative fraction of the Environment Canada daily corrected precipitation events at Iqaluit over the cold season between October 1954 and April 1996. This study classified major precipitation occurrences on the basis of cold seasons rather than on a yearly basis. As an example, the 1955 cold season consists of events that took place between October 1954 and April 1955. Water-equivalent precipitation of at least 0.2 mm was recorded during 7289 days. The daily accumulation

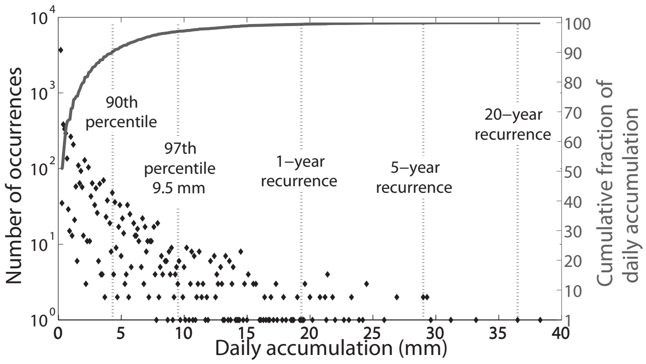

FIG. 2. Occurrence of daily accumulation events at Iqaluit over the cold-season months between October 1954 and April 1996. The 97th percentile is identified, as well as other key distribution characteristics (90th percentile and 1-year, 5-year and 20-year recurrence interval events). The cumulative fraction of daily accumulation is represented by the black line.

average of these events is 1.5 mm, with a standard deviation of 3.1 mm.

We defined major precipitation events during those 7289 days as those events occurring on days when daily accumulation exceeded the 97th percentile, using an approach similar to those of Jones (2000), Frich at al. (2002), and Beniston et al. (2007). Thus the 97th percentile value (9.5 mm) became the threshold value for major precipitation events at Iqaluit used in this study (Fig. 2). Recurrence intervals of 1, 5, and 20 years, are also superimposed on Figure 2 as a comparison tool.

Daily (rather than hourly) observations were used to identify major events, but hourly observations were used to determine the starting and ending points of these events. To calculate the total accumulation for an event, we counted the days on which precipitation began and ended and any days in between. However, only multi-day events in which daily accumulation exceeded the 9.5 mm threshold on at least one day were included in the analysis.

Hourly weather observations at Iqaluit from the Environment Canada public archive were then used to determine when precipitation took place and to identify the beginning and end of each event. With this information, we could also identify periods of intermittence in precipitation, and therefore determine the duration of an event on an hourly basis and compute its average precipitation rate.

Determination of the Storm Tracks

Cyclone tracks and synoptic evolution of the selected events were manually retrieved using reanalysis data. The NCEP-NCAR reanalysis data were used for events that took place before 1979, while the higher-resolution reanalysis data from NARR were used to analyze events of the subsequent years. Maps of the mean sea-level pressure in mb and the 500 mb thickness (the subtraction of the 1000 mb height from the 500 mb height) were generated using the meteorological data analysis software GEMPAK (Koch et al., 1983). The overlaying of these two fields every three hours (with NARR) or six hours (with NCEP-NCAR) allowed the manual tracking of the surface and upper-level low-pressure centres. Figure 3 illustrates an example of this product using the NARR data for an Atlantic-originating major event. When no extra-tropical cyclone was observed, the 500 mb thickness field was used to detect the presence of a short-wave trough. The speed of motion of major events refers to the average movement of the surface low-pressure centre and was determined at the same time when the storm tracks were identified.

QUANTITATIVE CHARACTERISTICS

In total, 194 events with 9.5 mm or more in total precipitation were observed at Iqaluit between October 1954 and April 1996, which is equivalent to an average of five events per cold season. Major events were more frequent at the beginning (October–November) and end (April) of the cold season than during the colder months of winter. October had the highest number of major events, with a total of 41. In contrast, February experienced 17 events over the 41-year period, which represents less than one major event every two years during the month of February. The fewer major events occurring from December to March illustrate the dry Arctic atmospheric conditions and suggest poorer storm efficiency in converting water vapour into precipitation compared to the other cold-season months. For example, in a drier atmosphere more ice crystals will sublimate before reaching the ground, limiting the amount of precipitation accumulation.

Major precipitation events produced accumulations ranging from 9.5 to 55.9 mm. More than 50% of the major events produced less than 13.5 mm of precipitation, and only 8% produced more than 30 mm (Fig. 4).

