# A Fog and Low Visibility Climatology for Selected Stations in the Western Canadian Arctic

by

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B.Sc., University of Shahid Beheshti, 2004
M.Sc., University of Shahid Beheshti, 2008

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# Supervisory Committee

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# Abstract

A detailed examination of low visibility (LV) occurrences and the weather types that cause low visibility, with a focus on fog, was performed for five weather stations in the western Canadian Arctic, in the vicinity of the Amundsen Gulf area of the eastern Beaufort Sea. A series of climatologies were developed that established patterns of LV occurrence as a proportion of all observations and as a function of LV events caused by fog. Frequency climatologies for other weather types were also performed; in particular, for snow, blowing snow, rain, and drizzle. Annual climatologies were used to identify trends in several weather parameters over the 1980-2015 period of study. Monthlies were used to identify typical patterns of occurrence over the course of a year, and hourlies over the course of a day. A dataset of multi-hour fog events was also created; some of these were related to synoptic patterns. Analysis was also broken down by season.

Results indicate several things. Monthly climatologies showed considerable diversity across the study area. Three distinct groupings were noted: Tuktoyaktuk and Ulukhaktok with a maximum frequency of LV conditions in February, Aklavik and Inuvik with a maxiumum frequency in October, and Sachs Harbour in August. The February maximum in Tuktoyaktuk and Ulukhaktok was related to cold air temperatures combined with small amounts of moisture from sea ice leads. The Alkavik and Inuvik October maximum was related to moisture advected over land from remaining open water, as well as diurnal snow melt adding moisture to the boundary layer that condenses as the evening cools off. The August maximum in Sachs Harbour is a reflection of proximity to open water and cold air temperatures.

Hourly climatologies in the spring/fall season showed most stations have maximum occurrence of LV events caused by fog in the early morning. This is a radiative effect; cooling overnight causes radiation fog that peaks in occurrence just as morning begins. This peak is pushed into the midday in the winter, and is much weaker in the summer, both reflections of the changing pattern of daylight hours.

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## 1. Introduction

Northern Canada is a remote region with low population density and climatic harshness. The great distances between population centers and the outdoor focus of the residents, e.g., for subsistence activities, means that transportation is a critical component of northern life. An absence of road and rail networks means that residents depend on aircraft and marine shipping for transportation, more than populations in southern Canada.

Most forms of transportation, particularly ship and aircraft operations, are strongly impacted by “poor” weather. While this includes storms, an important element of weather impacts is also felt through low visibility. A low visibility situation that impairs transportation can be caused by a variety of weather phenomenon – fog, falling or blowing snow, rain, haze, mist, drizzle; smoke is included. These weather “types” are more or less favored by particular synoptic weather conditions, as modified by local conditions of snow cover and sea ice state. Widespread occurrence of low visibility can significantly reduce visual range over thousands of square kilometers and cause serious dangers for small aircraft.

The phenomenon of low visibility is not well-understood in the North. There is little information about the general climatology of occurrence of low visibility events, and there is little information about the specific types of weather that cause low visibility events. Likewise, information about typical synoptic patterns that are responsible for setting the stage for low visibility events are also poorly known.

The weather forecasting process, while it usually depends on numerical models which calculate the atmosphere's dynamics, implementing physical laws in a computer environment, have a difficult time in the north due to a lack of observational data and the sometimes small spatial scales of occurrence of some phenomenon, such as fog. Forecasters can be assisted by climatological tools that are based on observed temporal and geographical distribution of the phenomena, captured over a long time period.

## 2. Research Question

In light of the gaps in basic knowledge of climatological patterns of low visibility occurrence, as well as the types of weather they are cause by, this work was undertaken to address some of these gaps in the western Canadian Arctic. The following research objectives (2.1) and specific research questions (2.2), stated below, were established to guide this effort.

### 2.1 Research objective

1) Establish climatologies to analyze the typical patterns of occurrence of weather restrictions to visibility in the Western Canadian Arctic with a particular focuses on those caused by fog.

2) Define multi-hour low visibility “events” and identify the physical mechanisms driving the occurrence those caused by fog as they relate to sea ice and synoptic patterns.

### 2.2 Research questions

The research objectives are guided by the following specific questions:

**1)** Are there typical times when LV event occurrence is favoured throughout the year (e.g. monthly) and over the course of a day? Does timing during the day vary by season?

**2)** What type of observed weather (e.g. fog, blowing snow) is responsible for the majority of LV events at the study sites?

**3)** To what extent can the occurrence of fog be explained by synoptic and climate conditions along the western Canada Arctic?

**4)** What is the trend of LV/VLV and fog occurrences – have they increased in recent years?

## 2.3 Study area

The region selected for this study is an area of the western Canadian Arctic surrounding the Amundsen Gulf area of the eastern Beaufort Sea (Fig. 3.1). It is well established by now that sea-ice cover has decreased in the northern hemisphere over the past several decades (Parkinson et al., 1999; 2003; Cavalieri et al., 2003; Barber and Hanesiak, 2004; Serreze et al., 2007). This region was selected for research because some of the greatest reductions of sea ice have occurred here (Fig. 1 in Stroeve et al. 2012). This should lead to an increase in the exchange of heat flux and momentum between the atmosphere and ocean, which should in turn result in an increased occurrence of fog in this area – this is the focus of the second hypothesis. Stations drawn from this area encompassed locations on the coast as well as inland, to get a feel for the potential impact of coastal proximity on fog patterns.

**Figure 3.1**: Study area showing the location of the five stations selected for analysis

# 3. Background

## 3.1 Low visibility

### 3.1.1 Definition of low visibility

Meteorological visibility by day is defined by the World Meteorological Organization to be “the greatest distance at which a black object of suitable dimensions situated near the ground can be seen and recognized when observed against a scattering background of fog, sky, etc.” (WMO, 1992).

Reductions to visibility – the situation termed “low visibility”– occur due to meteorological phenomena that result in the absorption and scattering of light. These phenomena are types of weather that introduce into the air the hydrometeors or particles that cause the drop in visibility. These consist of water droplets and ice crystals. Particulate matter (PM) suspended in the atmosphere will also reduce visibility. The specific types of weather associated with water particles include fog, mist, drizzle, rain and sometimes haze; for ice crystals, it is snow, blowing snow, or ice fog; and for particulates it is smog and sometimes haze.

There are two primary mechanisms by which the presence of suspended droplets and/or crystals can render an object indistinguishable to a distant observer: a reduction in brightness contrast between an object and its background, caused by scattering and absorption, and a blurring of object outlines, caused by scattering. A reduction of contrast occurs when the amount of available light decreases. This can occur when the light from the original source is lost due to absorption or is scattered away. In general this reduction of beam intensity is related to the concentration of droplets/particles and to their size distribution (Gazzi et al., 1997; 2001). In the case of absorption there is a dependency on the type of particles as well, because some are more effective absorbers than others (Wayne 1991). Scattering can prevent light from reaching the observer (back scattering), or a blurring can occur when the direct beams from an object and its background do not remain distinct by are crossed together by forward scattering (where original path of the beam of light is altered but it still arrives at the observer) (Bissonette, 1992). Scattering is a function of particle size, expressed most essentially as Rayleigh and Mie scattering. Rayleigh scattering is the term given for the general case in which the particles are much smaller than the wavelength of the light being affected (Wallace and Hobbs 2006). It proportionally affects small wavelengths of light and of little significance for short-distance visibility concerns. Mie scattering is the term given to the case in which the particles are similar in size or larger than the wavelength of the incident light, and is in fact one part of a broader theory that concerns scattering and absorption by spherical particles (Wallace and Hobbs 2006). Mie scattering and absorption are the more important processes at work to modify visibility. Scattering is also a function of refractive index (p74, Wayne 1991), in particular for droplets and ice crystals.

The types of observed weather that can cause reduced visibility are overviewed in the following subsections.

### 3.1.2 Weather types that lead to low visibility situations

#### 3.1.2.1 Fog

Fog is defined by National Oceanic and Atmospheric Administration (NOAA) to "consist of a collection of suspended water droplets or ice crystals near the Earth's surface that lead to a reduction of horizontal visibility below 1 km (5/8 of a statute mile)", and for operational purposes, prevailing visibility is the maximum visibility value common to sectors comprising one-half or more of the horizon circle (NOAA, 1995). The hydrometeors that comprise fog – water droplets and ice crystals – are typically 5 to 50 µm in diameter (Pruppacher et al., 1997) and form as a result of supersaturation generated by cooling, moistening and/or mixing of near surface air parcels of contrasting temperatures.

#### 3.1.2.2 Precipitation

Precipitation occurs when water droplets or ice crystals get large enough that they are able to overcome the updrafts of rising air that form clouds and fall to the ground under the influence of gravity. Precipitation includes snow, rain, hail, drizzle and sleet, the distribution of which varies enormously in time and space.

Rain can reduce visibility, however, it is rare that rain reduces visibility to less than one mile other than in the heaviest showers beneath cumulonimbus clouds. Drizzle, because of the greater number of drops in each volume of air, is usually more effective than rain at reducing the visibility, especially when accompanied by fog (Nav Canada, 2014).

Snow affects visibility more than rain or drizzle and can reduce visibility to less than 1.5 km, and often much lower, to between 0.4 – 0.8 km. Blowing snow occurs when strong winds pick up freshly-fallen snow and lifts it into the air. Under the right conditions, the resuspended snow can extend up as high as several hundred feet. In situations of sudden wind occurrences visibility can be abruptly reduced (Nav Canada, 2014).

Here, blowing snow is discussed separately because it has a different formation mechanism and it has a significant role in low visibility events of Arctic.

#### 3.1.2.3 Blowing Snow

Blowing snow is defined by the Atmospheric Environment Service (now Environment and Climate Change Canada) to be “snow lifted by the wind such that it obscures visible range at "eye level" to less than 9.7 km”. Drifting snow is a visual observation of snow moving along the ground and is a more subjective. Blowing snow is a complex phenomenon and is a function of several variables. This means threshold wind speeds that cause resuspension of snow can vary widely depending on the nature of the snow, including the presence of moisture on the ice particles, the size and shape of the particles, their possible bonding with other particles, air temperature and humidity, and the roughness of the surface (Li and Pomeroy, 1997). Some of these parameters are a function of time since the snow fell because modification of the snow particles occurs over time. This makes it very difficult to determine a single threshold wind speed value. However, Li and Pomeroy (1997), although they state that, “…there are no accepted or known methods for determining the variation of the threshold condition with the meteorological conditions that control snow physical properties…”, go on in that paper to arrive at a broad characterization for a threshold wind speed for initiation of dry snow resuspension of 7.7 m/s. An interesting aspect of blowing snow is the fact that it can undergo sublimation (e.g. Essery et al. 1999) – depending on the conditions and with enough fetch (~4000m), as much as 74% of the transported snow can be lost (Pomeroy et al. 1993). Although not explicitly encountered in the literature, this would presumably have the potential to humidify the boundary layer which would encourage the formation of fog.

#### 3.1.2.4 Haze

Haze is defined by Toth et al. (2010) to be “the weather phenomenon which leads to atmospheric visibility less than 10 km due to the presence of suspended solid or liquid particles, smoke, and vapor in the atmosphere”. Haze results in a uniform reduction in brightness and contrast, with a loss of colour definition (Toth et al., 2010). Urban haze is linked to high levels particulate emission from anthropogenic sources (Watson, 2002). The emission of pollutants, combined with the occurrence of stagnant synoptic conditions, allows for the formation of haze by altering aerosol composition through aqueous-phase reactions (Sun et al., 2006).

## 3.2 Definition of fog

Fog is defined by NOAA as “a cloud on the ground that reduces visibility below one kilometer” (NOAA, 1995). According to Houghton (1985), generally fog occurs when air reaches saturation, causing the formation of small water droplets that are suspended in the air. There are two main mechanisms that can cause fog to form: (a) by adding water vapour close to the surface (b) by cooling (Croft, 2003; Lutgens and Tarbuck, 2004). Both are further explained below.

## 3.3 Fog formation

*a) The addition of water vapor:*

“Precipitation or Frontal fog” and “steam fog” are fog formed by the addition of water vapour. The basic starting point stems from warmer rain falling through colder air below. As they fall evaporation from the raindrops saturates the colder air, producing fog. Such fog is called precipitation fog in general or frontal fog if the rain falls through a frontal inversion layer into the cooler airmass below. Often frontal fog will be related to a warm frontal inversion, but it can also occur under a cold frontal inversion (Toth. *et al.*, 2010).

“Steam fog” is formed when cold air moves over relatively warm water (Gultepe et al., 2007). Evaporation from the surface of the warm water supplies the cold air above with water vapour, raising the dew point to saturation in the cooler air. This results in fog just above the air-water interface. Roach (1995) notes that this type of fog is “also seen inland as ‘steam’ fog rising from ice-free streams or lakes in intense cold spells, or sunlit wet ground after a summer shower.”

*b) Cooling:*

The principle mechanism [at work for fog types that are caused by cooling] involves an underlying earth or ice surface that is relatively cooler than the overlying air. As the air moves over the surface turbulent mixing occurs, which causes the temperature of the overlying air to decrease. When the cooling reduces the dry bulb air temperature to the dew point temperature, condensation takes place and fog forms. There are three main types of fog that are formed through this mechanism: “radiation fog”, “upslope fog” and “advection fog”.

*Radiation fog*: Radiation fog forms under conditions of clear skies and light winds. This meteorological setting facilitates relatively high rates of heat loss from the ground due to outgoing long wave radiation during the night. This cools the air near the ground. If the dry bulb temperature is cooled to the dew point, radiation fog can form (Gultepe et al., 2007; Lutgens and Tarbuck, 2004). Radiation fog typically forms at night and dissipates during the day. However in midwinter, particularly in more northerly latitudes where the sun is low in the sky, it may linger all day. Radiation fog does not affect sea and lake surfaces because they do not cool by more than a small amount overnight.

The particular form taken by condensation processes at and near the surface depends on the wind. The ground cools first, thus the first stage of condensation is typically the formation of small water droplets. If there is no wind, droplets increase in size and are manifested as dew forming on grass, for example. If there is a gentle breeze, turbulent mixing spreads cooling upwards so that a shallow layer of radiation fog forms. When the wind is stronger, stratus cloud tends to form (Thornes, 2013).

*Advection fog*: In situations in which warm air flows over a relatively cold surface, the air near the surface can be cooled to the point of condensation and fog formation. Such fog is referred to as advection fog. It frequently forms over the ocean, in areas where there is cold sea surface water with warmer air that tends to flow over it. This is common, for example, over the ocean off the Canadian east coast, in which warm moist air derived from the Gulf Stream moves over the cold Labrador Current (Petterssen, 1956). Advection fog can also form over land without a marine influence; for example, warm air flowing over cold ground. Advection fog has also been observed over land in winter in the central United States as warm moist air flows over the cooler (sometimes snowy) surface (Friedlein, 2004).

*Upslope fog*: When moist air being cooled adiabatically when it moves up sloping terrain; if sufficiently moist, fog forms. George (1951) states that "upslope conditions by themselves are rarely the primary cause of fog formation (except along the higher and steeper portions of mountain ranges) since the source areas of the upslope flow are often quite dry".

## 3.4 Literature review

There have been few studies that focus on fog in the Arctic. More numerous are studies that focus on fog in general, although typically the focus is confined to specific areas. Below is reviewed previous research covering the North and other, selected fog studies that highlight various fog-formation mechanisms.

Mitchell *et al*. (1987) studied the impact of fog on commercial air transportation for two airports in Sacremento, California. Any type of disruption of flight activity due to fog was considered. This is a region that experiences frequent winter fog events. This study considered only one winter season in particular and provided a bit of an overview of relevant occurrences, such as the fact that one air freight company had abandoned Sacramento Airport altogether. More than 20% of aircraft operations were affected; despite this, airport officials did not feel this was a problem that would be alleviated by technological advances. The other airport in town, the Sacramento Executive Airport, was more adversely affected by fog. The difference was attributed to differing capabilities of the flight instrument systems. This paper demonstrates that fog/low visibility impacts can be enhanced or mitigated by type of airport and its level of equipment, and that, in particular, smaller airports, such as those found in the North, are likely to suffer greater impact. It also described the fog formation mechanism for this area, that of damp soil increasing surface humidity and a strong inversion caused by nighttime cooling under a persistent wintertime high pressure zone.

Ellrod *et al.* (2006) studied the effect of low visibility on five multi - vehicular highway accidents. Authors applied an algorigthm to data obtained from the Geostationary Operational Environmental Satellite (GOES) to predict fog formation; in particular, the multi-spectral infrared and visible channels. They stated that all of the accidents happened near, or shortly after, sunrise on major U.S. or Canadian highways. In their study, the fog was usually detectable from GOES products; however, the lead time was usually short (1- 3 hours).They also stated that all cases were mesoscale events, which would need all of the observational data from satellites and surface mesonets to be properly diagnosed. This is good paper because it provides a methodology by which fog occurrence may be linked to a major, easily available remote sensing platform.

Jobard and Atkinson (2011) developed a climatology of low visibility events (LVE) for the period 1981-2010 for west coast of Alaska. They established specific synoptic patterns responsible for multi-station LVE in the region. The significance of their work was the design of algorithms to handle the lack of data that is typical of Arctic weather stations. They developed an algorithm to build a database of Low Visibility (LV) events using observational data that maximized the use of the sparse available data sets at the arctic stations within the region. The database of LV events they developed enabled the authors to establish the climatology of LV events. They used subjective classification of synoptic fields during occurrences of multi-station LVE, sea surface temperature, radio-soundings, and winds in the synoptic assessments. Climatology results indicated regionally coherent patterns of seasonal variability of low visibility events, with a maximum frequency occurring in early summer and a minimum in September and October.

Westcott (2007) investigated the connection between synoptic conditions and dense fog over the US Midwest between 1974 and 1996. They classified dense fog events by duration into short duration events (< 3 hours), medium duration events (3>hours <5), and long duration events (> 5 hours). They found that the long duration events formed earlier in the evening and all fog groups usually disappeared few hours after sunrise.

Although it has been usually stated that fog occurs in the Midwest as warm moist air advects over cold, usually snowy surfaces, they found that snow was present only in 30% of fog events during the winter session. Also, the percentage of long and short events was independent of existing snow in the area. Based on these results, they concluded that snow is not the main cause of cooling the overlaying air for the formation of dense fog. Short duration events formed mostly behind cold fronts; however, most of long duration events occurred in the warm sectors of environment. In addition, they observed that precipitation usually occurred at the beginning of fog formation events.

Tardiff *et al*. (2007) investigated the characteristics of fog in a region centered on New York City. They used hourly surface observations to determine fog events in different locations which are under the impact of various physiographic features. Events are defined according to frequency, duration, and intensity. Also, they used a quantitative evaluation to obtain the probability that mechanisms leading to fog formation are happening in the region. The results show that the presence of the urban heat island of

New York City decreases the probability of fog occurrence, however, the probability of fog occurrence is increased at the marine environment. The most common type of fog was precipitation fog, which occurs mainly in winter. Also, fog caused by cloud-base lowering was frequent during winter and spring sessions.

# 4. Methodology

## 4.1 Datasets and analysis procedure

In this section *data collection* and sources, analysis methodology, and the geographical region of study are overviewed. This includes the methods used to identify low visibility and very low visibility events, and to create time series of low visibility events.

### 4.1.1 Description of the datasets

#### 4.1.1.1 Surface observational data

The surface observational data used in this study were drawn from the Historical Climate data archives held by Environment and Climate Change Canada. The following parameters were obtained: dry bulb and dew point temperature, wind speed and direction, visibility, and observed weather. From the parameter field called "observed weather" the following weather elements were utilized: fog, blowing snow, snow, drizzle, rain and smoke.

#### 4.1.1.2 Station selection and data limitations

Relatively few weather stations in the western Canadian Arctic report uninterrupted hourly observations for the 1980-2015 period of interest. The main reason for the lack of data availability is the expense and difficulty associated with the maintenance of instruments. A lack of data presents several problems. First, is the capacity of weather stations to represent the major landscape types that are present in the North. Most weather stations in the Canadian Arctic are situated on the coast, which means large interior regions, especially in the islands, are unrepresented. Second is the capacity of station data to provide a spatially detailed representation of the region. Station areal density is very low and many local- and meso-scale details are not resolved. Finally, stations have often moved or have periods of missing data which hamper efforts to construct time series that reflect changing weather patterns.

This study has attempted to address these issues in the following manner. The representation of different regions is explicitly considered by selecting appropriate stations (Table 4.1, Fig. 3.1). The issue of spatial detail is addressed by linking site-specific observations to the broader synoptic and meso-scale circulation patterns using reanalysis data. Concerns about station moves and missing are handled by using stations with the longest continuous time series available.

The weather station parameters used in this study are all human-observed – these stations have never employed the automated visibility and precipitation-type sensors that are employed now on NOAA/National Weather Service Automated Station Observing Systems (ASOS). Thus, although different observers have come and gone, the timing of which is information that is not available from ECCC, the observations are consistent in that they have always been taken in the same manner. There was never a break point between times when, for example, a new instrument took over from a human observer.

Despite this they nonetheless have data records that are sufficiently long and continuous to create a database of low visibility (LV) events. With no alternative dataset, these records represent the best opportunity to develop a climatology of low visibility events. Stations possessing continuous or near-continuous data for the 1980-2015 period were used to develop a statistically stable climatology, and to allow calculation of trends

**Table 4.1**: Location and general geographic zone for the five stations used in the study.

| Stations | Area | Lat Lon | Elevation |
|---|---|---|---|
| Aklavik | Inland Mackenzie Delta | 68° 13′ 8″ N<br>135° 0′ 31″ W | 7 m |
| Inuvik | Inland Mackenzie Valley | 68° 21′ 42″ N<br>133° 43′ 50″ W | 68 m |
| Sachs Harbour | Beaufort Sea | 71°59′08″N<br>125°14′53″W | 86 m |
| Tuktoyatuk | Mackenzie Delta coast | 69° 26′ 34″ N<br>133° 1′ 52″ W | 5 m |
| Ulukhaktok (Holman) | Archipelago | 70°44′11″N<br>117°46′05″W | 36 m |

#### 4.1.1.3 Reanalysis data for synoptic analysis

Plots of large scale weather features – synoptic plots – were created using reanalysis data. A reanalysis is a set of gridded fields of meteorological variables that have been created by running a weather forecast model for previous time periods using observational data that were available at that time. These are called “hindcasts”. They are a good way to plot maps of the variables for specific times back to when the reanalysis was started. Two reanalyses were used: the National Centers for Environmental Prediction/National Center for Atmospheric Research NCEP/NCAR global reanalysis (Kalnay et al. 1996), and the North America Regional Reanalysis (Compo et al. 2006). For NCEP/NCAR that was 1948. For NARR that was 1979. The resolution of NCEP/NCAR is 2.5 degrees of latitude and longitude and a grid is available every six hours. For the NARR it is 32km latitude/longitude and a grid is available every three hours. The NCEP/NCAR global reanalysis was used to examine synoptic patterns over a large spatial scale. If finer resolution was required, the NARR reanalysis was used.

Reanalysis data were used to create contour plots showing the spatial distribution of selected variables for times when multi-hour fog events were recorded. Variables were typically pressure and specific humidity. Plots of means as well as anomalies were created where needed to emphasize a concept. The plots were created using an on-line tool available from the US National Oceanic and Atmospheric Administration (NOAA) at their Earth Research Systems Laboratory website.

#### 4.1.1.4 Sea ice data

Sea ice data were obtained from the archives held by the Canadian Ice Service, a division of Environment and Climate Change Canada. These took the form of scanned charts that depict sea ice concentration, percent cover, and extent. They were not available before 1983.

#### 4.1.1.5 Sea surface temperature data

Sea surface temperature (SST) data were obtained from NASA’s holdings of SST data generated by the MODIS sensor carried on board the Terra and Aqua satellites. A high resolution (4 km) 8-day integrated image was downloaded for August 28 – September 4, 2016. The image was plotted and SST values for the water just off of Tuktoyaktuk and Ulukhaktok were obtained.

### 4.2 Methods

Two different methods were used to analyze low visibility events. First, a series of frequency analyses of the number of low visibility and very low visibility (LV/VLV hereafter) events were performed, organized by different time frames. Second, an algorithm was applied to identify multi-hour LV events caused by fog, to create a database of these occurrences. These are described in detail below.

### 4.2.1 Low visibility climatology

A climatology establishing the typical patterns of occurrence of LV and VLV events hour-by-hour over the course of a day, month-by-month over the course of a year, and annually over the period of record, was created using a series of frequency analyses.

Counts of LV/VLV events were obtained in the following manner. Using visibility thresholds three visibility categories were established: 0 for “good” conditions, 1 for “low visibility” (LV) conditions, and 2 for “very low visibility” (VLV) conditions.

Establishing visibility thresholds is not simple and depends on the application, both for operational settings as well in research. The approach used to define “low visibility” and “very low visibility” was established after consulting the definitions used operationally by various government weather and transportation agencies as well as by other authors in research settings.

NavCanada identifies the following threshold for visibility, or “runway visual range”, that governs when rules for low visibility operations come into effect at an airport: “Reduced visibility operations are operations that occur at an aerodrome when the visibility is below Runway Visual Range (RVR) 2600 [½ statute mile (sm)] down to and including RVR 1200 m (¼ sm)”.

In addition to the operational setting, for research applications a range of thresholds have been used, depending on the needs of their studies. For example, a threshold of 400 m was used by (Baars et al., 2003) in their study of determining fog type in the Los Angeles area, and by Witiw and LaDochy (2008) in their study of the relationship between coastal fog in southern California and the Pacific Decadal Oscillation (PDO). Friedlein (2004) used 500 m for their work on dense fog in Chicago International Airport. Rattenbury (2009) worked with reindeer herders in northwest Alaska to determine visibility thresholds that are problematic for them, and found they begin to experience difficulties when visibility ranges between 500 m and 5000 m.

For this study a visibility threshold of 2600 m was selected for LV, regardless of the cause (fog, blowing snow, rain, drizzle or blowing snow). This threshold corresponds to the threshold for low visibility specified by NavCanada. A second visibility threshold of 600 m was used to examine very low visibility conditions.

These thresholds were used to assign the hourly visibility values that were obtained from the weather station data to one of the three visibility categories. This was done treating each hourly observation as an independent event; that is, without consideration of the category that the previous or subsequent hourly value had been assigned to. Total counts in each visibility category were obtained for the period of record on an hourly and monthly time frame; annual totals were also obtained for long-term trend assessment. Hourly values were further broken out by season. Seasonality in the north is not the same as for locations in the mid-latitudes, and for this study winter is defined to be the November through March period; Summer, June through August; and a single third season, representing the spring and fall shoulder seasons, is defined as April, May, September, and October.

For plotting and analysis purposes these visibility categories were used; the number of times an observation of fog was coincident was also noted for each visibility category and recorded as a percentage. That is, if fog was called for every occurrence of a Very Low Visibility category designation, the resulting percentage would be 100%. This allowed examination of the relative importance of fog as a mechanism causing a reduction of visibility. It is conceivable to have a number of LV events that are all caused by blowing snow or some other mechanism. In this case, the percentage of fog as a causative mechanism would be zero.

There were two concerns with the weather station data. The first is there are often not very many observations, which means it can be problematic to compare frequency totals expressed as percentages amongst different time periods. For this reason the frequency plots are presented with numbers that indicate the total number of events. To aid interpretation, the frequency plots also include the total number of observations for each time period, indicated as dots (see figure captions). The second is concern is that the number of observations available between time periods is usually not consistent. To account for this the total number of LV/VLV events is expressed as a proportion of the total number of observations for that period, which allows for intercomparison.

An analysis of selected weather types causing LV/VLV conditions is also presented: fog, snow, blowing snow, rain, drizzle. It must be remembered that often there is more than one weather type listed during a single hourly observation; for this reason, the percentages on the plots (e.g., Fig. 5.7) can often sum to greater than 100%.

#### 4.2.1.1 Trends over period of record

Annual values for the proportion of LV and VLV events caused by fog, snow, blowing snow, rain, and drizzle were examined for trends over the period of record. Trend analysis is presented at the end of the results section.

### 4.2.2 Multi-hour low visibility events

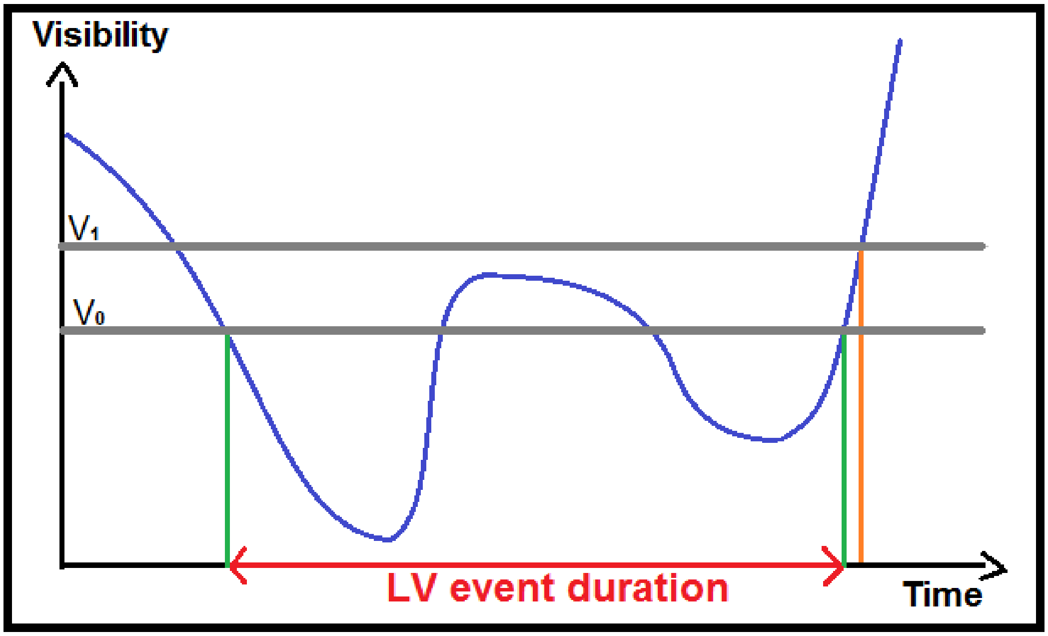

**Figure 4.1:** Schematic illustration of the definition used to identify LV events (Jobard and Atkinson 2011).

A database of low visibility "events" of several hours' duration was created using an algorithm adopted from Jobard and Atkinson (2012) and applied to identify occurrences when LV conditions were being observed (i.e. visibility less than 2600 m) and fog was present. The basic operation of the algorithm is as follows: an LV event is considered to begin when visibility falls below a specified threshold V0 (i.e., LV conditions) and ends when visibility goes above the threshold. This simple method is then enhanced to account for periods just before or after an event during which the visibility is just above threshold, or very short periods within a longer event during which the visibility rises briefly above V0. In these cases the visibility has to exceed a second threshold defined by V1 = 1.2V0 (Fig. 4.1). The explicit accounting of short-duration breaks in an otherwise continuous event reduces the likelihood that the algorithm identifies two short-duration LV events instead of one, which limits the potential of overcounting. Operation of this event identification algorithm resulted in a database of events that includes LV event start and end date and time.

A limitation of this for this study is the fact that four of the five stations have daytime-only observing schedules, which means that these sites will not contain events exceeding half a day in duration, even though a fog-induced LV event might in fact have lasted several days.

