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# Characteristics, atmospheric drivers and occurrence patterns of freezing precipitation and ice pellets over the Prairie Provinces and Arctic Territories of Canada: 1964–2005

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ABSTRACT

Freezing precipitation and ice pellet events on the Canadian Prairies and Arctic territories of Canada often lead to major disruptions to air and ground transportation, damage power grids and prevent arctic caribou and other animals from accessing the plants and lichen they depend on for survival. In a warming climate, these hazards and associated impacts will continue to happen, although their spatial and temporal characteristics may vary. In order to address these issues, the occurrence of freezing rain, freezing drizzle, and ice pellets from 1964 to 2005 is examined using hourly weather observations at 27 manned 24 h weather stations across the different climatic regions of the Prairie Provinces and Arctic Territories of Canada. Because of the enormous size of the area and its diverse climatic regions, many temporal and spatial differences in freezing precipitation and ice pellet characteristics occur. The 12 most widespread freezing rain events over the study area are associated with only two atmospheric patterns with one linked to strong warm advection between low and high pressure centres and the other pattern associated with chinooks occurring east of the Rocky Mountains. Given the annual patterns of freezing rain occurrence found in this study, it is proposed that a maximum of five regimes exist and three occur within the Prairies and Arctic.



## 1. Introduction

Many regions of the world experience precipitation when surface temperatures are near 0 °C. As a result of small changes in atmospheric conditions, this precipitation can occur in various forms including freezing rain, freezing drizzle, or ice pellets (Stewart et al., 2015). Note that we use the term freezing precipitation to collectively refer to freezing rain and freezing drizzle (American Meteorological Society, 2015). Freezing rain tends to occur when snow falls into an above-freezing layer aloft where it melts before reaching the surface as supercooled drops. Freezing drizzle occurs through all-liquid processes within clouds at temperatures <0 °C. Ice pellets generally form if melting snowflakes fall back into a sub-freezing layer closer to the surface which is deep enough so that they have enough time to re-freeze before reaching the surface, or the melted snowflakes are nucleated in this sub-freezing layer and are then able to freeze.

It is critical to assess when and where such precipitation occurs because of its hazardous impacts (see, for example, Kunkel et al., 2013). In a warming climate, these hazards and associated impacts will continue to occur and an understanding of past conditions and their changes is required to advance our understanding of their future likelihood (Cheng et al., 2007; Lambert and Hansen, 2011; Kodra et al., 2011).

Several climatological and impact studies concerning freezing precipitation have been carried out over various regions of the world. For example, climatologies of freezing precipitation have been developed for Europe (Carriere et al., 2000) and the United States (Cortinas, 2000; Changnon, 2003; Cortinas et al., 2004; Houston and Changnon, 2007). Freezing precipitation events can significantly impact ecosystems (Millward and Kraft, 2004; Zhou et al., 2011), wildlife (Gunn et al., 1981; Miller and Barry, 2009; Tyler, 2010), transportation (Andrey et al., 2003) and urban infrastructure (Lecomte et al., 1998; Armenakis and Nirupama, 2014).

Studies examining freezing precipitation in Canada have been limited. MacKay and Thompson (1969) examined hourly weather reports over a ten-year (1957–1966) period and published the first Canadian climatology of freezing precipitation. Stuart and Isaac (1999) updated this climatology for the period 1961–1990 by characterizing the frequency of occurrence and amounts of hourly precipitation types including dry and wet snow, ice/snow pellets, freezing rain and freezing

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drizzle at selected stations across Canada. Their analyses indicated that hazards are more severe on the Canadian east coast, in comparison with central and western Canada. Cortinas et al. (2004) documented the spatial and temporal features of freezing precipitation and ice pellets across the United States and Canada from 1976 to 1990. Their analyses showed that the spatial variability in the annual frequency of freezing precipitation and ice pellets across the continent was large. Furthermore, they found that the climatology was impacted by several factors including topographical features, proximity to water bodies and location relative to climatological storm tracks. Hanesiak and Wang (2005) and Wang (2006) assessed changes in the frequency of occurrence of several inclement weather conditions in the Canadian Arctic including freezing precipitation. They reported an increasing trend in monthly freezing precipitation events at selected stations from 1953 to 2004. Roberts and Stewart (2008) incorporated several datasets including surface observations, rawinsonde data, and model re-analysis products to analyze the occurrence of freezing rain and ice pellets between 1980 and 2004 at four locations in the eastern Canadian Arctic. Although freezing rain and ice pellet occurrences were uncommon, they developed under a variety of synoptic and surface conditions. Recently, Groisman et al. (2016) examined trends in freezing rain in North America and Northern Eurasia over a 40 year period (1975–2014) and found an increase of about 1 d $y^{-1}$ at North American stations north of the Arctic Circle using data from the Integrated Surface Database (Smith et al., 2011).