In general, major events were of short duration. A total of 177 events (91%) lasted 24 hours or less, 15 (8%) lasted between 32 and 48 hours, and two events (1%) lasted between 49 and 62 hours. No event extended beyond three days. The shortest event lasted five hours and produced 13.3 mm of precipitation, while the longest lasted 62 hours and produced 46.2 mm. On average, a major precipitation event at Iqaluit produced 16.7 mm of precipitation, with an average precipitation rate of 0.8 mm per hour.

SYNOPTIC CHARACTERISTICS

Storm Tracks

The storm tracks were manually retrieved using NCEP-NCAR and NARR reanalysis data. On the basis of this information, events were classified according to where they originated into four storm tracks. The three dominant origins of systems leading to major precipitation events at Iqaluit were south, west, and Atlantic. The remaining storm tracks were classified as “other” (Fig. 5). Table 1 groups the storm events by origin (south, west, Atlantic, and other) and

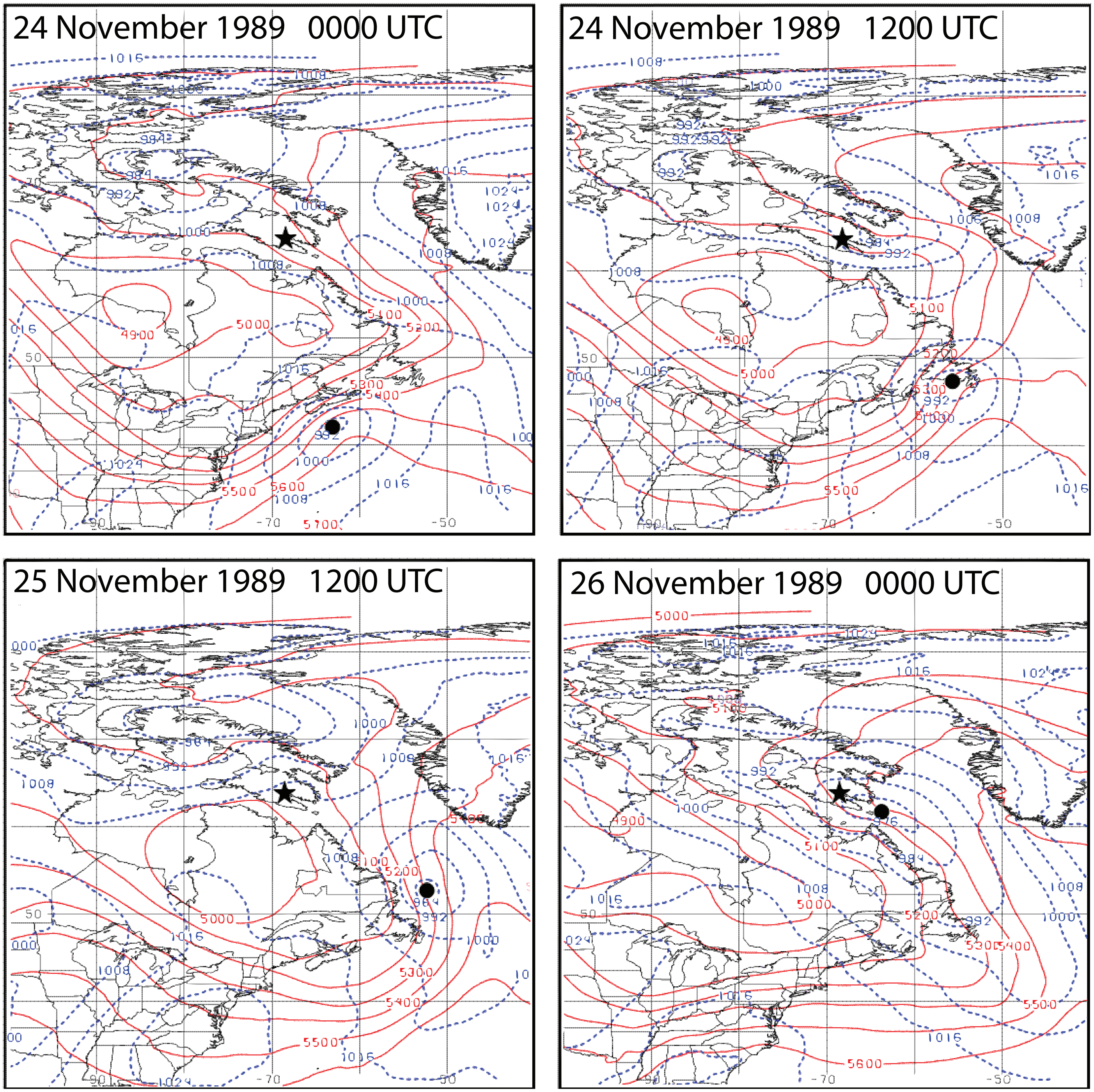

FIG. 3. Example maps showing the NARR mean sea-level pressure (blue dotted lines) and 500 mb thickness (red solid lines) at four times during the Atlantic-originating major event that took place on 25 November 1989. The black dot indicates the surface low-pressure centre, and the black star indicates Iqaluit.

shows the number of events and average speed of motion (km per hour) along each sub-track.

As shown in Figure 5, storms were mainly from the south (1a, b), the west (2a, b), and the Atlantic (3a, b). Each main group was broken down into two sub-tracks to produce more homogeneous groups. Events that either followed no specific track or were not associated with synoptic activity were grouped as "other" (not shown in Fig. 5). Of the systems resulting in major precipitation events at Iqaluit, the south-originating storms were the most common, accounting for 78 (40%) of the 194 events (Table 1). Storms originating from the west formed the second-largest group, accounting for 57 (29%) of these events. Cyclones following this track were initiated in the foothills of the Rocky Mountains, as a result of either lee-cyclogenesis or orographic lifting. The Atlantic-originating storms were the third most common systems, accounting for 44 (23%) of major events. The predominant region of formation for this group was over the Atlantic Ocean near the northeastern coast of the United States. In contrast to the two other storm-track

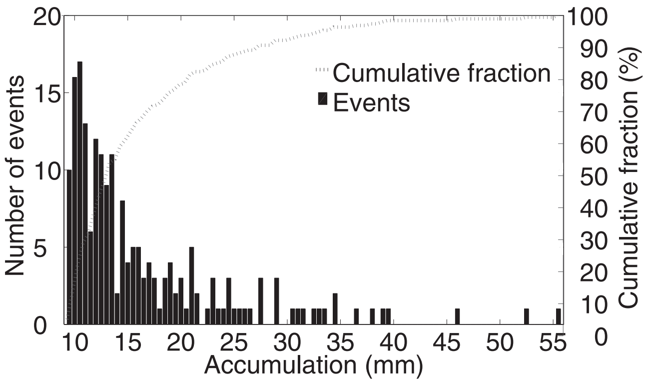

FIG. 4. Number of events and the cumulative fraction (%) of accumulation (mm) during the 194 major precipitation events at Iqaluit over the 1955–96 cold season.

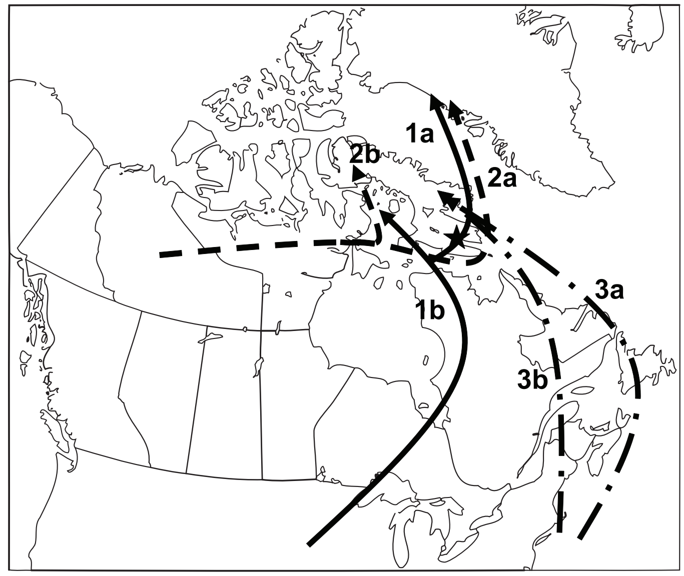

FIG. 5. Cyclone tracks and sub-tracks associated with the major cold-season precipitation events at Iqaluit (black star). Solid lines (1a, 1b) are the south-originating storms, dashed lines (2a, 2b) are the west-originating storms, and long-dashed lines (3a, 3b) are the Atlantic-originating storms.

groups, Atlantic-originating storms decayed over a single common region, the northern part of Baffin Island. Analysis of the 500 mb thickness field of the 15 (8%) events classified under "other" showed that these events are not associated with synoptic-scale perturbation. Instead, we noted the presence over southern Baffin Island of a short-wave trough, which is able to provide the upper-level forcing for an upward air circulation without generating a surface low-pressure system.