### 4.2.3 Synoptic analysis

A synoptic analysis was performed on the events database. For each event the prevailing synoptic pattern was visually examined and assigned a category. From this several typical pattern categories were defined. Presented in the Results section, for each station, are two examples of multi-hour fog events with synoptic analysis. Of the two examples selected for presentation one is designed to show a well-defined synoptic pattern with strong pressure gradients, and the other is a poorly defined pattern. The rationale for including poorly defined pattern is that in many cases patterns were not particularly strong, so they need to be included in the analysis.

# 5. Results

Results are organized by station with the climatology of LV/VLV elements coming first, the relative proportion of different weather types coming second, and the synoptic analyses of selected fog events coming last.

## 5.1 Aklavik

### 5.1.1 Visibility climatologies

#### 5.1.1.1 Hourly climatologies

An important point to note about observations from Aklavik is they take place during business hours, when the airport is open. Thus observations are not taken at night between 1900hrs–0600hrs, inclusive. All results and discussion are limited to “daylight” hours at Aklavik.

Considering the annual timeframe (Fig. 5.1), Aklavik exhibited a tendency for LV events caused by fog to be most frequent at 0700/0800 hrs (50%), and then decreased steadily for the rest of the day (1600hrs), dropping to 20%. The proportion of VLV events caused by fog are much higher and tended to remain high into the mid-afternoon at 80% to 90%. A decrease begins at 1100-1200hrs, which becomes very rapid after 1200hrs, dropping to 15%. It looks like the trend then reverses as evening begins, with a slight increase back above 10%, observed at 1800hrs (Fig. 5.1).

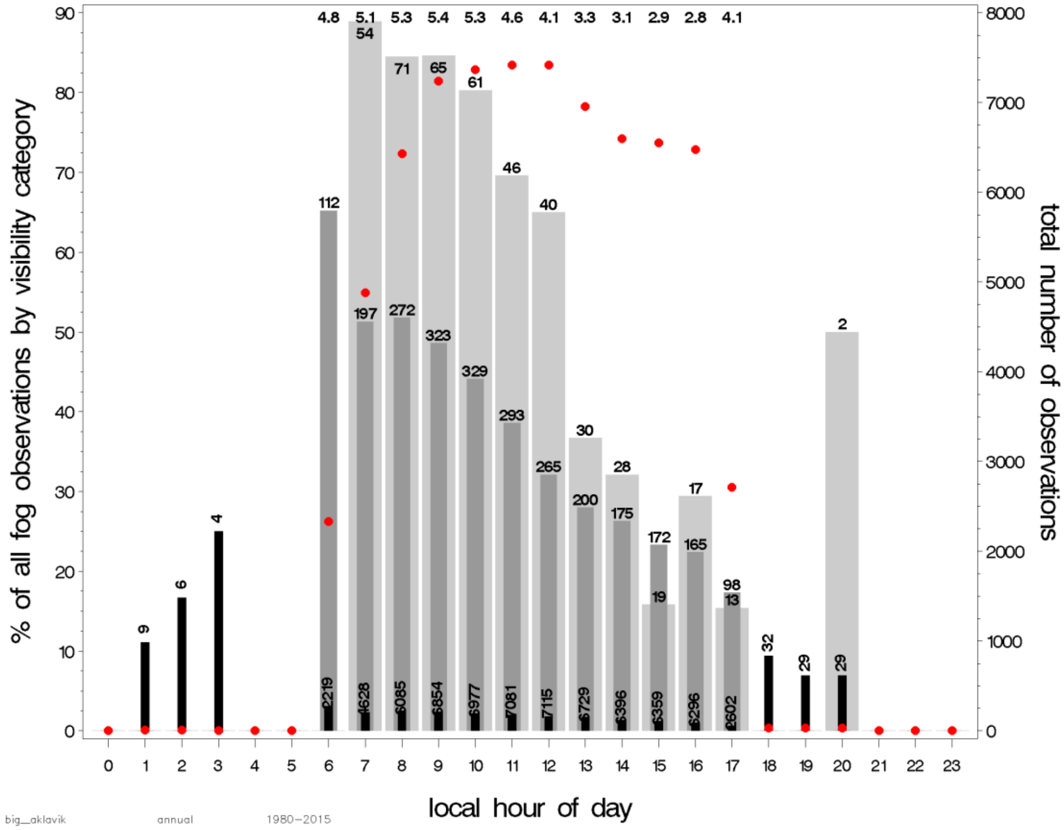

**Figure 5.1:** Total counts of hourly occurrences of LV and VLV events for Aklavik, with an indication of the influence of fog, for all months of the year. Light grey bars represent the proportion of VLV events associated with a coincident observation of fog. Total VLV counts are the small number at the top of the light grey bar. Dark grey bars represent the proportion of LV events associated with a coincident observation of fog. Total LV counts are the small number at the top of the grey bar. Black bars represent the proportion of total available observations that were not in the VLV/LV category and which had fog associated with them. Total non-VLV/LV counts are the small rotated number at the top of the black bars. The total percent of all observations for which VLV/LV conditions existed are printed as the small number at the top of each column. The red dots represent the total number of observations available in that hour.

In winter (Fig. 5.2), LV the proportion of LV events caused by fog started at relatively low levels (20%-30%) and did not exhibit much of a decrease until after 1300hrs, at which time it dropped by 10% but then started slowly rising again. VLV events were higher (~40%) in the morning (0800 – 1200hrs), but then dropped to a low value (8%) and then slowly until 1700hrs (Fig. 5.2).

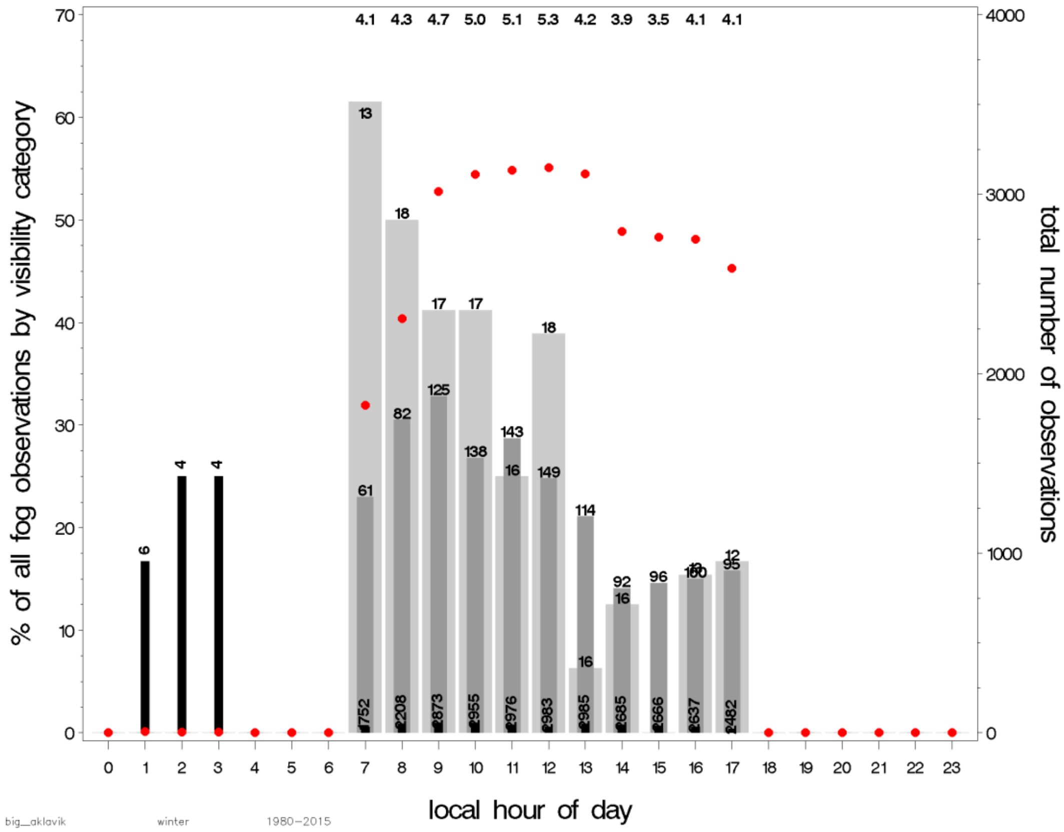

**Figure 5.2:** Total counts of hourly occurrences of LV and VLV events for Aklavik, with an indication of the influence of fog, for winter months (month=11, 12, 1, 2, 3). Please refer to the caption in Figure 5.1 for a complete description of this plot.

In summer, the proportion of LV events caused by fog were again more common in the first part of the observation period, that is, 0700hrs – 1100hrs. Percentages in the morning timeframe ranged from 75-80% for LV events. After 1100hrs the proportion decreases until 1500hrs after increases back above 85%. Importantly, no VLV events occurred in Aklavik in summer (Fig. 5.3). It is important to note that there are not very many LV events observed in the afternoon at Aklavik, making the fog proportion results less reliable. For example, over the 26-year study period, for 1600hrs in the summer months, only seven LV events were observed.

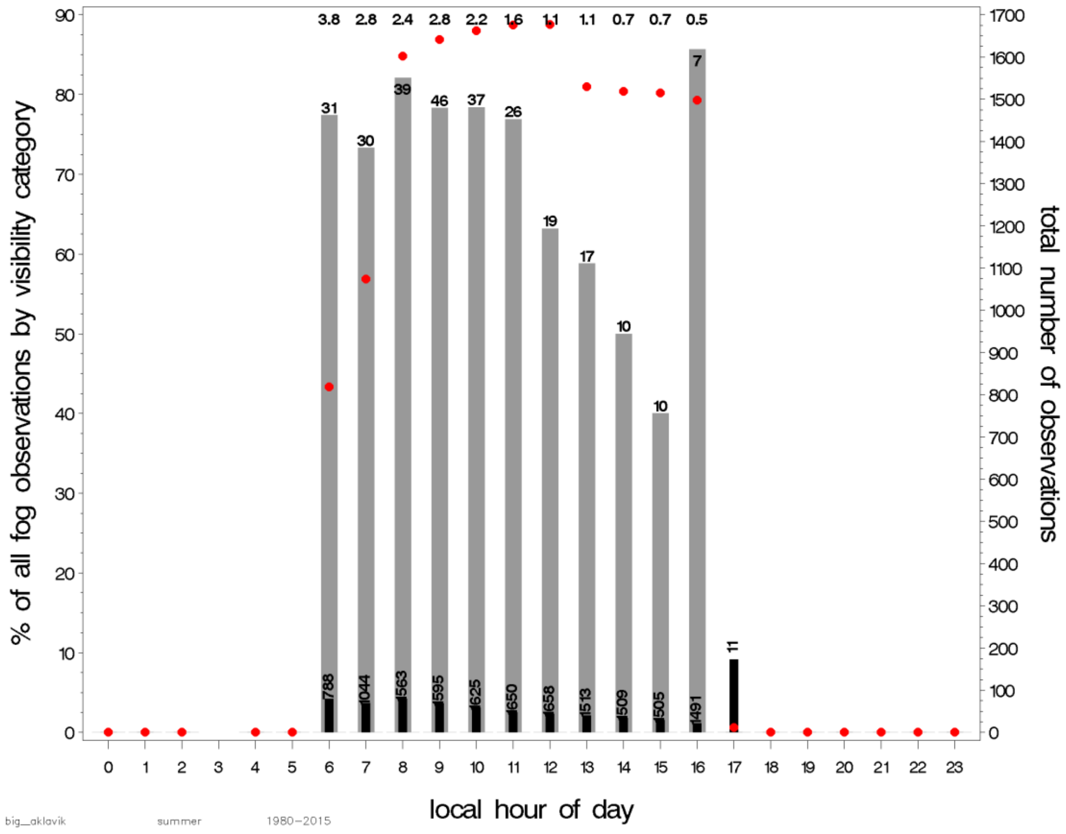

**Figure 5.3:** Total counts of hourly occurrences of LV and VLV events for Aklavik, with an indication of the influence of fog, for summer months (month= 6,7, 8). Please refer to the caption in Figure 5.1 for a complete description of this plot.

In fall and spring (Fig. 5.4) the general pattern of high in the morning a low in the afternoon was repeated for LV events: proportions started at 60% and then decreased steadily throughout the day to a low of 25%. Again a spike at 1700hrs was observed, but as for summer, there were only three LV events observed over the entire period of record. VLV event proportions did not exhibit an immediate decrease as they did in winter, but rather remained at an elevated level (~95%) until 1100hrs. VLV events decreased after 1100hrs to ~50%, but again, there are very few VLV events at 1500 and 1600hrs, rendering proportions possibly unreliable (Fig. 5.4).

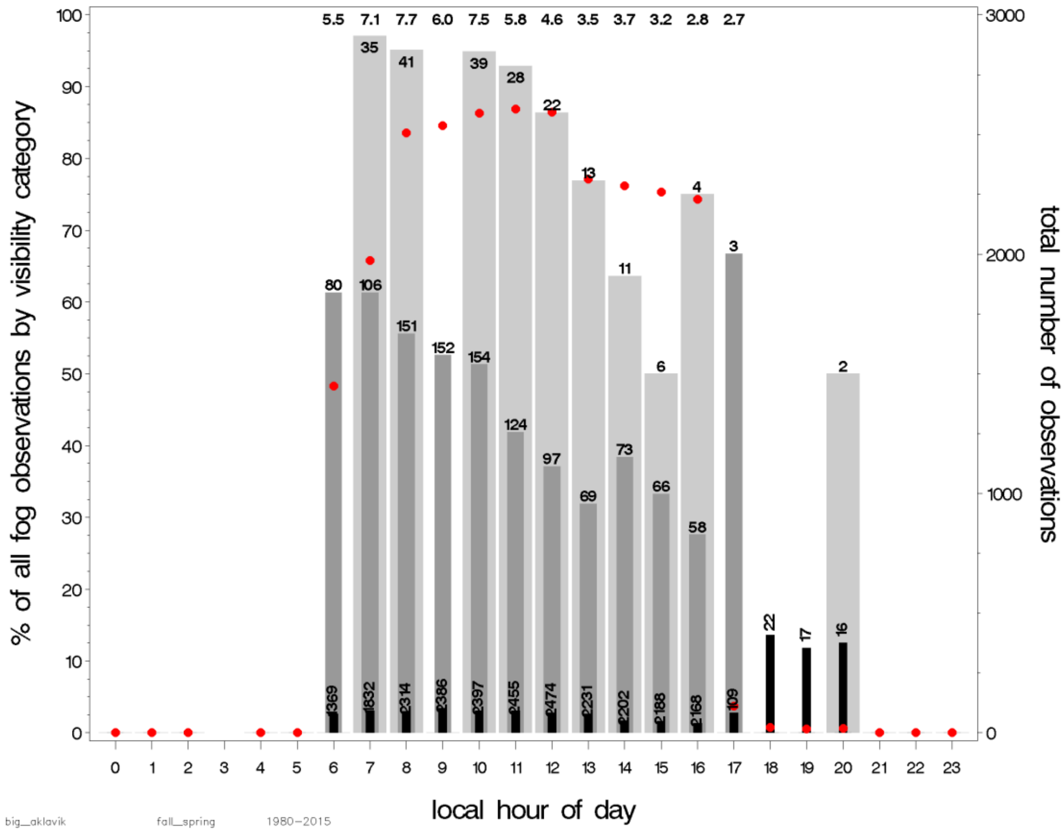

**Figure 5.4:** Total counts of hourly occurrences of LV and VLV events for Aklavik, with an indication of the influence of fog, for fall and spring months (month=4, 5, 9, 10). Please refer to the caption in Figure 5.1 for a complete description of this plot.

#### 5.1.1.2 Monthly climatologies

At Aklavik the occurrence of LV and VLV events exhibited strong seasonality. LV and VLV events were relatively frequent in the January-April time period. The proportion of these events caused by fog is relatively low, around 20-50%. The number of LV events drops off in the late spring-summer period (May-July); VLV events are very low in June and July, however the proportion of LV events caused by fog increases. (It is important to note that the total number of available observations drops off in July and August – this is a result of subsistence hunting/gathering practices.) LV event frequency again rises into the September-December period, with the largest total number of LV occurrences observed in October. VLV events occur again during this period. The proportion of LV and VLV events caused by fog is greater than in the January-April time period (Fig. 5.5).

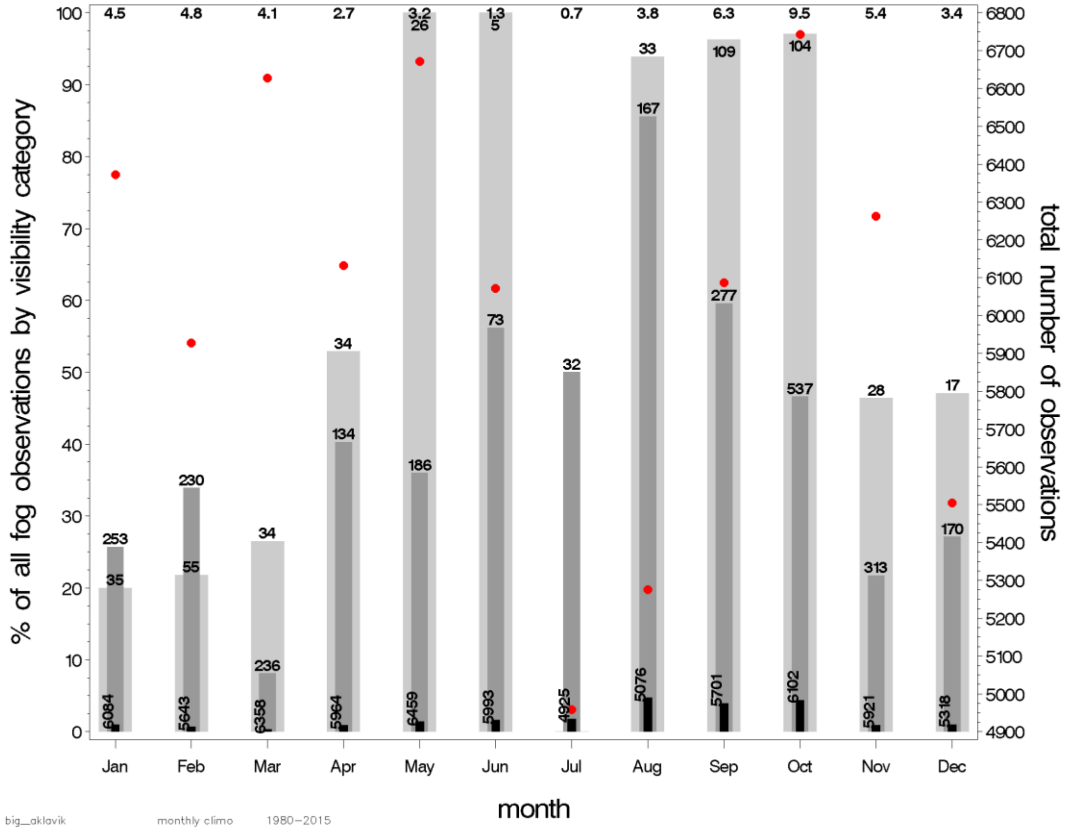

**Figure 5.5:** Total counts of monthly occurrences of LV and VLV events for Aklavik, with an indication of the influence of fog. Please refer to the caption in Figure 5.1 for a complete description of this plot. Note that July recorded one VLV event but the algorithm for the plots does not plot a bar if the total number of events is <2.

### 5.1.1.3 Annual trends

At Aklavik the total number of observations available per year was fairly low in the first few years and then roughly stabilized, although there was a ~10% variability from one year to the next. (Fig. 5.6). There is no significant trend in the total occurrence of LV/VLV events combined (Table 5.1). There is noticeable interannual variability (Fig. 5.6).

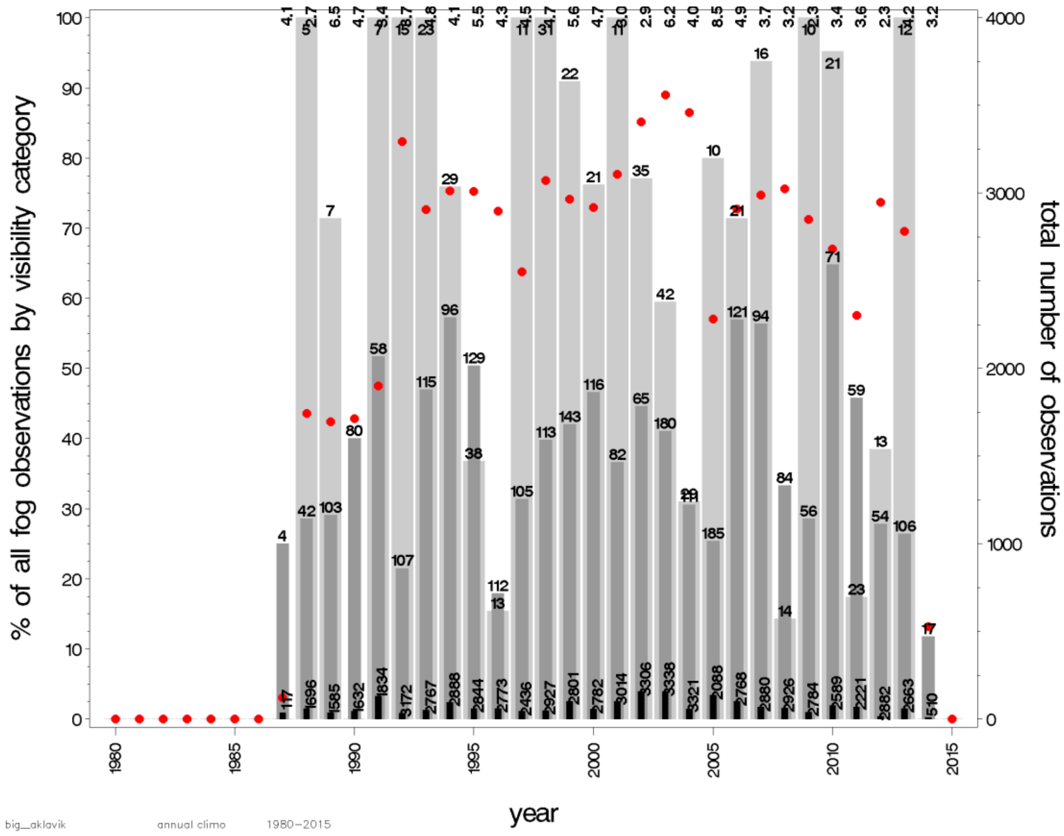

**Figure 5.6:** Total counts of annual occurrences of LV and VLV events for Aklavik, with an indication of the influence of fog. Please refer to the caption in Figure 5.1 for a complete description of this plot.

### 5.1.2 Low visibility event causes by weather type

Examining what proportion of weather type observations were responsible for LV/VLV events helps to place in context the relative importance of fog as a weather occurrence that causes potential disruption. This analysis was of particular interest because the north has frequent occurrences of snow and blowing snow, which can also be problematic for visibility.

#### 5.1.2.1 Hourly by type

For Aklavik, the hourly climatology of weather events indicates a general tendency for greater frequency of blowing snow and fog events to occur in the mid-late morning. Blowing snow is the most frequent cause of LV events for all times of the day. Fog started high, decreased to a low point in the early-mid afternoon, and then showed an increase into the late afternoon (Fig. 5.7).

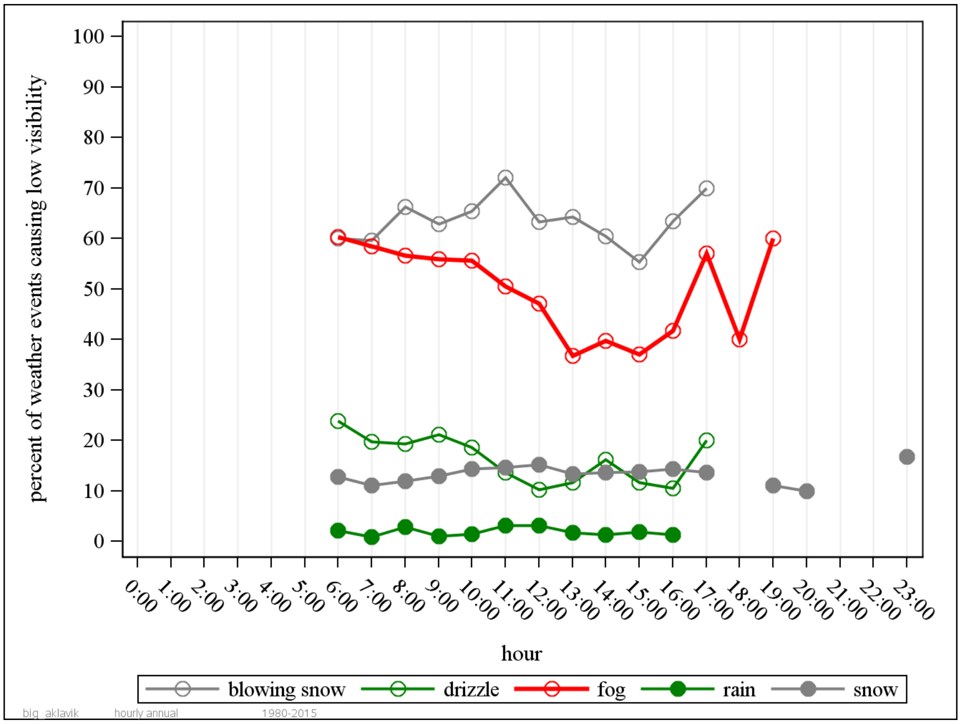

**Figure 5.7:** Percent of hourly occurrences that different weather types were associated with an LV/VLV event for Aklavik, for all months of the year.

Aklavik hourlies in the fall and spring were similar to the annual progression, except that fog accounts for a greater proportion of the events, similar to the number of blowing snow events. Total fog event numbers peak in the early morning, decline until 1300hrs, and then rise again into the afternoon (Fig. 5.8).

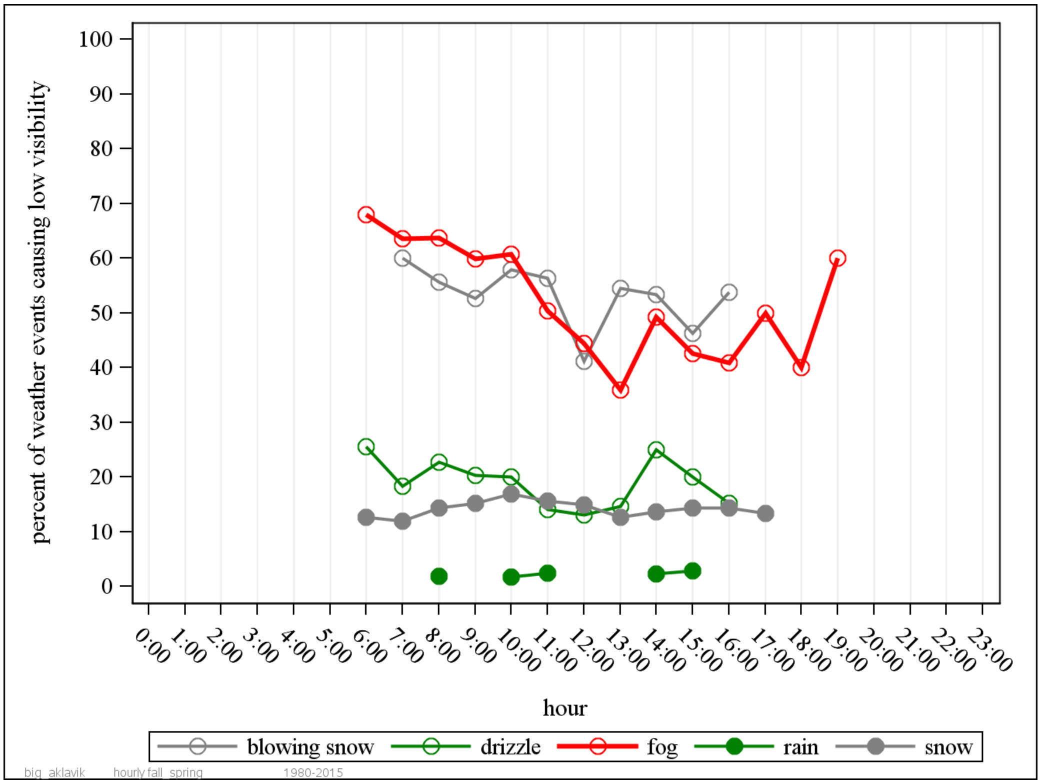

**Figure 5.8:** Percent of occurrences that different weather types were associated with an LV/VLV event for Aklavik, by hour, for the fall and spring months (month= 4, 5, 9, 10).

Aklavik hourlies in the summer showed fog, drizzle and smoke interestingly enough declining throughout the day from an early morning peak. Fog rises again in the late afternoon. Snow frequency rises throughout the day to a peak in the mid afternoon (Fig. 5.9).

Finally, Aklavik hourlies in the winter showed event totals for blowing snow that remained high throughout the day. Event types were dominated by fog and blowing snow. Fog events were frequent until noon, declined into the mid afternoon, and then rose again (Fig. 5.10).

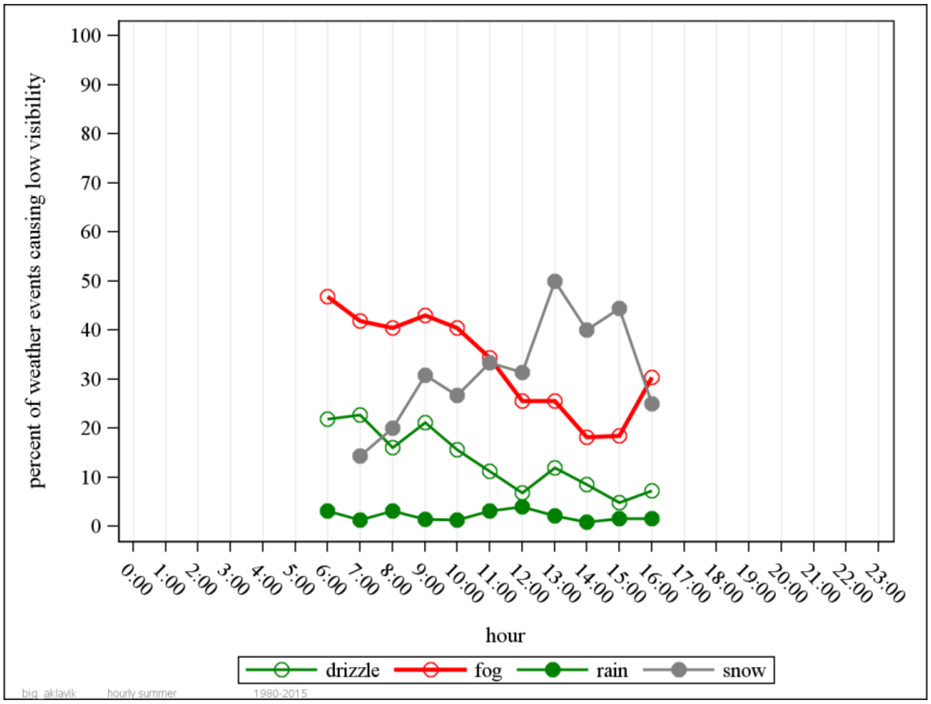

**Figure 5.9:** Percent of occurrences that different weather types were associated with an LV/VLV event for Aklavik, by hour, for the summer months (month= 6, 7, 8).