Several studies have examined the different synoptic patterns which lead to freezing precipitation in North America. For example, Rauber et al. (2001) performed a manual synoptic typing on 411 freezing precipitation cases occurring during the period 1970–1994 over the United States east of the Rocky Mountains. They were able to sort these cases into seven common synoptic patterns, four of which were more general, with the other three being more specific to the Appalachian Mountain region. The four general categories were described as A) Arctic front-anticyclone, B) warm front occlusion, C) cyclone-anticyclone, and D) west quadrant of Arctic high pressure (Rauber et al., 2001). In a study of freezing rain events in Ottawa, Canada, Cheng et al. (2004) found that 92% of the events could be associated with these four general patterns. Ressler et al. (2012) studied freezing precipitation events in the Montreal region. They separated 46 cases into three categories (west, central and east) depending on the location of the long-wave trough in the 500 hPa geopotential height pattern, and found that the concomitant sea level pressure composite patterns could, in general, be related to the types specified by Rauber et al. (2001).

The incidence of freezing precipitation and ice pellets in the Arctic Territories and Prairie Provinces of Canada can result in major disruptions to road transportation, aviation services, power utility services, and forage availability for various species. For example, a storm on October 4, 2012 deposited 8 cm of ice, cutting the power to thousands of customers in southeastern Manitoba (Environment Canada, 2012). On November 1 of that same year, a broad swath of freezing rain swept across central and southern Alberta resulting in major impacts to transportation (Global News, 2012). Furthermore, northern residents have reported an increase in ice storms which impact their traditional way of life and threaten the survival of Arctic caribou (ACIA, 2005; WWF, 2016).

Given the importance of this issue and the paucity of studies focussed on the western and northern areas of Canada, the overall objective of this study is to characterize patterns of past occurrence of freezing precipitation and ice pellets and interpret atmospheric drivers associated with these events. These areas have some of the most variable climates in the world and they experience wide swings in winter and spring temperatures in particular (see, for example, Stewart et al., 1998).

The article is organized as follows. Section 2 describes the study area and datasets. The occurrence of freezing precipitation and ice pellets at various temporal scales and their associated atmospheric profiles are presented in Section 3. Section 4 examines the synoptic patterns and characteristics associated with long-lived and widespread freezing rain events. Freezing rain transition regimes are introduced and described in Section 5. Concluding remarks are provided in Section 6.

## 2. Study area and data

### 2.1. Study area

The landscapes of Canada are diverse and their climates are influenced by factors including latitude, amount of insolation, topography, ocean currents, local features, and the character of weather systems (Phillips, 1990). The climatic regions represented in this study (Fig. 1) are based on work by Hare and Thomas (1979) and the Ecological Stratification Working Group (Environment Canada, 1989). These regions are typically broad areas integrating vegetation composition and landform physiography and are characterized by distinctive ecological responses to climates.

The Prairie climate region (Fig. 1) is characterized by warm summers and cold winters. Average annual precipitation is around 450 mm with a peak in early summer. In the Northwest Forest climate region, winters are cold and summers are moderate with mean daily temperatures above freezing for 5–7 months. Annual precipitation, averaging around 900 mm, is distributed throughout the year. Precipitation peaks during summer with a minimum in the spring. Cool summers and very cold winters characterize the Northeast Forest climate region. Late summer and early fall precipitation account for much of the annual amounts of 250 to 350 mm. The climate of the Mackenzie region is characterized by cool summers and very cold winters. There are only 4–5 months during which the mean daily temperature exceeds the freezing point. Most precipitation falls in summer and fall months giving an average annual precipitation of 700 mm in southern areas and only 250 mm in northern areas. The Arctic Tundra and Arctic Mountain climate regions are typified by long cold winters with only 2–3 months with above-freezing mean daily temperatures. Precipitation averages approximately 170 mm $y^{-1}$, the majority being in the form of snow. The climate of the Yukon/North BC Mountains region is extremely variable due to the large variations in terrain, and is characterized by cool summers and cold winters. Annual precipitation varies from 200 mm along the Arctic coast, 700 mm in southeastern Yukon to over 1600 mm in southwestern Yukon. Precipitation is generally highest during winter months, whereas there is a large moisture deficit during summer months.

### 2.2. Data

Environment and Climate Change Canada's (ECCC) surface weather network uses a variety of automated systems and human observations to measure and observe numerous weather parameters. The automated measurements are subject to subsequent manual and automated quality control procedures to correct for instrumentation errors as well as transmission and recording errors, and information is tabulated at various temporal scales ranging from hourly to annually. The standard procedures for observing, recording and reporting weather conditions are described in the manual of surface weather observations (MANOBS, 2015).

Climate data used in this study were obtained from the National Climate Data and Information Archive (http://www.climate.weatheroffice.ec.gc.ca) which is operated and maintained by ECCC. Several criteria were applied in selecting stations for this study. An important requirement was that the observing program be hourly and manned 24 h per day throughout the year. Furthermore, the station had to report observations over a long term (at least 40 consecutive years). These criteria reduced an initial inventory of 256 stations to 51. From these, stations with significant periods of missing observations were eliminated as we wanted to characterize the duration of events. Consequently, data from 27 stations between 1964 and 2005 were selected (Fig. 1). Data