A large variability in the synoptic activity during the major events was observed. In contrast to Iqaluit, storms leading to major precipitation events in other regions of the Arctic and at mid latitudes exhibit less storm-track variability. For example, Beaufort Sea storms mainly enter the region with a significant westerly component, arriving either from the Pacific or from the northwestern Arctic Ocean (Hudak and Young, 2002). Similar conclusions are derived for the Russian side of the Arctic, with all primary and secondary cyclones exhibiting a significant westerly component (Whittaker and Horn, 1984). On rare occasions over eastern Russia, cyclones originate from the south and have a northward track, but a westerly component is always present.

SURFACE CHARACTERISTICS

Precipitation

Hourly weather observations at Iqaluit during the major events recorded precipitation in both liquid and solid phases. Liquid precipitation consisted of rain and freezing rain, whereas solid precipitation included snow, ice crystals, ice pellets, and snow grains. The monthly hours of occurrence of liquid and solid precipitation are illustrated in Figure 6. Precipitation was dominated by snow, observed for 3998 hours and representing 90% of the total hours of precipitation. The months of October, November, and April had the highest occurrence of precipitation. The colder and drier months, December through March, experienced overall fewer hours of precipitation than the other months. Liquid precipitation and freezing rain peaked during October.

The number of occurrences of major events per precipitation type and combination of precipitation types is shown in Table 2. The dominance of snow is also shown by the number of events (a total of 142, or 73%) that produced this single type of precipitation. Rain alone accounted for four events (2%), which were associated with either south- or west-originating systems. Mixed precipitation was observed from each storm track group during a total of 48 (25%) events: precipitation consisting of snow and liquid precipitation was observed in 20 events, a mixture of snow and other types of solid precipitation was observed in 22 events, and six events combined a variety of solid and liquid precipitation types.

Surface Wind

The topographic features surrounding Iqaluit played a crucial role in influencing the wind speed during major precipitation events. Wind exhibited a strong bi-directional distribution in the northwest to southeast corridor resulting from the channeling effects of the surrounding topography (Fig. 7). Strong winds (≥ 40 km/h) were reported for 60% of the observations, in contrast to calm conditions for 9%.

Indeed, the northwest-southeast wind pattern was observed in 77% of the instances. In terms of duration, 44% of the time wind was from the southeast during the extreme events, and 33% of the time it was from the northwest. A bi-directional distribution of the wind direction was noted, with northwesterly winds dominating for the Atlantic-originating storm tracks, and southeasterly winds dominating for the three other storm track groups (Fig. 7). Northeasterly and easterly winds were observed in all origin groups

TABLE 1. Number of storm events and speed of motion, by origin group and sub-tracks.

Origin Group	Sub-track	Number of Events	Total Events	Speed of Motion (km/h)	Average Speed (km/h)
South	1a	59	78	43	42
	1b	19		40	
West	2a	29	57	38	34
	2b	28		29	
Atlantic	3a	37	44	35	37
	3b	7		49	
Others	4	15	15	–	–

TABLE 2. Number of occurrences of major events, by precipitation type. Liquid type consists of rain and freezing rain, whereas solid type consists of snow grains, ice pellets, and ice crystals.

Origin Group	Only Snow	Only Rain	Snow and Liquid Type	Snow and Solid Type	Snow, Liquid and Solid Types	Total
South	60	2	4	10	2	78
West	40	2	8	5	2[1]	57
Atlantic	33	0	4	5	2	44
Other	9	0	4	2	0	15
Total	142	4	20	22	6	194

[1] No snow was observed.

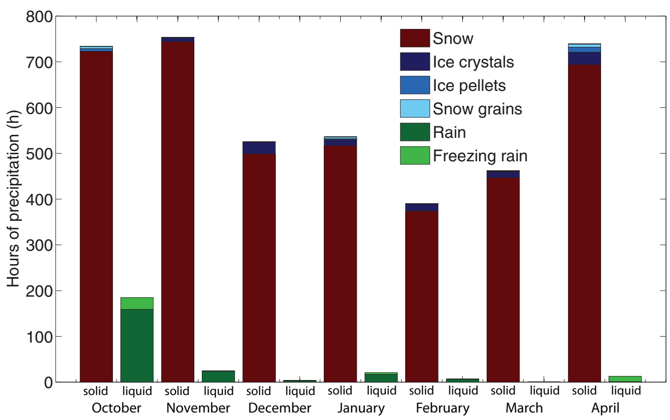

FIG. 6. Monthly hours of precipitation of each precipitation type during the 194 major precipitation events of 1955–96.

and accounted for 13% of the observations. Only 1% of the wind observations were from the southwest, and these occurred exclusively during Atlantic-originating events.