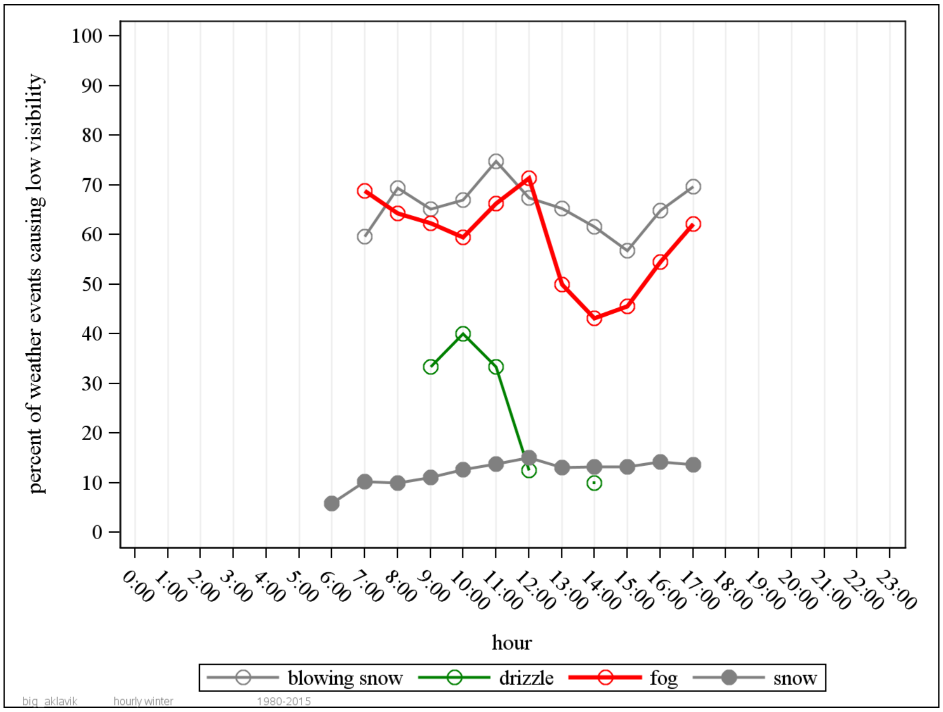

**Figure 5.10:** Percent of occurrences that different weather types were associated with an LV/VLV event for Aklavik, by hour, for the winter months (month= 11, 12, 1, 2, 3)

#### 5.1.2.2 Monthly by type

At Aklavik the monthly climatology indicates that blowing snow occurrences are responsible for a relatively consistent proportion of LV/VLV events, 40 to 66%. Fog occurrences are also relatively consistent between 40 and 71% in all months except June and July, when the proportion drops as low as 15%. Snow occurrences are responsible for relatively few LV/VLV events, from 10 to 18%, except June and August, when the proportion rises to as high as 35%. Drizzle occurrences are responsible for only 5 to 22% in the late spring/early summer period (May through July) and winter (November and December), but are relatively high in August through October. Rain is observed only in the June through September period and rarely is responsible for LV/VLV events (Fig. 5.11).

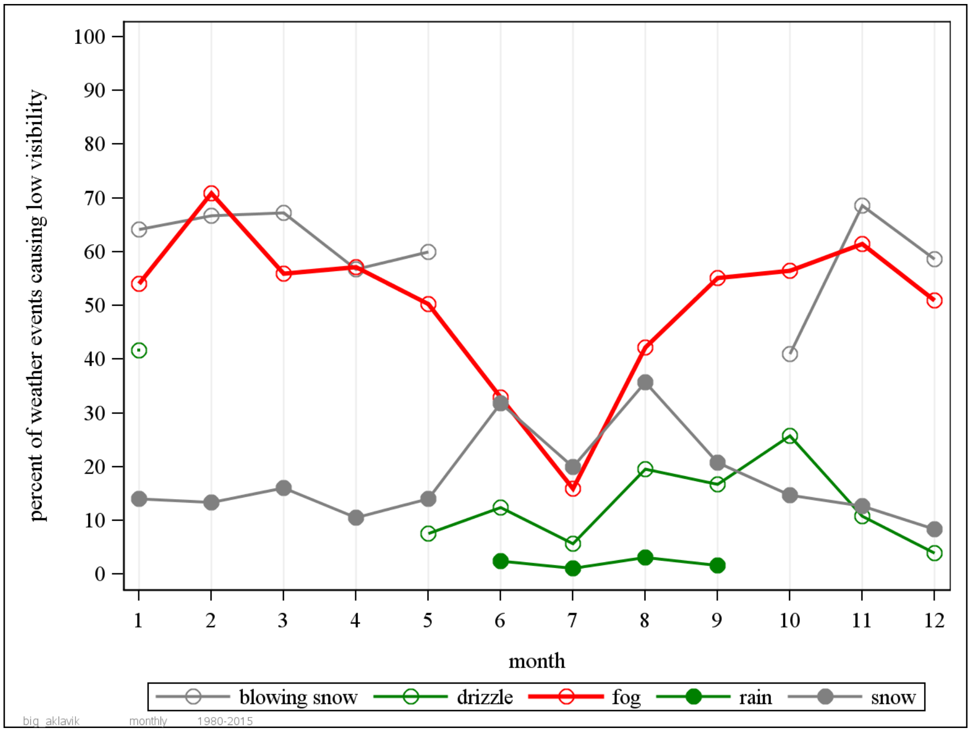

**Figure 5.11:** Percent of occurrences that different weather types were associated with an LV/VLV event for Aklavik, by month.

### 5.1.2.3 Annual by type

At Aklavik (Fig. 5.12) the occurrence of blowing snow was most likely to be responsible for LV events. From 1987 through 2006 between 40 and 100% of all blowing snow occurrences were severe enough to trigger an LV/VLV event. It is of interest to note that the proportion declined after 2006 to range around 20%; interannual variability also increased. The decrease was significant at 17.0 +/- 4.1% per decade (Table 5.2). Fog is the next most likely weather type to cause LV/VLV events. Over the entire period of record between 30 and 70% of all fog occurrences were severe enough to trigger an LV/VLV event. The proportion of drizzle was also noted to have a statistically significant decrease at 10.2 +/- 2.9% per decade.

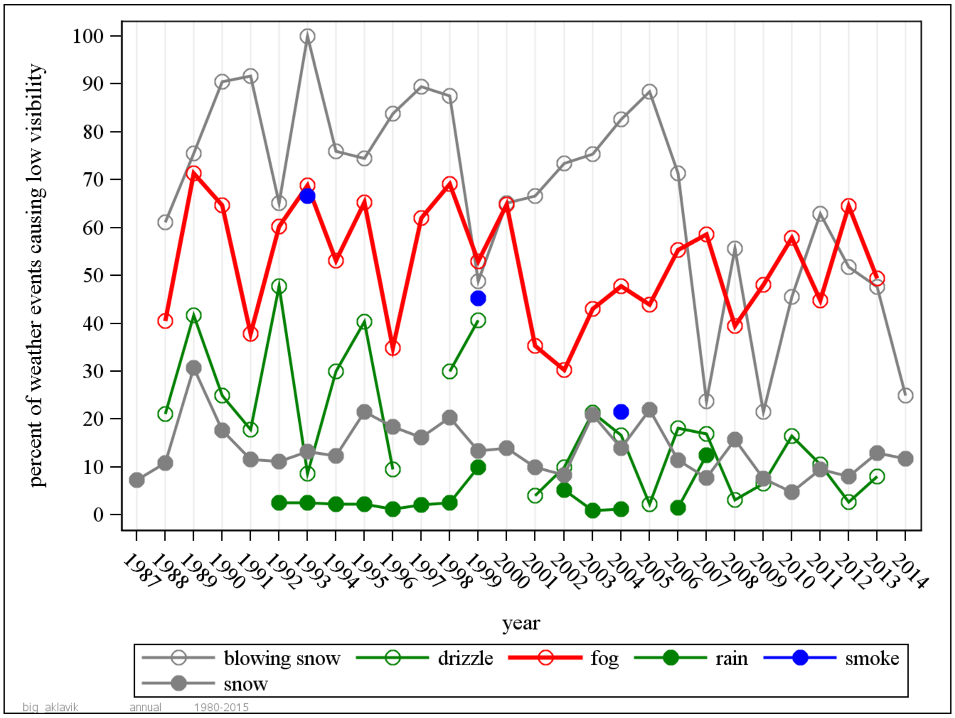

**Figure 5.12:** Percent of occurrences that different weather types were associated with an LV/VLV event for Aklavik, by year.

### 5.1.3 Synoptic analysis

As mentioned in chapter two, the occurrence of fog is a function of either increasing atmospheric moisture content, reducing saturation point of the air, i.e. by reducing temperature, or both.

Moisture needed for the formation of fog can be provided by large-scale, as well as local-scale processes. Large scale processes are associated with synoptic patterns. Most moisture advection to CAA at the large scale is from the Bering Sea, Gulf of Alaska, Great Lakes, Great Bear Lake, and even the Gulf of Mexico. Local moisture sources on the other hand consist of melting snow and open waters of the ocean or local lakes.

An example of a large-scale moisture advection event occurred at Aklavik on 29 December 2005. At the surface a powerful low was located over Gulf of Alaska, with a trough extending northwards over Great Bear Lake. An area of high pressure was located over the western Hudson Bay. These two features formed a strong pressure gradient between them which can rapidly advect air from the western Hudson Bay region over the western Arctic Archipelago and the Mackenzie Delta region. This pattern advected air from the vicinity of the Great Lakes and Great Bear Lake into the study region (Fig. 5.13a). Examining the specific humidity anomaly at 1000 hPa shows that an unusual amount of moisture was being drawn into the study area, as compared to the 30 year mean for this time period (Fig. 5.13b). This moisture in turn was likely moved over the Great Lakes by a low pressure feature situated just south of the Great Lakes. The addition of moisture caused the fog, and the fact that this was the result of a large-scale pressure pattern, which lasted several hours, also allowed the advection of moisture, and so the fog event, to also continue for several hours.

An example of a fog event driven by local conditions occurred at Aklavik on 20 February 1991. There is no unusual synoptic-scale advection of moisture (Fig. 5.14a). However on this day very low temperatures were observed at Aklavik, below -28 C, which created conditions suitable for radiation fog (Fig. 5.14b). This is fairly typical in the north: excessive long-wave radiation from the surface causes a temperature drop which also reduces the saturation vapour pressure; this eventually results in condensation. The coldest part of the atmosphere is next to the radiating surface, which is the ground, which also means this is where condensation occurs.

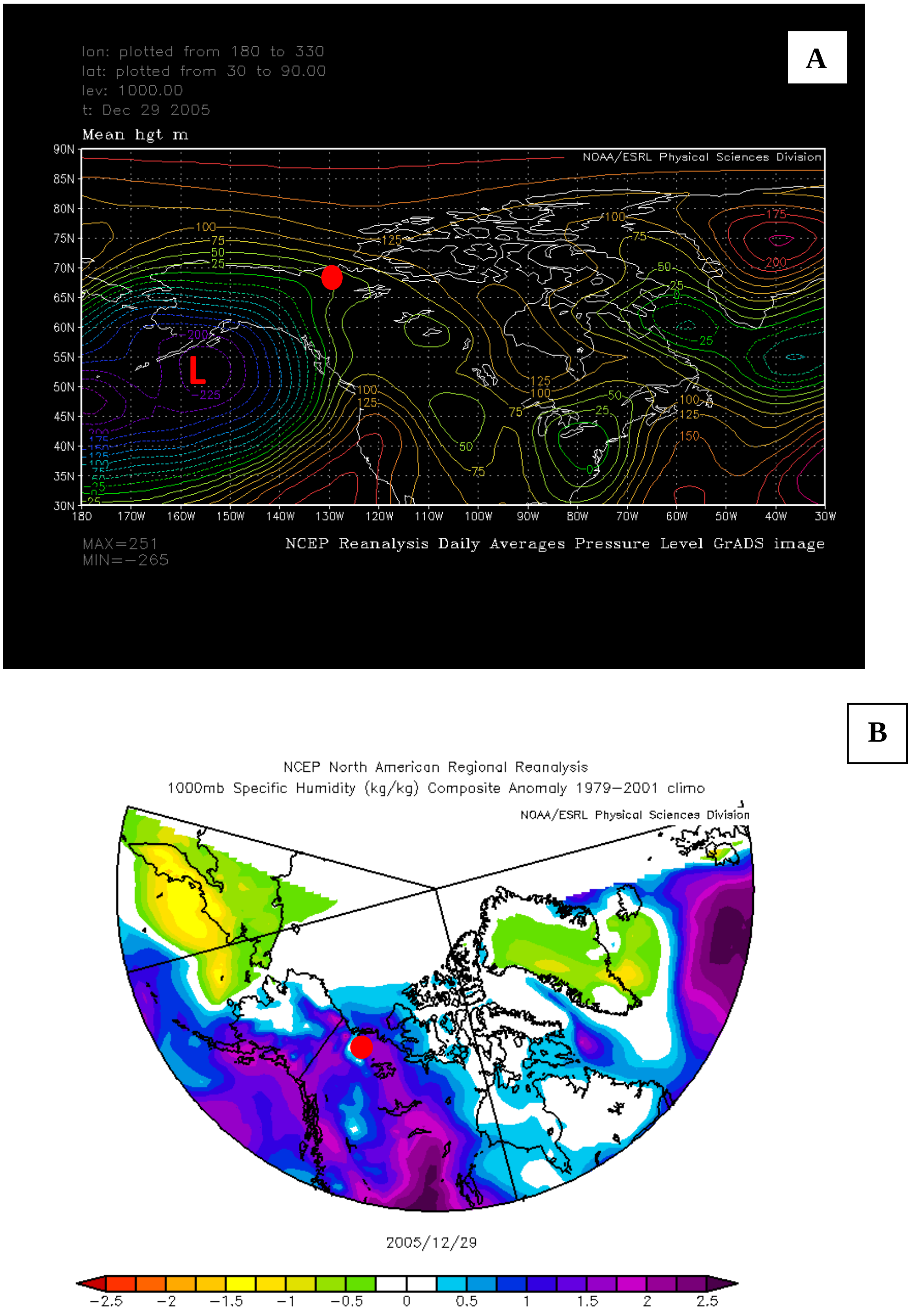

**Figure 5.13:** Selected atmospheric variables for the Aklavik fog event of 29 December 2005. A) height of the 1000hPa pressure surface (m). B) 1000hPa specific humidity anomaly (mean period is 1979-2001).

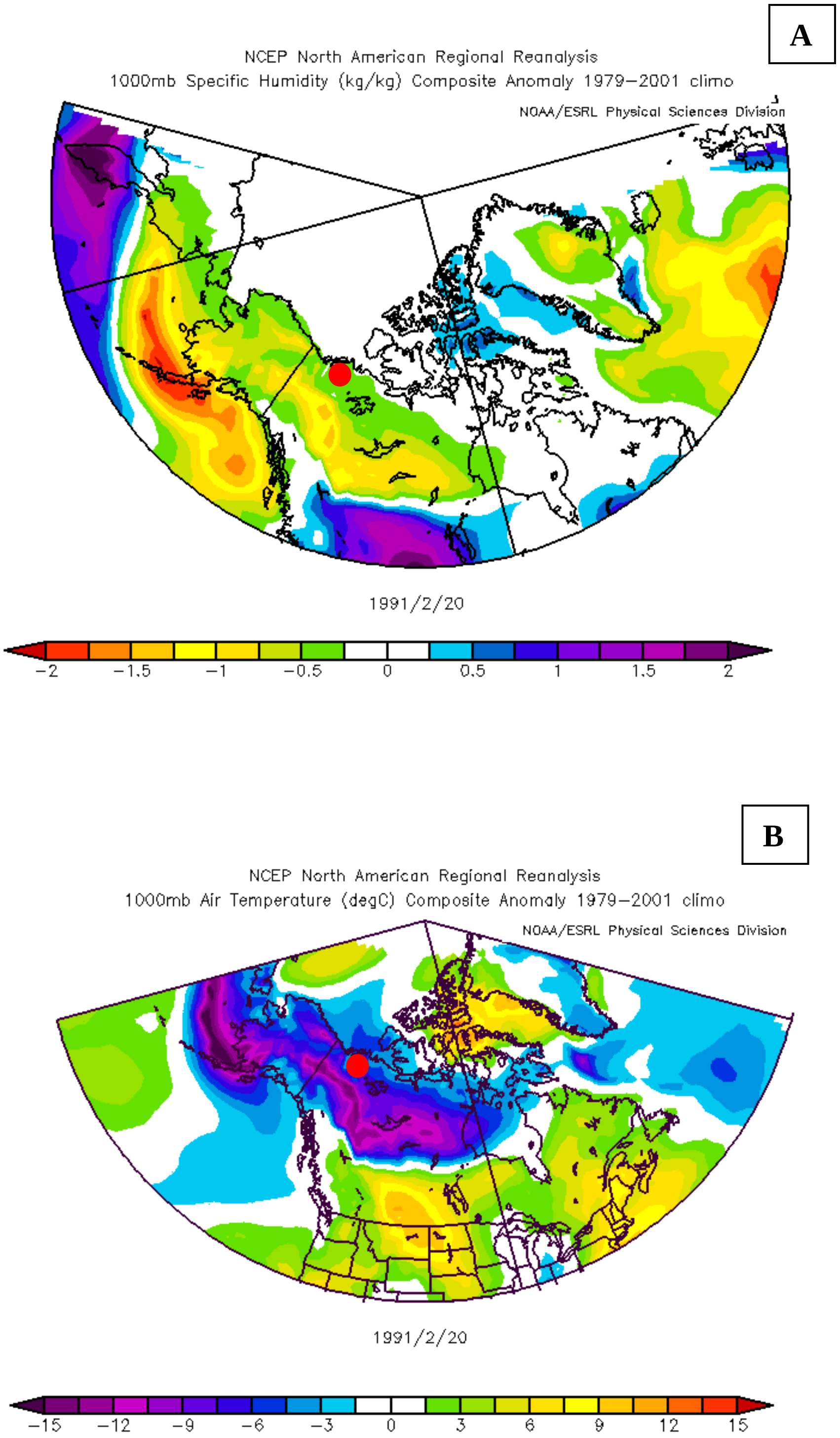

**Figure 5.14:** Selected atmospheric variables for the Aklavik fog event of 20 February 1991. A) 1000hPa specific humidity anomaly (mean period is 1979-2001). B) 1000hPa air temperature anomaly.

## 5.2 Inuvik

### 5.2.1 Visibility climatologies

#### 5.2.1.1 Hourly climatologies

At the average annual hourly timeframe, Inuvik exhibited LV events caused by fog to increase in frequency up to 55% by early morning. After 0600hrs a gradual decrease through the afternoon to 26% is observed. LV events then show an increasing frequency during night. VLV events are observed in all hours, with a maximum in the early morning near 97%, dropping gradually to 67% at 1400hrs. There is a strong drop off at 1500hrs to 35% (Fig. 5.15).

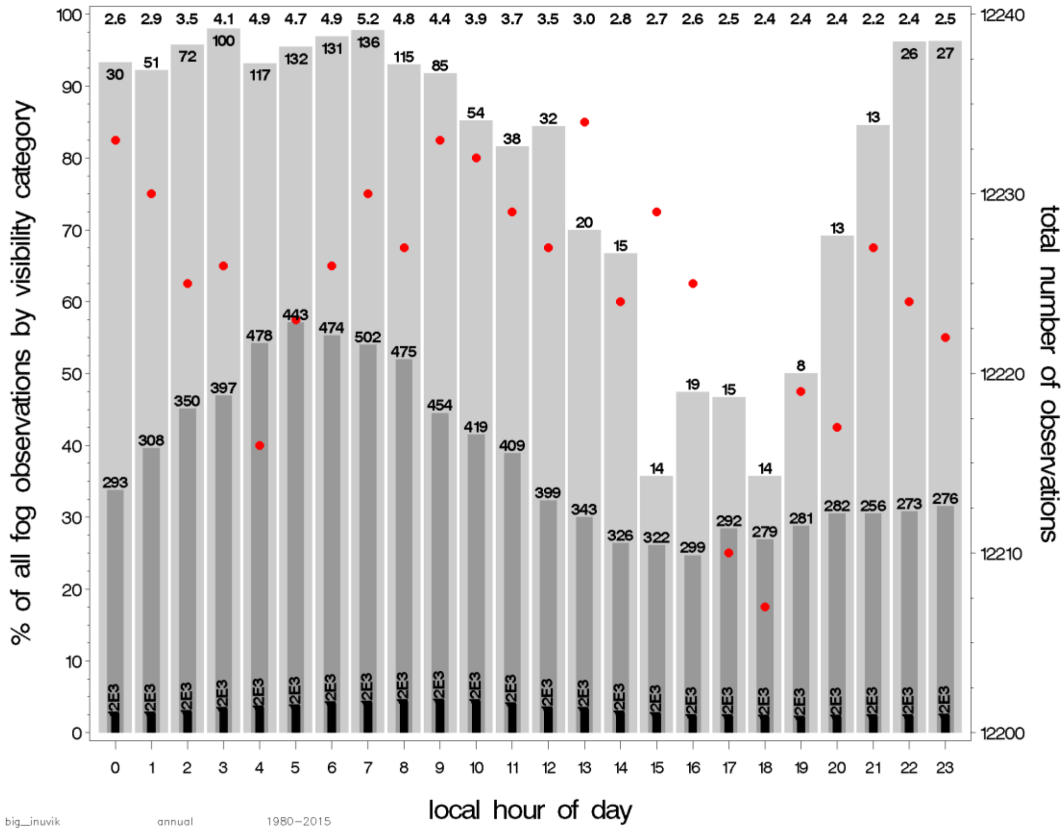

**Figure 5.15:** Total counts of hourly occurrences of LV and VLV events for Inuvik, with an indication of the influence of fog, for all months of the year. Light grey bars represent the proportion of VLV events associated with a coincident observation of fog. Total VLV counts are

the small number at the top of the light grey bar. Dark grey bars represent the proportion of LV events associated with a coincident observation of fog. Total LV counts are the small number at the top of the grey bar. Black bars represent the proportion of total available observations that were not in the VLV/LV category and which had fog associated with them. Total non-VLV/LV counts are the small rotated number at the top of the black bars. The total percent of all observations for which VLV/LV conditions existed are printed as the small number at the top of each column. The red dots represent the total number of observations available in that hour.

In winter, Inuvik shows no diurnal patterns in the frequency of either LV or VLV events caused by fog; VLV events vary throughout the day (Fig. 5.16).

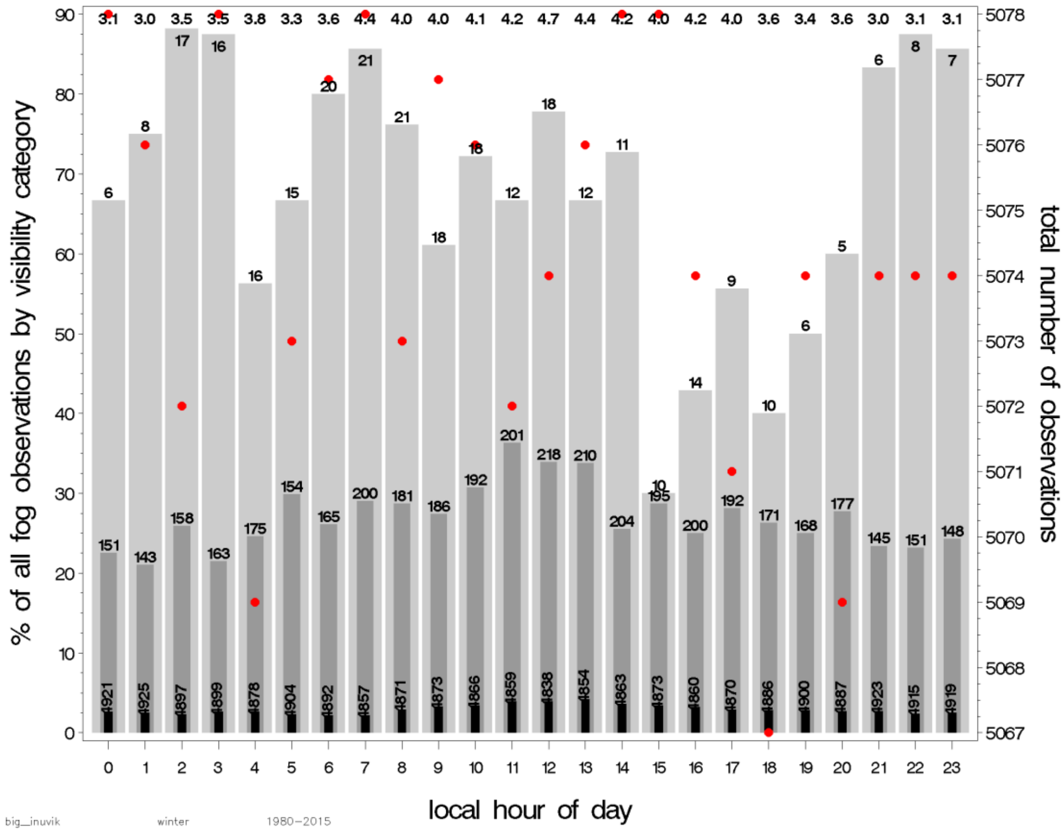

**Figure 5.16:** Total counts of hourly occurrences of LV and VLV events for Inuvik, with an indication of the influence of fog, for winter months (month=11, 12, 1, 2, 3). Please refer to the caption in Figure 5.15 for a complete description of this plot.

Significantly, VLV events are observed at Inuvik in summer only in the midnight to 0900 hrs period, and all events are associated with fog. LV observations after 0800 hrs show a gradual decrease through the afternoon leading to a minimum at 1500 hrs. LV events have a trend with a slight increase in during night and remain roughly consistent after 0000hrs (Fig. 5.17).

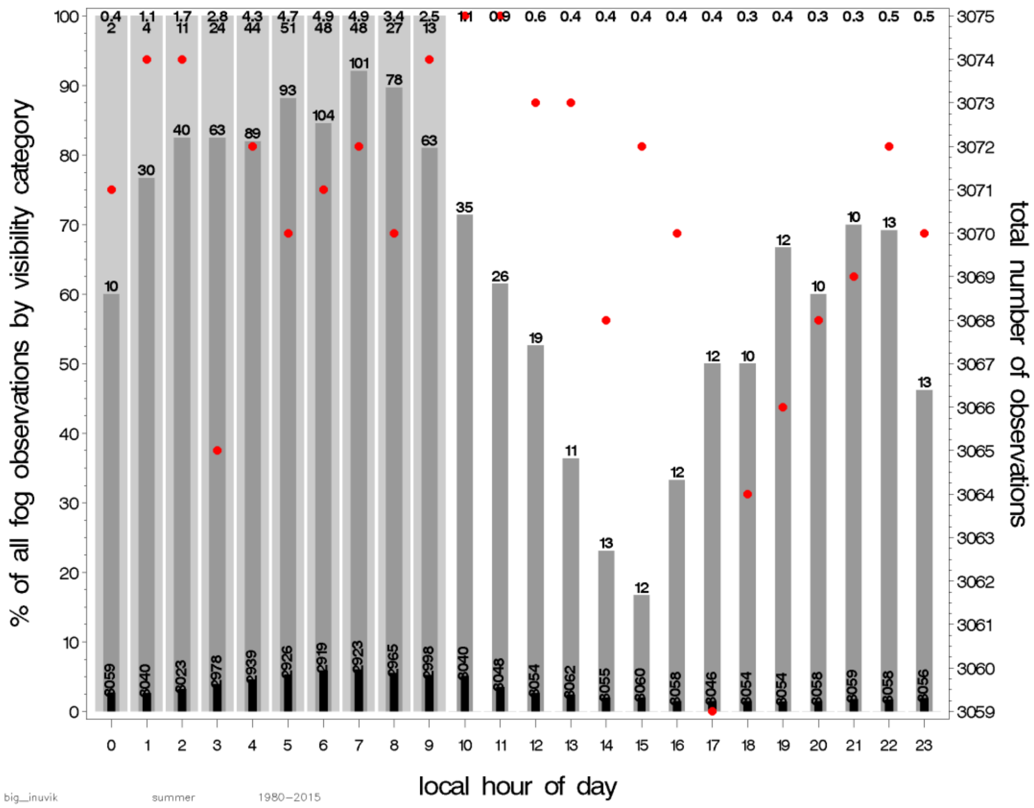

**Figure 5.17:** Total counts of hourly occurrences of LV and VLV events for Inuvik, with an indication of the influence of fog, for summer months (month= 6, 7, 8). Please refer to the caption in Figure 5.15 for a complete description of this plot.

In fall and spring, Inuvik exhibited a marked tendency for LV events caused by fog to be high in the early morning (0400hrs) and gradually decrease through noon, with a subsequent increase during afternoon to night. There is a weak trend in the frequency of VLV events to be less frequent in the late afternoon (Fig. 5.18).

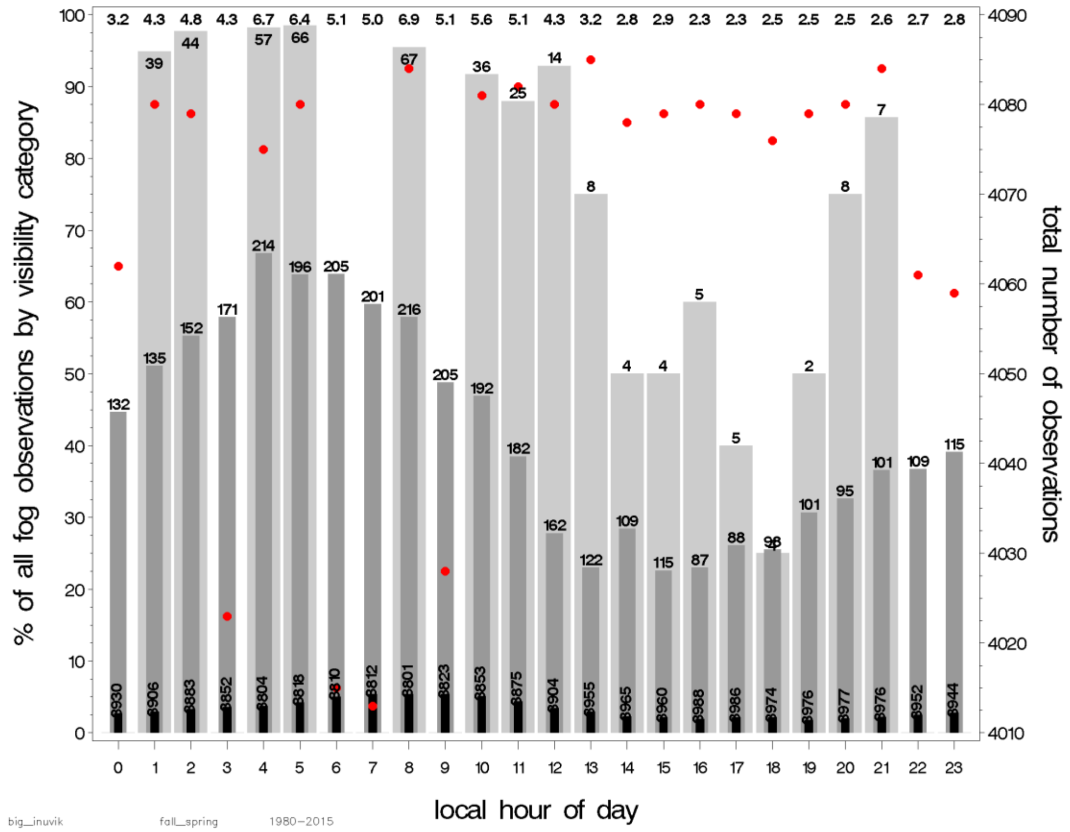

**Figure 5.18:** Total counts of hourly occurrences of LV and VLV events for Inuvik, with an indication of the influence of fog, for fall and spring months (month=4, 5, 9, 10). Please refer to the caption in Figure 5.15 for a complete description of this plot.

#### 5.2.1.2 Monthly climatologies

At Inuvik the occurrence of LV and VLV events exhibited seasonality. The number of LV events drops off in the fall-winter period (September-March). LV event frequency again rises into the April-July period, with the largest total number of LV occurrences observed in July. VLV events occur again during this period. The largest total number of LV occurrences observed in June (Fig. 5.19).

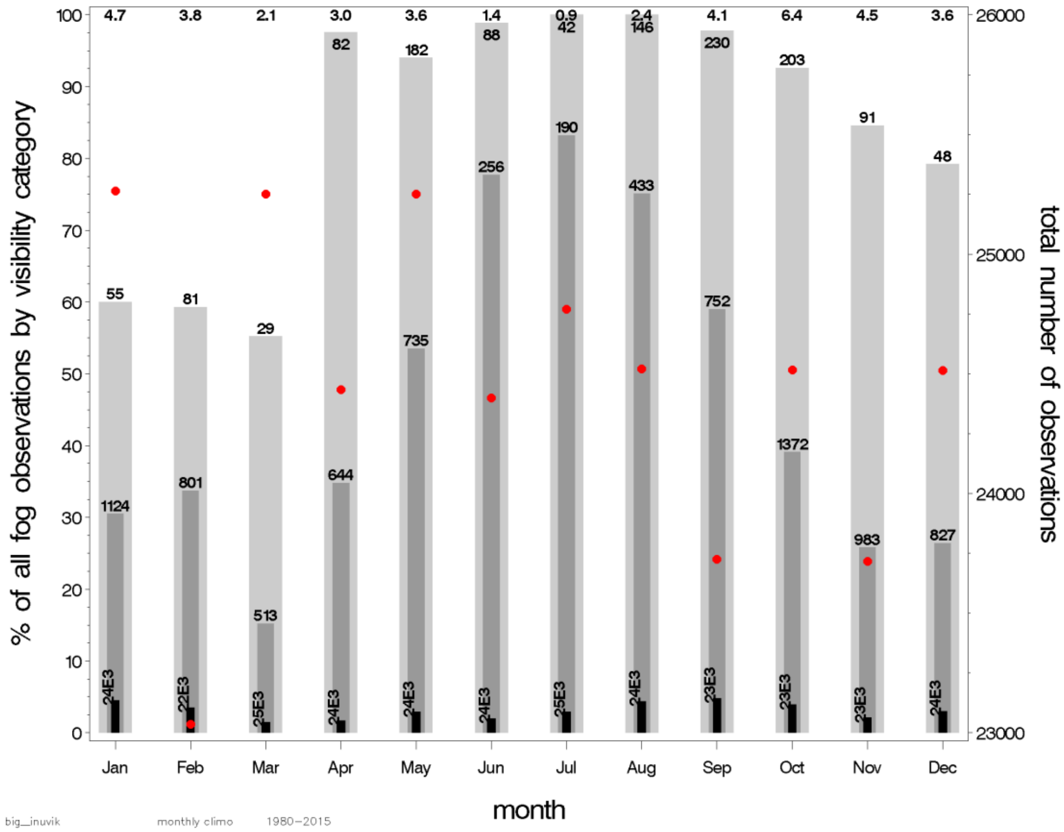

**Figure 5.19:** Total counts of monthly occurrences of LV and VLV events for Inuvik, with an indication of the influence of fog. The layout of the plot is the same as for Figure 5.15; please refer to the caption in Figure 5.15 for a complete description of this plot.

#### 5.2.1.3 Annual trends

At Inuvik the total number of observations available per year remains very consistent over the study period (1980-2015). There was no significant trend in the frequency of combined LV/VLV events (Table 5.1). Interannual variability was high (Fig. 5.20).

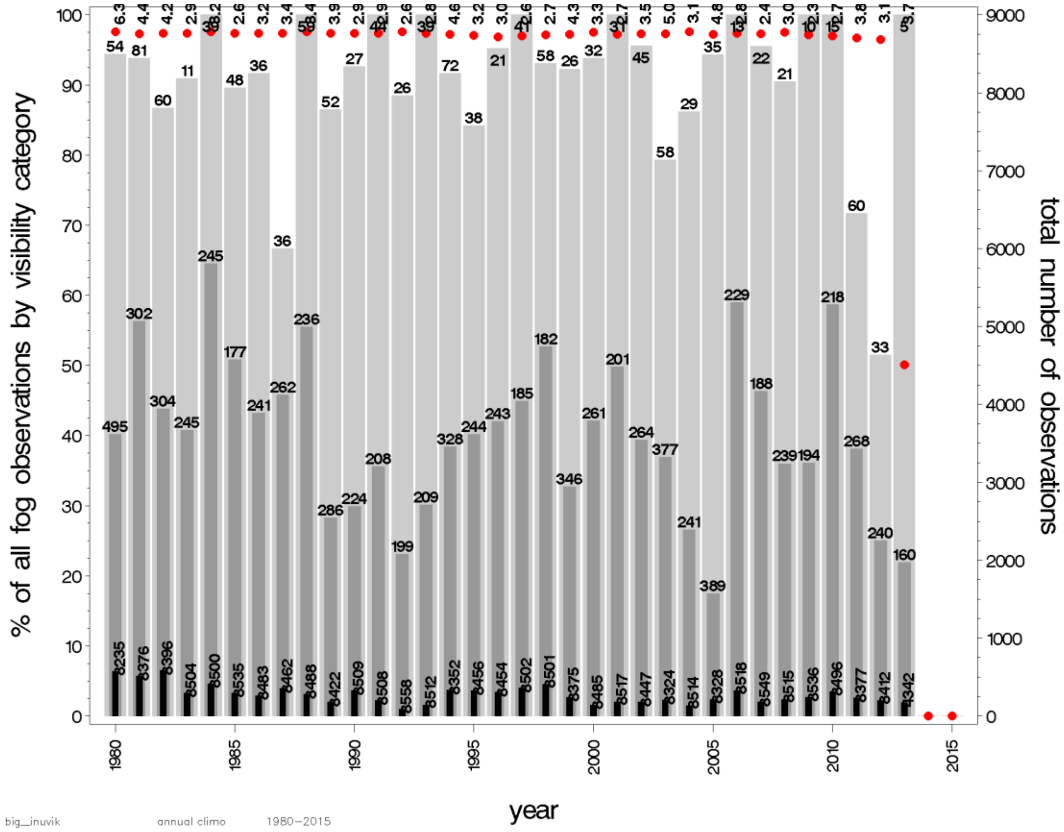

**Figure 5.20:** Total counts of annual occurrences of LV and VLV events for Inuvik, with an indication of the influence of fog. The layout of the plot is the same as for Figure 5.15; please refer to the caption in Figure 5.15 for a complete description of this plot.

### 5.2.2 Low visibility event causes by weather type

#### 5.2.2.1 Hourly by type

For Inuvik, as at Aklavik, the hourly climatology of weather events for the entire year indicates blowing snow is steady at 50-60% LV occurrence for all hours of the day. Fog is the next highest, with a peak in the early morning that declines to a minimum throughout the early-mid afternoon. Drizzle follows a similar trend, at lower percentage LV occurrence (Fig. 5.21).

Inuvik hourlies in the fall and spring were similar to the annual progression, except that smoke does not occur. Fog and drizzle event numbers peak in the early morning, with the decline into the afternoon again driven by a marked decrease in all events, except blowing snow, which is steady but move variable in the afternoon (Fig. 5.22).

Inuvik hourlies in the summer again showed a strong early morning peak in fog numbers, with a smaller peak for drizzle. Some LV events were caused by snow (Fig. 5.23).

Inuvik hourlies in the winter showed consistent numbers in all observed parameters. Drizzle had large interannual variability (Fig. 5.24).

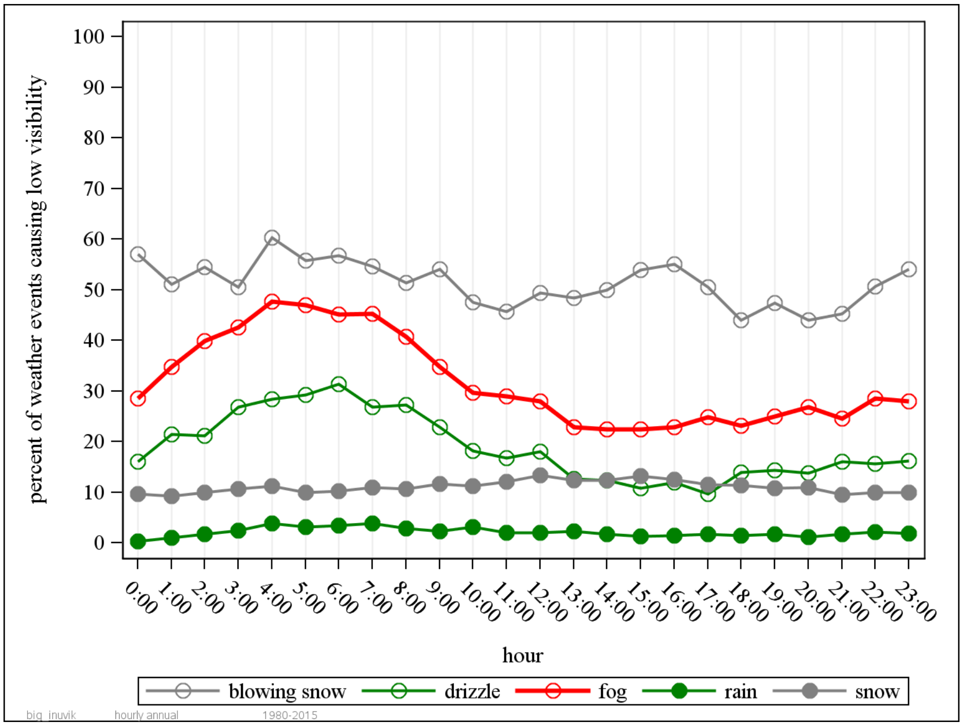

**Figure 5.21:** Percent of hourly occurrences that different weather types were associated with an LV/VLV event for Inuvik, for all months of the year.

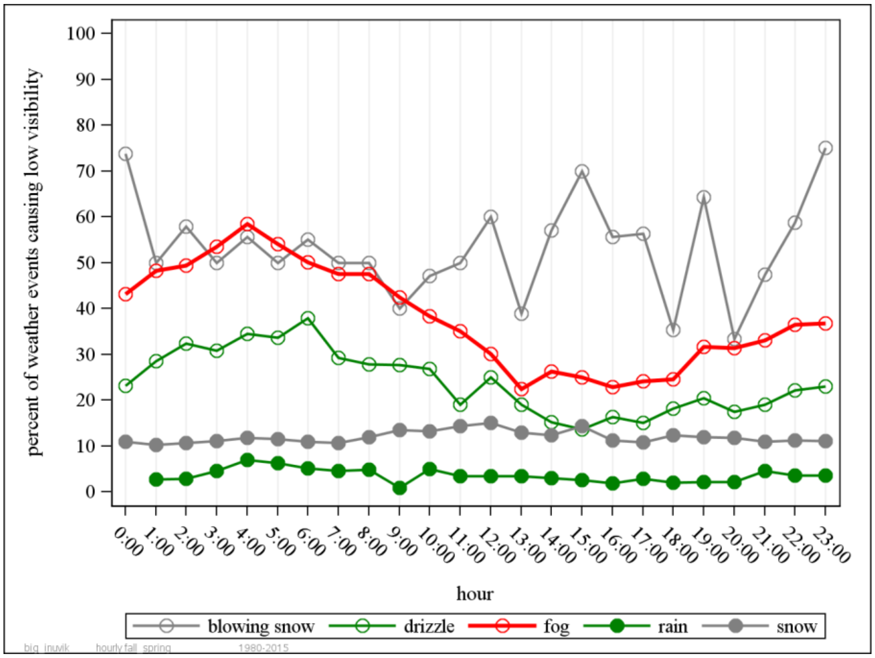

**Figure 5.22:** Percent of occurrences that different weather types were associated with an LV/VLV event for Inuvik, by hour, for the fall and spring months (month= 4, 5, 9, 10).

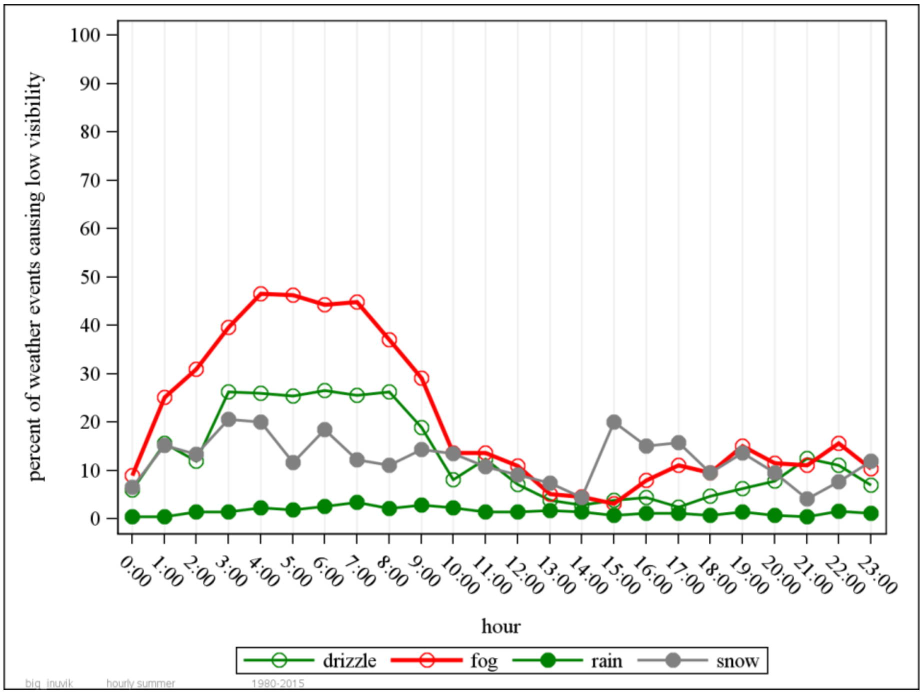

**Figure 5.23:** Percent of occurrences that different weather types were associated with an LV/VLV event for Inuvik, by hour, for the summer months (month= 6, 7, 8).

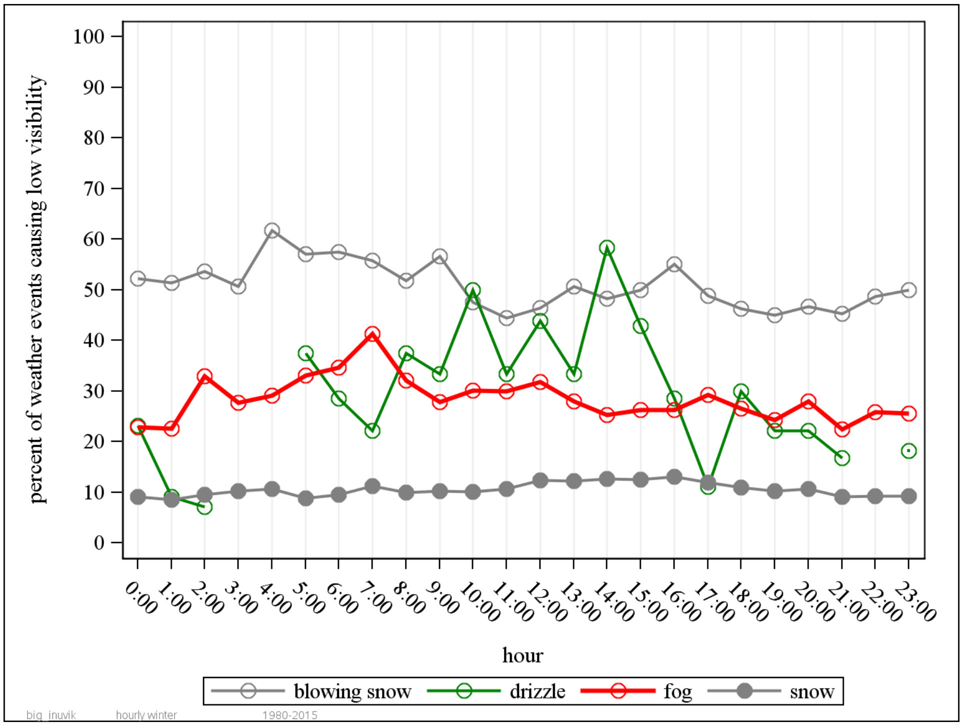

**Figure 5.24:** Percent of occurrences that different weather types were associated with an LV/VLV event for Inuvik, by hour, for the winter months (month= 11, 12, 1, 2, 3).

#### 5.2.2.2 Monthly by type

At Inuvik the monthly climatology shows that blowing snow occurrences are responsible for a relatively consistent proportion of LV/VLV events in the late fall and winter months (September – February), 40 to 65%, but as spring begins, variability increases. Fog occurrences are also relatively consistent between 25 and 42% in all months except March and July, when the proportion drops as low as 20 %. During April-June and September-November, the proportions of fog events causing LV/VLV are greater. Snow occurrences are responsible for relatively few LV/VLV events, from 8 to 15%; no particular time of year is favored. Drizzle occurrences are responsible for only 15 to 28% of LV/VLV events in all months except February and July, when the proportion drops as low as 5%. It is variable in the winter/spring, low in the summer (July), and rises continually until November. Rain is observed only in the April through October period and rarely is responsible for LV/VLV events, although it does rise somewhat in importance in September (Fig. 5.25).

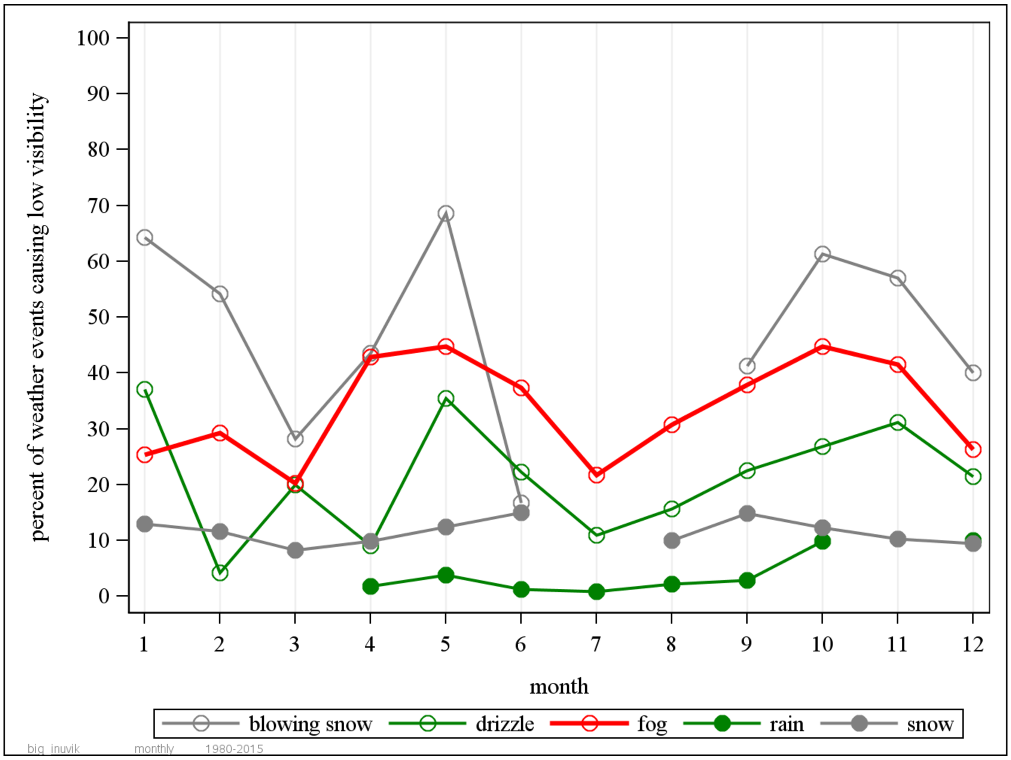

**Figure 5.25:** Percent of occurrences that different weather types were associated with an LV/VLV event for Inuvik, by month.

### 5.2.2.3 Annual by type

At Inuvik, as at Aklavik, the occurrence of blowing snow was usually most likely to be responsible for LV events, although there was a lot of interannual variability. Fog is the next most likely weather type to cause LV/VLV events. Over the entire period of record between 20 and 50% of all fog occurrences were associated with LV/VLV events. Drizzle occurrences, although variable, were more frequently associated with LV/VLV events up to1989; since then the proportion of LV/VLV events has dropped. Only about 5 to 20% of snow occurrences are responsible for LV/VLV events. The occurrence of rain is responsible for very few LV/VLV events (Fig. 5.26). Only drizzle showed a statistical change over the period of record, showing a reduction of 4.7 +/- 1.3% per decade (Table 5.2).

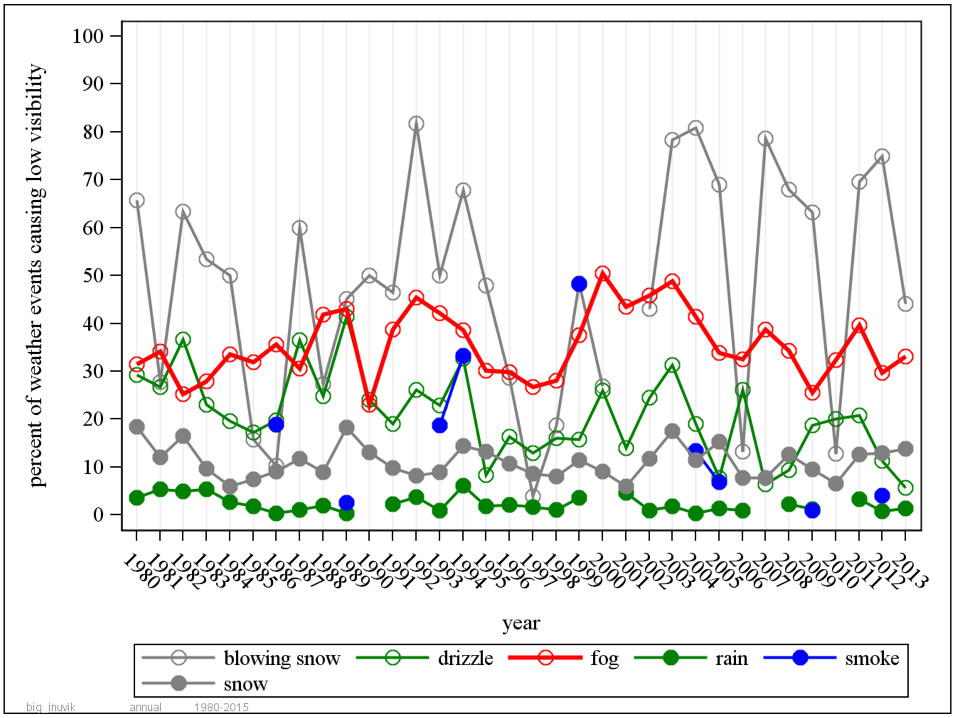

**Figure 5.26:** Percent of occurrences that different weather types were associated with an LV/VLV event for Inuvik, by year.

### 5.2.3 Synoptic analysis

An example of a large-scale advective moisture event occurred at Inuvik on 10 September 2006. At the surface a strong low with was located over the western CAA. An area of high pressure was located over the Beaufort Sea. The juxtaposition of these features created a strong pressure gradient along the west half of the north coast of North America that resulted in a strong flow into the Mackenzie Delta region from the northwest (Fig. 5.27a). The 1000 hPa specific humidity anomaly shows that an unusual amount of moisture was being drawn into the study area on 10 September 2006, as compared to the 30 year mean for this time period (Fig. 5.27b).

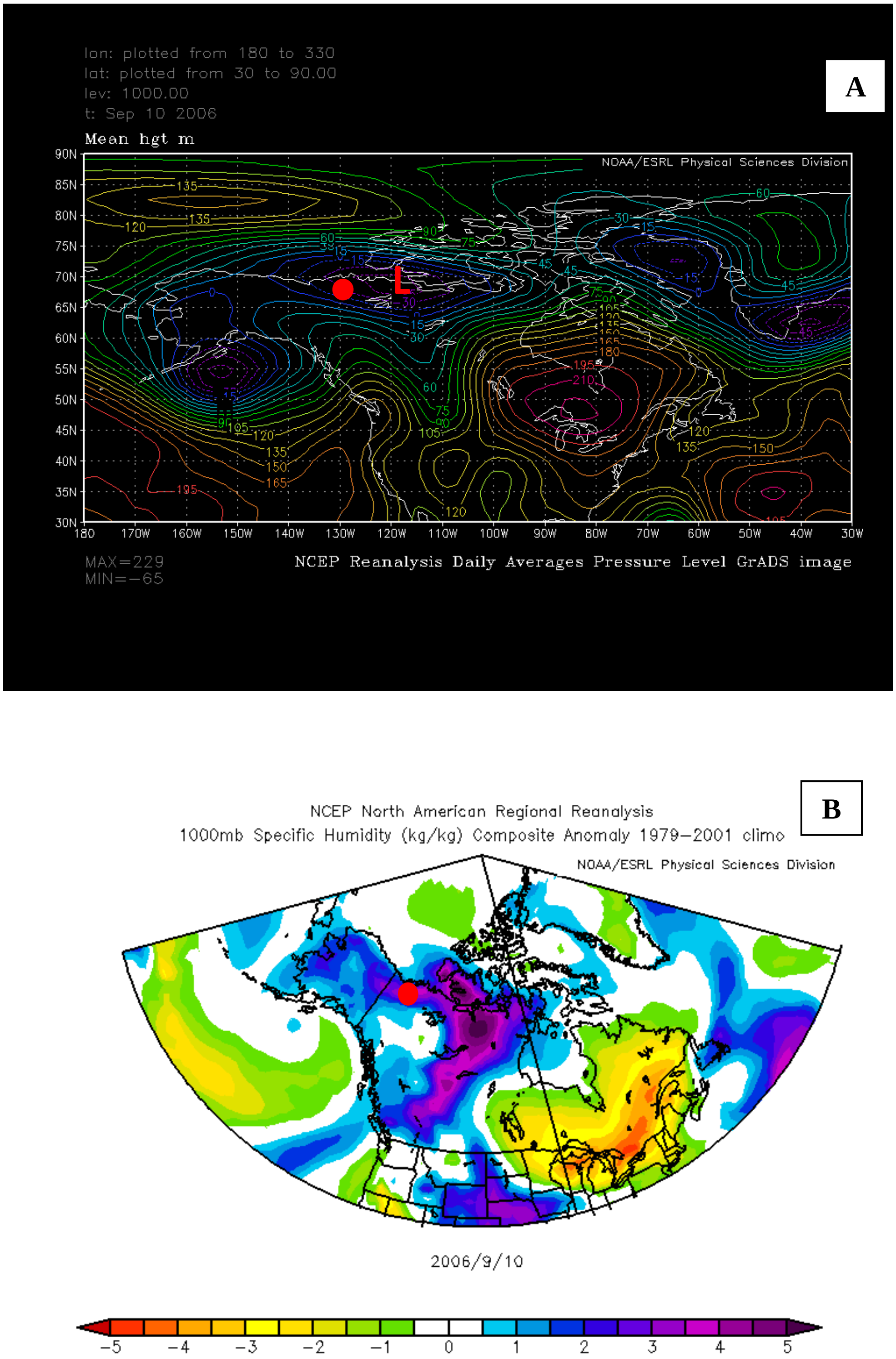

**Figure 5.27:** Selected atmospheric variables for the Inuvik fog event of 10 September 2006. A) height of the 1000hPa pressure surface (m). B) 1000hPa specific humidity anomaly (mean period is 1979-2001).

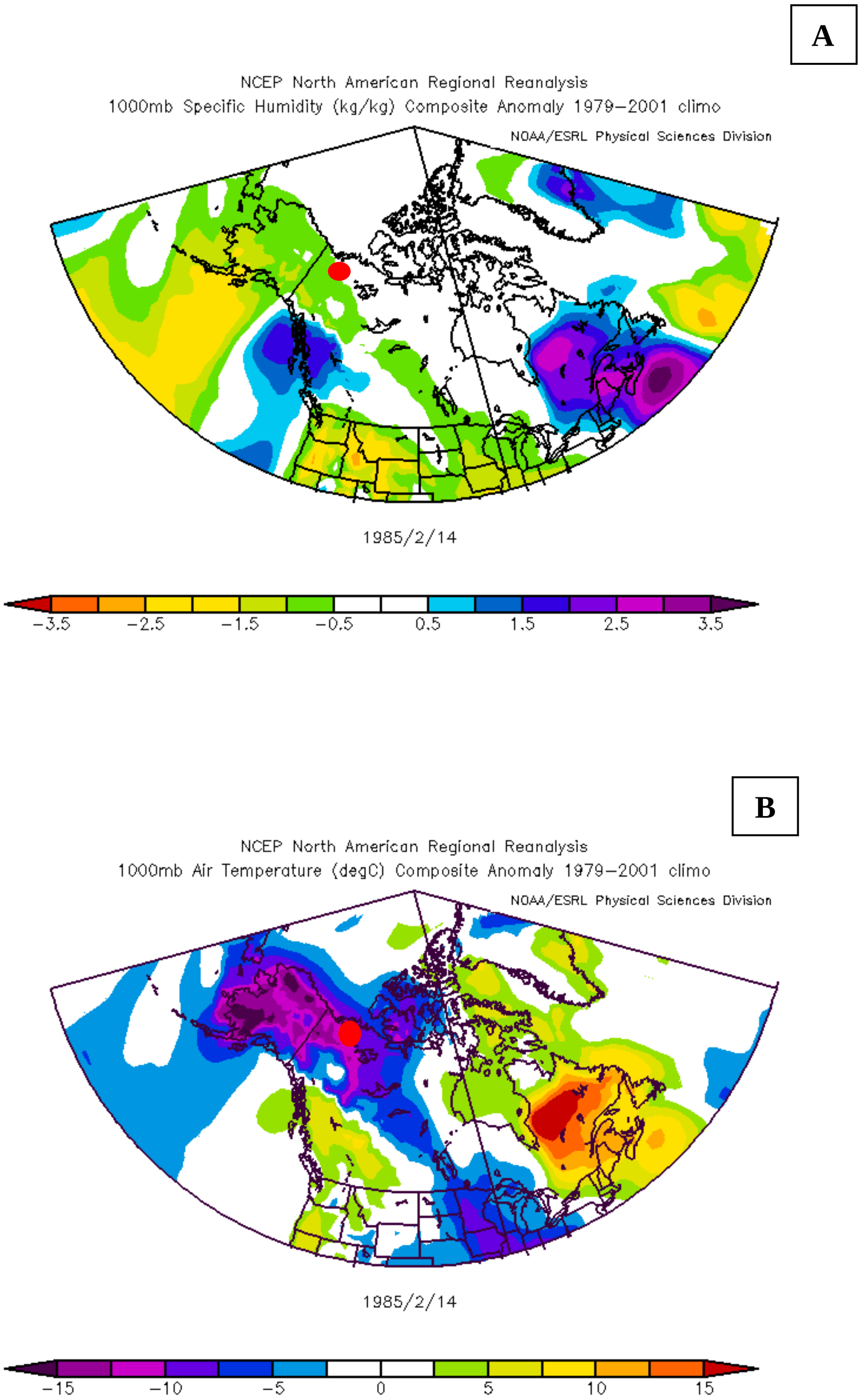

**Figure 5.28:** Selected atmospheric variables for the Inuvik fog event of 14 February 1985. A) 1000hPa specific humidity anomaly (mean period is 1979-2001). B) 1000hPa air temperature anomaly.