Comparing these results to those of other studies revealed a distinct wind characteristic for major cold-season precipitation events. Nawri and Stewart (2006) showed that northwesterly winds were dominant during the cold season, southeasterly winds occurring only during October. Moreover, Nadeau (2007) found that 89% of the winds recorded during high-wind events were northwesterly. In contrast, southeasterly winds at Iqaluit were observed during 44% of the major precipitation events. However, Nawri and Stewart (2006) and Nadeau (2007) never considered precipitation. Thus, the high occurrence of southeasterly winds during major precipitation events suggests that southeasterly winds are more likely to be linked with major precipitation events than with other types of weather.

Frontal Structures

It is well known that extra-tropical cyclones are associated with a warm or a cold front (Bjerknes, 1919). Roberts et al. (2008) examined six autumn storms over Iqaluit in 2005, of which two were associated with a warm front, and one with a cold front, with temperature changes ranging from 5˚ to 15˚C.

Therefore, our next step was to investigate how frontal forcings had contributed to generating the major events at Iqaluit. On the basis of the previous observations, we considered an event to be linked with a surface front when a temperature variation of ±10˚C or more was observed before or during the event. Table 3 shows the number of occurrences of surface warm and cold fronts during major precipitation events. Surface frontal structures were observed in the majority of the cases. Warm fronts were observed during 109 events, and cold fronts, during 17 events. A total of 68 cases, representing 35% of the events, were not associated with an analyzed frontal passage. The high occurrence of surface fronts, especially warm fronts, illustrates the critical role of cyclonic activity in systems leading to major precipitation events at Iqaluit.

DISCUSSION

Factors Influencing Precipitation Accumulation

The duration, precipitation rate, and speed of motion of the events were analyzed to determine which of these variables were the key factors influencing precipitation accumulation (Fig. 8). Precipitation accumulations under 24 mm were associated with shorter events (24 hours or less) for all origin groups (Fig. 8a). Events producing 24–40 mm of accumulation were associated with both short and

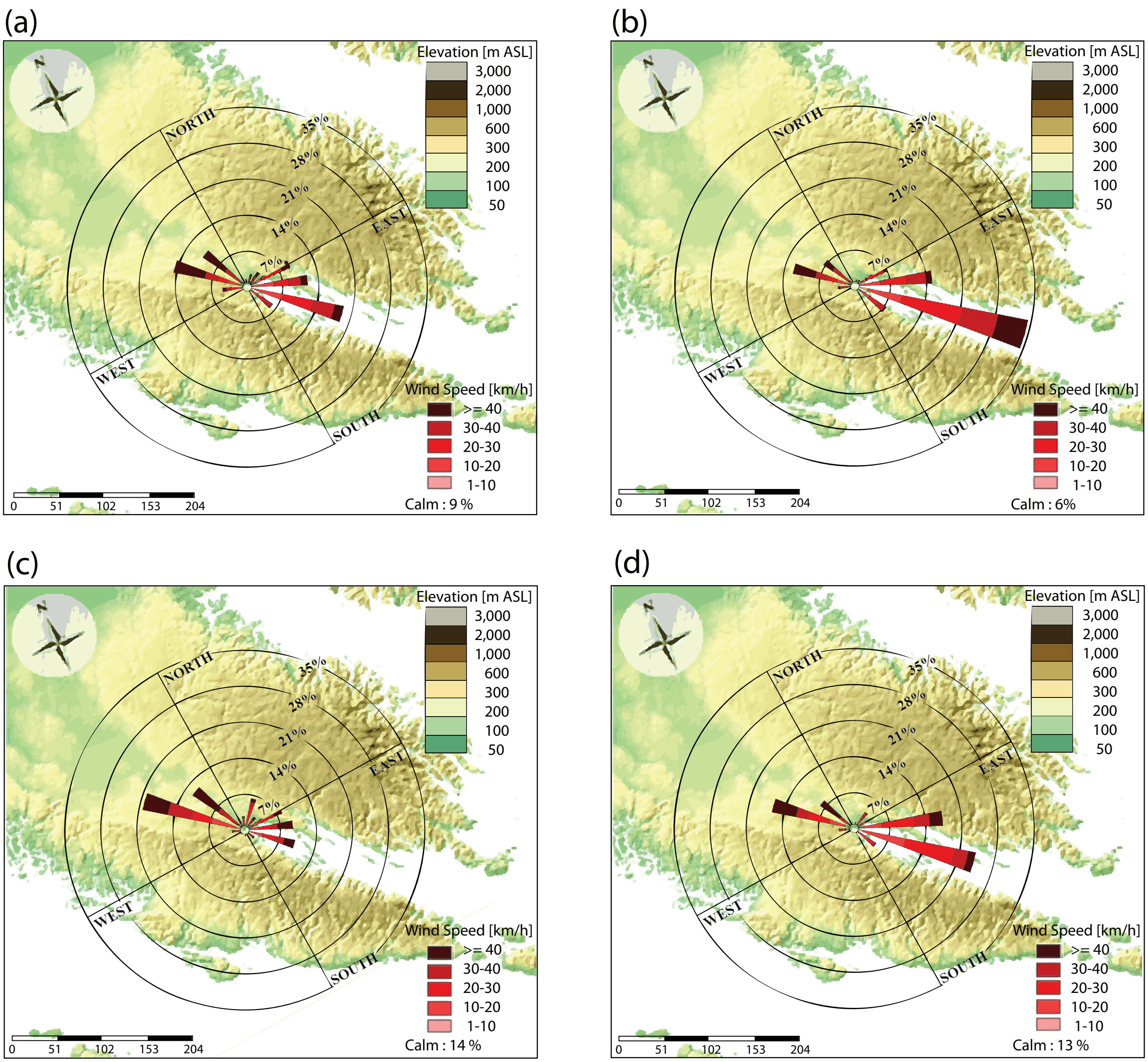

FIG. 7. Percent frequency of surface wind direction (in 20˚ intervals) and speed (km/h) observed during (a) the 78 south-originating events, (b) the 57 west-originating events, (c) the 44 Atlantic-originating events, and (d) the 15 other events (background map adapted from the Atlas of Canada, 2008). Each wind bar is divided into five wind speed classes: 1–10 km/h, 10–20 km/h, 20–30 km/h, 30–40 km/h, and 40 or more km/h.

long events. For example, precipitation accumulations of approximately 30 mm were associated with an event lasting between 13 and 48 hours. Although some large-accumulation cases (> 25 mm) were associated with the shortest duration, especially for the south-originating group, the events producing precipitation accumulations over 40 mm were all associated with the longest events. The observed discontinuity at 24 hours is associated with daily precipitation data being the main source of data in this study. The event durations were derived from hourly weather observations, which are manually observed and associated with uncertainties; as a result, a large number of events had a duration of 24 hours.

Higher precipitation rates do not necessarily imply higher precipitation accumulation (Fig. 8b). The maximum precipitation rate during a major precipitation event was 2.7 mm per hour, recorded during a south-originating event on 17 April 1996 that produced 13.3 mm of precipitation; the event was ranked 106th out of 194. In contrast, some of the highest precipitation accumulation events were associated with the lower precipitation rate. Indeed, the most severe precipitation events for the south-, west-, and Atlantic-originating groups were associated with precipitation rates ranging from 0.7 mm per hour for the south-originating system, to 1.1 mm per hour for the west-originating system.

TABLE 3. Frontal structures observed during the 194 major cold-season precipitation events.

	Surface Front		
Origin Group	Warm	Cold	None
South	43	6	29
West	32	5	20
Atlantic	27	5	12
Other	7	1	7

The speed of motion of the events does not tend to be a critical issue for large accumulation, regardless of the origin group. As illustrated on Figure 8c, a given speed of motion can be associated with either low or high precipitation accumulation. For example, a system moving at a speed of approximately 55 km per hour can be associated with both the highest and some of the lowest precipitation accumulations, just as a system moving at a speed of approximately 20 km per hour can be associated with a precipitation accumulation of 10.5 mm or 40 mm.

The factors influencing precipitation accumulation were the same for all origin groups. Longer duration events tended to produce higher amounts of precipitation, and shorter events, lower amounts. In contrast, speed of motion was not specifically linked with precipitation amount.

Severity per Origin Group

We investigated whether one or more origin groups lead to the formation of the most severe events at Iqaluit. We plotted the cumulative fraction of occurrences of events from each origin group (south, west, Atlantic, other) as a function of the rank of the events; the event producing the largest amount of precipitation was ranked first, and the one producing the smallest amount was ranked 194th. The cumulative fraction of occurrence for each origin group is illustrated in Figure 9.