An example of a fog event driven by local conditions occurred at Inuvik on 14 February 1985. There is no synoptic-scale advection of moisture (Fig. 5.28a) However on this day very low temperatures were observed at Inuvik, which created conditions suitable for ice fog. This situation of anomalous low temperatures persisted for several days until temperatures went back above -45C on 17 February (Fig. 5.28b).

## 5.3 Sachs Harbour

### 5.3.1 Visibility climatologies

#### 5.3.1.1 Hourly climatologies

Considering the annual timeframe, Sachs Harbour also exhibited a similar tendency for LV events caused by fog to be most frequent in the morning. Unlike Aklavik, the frequency with which fog was responsible for LV/VLV events was greater – accounting for 70% of LV observations at the peak in the early morning – and the decrease into the afternoon is slower, dropping only to 50%. VLV events are observed in all hours, with a maximum at 0600 hrs near 90%, dropping gradually to 70% by 1700hrs. Real numbers for VLV events are much higher than at Aklavik. At Sachs Harbour they are mostly in the 250-400 range which is greater than for other stations (Fig. 5.29).

In winter, Sachs Harbour exhibited a marked tendency for LV and VLV events caused by fog to occur in the early morning 0500hrs–2300hrs. Percentages in the morning timeframe ranged from 26-68% for LV events, and 30-75% for VLV events. LV and VLV events were observed during a day except few hours from 0000-0400 hrs, when there were not enough station observations to draw any conclusions (Fig. 5.30).

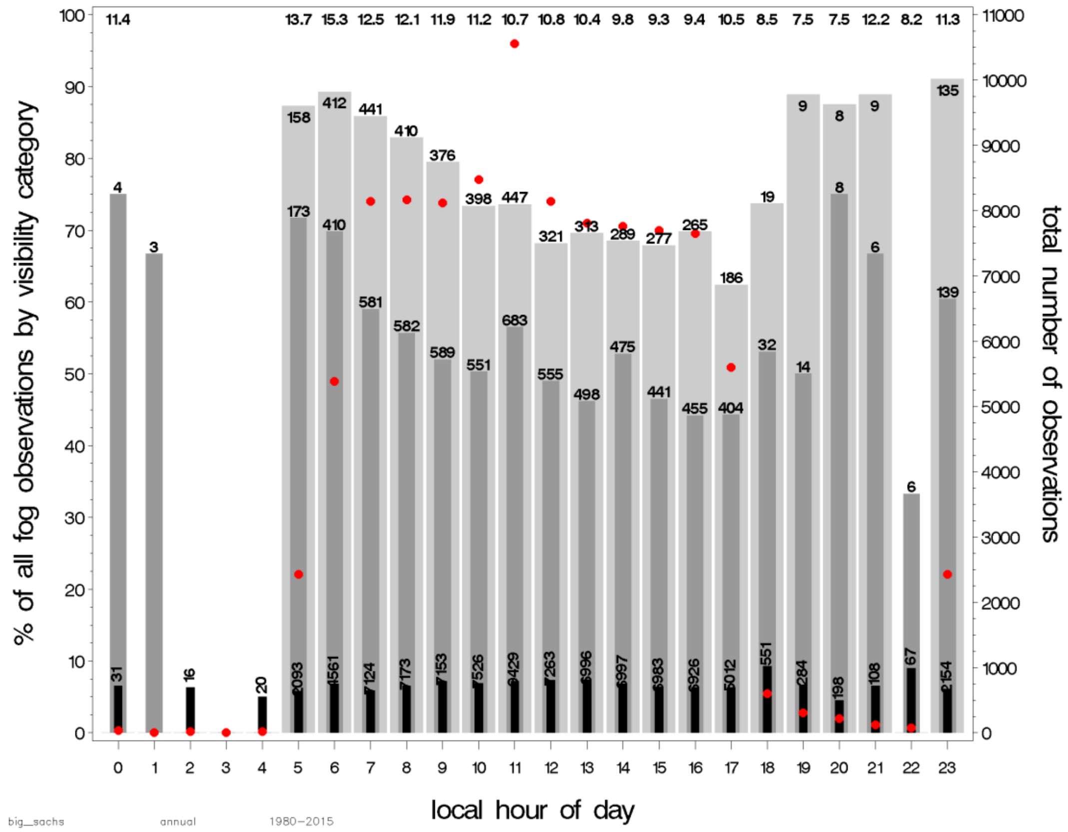

**Figure 5.29:** Total counts of hourly occurrences of LV and VLV events for Sachs Harbour, with an indication of the influence of fog, for all months of the year. Light grey bars represent the proportion of VLV events associated with a coincident observation of fog. Total VLV counts are the small number at the top of the light grey bar. Dark grey bars represent the proportion of LV events associated with a coincident observation of fog. Total LV counts are the small number at the top of the grey bar. Black bars represent the proportion of total available observations that were not in the VLV/LV category and which had fog associated with them. Total non-VLV/LV counts are the small rotated number at the top of the black bars. The total percent of all observations for which VLV/LV conditions existed are printed as the small number at the top of each column. The red dots represent the total number of observations available in that hour.

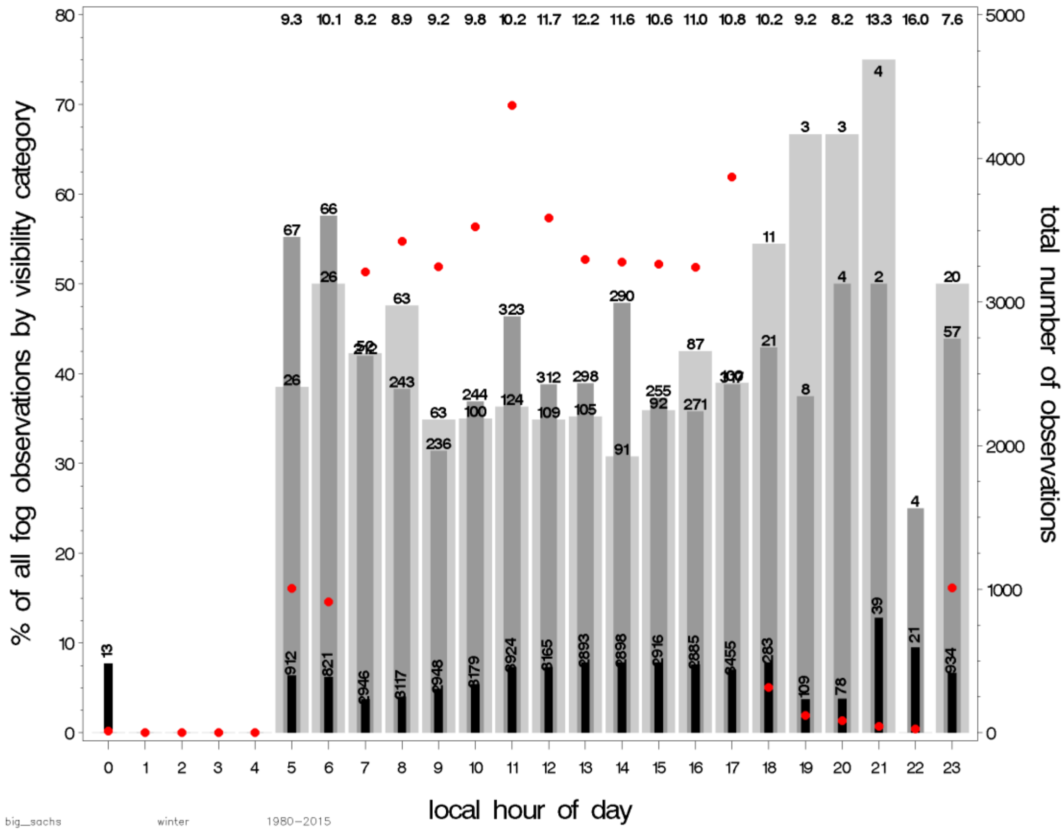

**Figure 5.30:** Total counts of hourly occurrences of LV and VLV events for Sachs Harbour, with an indication of the influence of fog, for winter months (month=11, 12, 1, 2, 3). Please refer to the caption in Figure 5.29 for a complete description of this plot.

In summer, the proportion of LV and VLV events caused by fog at Sachs Harbour were unusual because they exhibited almost no decreasing trend. When there is an LV or VLV event at Sachs Harbour in the summer fog is almost always the reason for it (Fig. 5.31). Interestingly, the total counts for VLV events exceed those for LV events in all hours of the day.

In fall and spring, the proportion of LV caused by fog again remains fairly consistent throughout the day at about 50%. VLV events start high, ~85%, and decrease slowly to ~75% by 1600 hrs (Fig. 5.32).

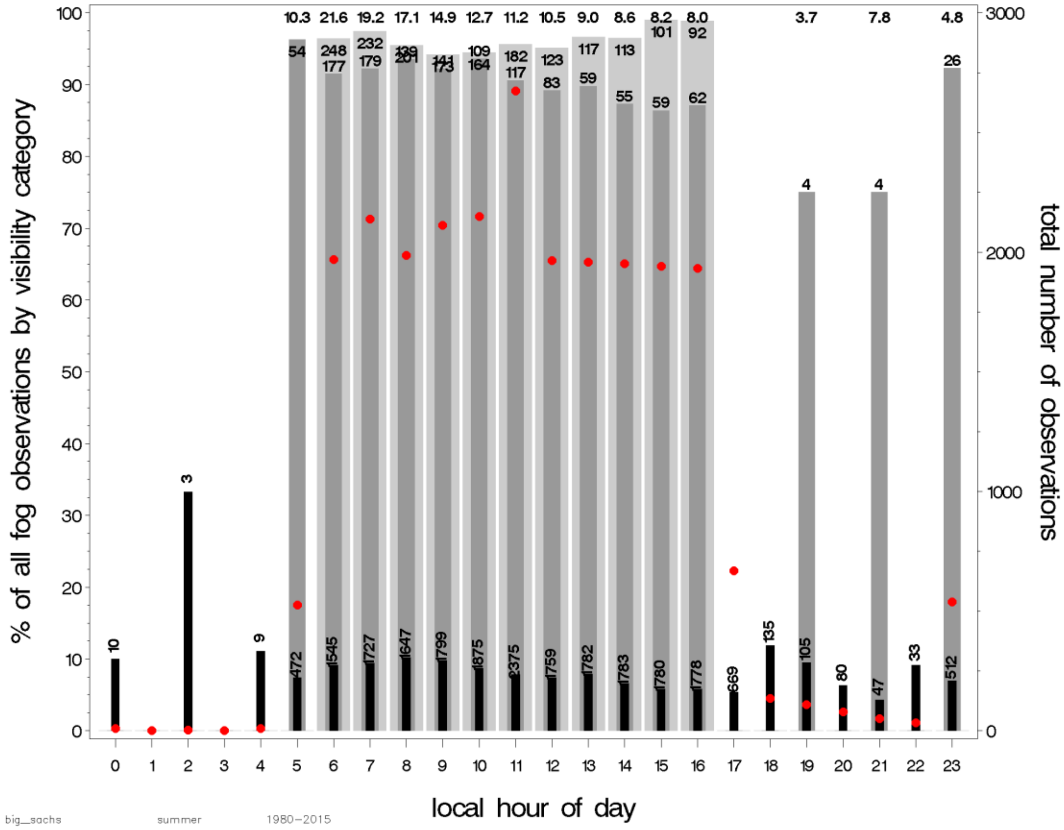

**Figure 5.31:** Total counts of hourly occurrences of LV and VLV events for Sachs Harbour, with an indication of the influence of fog, for summer months (month= 6, 7, 8). Please refer to the caption in Figure 5.28 for a complete description of this plot.

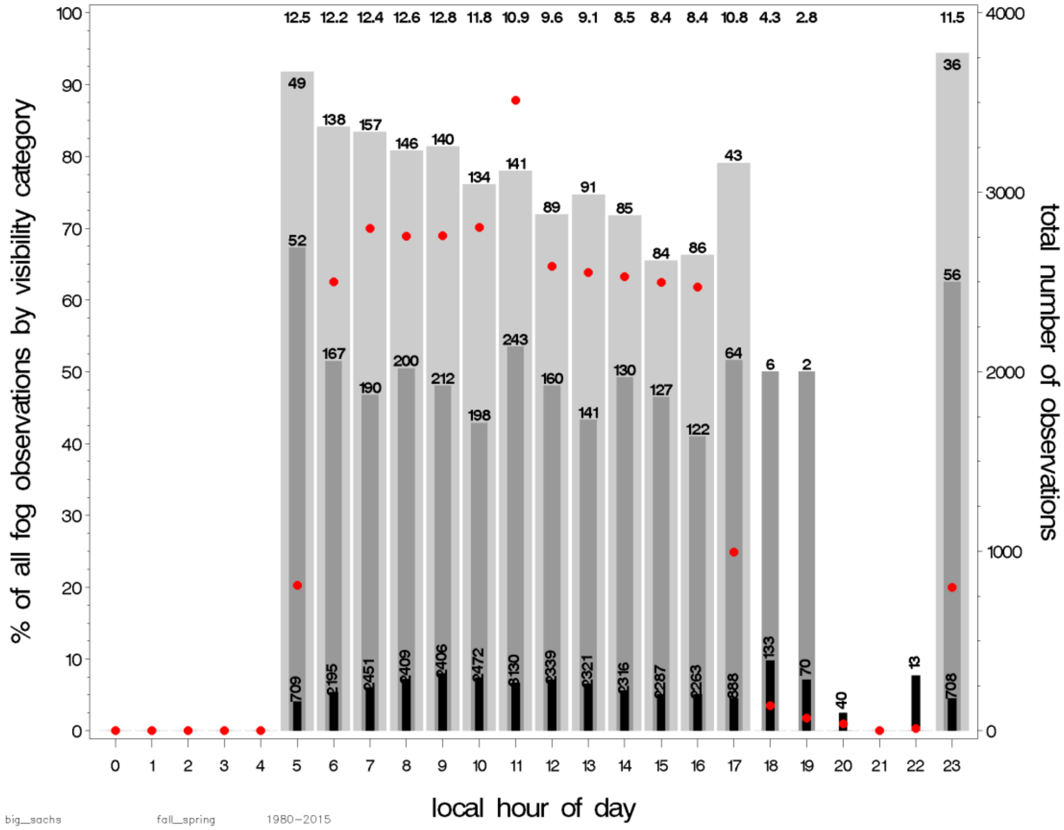

**Figure 5.32:** Total counts of hourly occurrences of LV and VLV events for Sachs Harbour, with an indication of the influence of fog, for fall and spring months (month=4, 5, 9, 10). Please refer to the caption in Figure 5.29 for a complete description of this plot.

#### 5.3.1.2 Monthly climatologies

At Sachs Harbour the occurrence of LV and VLV events exhibited seasonality. The proportion of these events caused by fog ranged from 25-98%. The number of LV and VLV events drops off in the September-April time frame, as does the proportion of events caused by fog. LV and VLV event frequency again rises into the May-August period, with the largest total number of LV and VLV occurrences observed in August. The proportion of LV and VLV events caused by fog is greatest in the June-August time period (Fig. 5.33).

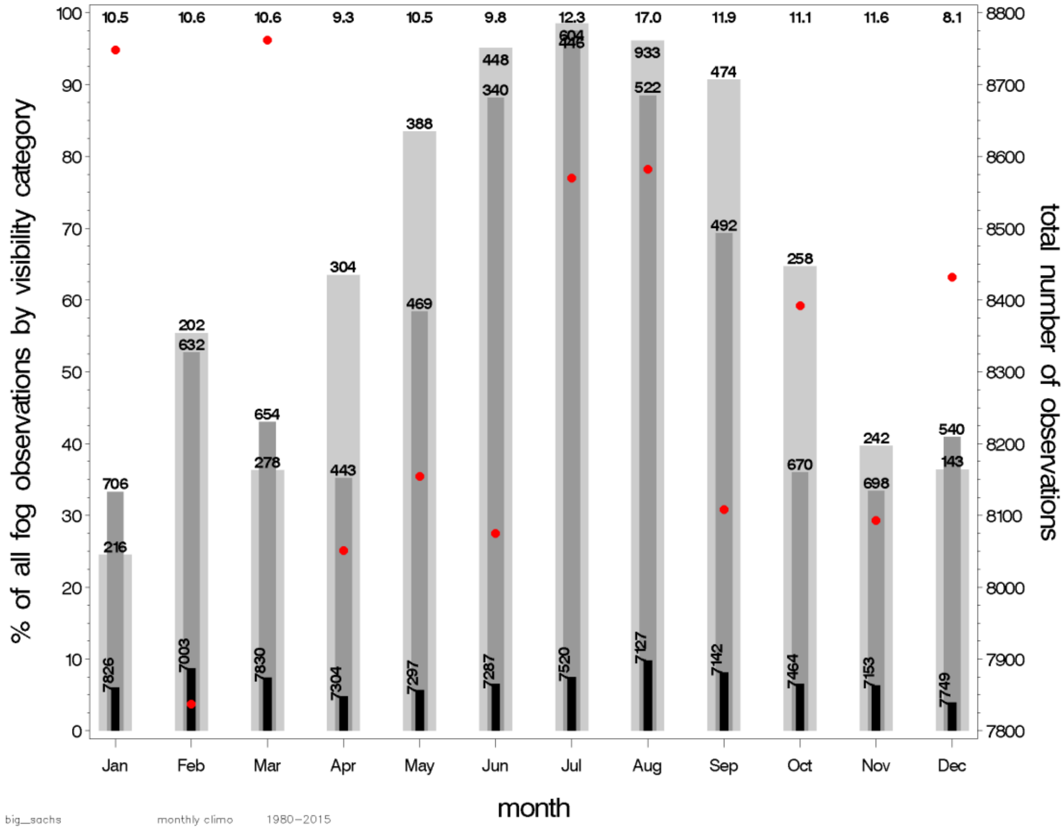

**Figure 5.33:** Total counts of monthly occurrences of LV and VLV events for Sachs Harbour, with an indication of the influence of fog. The layout of the plot is the same as for Figure 5.29; please refer to the caption in Figure 5.29 for a complete description of this plot.

### 5.3.1.3 Annual trends

At Sachs Harbour the total number of observations available per year shows a large variability over the study period (1980-2015) (Fig. 5.34). There is no discernible trend in the total occurrence of combined LV/VLV events caused by any type of weather occurrence (Table 5.1).

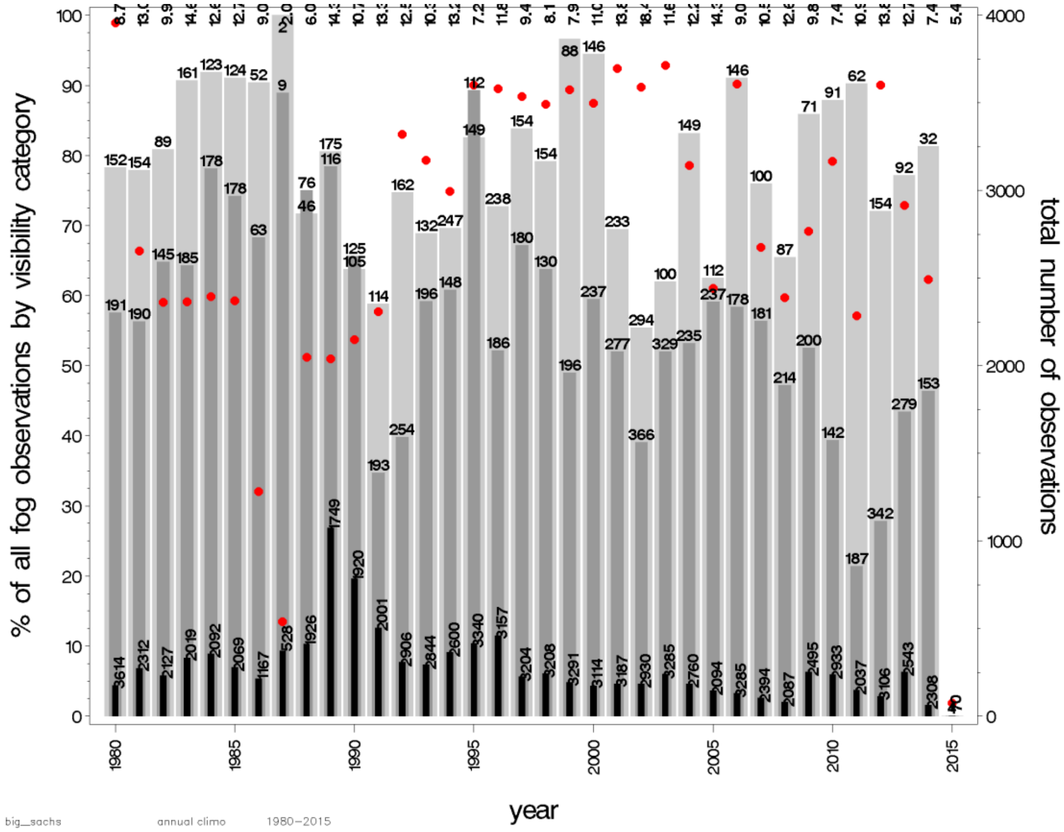

**Figure 5.34:** Total counts of annual occurrences of LV and VLV events for Sachs Harbour, with an indication of the influence of fog. The layout of the plot is the same as for Figure 5.29; please refer to the caption in Figure 5.29 for a complete description of this plot.

### 5.3.2 Low visibility event causes by weather type

#### 5.3.2.1 Hourly by type

For Sachs Harbour, the hourly climatology of weather events for the entire year shows blowing snow high throughout the day except for a late afternoon drop; drizzle and fog start high, decline throughout the afternoon, and then rise again. Snow and rain are fairly consistent, although the proportion of rain occurrences that cause LV events is higher than for other stations (Fig. 5.35). Note that only the hours from 0600 – 1600, inclusive, are being considered because they have the largest numbers of obsevations.

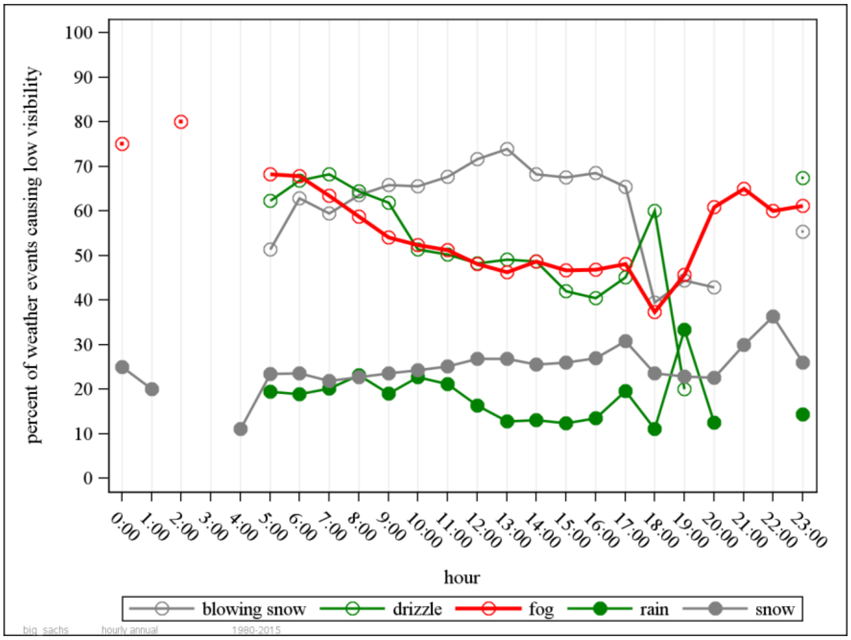

**Figure 5.35:** Percent of hourly occurrences that different weather types were associated with an LV/VLV event for Sachs Harbour, for all months of the year.

Sachs Harbour hourlies in the fall and spring were similar to the annual progression. Blowing snow numbers remain high throughout the day and fog and drizzle decrease slowly throughout the day, until late afternoon (Fig. 5.36).

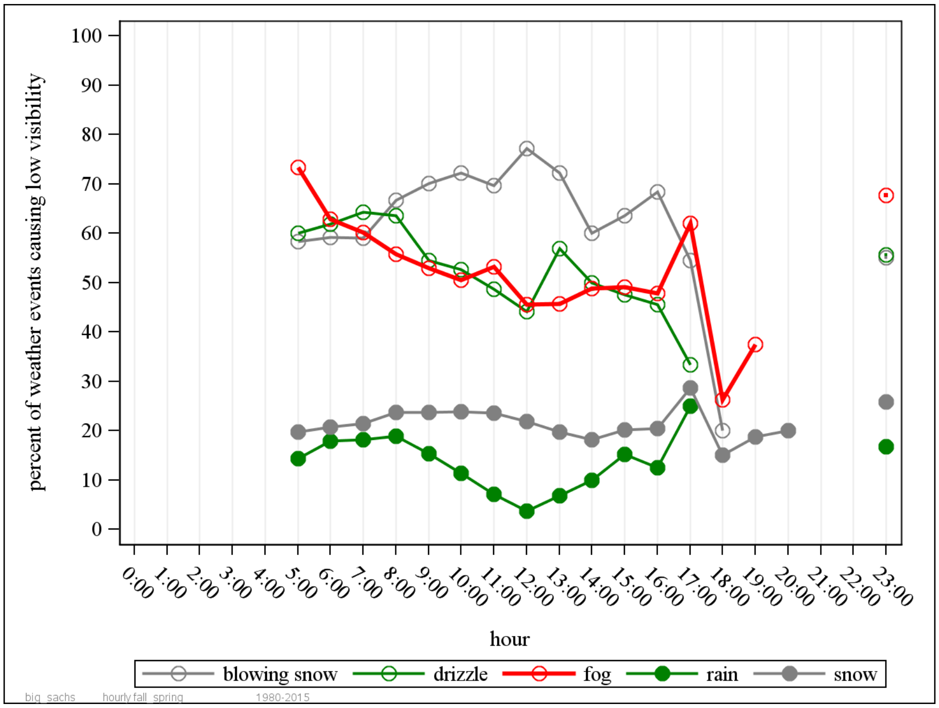

**Figure 5.36:** Percent of occurrences that different weather types were associated with an LV/VLV event for Sachs Harbour, by hour, for the fall and spring months (month= 4, 5, 9, 10).

Sachs Harbour hourlies in the summer again showed high values for fog and drizzle that both declined through the day and then both increased late in the day. Snow and rain were lower but consistent throughout the day (Fig. 5.37).

Finally, Sachs Harbour hourlies in the winter also showed event totals peaking at noon and night. Event types were dominated by blowing snow, which increased through the morning, and then fog and snow, which both increase again after late afternoon (Fig. 5.38).

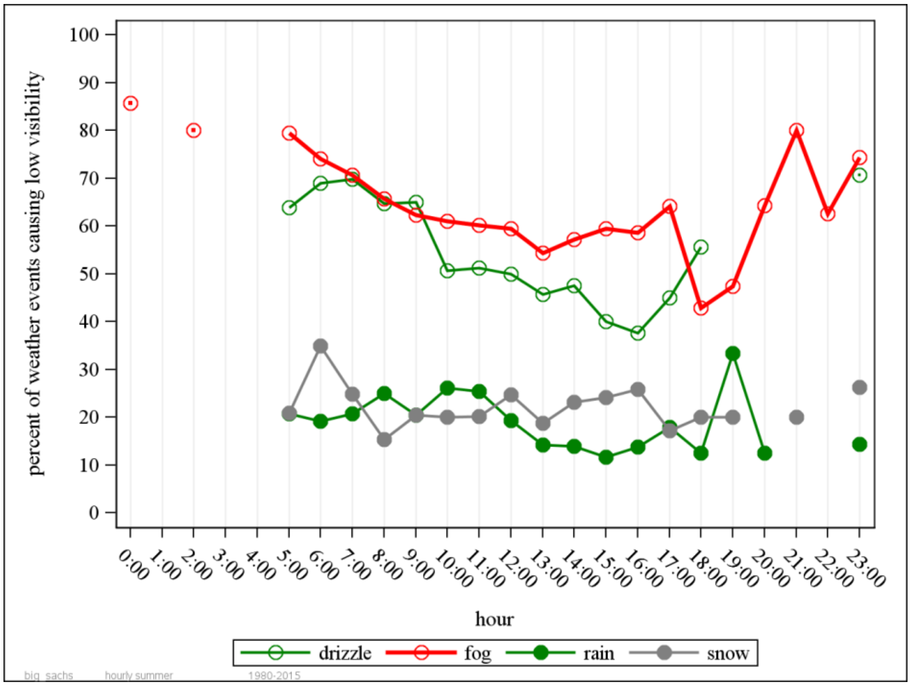

**Figure 5.37:** Percent of occurrences that different weather types were associated with an LV/VLV event for Sachs Harbour, by hour, for the summer months (month= 6, 7, 8).

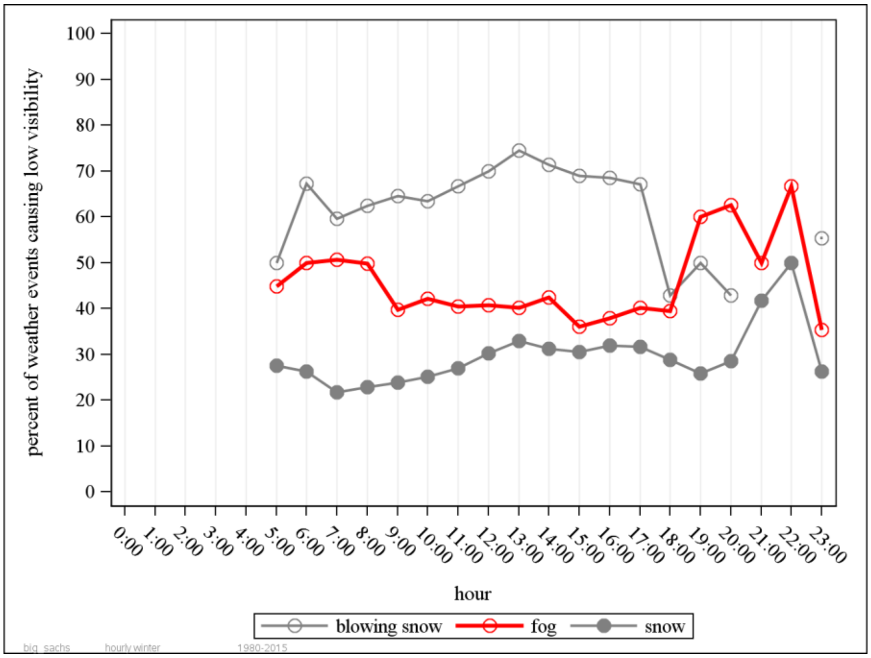

**Figure 5.38:** Percent of occurrences that different weather types were associated with an LV/VLV event for Sachs Harbour, by hour, for the winter months (month= 11, 12, 1, 2, 3).

#### 5.3.2.2 Monthly by type

At Sachs Harbour the monthly climatology indicates that blowing snow occurrences are responsible for a relatively consistent proportion of LV/VLV events, 52 to 73%, with no particular time of year favoured, except in summer when blowing snow is not observed. Fog occurrences tended to be more frequently responsible for LV/VLV events in the late spring-summer period (May to September; between 60 and 70%) and less so during the rest of the year (40 to 50%). Drizzle occurrences are responsible for 40 to 65% of LV/VLV events in the period April through November. Snow occurrences are responsible for LV/VLV events, from 28 to 32%. Rain is observed only in the May through October period and is responsible for relatively few LV/VLV events (Fig. 5.39).