Both south- and Atlantic-originating storms show a greater frequency of occurrence within the top-ranked precipitation events. For example, 29% of the south-originating and 32% of the Atlantic-originating events are ranked in the top 50, in contrast to only 18% and 20% of the west-originating and other cases (Fig. 9). Similarly, 56% of the south-originating and 59% of the Atlantic-originating events are ranked in the top 100, compared to 46% for the west-originating events; the gap is even greater for the events classified in the "other" group: only 27% of those events make the top 100. The highest occurrences of "other" events are observed between the 104th and 154th rank; 60% of the events belonging to this group are situated in this interval (Fig. 9). Such a distribution suggests a tendency for storms to be generated in the absence of synoptic forcing, and therefore, to the formation of less severe events.

Overall, the south- and Atlantic-originating systems tended to be associated with the most severe events, whereas west-originating and "other" events tended to produce lower-accumulation major events.

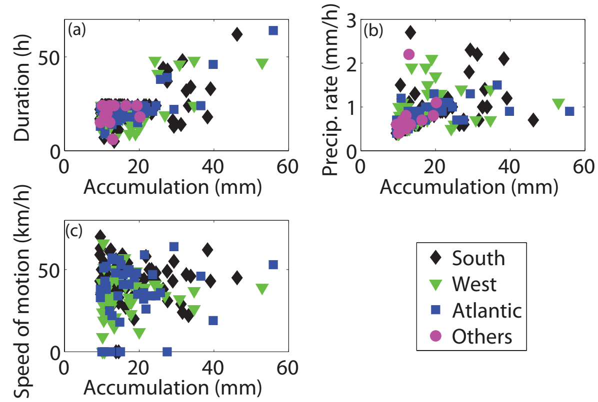

FIG. 8. Precipitation accumulation (mm) as a function of (a) storm duration, (b) precipitation rate (mm/h), and (c) speed of motion (km/h) for the 194 major precipitation events at Iqaluit, by origin group.

Tendency of Occurrence (1955–96)

Cyclonic activity and precipitation in the Arctic have increased (Groisman et al., 2003; Zhang et al., 2004) or are expected to increase in the future (Saha et al., 2006). These hypotheses have been formulated for the entire Arctic region, and to our knowledge, none of the studies focused on a particular region.

To begin to address the regional focus issue, the cold-season occurrences of major precipitation events at Iqaluit are illustrated on Figure 10. Although corrected data are unavailable for the years after 1996, the frequency distribution is extended until 2006 using uncorrected precipitation data. The decision to include uncorrected precipitation data in the analysis was made after comparing the major precipitation event distributions of the two data sets (corrected and uncorrected). The two data sets are correlated at the 0.05 confidence interval, and their similarity is illustrated in Fig. 10.

The non-significant decrease in storm activity observed until 1996 is in line with the results of Curtis et al. (1998), who observed a decrease in annual precipitation in the western Arctic. However, this trend is non-significant for the present study on major events at Iqaluit. The same conclusion is obtained where no significant trend is observed when each storm track group is analyzed separately (not shown). Despite other studies such as Zhang et al. (2004), who reported an increase in cyclonic activity over the past 50 years, as well as McCabe et al. (2001), Wang et al. (2004), and Yin (2005), who reported a northward shift, these trends do not translate into major precipitation events, or at least, not in Iqaluit.

CONCLUSION

Although precipitation and storms over the western Canadian Arctic have been examined (e.g., Hanesiak et al., 1997; Curtis et al., 1998; Hudak and Young, 2002), few published studies have focused on the nature of precipitation

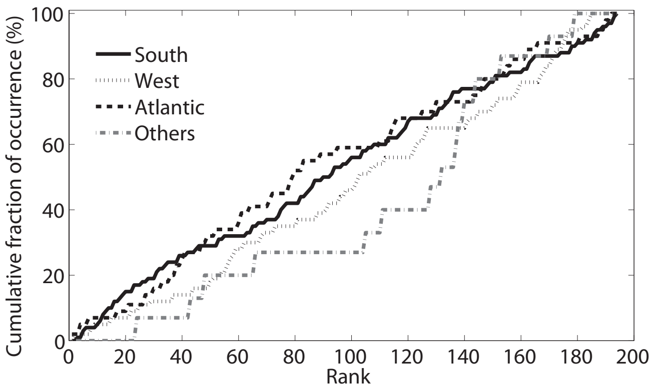

FIG. 9. Cumulative fraction of occurrence (%) of major events for each origin group as a function of the event ranking (by accumulation).

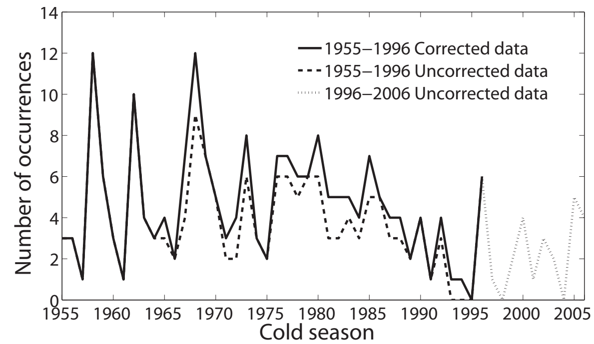

FIG. 10. Cold-season occurrences of major precipitation events (1955–2006). The thick solid line represents the 1955–96 occurrences of extreme events using corrected precipitation data. The dashed line represents those same occurrences, but using uncorrected precipitation data. The thin dotted line represents the occurrence of major precipitation events between 1997 and 2006, a period for which only uncorrected precipitation data are available. Note that for the period from 1955 to 1964, the occurrence of major events is the same using both datasets.

systems over the eastern Arctic. Roberts and Stewart (2008) and Hanesiak et al. (2009) have focused on specific storm events at Iqaluit in the 21st century, but did not investigate their climatology. To provide an overview of major precipitation events over the region, this study has documented key characteristics of such cold-season events at Iqaluit, Nunavut, for the period 1955–96.

The duration of the events and their precipitation rate were the most important factors influencing the amount of precipitation accumulation. On average, a major precipitation event at Iqaluit produced 16.7 mm of precipitation, mainly as snow, with an average precipitation rate of 0.8 mm/h. Larger precipitation accumulation tended to be associated with longer duration events and low precipitation rates. In contrast, the speed of motion of a system was not a definitive factor influencing the precipitation amount. For example, fast-moving systems were associated with both low and high precipitation accumulation events.

In contrast to other regions of the Arctic, a large variability in the origin region and storm tracks of systems leading to major events was observed here. Systems affecting Iqaluit were from the south, the west, the Atlantic, or the Arctic Ocean, or were triggered by short-wave troughs. In addition, systems either passed east or west of Iqaluit. The most severe events at Iqaluit tend to be associated with south and Atlantic-originating systems. Storms with no obvious origin tend to be associated with the lower-accumulation major events, and west-originating events produced a wide diversity of accumulation amounts. In contrast, storms affecting the Beaufort Sea or northern Russia were mainly from the south or the west (e.g., Whittaker and Horn, 1984; Hudak and Young, 2002).

The presence of a surface front was observed during 126 cases, illustrating the critical role of cyclonic activity in generating major precipitation events. Warm fronts were typical of these events, observed during 109 events (56%), whereas cold fronts accounted for only 17 events. As expected for cold-season precipitation events, 142 events produced only snow. However, more than a quarter of the events produced at least one other type of precipitation, which is attributable at least in part to the high occurrence of warm fronts.

Finally, the surrounding topographic features influenced the surface wind direction during the events. In 77% of the cases, wind direction was in the northwest–southeast corridor, parallel to the terrain. Moreover, it was not uncommon for major precipitation events to be associated with strong winds; 60% of the major events recorded winds of 40 km per hour or higher.

Despite the increase in cyclonic activity in the Arctic reported by McCabe et al. (2001) and Zhang et al. (2004), no trend in the occurrence of major precipitation events has been observed over the last 41 years. However, there is a great deal of variability in the occurrence of such events.

Limitations to the accuracy of the identification of the major events may arise from the applied threshold based on daily precipitation accumulation. This method might have underestimated the number of major events that potentially affected Iqaluit over the study period because the multi-day events that produced less than 9.5 mm accumulation each day were not included in this study. Better precipitation data in the Canadian Arctic are required to identify major precipitation events with greater accuracy. However, to our knowledge, this study is the first to document the climatology of major cold-season precipitation events that affect southern Baffin Island. Coupled with upper-air and surface dataset of snowstorm events (Hanesiak et al., 2009), this work will serve as a basis for improving the simulation and prediction of major precipitation events in the Arctic.

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