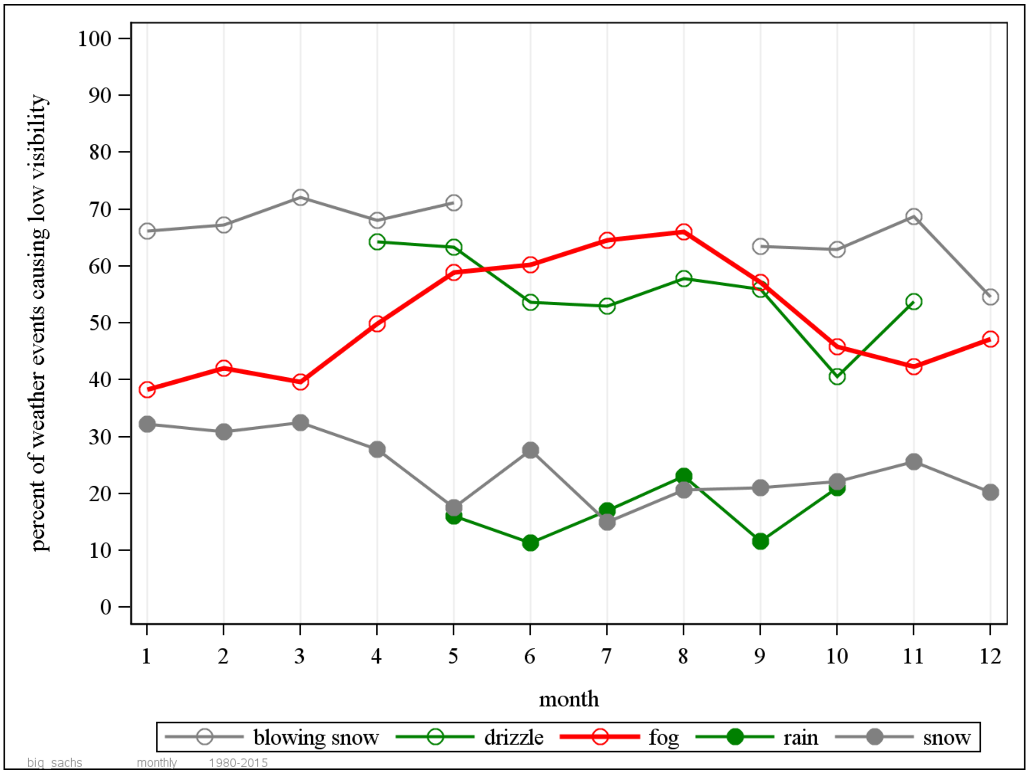

**Figure 5.39:** Percent of occurrences that different weather types were associated with an LV/VLV event for Sachs harbour, by month.

### 5.3.2.3 Annual by type

A notable point about Sachs Harbour is that drizzle was almost equally likely as blowing snow in terms of the proportion to be associated with LV/VLV events. Fog is the next most likely weather type to cause LV/VLV events. From 1980 to 1986 is 38% but it decreased to13% in 1987. From then until the mid 2000s it showed a steady increasing trend back up to its early 1980s levels. Snow occurrences were associated with LV/VLV events about 1% to 28%. The occurrence of rain is responsible for 3% to 22% LV/VLV events (Fig. 5.40). Only drizzle shows a moderately significant trend over the entire period of record, a decrease of 4.9 +/- 2.6% per decade (Table 5.2). Like fog, rain also suggests a decline in the late 1980s that then recovered back to earlier levels.

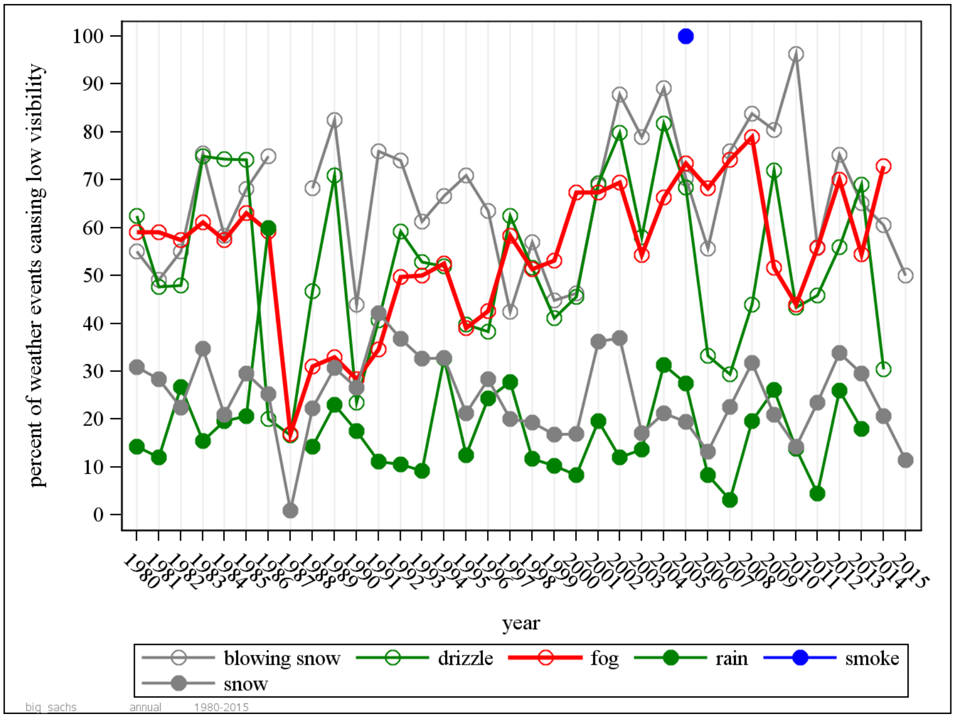

**Figure 5.40:** Percent of occurrences that different weather types were associated with an LV/VLV event for Sachs Harbour, by year.

### 5.3.3 Synoptic analysis

An example of an advective moisture by large scale occurred at Sachs Harbour on 10 August 2004. At the surface a broad and deep low pressure area is located over Chukchi Sea with a wide trough extending along a west-east axis. This is linked by a ridge to another zone of high pressure over the northern Great Lakes (Fig. 5.41a). This pattern pumped moisture into the study area from the southern Beaufort Sea and the southerly flow that was set up transferred this advected moisture, as well as moisture derived from local sea ice melt, to Sachs Harbour. The moisture anomaly (Fig. 5.41b) indicates that moisture advection was occurring on a large scale as a result of the very large low pressure zone over the Chukchi Sea.

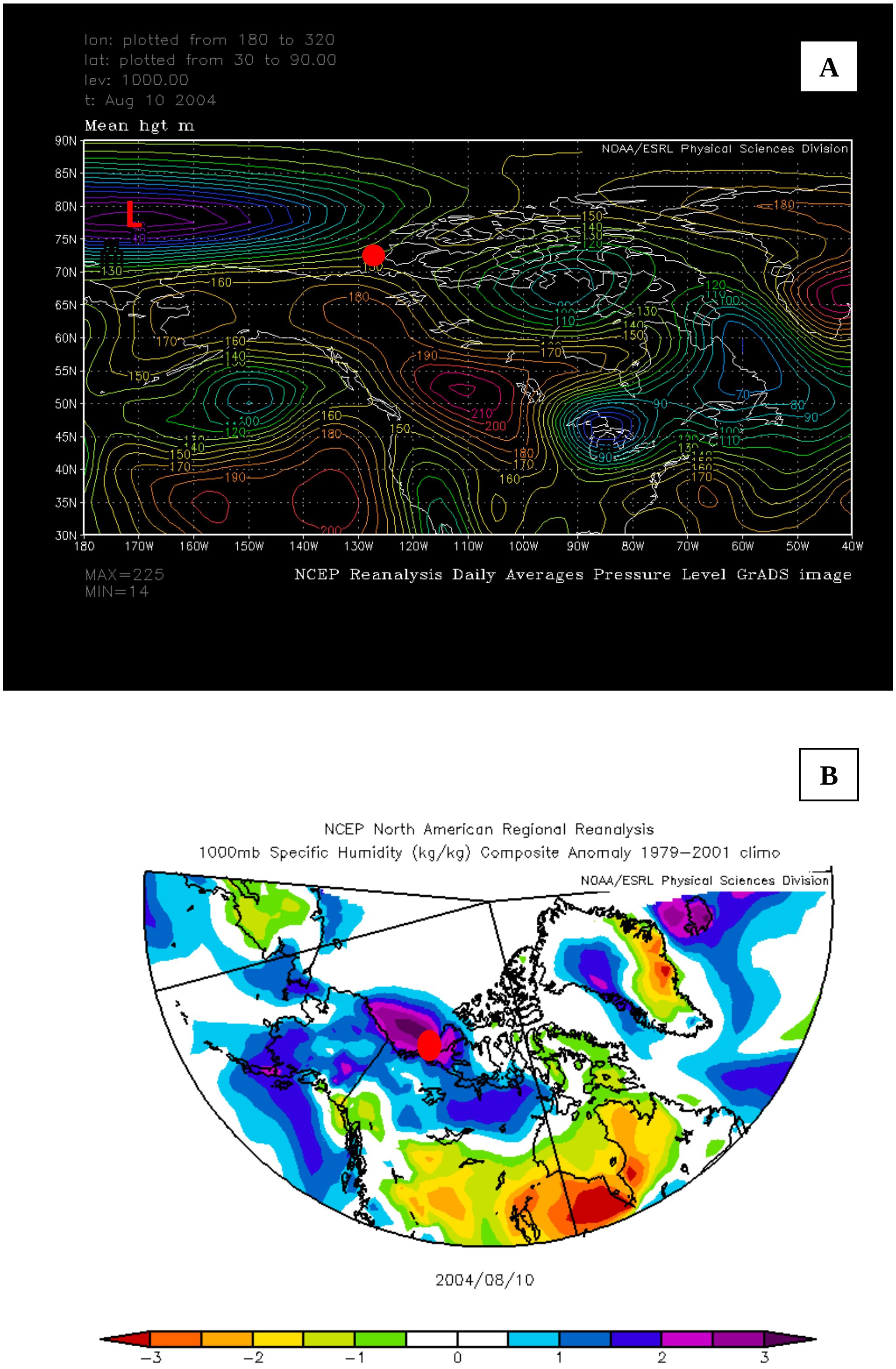

**Figure 5.41:** Selected atmospheric variables for the Sachs Harbour fog event of 10 August 2004. A) height of the 1000hPa pressure surface (m). B) 1000hPa specific humidity anomaly (mean period is 1979-2001).

An example of a fog event driven by local conditions occurred at Sachs Harbour on 2 August 2005. There is no synoptic-scale advection of moisture.  At this time sea ice at the southern Sachs Harbour is melted (Fig. 5.42a) and wind direction at the station is southwest (210 degrees). So, it brings enough moisture to formation of fog. The large-scale reanalysis plot does not show excess moisture (Fig. 5.42b) which means a multi-hour fog event must be driven by local moisture.

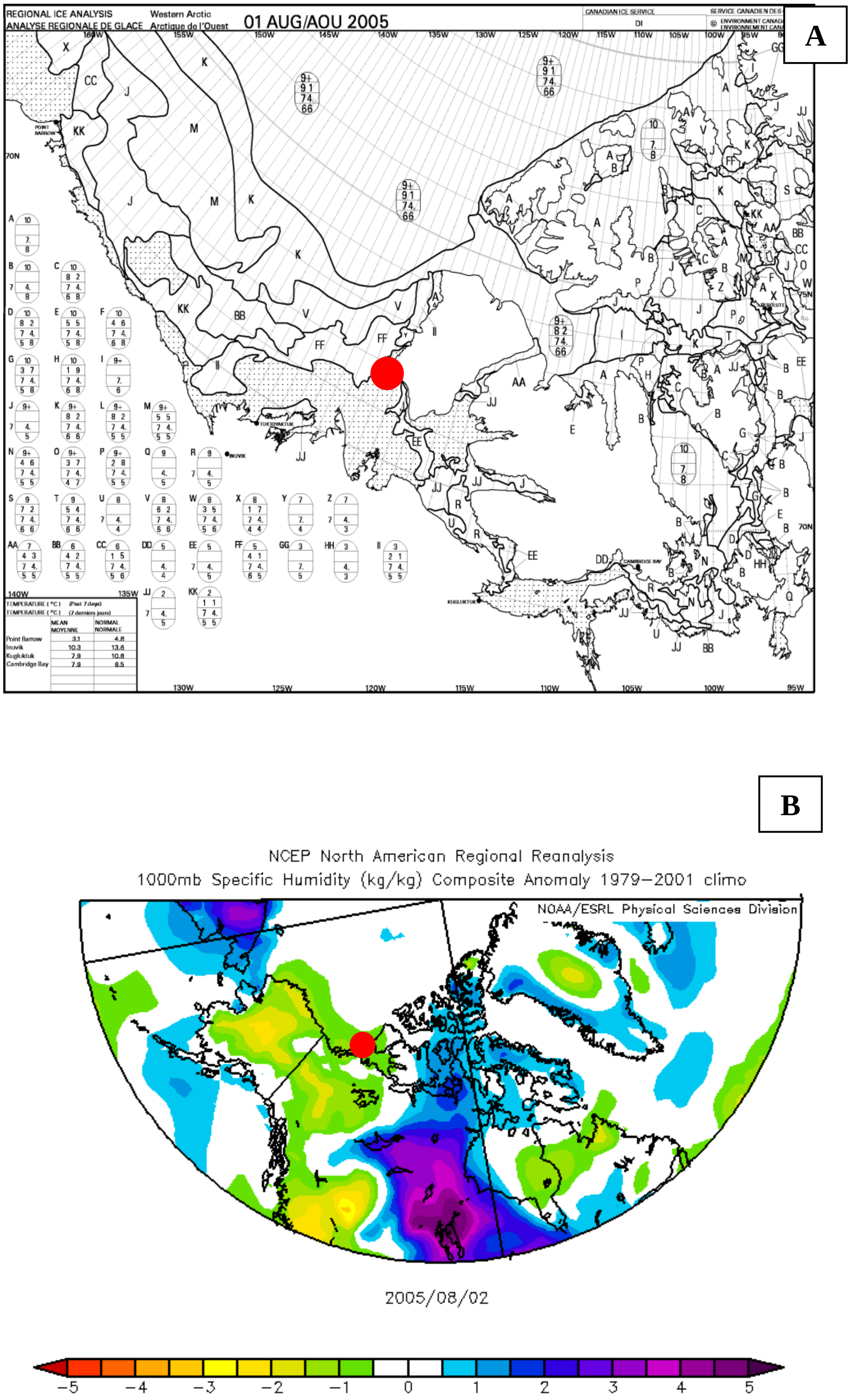

**Figure 5.42:** A) Sea ice conditions for the week ending 1 August 2005. The dotted shading indicates areas of ice-free water. B) 1000hPa specific humidity anomaly in kg/kg (mean period is 1979-2001).

## 5.4 Tuktoyaktuk

### 5.4.1 Visibility climatologies

#### 5.4.1.1 Hourly climatologies

Observations from Tuktoyaktuk are most frequent from 0700 to 2200 hrs, which is a greater daily duration than the other stations, except Inuvik.

Considering the annual timeframe, Tuktoyaktuk exhibited a small early morning peak in total frequency of LV/VLV events (almost 7%) that drops a little during the day (to just above 4%). The frequency with which fog caused LV events was greatest at 0600hrs (~80%); it decreased until 1500hrs (30%) after which after it increased until 2100hrs (50%). VLV events follow a similar trend but the proportion of association with fog is 10%-20% greater than LV events (Fig. 5.43). VLV events are more frequently associated with fog, but less frequent overall.

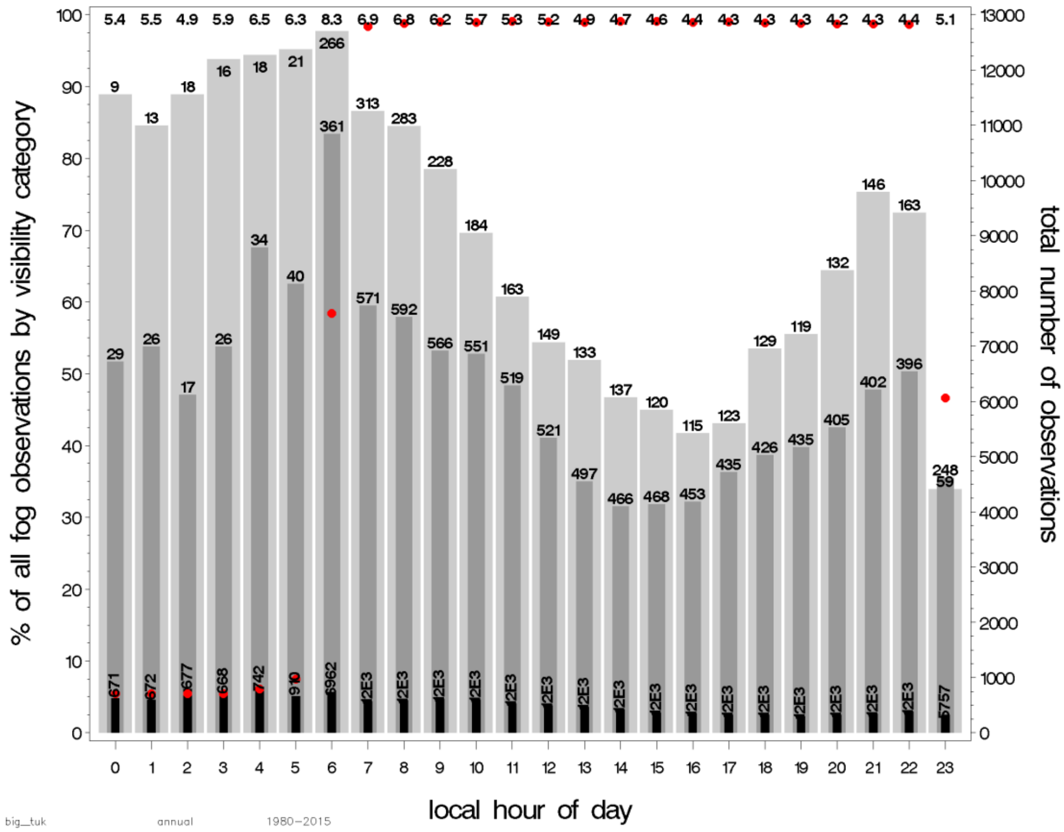

**Figure 5.43:** Total counts of hourly occurrences of LV and VLV events for Tuktoyaktuk, with an indication of the influence of fog, for all months of the year. Light grey bars represent the proportion of VLV events associated with a coincident observation of fog. Total VLV counts are the small number at the top of the light grey bar. Dark grey bars represent the proportion of LV events associated with a coincident observation of fog. Total LV counts are the small number at the top of the grey bar. Black bars represent the proportion of total available observations that were not in the VLV/LV category and which had fog associated with them. Total non-VLV/LV counts are the small rotated number at the top of the black bars. The total percent of all observations for which VLV/LV conditions existed are printed as the small number at the top of each column. The red dots represent the total number of observations available in that hour.

In winter, Tuktoyaktuk showed a slow increase in the overall frequency of LV/VLV events that peaks at noon/early afternoon, ranging between ~7.3-7.4%. The proportion of LV events caused by fog range from ~50% down to ~25% in early/mid afternoon. VLV events caused by fog had magnitudes and trends that vary in a manner similar to LV events (Fig. 5.44).

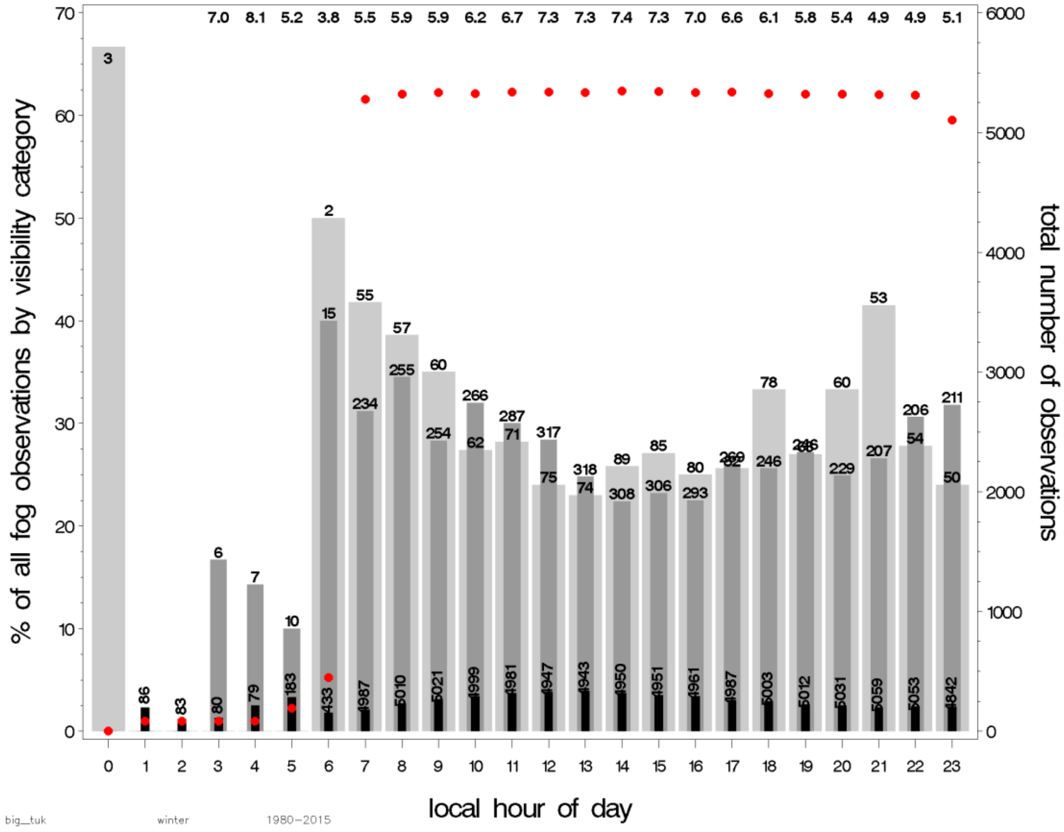

**Figure 5.44:** Total counts of hourly occurrences of LV and VLV events for Tuktoyaktuk, with an indication of the influence of fog, for winter months (month=11, 12, 1, 2, 3). Please refer to the caption in Figure 5.43 for a complete description of this plot.

In summer, Tuktoyaktuk exhibited a strong drop in the overall percentage of LV/VLV events, from ~8% in the early morning to less than 1% in the mid-afternoon. The proportion of LV and VLV events that were caused by fog remained high throughout the day, above 80% (Fig. 5.45). There were no VLV events after 1000 hrs.

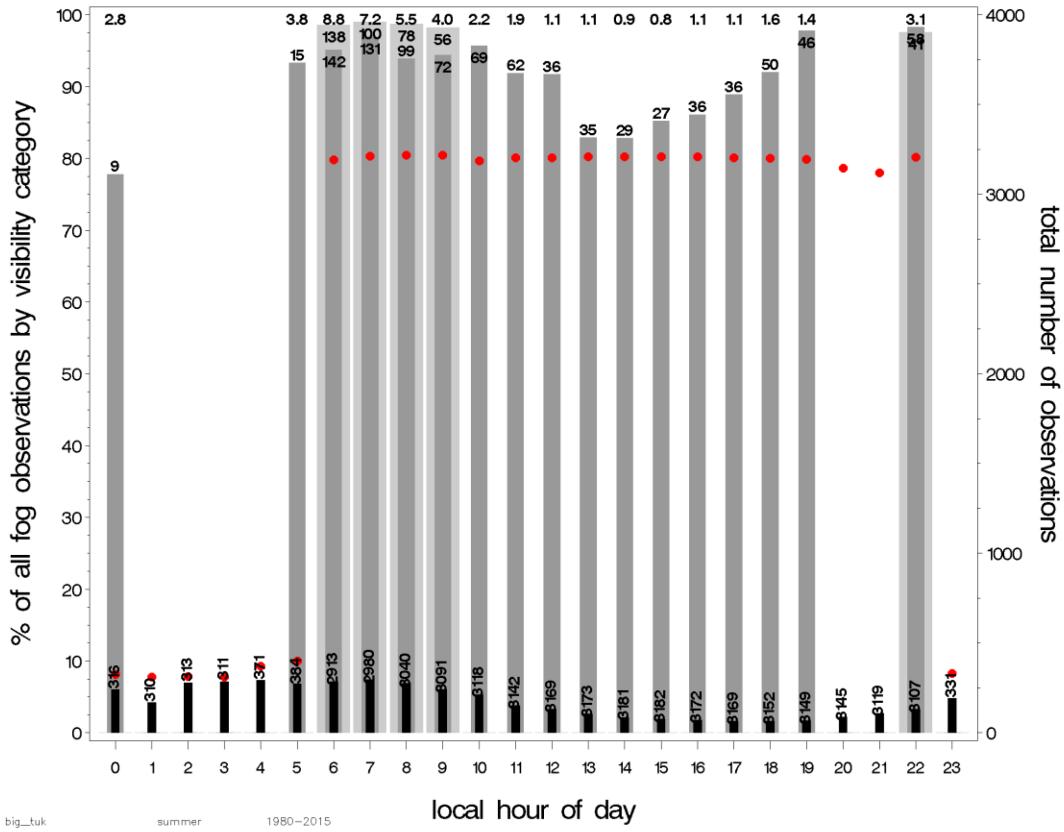

**Figure 5.45:** Total counts of hourly occurrences of LV and VLV events for Tuktoyaktuk, with an indication of the influence of fog, for summer months (month= 6, 7, 8). Please refer to the caption in Figure 5.43 for a complete description of this plot.

In fall and spring, Tuktoyaktuk exhibited a drop in the overall percentage of LV/VLV events that was not as pronounced as in summer, from ~9% in the early morning to ~3.5% in the mid-afternoon. The proportion of LV events caused by fog goes from 70% to 40%, and the proportion of VLV events caused by fog goes from 95% to 70% (Fig. 5.46).

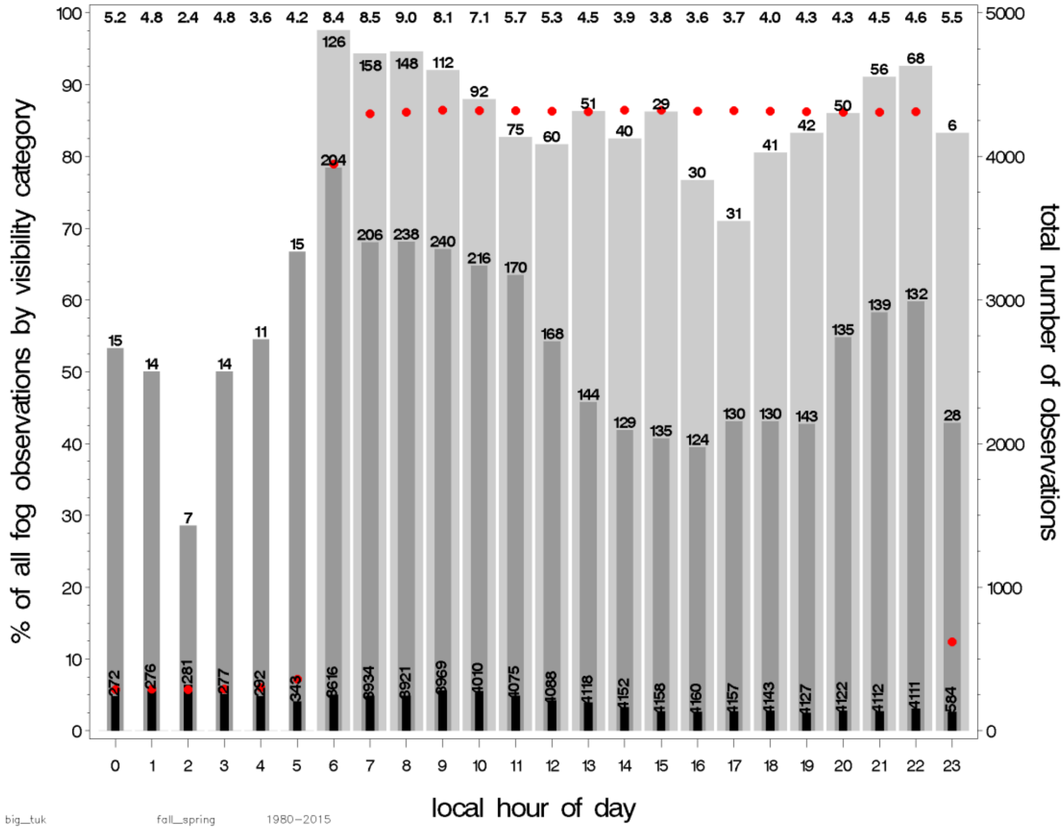

**Figure 5.46:** Total counts of hourly occurrences of LV and VLV events for Tuktoyaktuk , with an indication of the influence of fog, for fall and spring months (month=4, 5, 9, 10). Please refer to the caption in Figure 5.43 for a complete description of this plot.

### 5.4.1.2 Monthly climatologies

At Tuktoyaktuk the overall occurrence of LV and VLV events do not show a very strong pattern, ranging from 2.3% to 8.6%, with the lowest values in July and August and the highest values in January/February. The proportion of LV and VLV events caused by fog, varies widely, spanning the range 17-98%; it is low in the winter and high in the summer. The raw counts of LV events is greatest in the winter, whereas for VLV events it is the spring months (March and April) (Fig. 5.47).

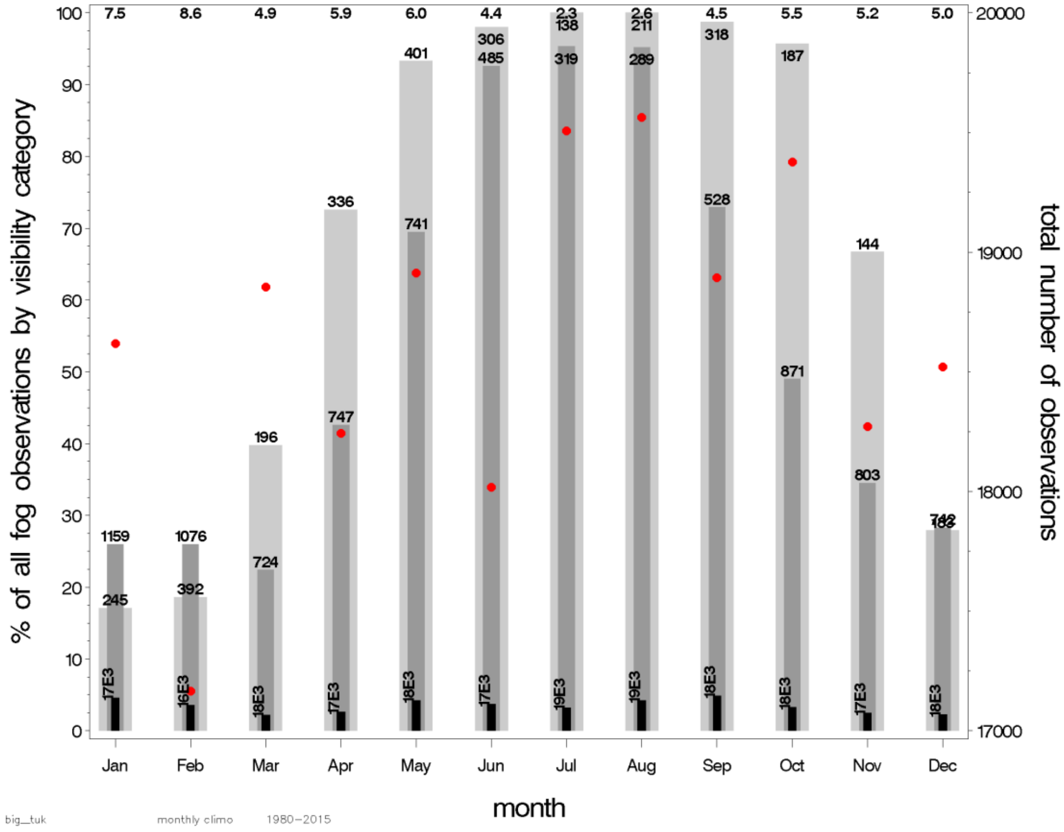

**Figure 5.47:** Total counts of monthly occurrences of LV and VLV events for Tuktoyaktuk , with an indication of the influence of fog. The layout of the plot is the same as for Figure 5.42; please refer to the caption in Figure 5.42 for a complete description of this plot.

### 5.4.1.3 Annual trends

At Tuktoyaktuk the total number of observations available per year starts high and then settles to a relatively steady value after 1987 (Fig. 5.48). There is no statistical trend in the total frequency of combined LV/VLV events (Table 5.1).

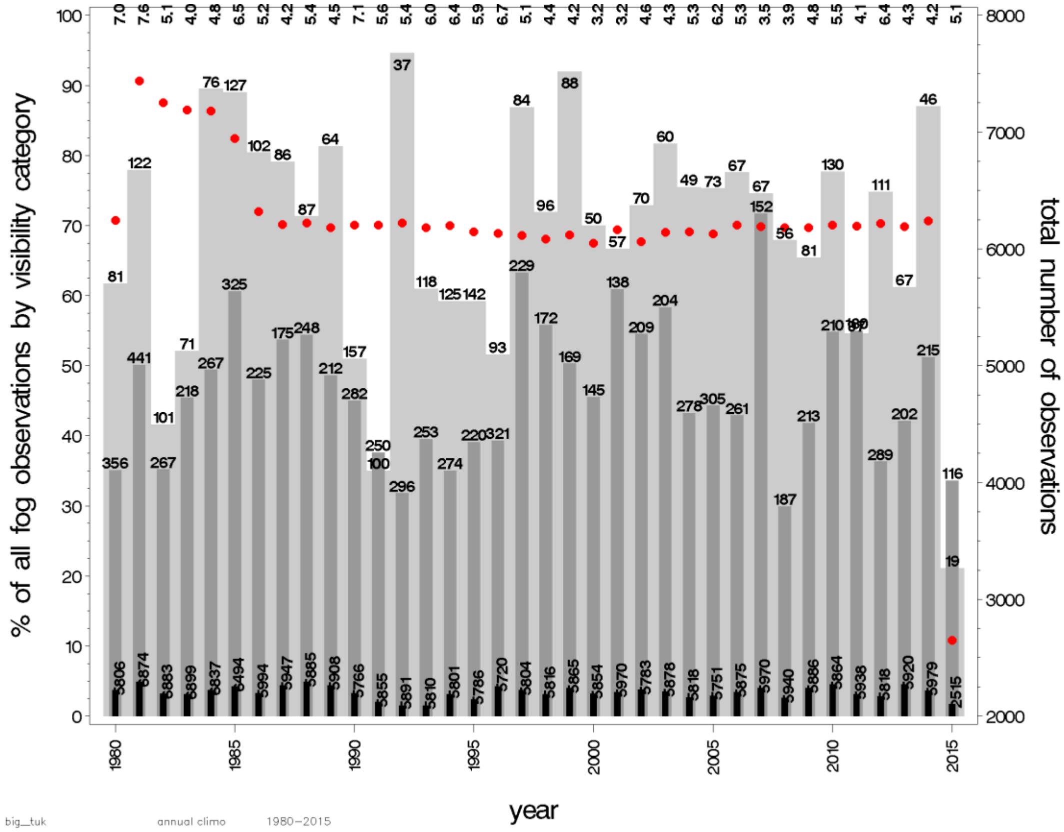

**Figure 5.48:** Total counts of annual occurrences of LV and VLV events for Tuktoyaktuk, with an indication of the influence of fog. The layout of the plot is the same as for Figure 5.43; please refer to the caption in Figure 5.43 for a complete description of this plot.

## 5.4.2 Low visibility event causes by weather type

### 5.4.2.1 Hourly by type

For Tuktoyaktuk , the hourly climatology of weather events for the entire year indicates that fog and blowing snow are the dominant weather event for all times of the day, with neither showing much of a decline during the day. Drizzle had lower proportions and decreased through the morning, remaining low through the afternoon, and rising in the night (Fig. 5.49). Note that only the hours from 0600 to 2300 inclusive are being considered.

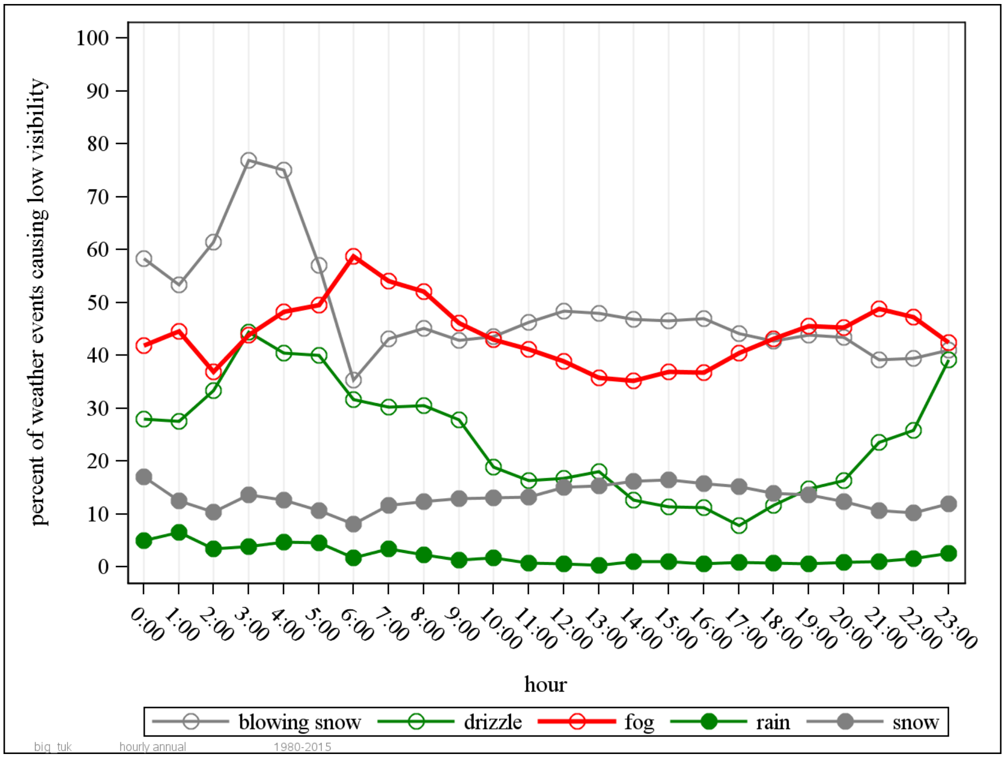

**Figure 5.49:** Percent of hourly occurrences that different weather types were associated with an LV/VLV event for Tuktoyaktuk , for all months of the year.

Tuktoyaktuk hourlies in the fall and spring showed the proportion of blowing snow and fog occurrences resulting in LV/VLV conditions was equally high in the morning, at ~60%, with both declining at a similar rate into the afternoon, to ~40%. Drizzle was responsible for ~30% of events, which dropped off during the day to under 10%. Snow and rain remained low (Fig. 5.50).

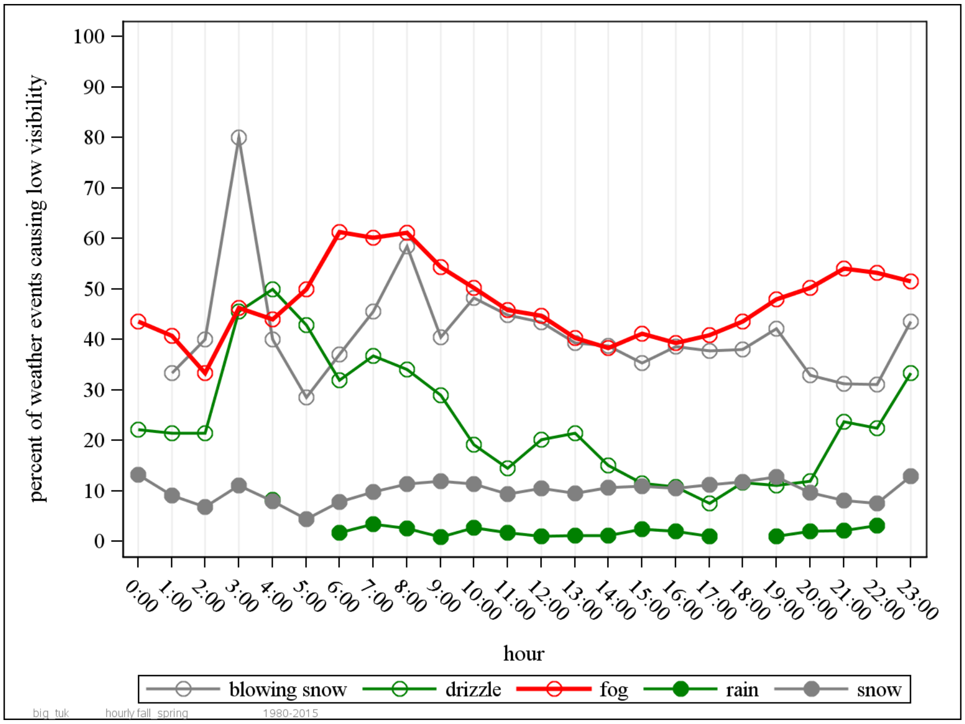

**Figure 5.50:** Percent of occurrences that different weather types were associated with an LV/VLV event for Tuktoyaktuk, by hour, for the fall and spring months (month= 4, 5, 9, 10).

Tuktoyaktuk hourlies in the summer showed a strong early morning peak in the proportion of fog events that resulted in LV/VLV situation (~60%); drizzle was not as high, starting at ~40% after midnight. Both declined through the day: fog to 30% and drizzle going down to 10% by mid-afternoon. Rain and snow were relatively consistent at ~10% (Fig. 5.51).

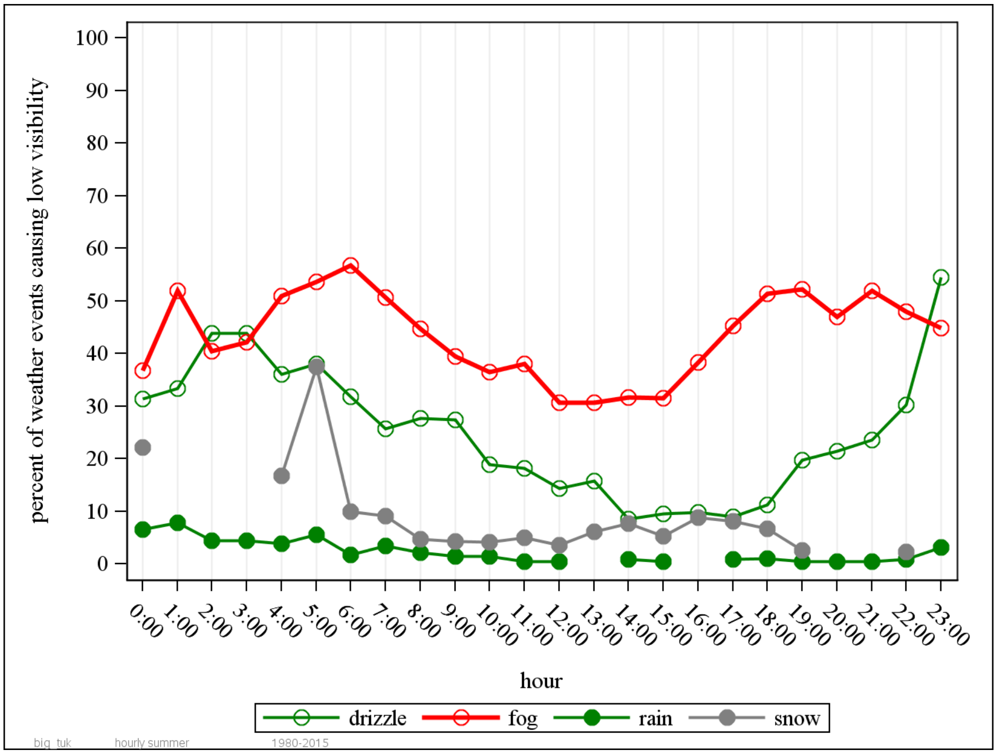

**Figure 5.51:** Percent of occurrences that different weather types were associated with an LV/VLV event for Tuktoyaktuk, by hour, for the summer months (month= 6, 7, 8).

Tuktoyaktuk hourlies in the winter showed the proportion of fog events causing LV/VLV conditions starting at ~50% and decreasing slowly to ~30%. Blowing snow starts ~40% and increases slowly to ~50%. Snow sees a small increase from ~10% to ~20% during the day (Fig. 5.52).

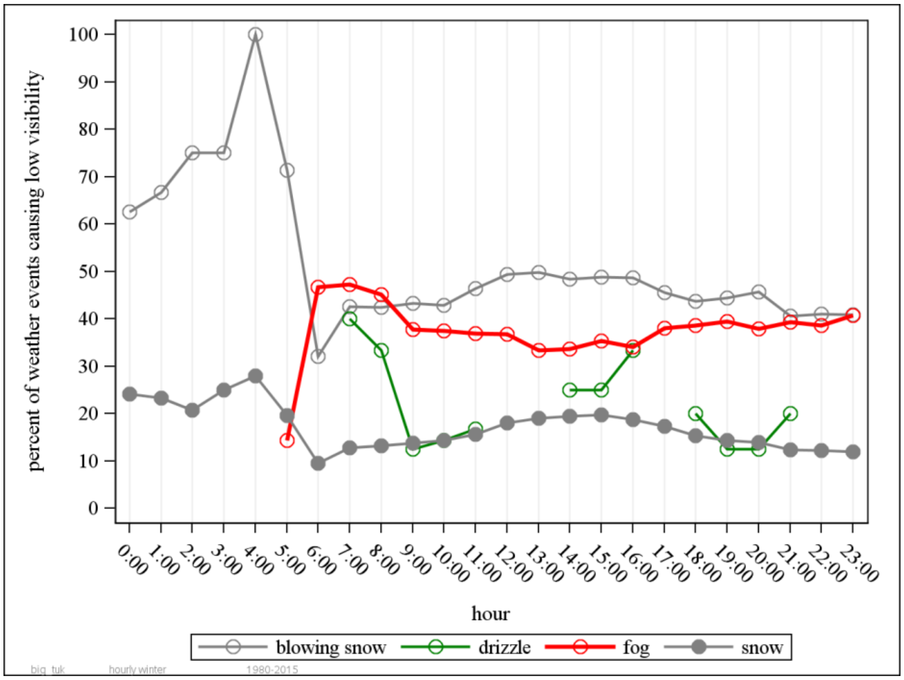

**Figure 5.52:** Percent of occurrences that different weather types were associated with an LV/VLV event for Tuktoyaktuk, by hour, for the winter months (month= 11, 12, 1, 2, 3).

#### 5.4.2.2 Monthly by type

At Tuktoyaktuk the monthly climatology indicates that fog occurrences are responsible for a relatively consistent proportion of LV/VLV events, 42% to 55%, except through April to June, when the proportion rises to almost 55%. Mid-summer is a low point, with the proportion rising again to a secondary peak in September. Blowing snow occurrences are also relatively consistent between 35% and 55% in all months where it is observed; a high point occurs in January-February. Drizzle occurrences are found 18% to 40% of LV/VLV events, with a high point reached during late spring and a low point in November. Snow occurrences are responsible for relatively few LV/VLV events, from 5% to 25%, with the greatest proportion observed in February. Rain is observed only in the May through October period and rarely is responsible for LV/VLV events (Fig. 5.53).

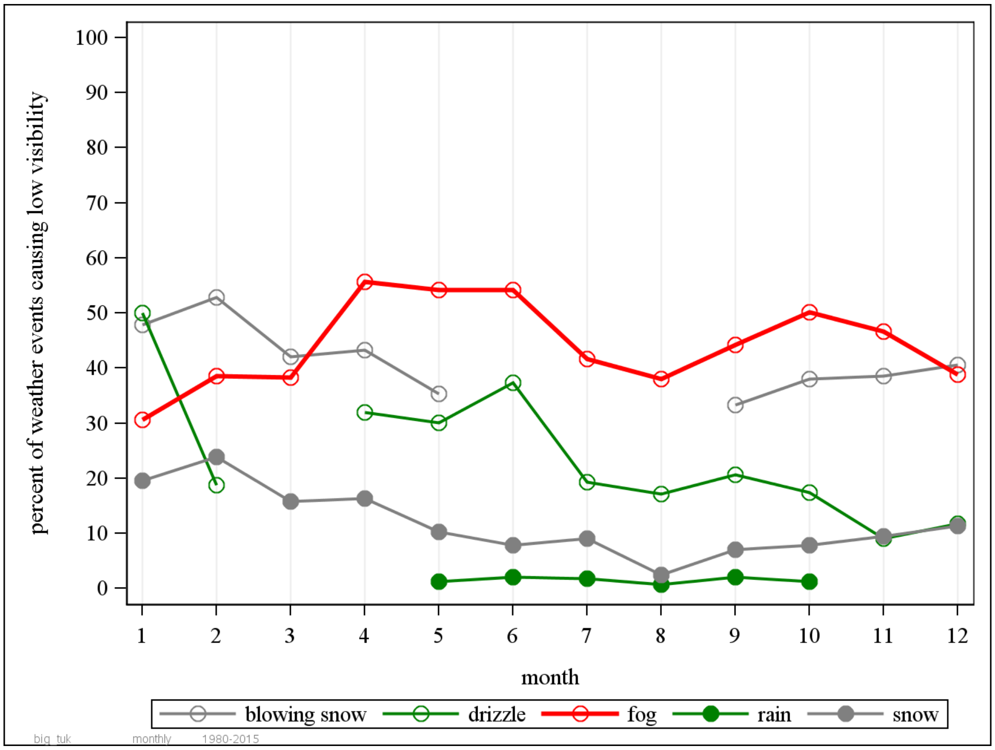

**Figure 5.53:** Percent of occurrences that different weather types were associated with an LV/VLV event for Tuktoyaktuk, by month.

### 5.4.2.3 Annual by type

At Tuktoyaktuk the occurrence of blowing snow and fog are most likely to be responsible for LV events. Drizzle is the next most likely weather type to cause LV/VLV events, ranging between 2 and 58% over the entire period of record. Snow occurrences were more frequently associated with LV/VLV events, ranging from 8 to 25%. The occurrence of rain is responsible for very few LV/VLV events (Fig. 5.54).

At Tuktoyaktuk, snow as a cause of LV/VLV events showed a significant decrease of 2.8 +/- 0.6% per decade. Blowing snow and drizzle also showed significant declines of 4.1 +/- 1.6% and 3.1 +/- 1/5 % per decade, respectively, although the statistical strength of the trend of these was not as strong as snow (Table 5.2).

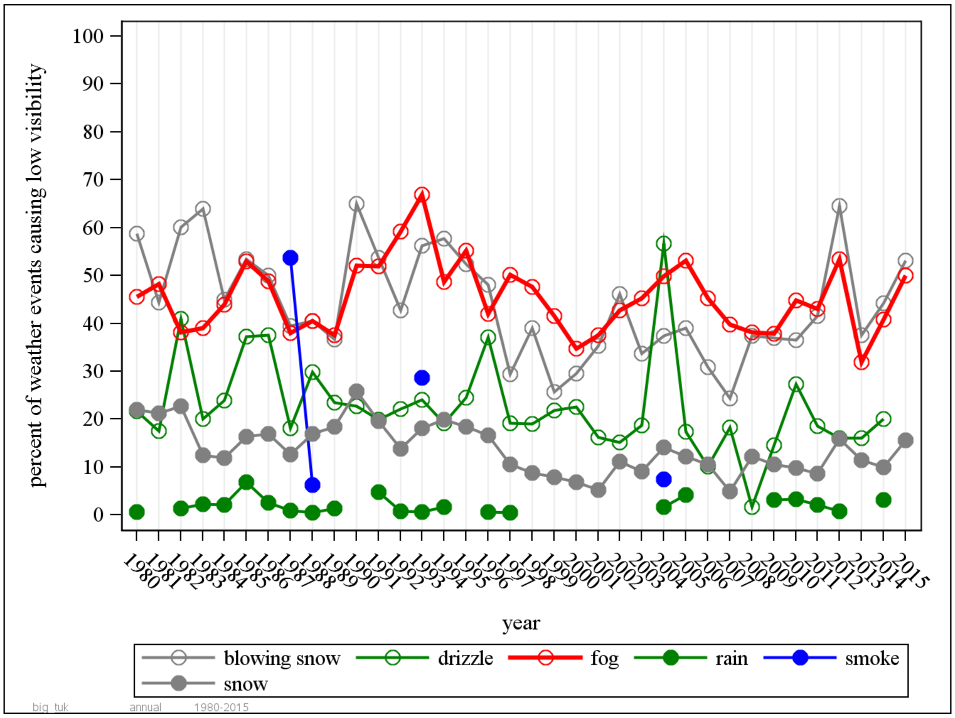

**Figure 5.54:** Percent of occurrences that different weather types were associated with an LV/VLV event for Tuktoyaktuk, by year.

### 5.4.3 Synoptic analysis

An example of an advective moisture event by meso-scale flow occurred at Tuktoyaktuk on 6 October 2012. Although the surface pressure pattern shows a low pressure centered over the Bering Sea and a high pressure region over the Gulf of Alaska, an examination of the winds at Tuktoyaktuk indicates that the winds were not coming from the west/southwest, which this feature would suggest, but rather from the northwest. A closer examination of the pressure patterns using a higher-resolution reanalysis data shows a small low pressure system just to the northeast of the Mackenzie Delta (5.55a). It is this feature that is moving moisture from Amundsen Gulf into the Tuktoyaktuk vicinity. The 1000 hPa specific humidity anomaly shows that, although an unusual amount of moisture was being drawn into the study area from the Bering Sea region, as compared to the 30 year mean for this time period (5.55b), it is likely not this moisture that is driving this fog event.

An example of a fog event driven by local conditions occurred at Tuktoyaktuk on 2 February 1990. There is no synoptic-scale advection of moisture and no moisture anomaly (Fig. 5.56a). However on this day very low temperatures were observed at Tuktoyaktuk, below -40 C (Fig. 5.56b).

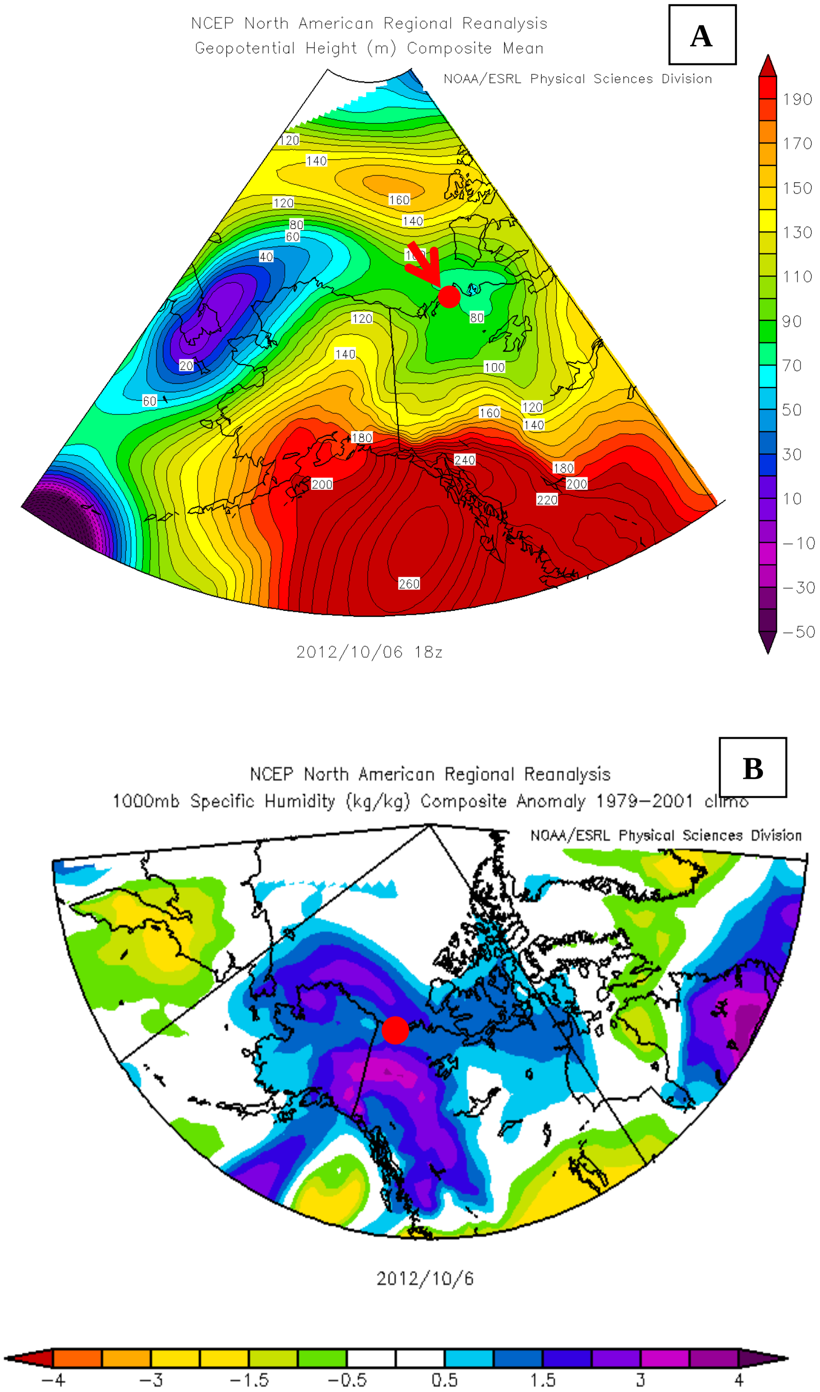

**Figure 5.55:** Selected atmospheric variables for Tuktoyaktuk the fog event of 6 October 2012. A) height of the 1000hPa pressure surface (m). B) 1000hPa specific humidity anomaly (mean period is 1979-2001).

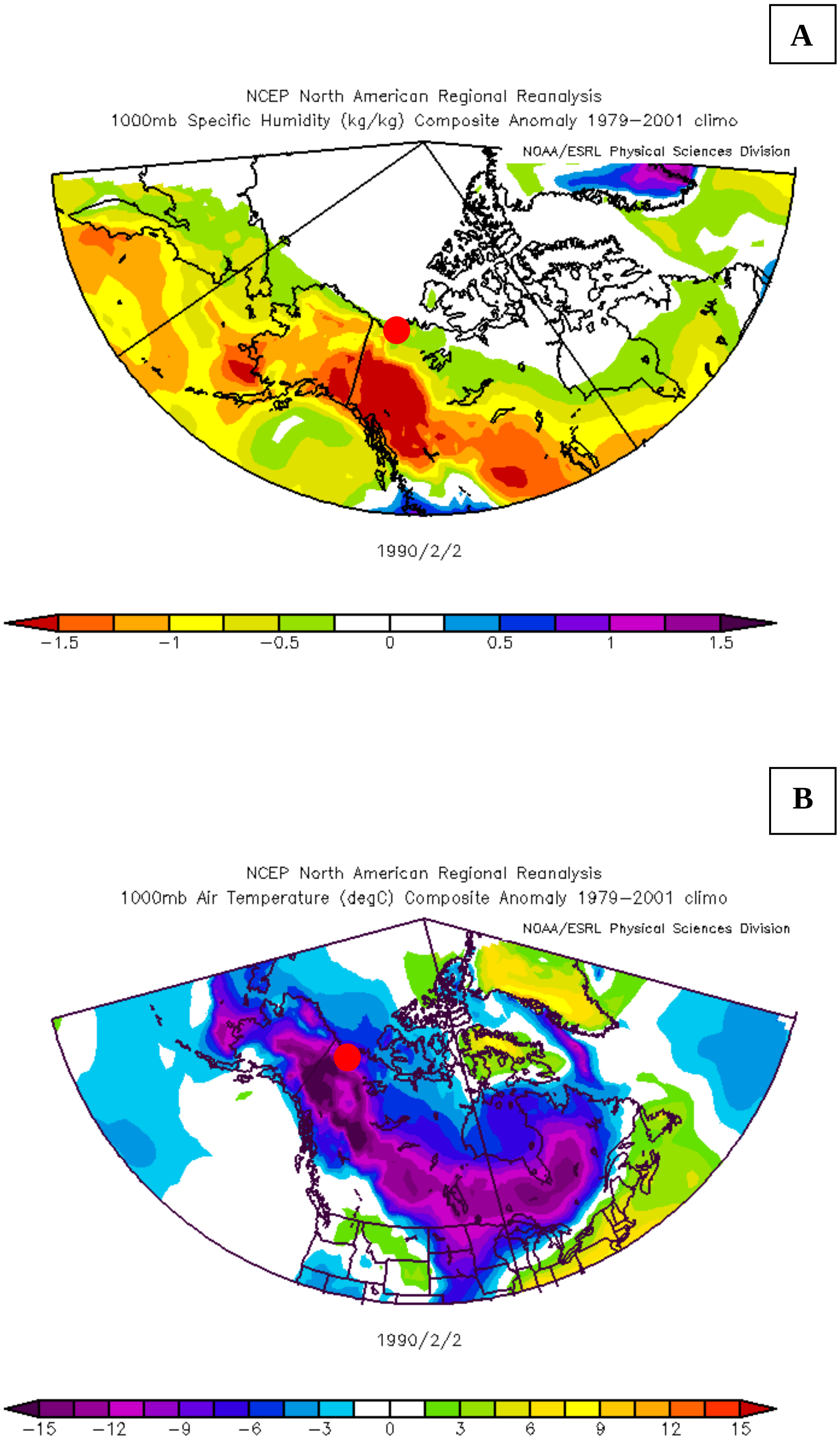

**Figure 5.56:** Selected atmospheric variables for Tuktoyaktuk the fog event of 20 February 1991. A) 1000hPa specific humidity anomaly (mean period is 1979-2001). B) 1000hPa air temperature anomaly

## 5.5 Ulukhaktok

### 5.5.1 Visibility climatologies

#### 5.5.1.1 Hourly climatologies

Considering all seasons of the year, using hours with enough observations to be reliable (0700 to 1700hrs), Ulukhaktok exhibited the often-observed pattern whereby both LV and VLV events caused by fog are frequent in the early part of the morning (0700hrs), accounting for 55 and 85% of observations, respectively. LV event proportions drop to ~40% and then remain roughly consistent after 1200hrs, whereas VLV event proportions also drop but exhibit a slight rise to the end of the daytime observing period (1700hrs), up to 47% of observations. After 0800hrs a gradual decrease in LV and VLV overall percentages was observed, with values reaching their low points around noon (Fig. 5.57). Raw counts are relatively consistent throughout the 0700-1700hrs period.

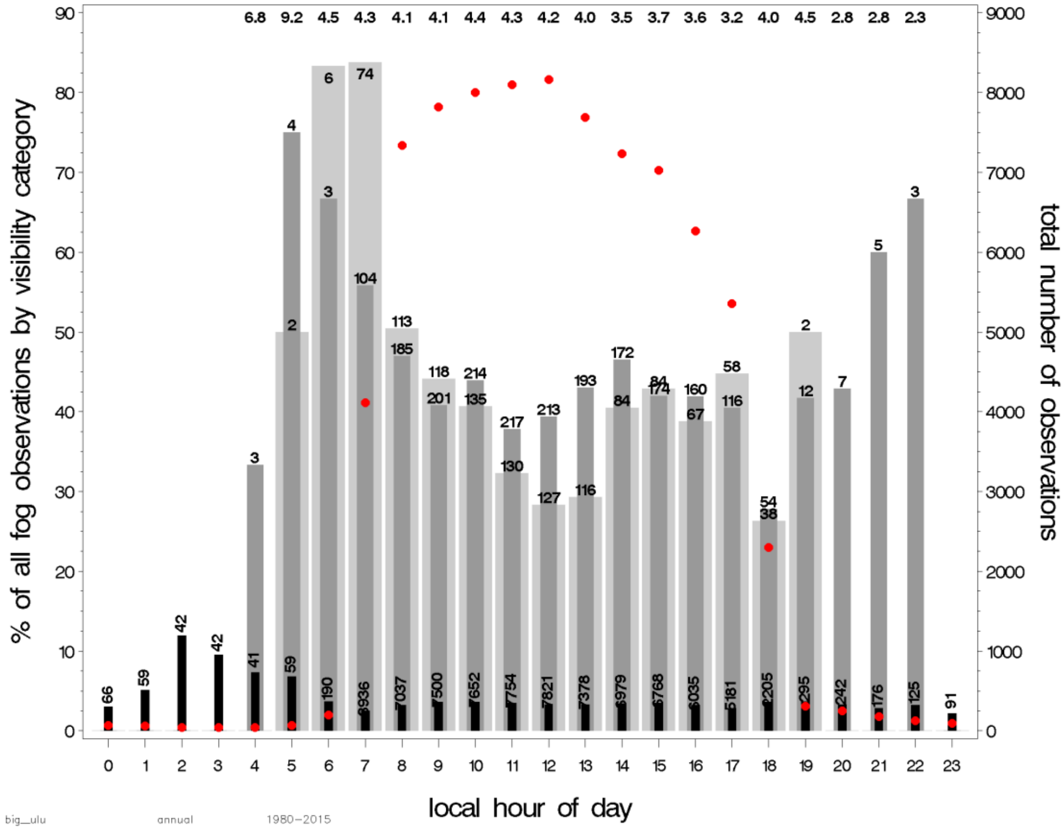

**Figure 5.57:** Total counts of hourly occurrences of LV and VLV events for Ulukhaktok , with an indication of the influence of fog, for all months of the year. Light grey bars represent the proportion of VLV events associated with a coincident observation of fog. Total VLV counts are the small number at the top of the light grey bar. Dark grey bars represent the proportion of LV events associated with a coincident observation of fog. Total LV counts are the small number at the top of the grey bar. Black bars represent the proportion of total available observations that were not in the VLV/LV category and which had fog associated with them. Total non-VLV/LV counts are the small rotated number at the top of the black bars. The total percent of all observations for which VLV/LV conditions existed are printed as the small number at the top of each column. The red dots represent the total number of observations available in that hour.

In winter, Ulukhaktok exhibited a slow rise in the total frequency of LV/VLV events, from ~4% to a peak of 6.5% around noon (considering the 0800 to 1800hrs time frame). The proportion of LV events caused by fog is variable but rises slowly into the early afternoon, at values between 20 and 30%. The proportion of VLV events drops from 15% to 10%, then rises again into the afternoon (Fig. 5.58).

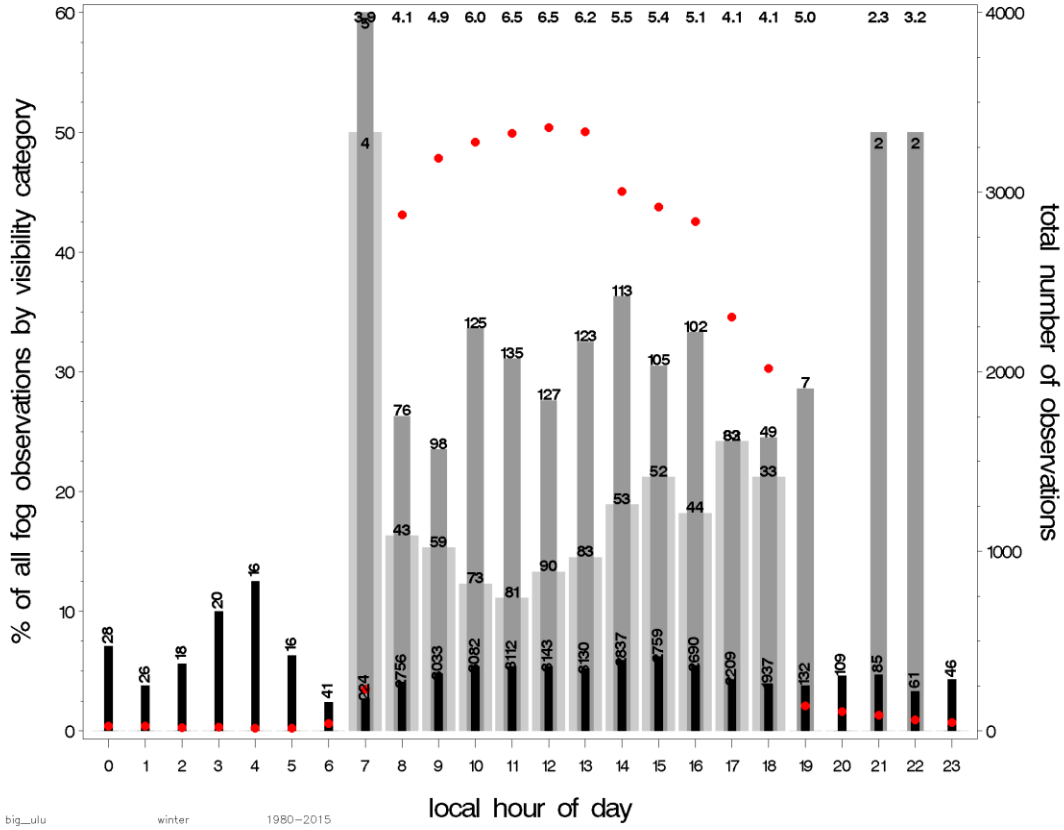

**Figure 5.58:** Total counts of hourly occurrences of LV and VLV events for Ulukhaktok, with an indication of the influence of fog, for winter months (month=11, 12, 1, 2, 3). Please refer to the caption in Figure 5.57 for a complete description of this plot.

In summer, Ulukhaktok exhibited a slow decline in the total frequency of LV/VLV events, from ~5.5% down to ~2% around noon. The proportion of LV and VLV events caused by fog is high, above 80%, and remains consistent throughout the day (Fig. 5.59).

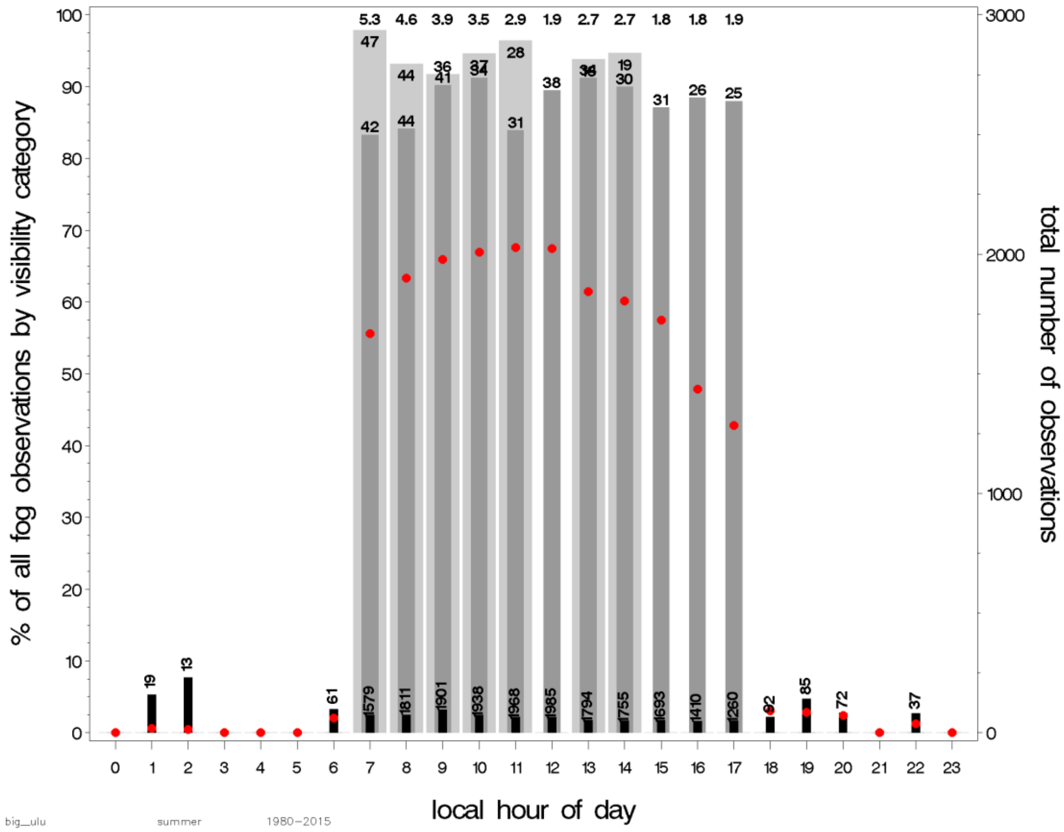

**Figure 5.59:** Total counts of hourly occurrences of LV and VLV events for Ulukhaktok , with an indication of the influence of fog, for summer months (month= 6, 7, 8). Please refer to the caption in Figure 5.57 for a complete description of this plot.

In fall and spring, Ulukhaktok again exhibited a slow decline in the total frequency of LV/VLV events over the course of the day, from ~3.6% to ~1.7%. Both LV and VLV events caused by fog range between 30 and 50% without a strong increasing or decreasing trend during the day (Fig. 5.60).

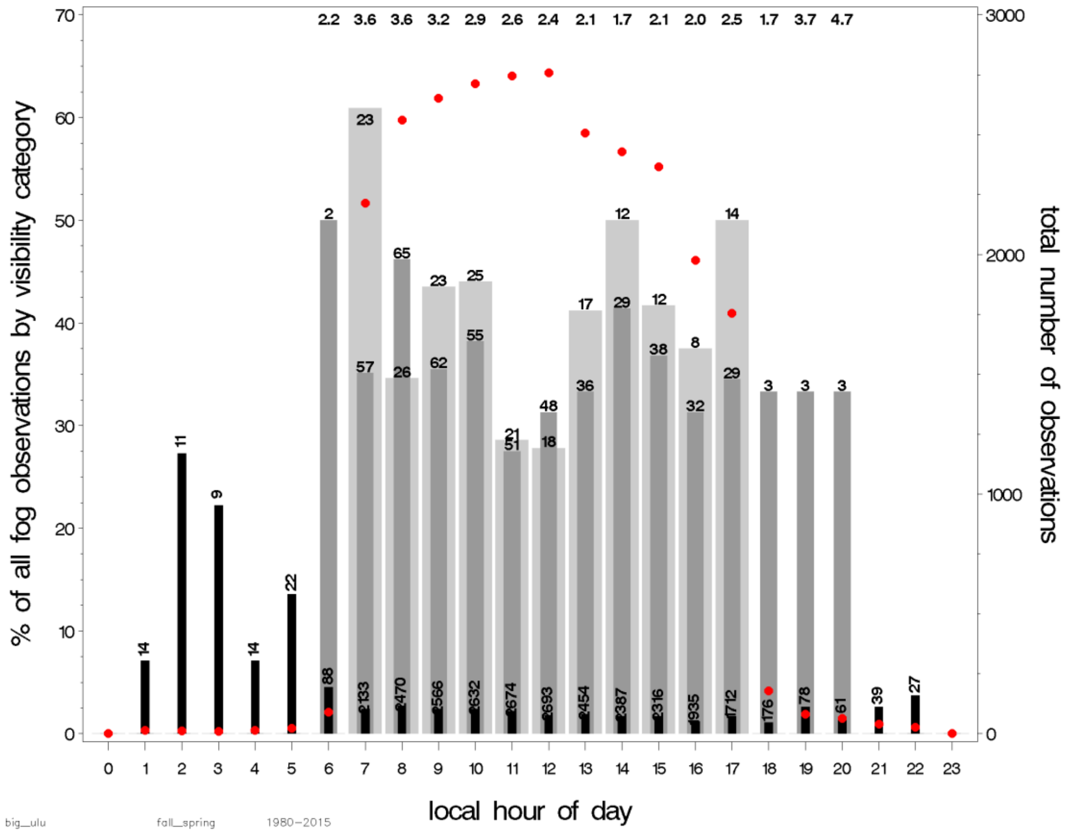

**Figure 5.60:** Total counts of hourly occurrences of LV and VLV events for Ulukhaktok , with an indication of the influence of fog, for fall and spring months (month=4, 5, 9, 10). Please refer to the caption in Figure 5.57 for a complete description of this plot.

#### 5.5.1.2 Monthly climatologies

At Ulukhaktok the occurrence of LV and VLV events exhibited strong seasonality. The proportion of these events caused by fog varies widely (10-98%). The number of LV events drops off in the fall-winter period (September-December), and VLV events cease completely during this time. LV event frequency again rises into the February -August period, with the largest total number of LV occurrences observed in August. VLV events occur again during this period. The proportion of LV and VLV events caused by fog is greatest in the May-September time period (Fig. 5.61).

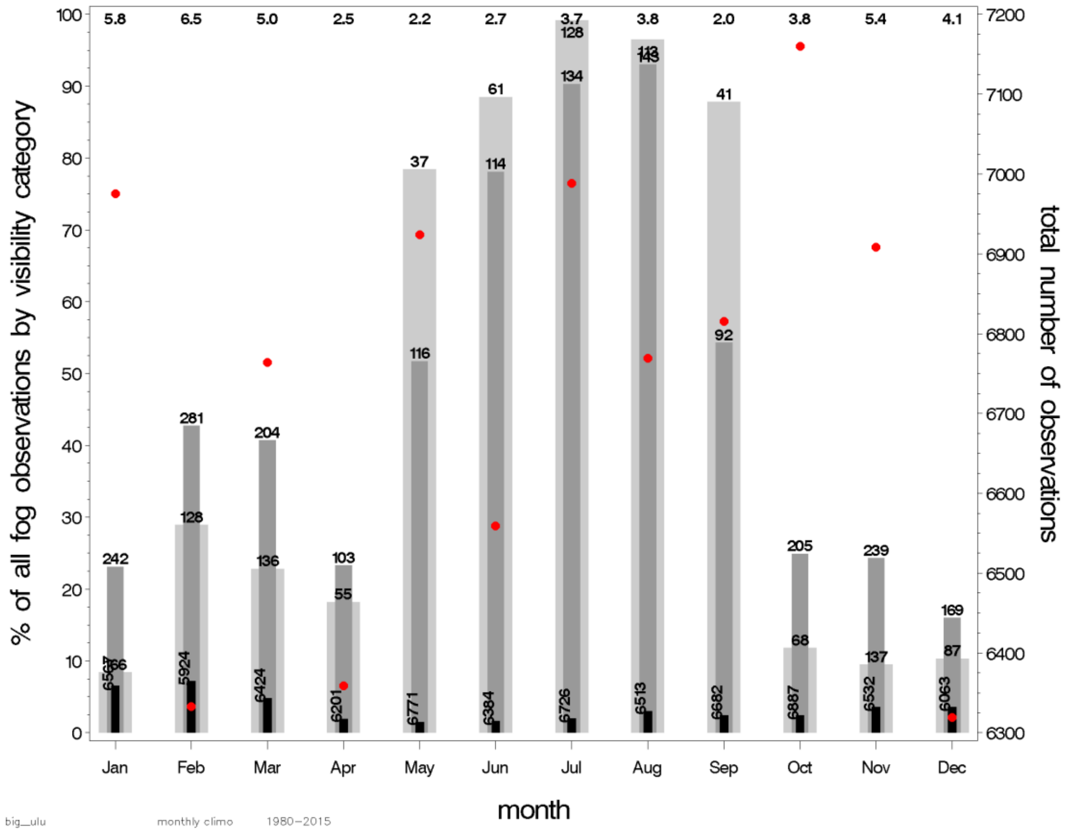

**Figure 5.61:** Total counts of monthly occurrences of LV and VLV events for Ulukhaktok, with an indication of the influence of fog. The layout of the plot is the same as for Figure 5.56; please refer to the caption in Figure 5.57 for a complete description of this plot.

#### 5.5.1.3 Annual trends

At Ulukhaktok the total number of observations available per year was quite variable over the period of data at this station (1987-2014)(Fig. 5.62). There was no significant trend in the overall proportion of LV/VLV events (Table 5.1). However, the proportion of LV and VLV events caused by fog appears to have a distinct cycle that lasts ~20 years, and there was a significant decline in fog as a cause of LV events of 16.2 +//- 4.4% per decade, and a less strongly significant decline in fog as a cause of VLV events of 9.3 +/- 5.2% per decade (Table 5.2). Note that a linear trendline appears to be an oversimplification of the actual trend, which appears to decline rapidly and then level out at between 20% to 40% in the latter decade or so of the record.

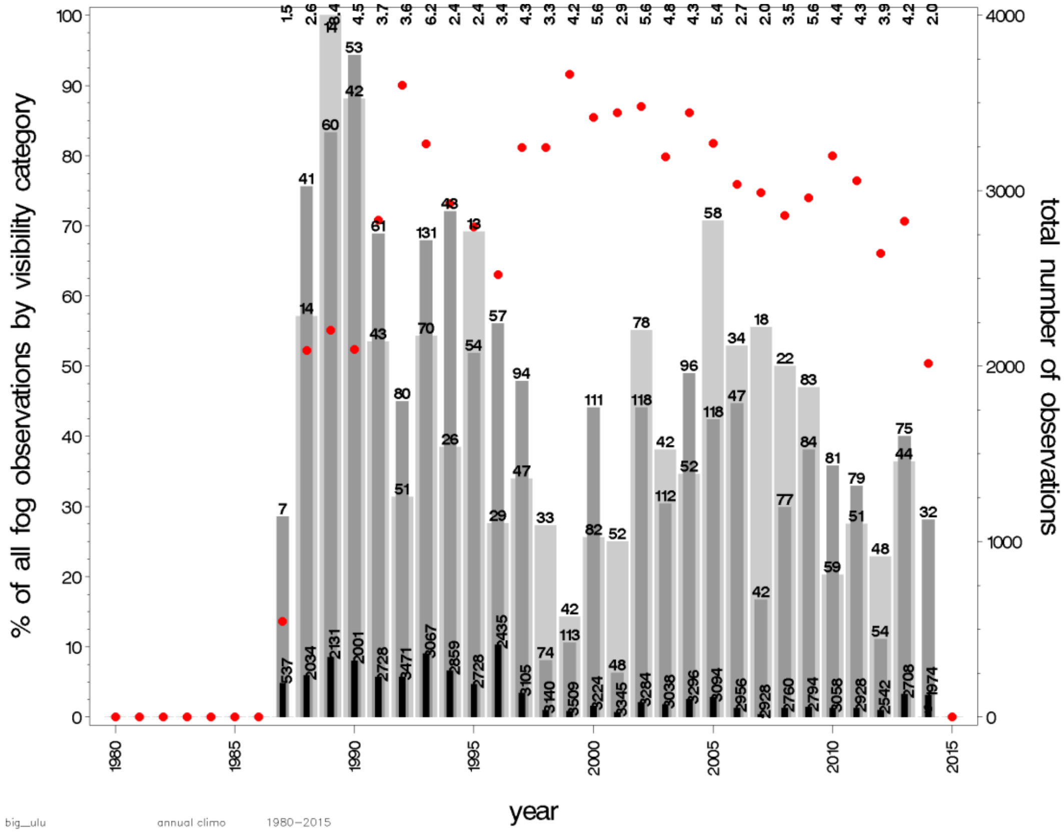

**Figure 5.62:** Total counts of annual occurrences of LV and VLV events for Ulukhaktok, with an indication of the influence of fog. The layout of the plot is the same as for Figure 5.57; please refer to the caption in Figure 5.57 for a complete description of this plot.

### 5.5.2 Low visibility event causes by weather type

### 5.5.2.1 Hourly by type

For Ulukhaktok, blowing snow is about 50% and remains fairly consistent. Fog starts high and drops to a stable level for the rest of the day. Drizzle is lower and steady, rising at the end of the day (Fig. 5.63). Note that results spanning the 0700-1700 hrs timeframe should be considered reliable.

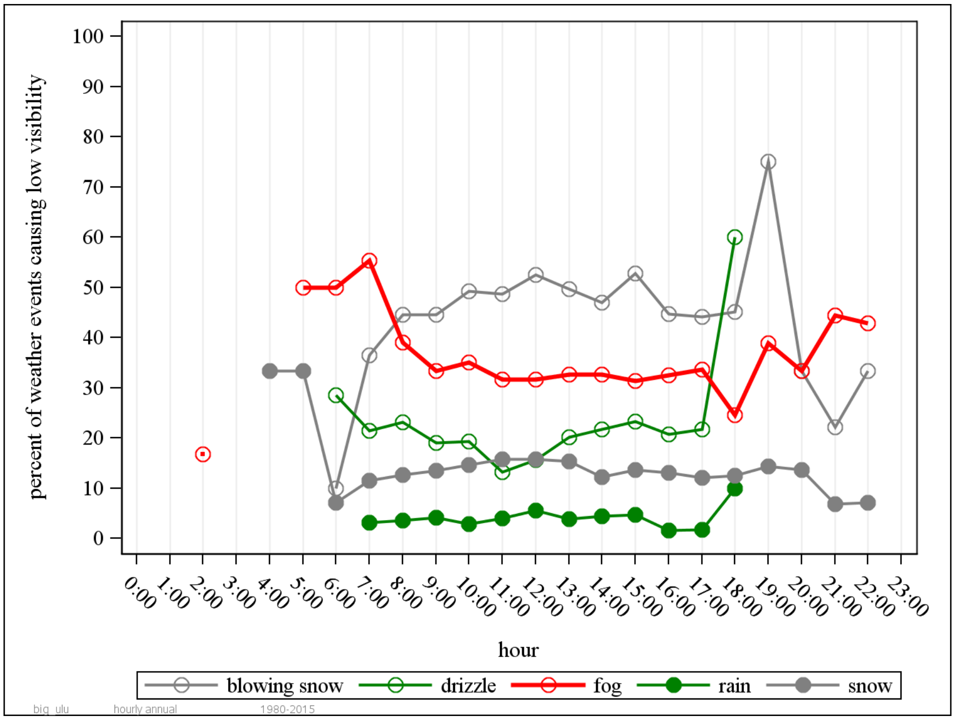

**Figure 5.63:** Percent of hourly occurrences that different weather types were associated with an LV/VLV event for Ulukhaktok, for all months of the year.

Ulukhaktok hourlies in the fall and spring were similar to the annual progression, except that fog accounts for a greater proportion of the events (Fig. 5.64).

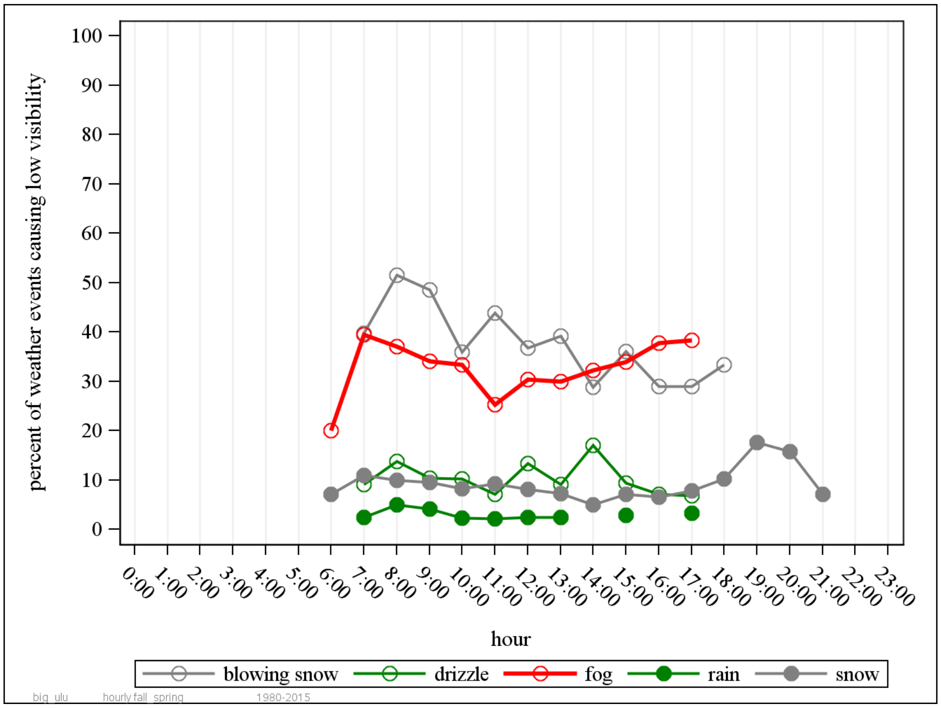

**Figure 5.64:** Percent of occurrences that different weather types were associated with an LV/VLV event for Ulukhaktok, by hour, for the fall and spring months (month= 4, 5, 9, 10).

Ulukhaktok hourlies in the summer again showed fog at relatively high proportions. Drizzle was less (Fig. 5.65).

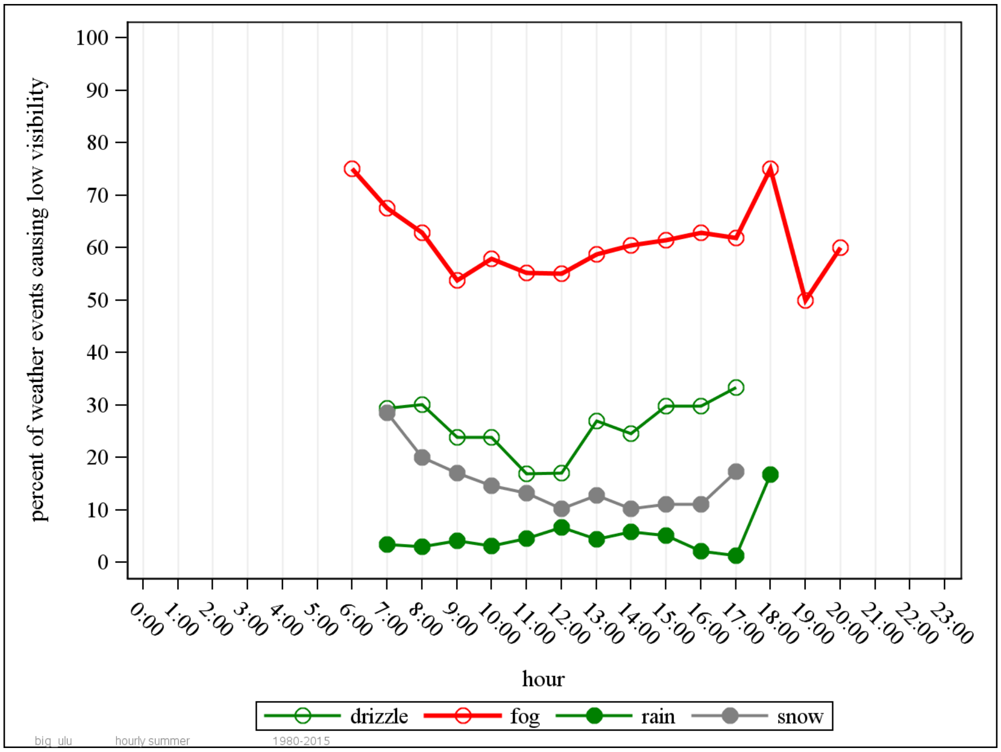

**Figure 5.65:** Percent of occurrences that different weather types were associated with an LV/VLV event for Ulukaktok, by hour, for the summer months (month= 6, 7, 8).

Finally, Ulukaktok hourlies in the winter also showed event totals for all parameters in general rising into the afternoon then decreasing. Event types were dominated by blowing snow (Fig. 5.66).

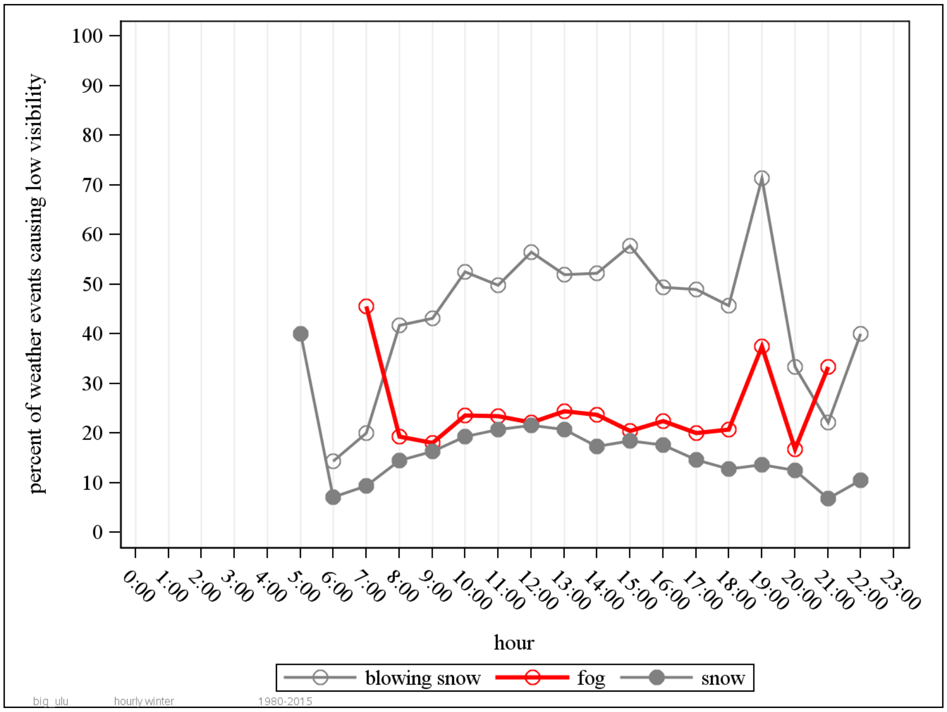

**Figure 5.66:** Percent of occurrences that different weather types were associated with an LV/VLV event for Ulukaktok, by hour, for the winter months (month= 11, 12, 1, 2, 3).

### 5.5.2.2 Monthly by type

At Ulukhaktok the monthly climatology shows that the proportion of LV/VLV events that are caused by fog occurrences can be broken into two distinct periods – high in the late spring-summer period (May-August; above 45%), and low in the fall-winter period (ranging around 20%). Blowing snow occurrences are relatively high in the winter and roughly consistent between 40 to 55%, and decline starting in April into the summer. Snow occurrences are responsible for between 5% and 30% of LV/VLV events, and is fairly consistent from the November through March period, lowest in May, and peaks in July. Drizzle occurrences are responsible for a relatively consistent 30% in April through July, and then declines rapidly into the fall. Rain is observed only in the June through September period and is rarely responsible for LV/VLV events (Fig. 5.67).

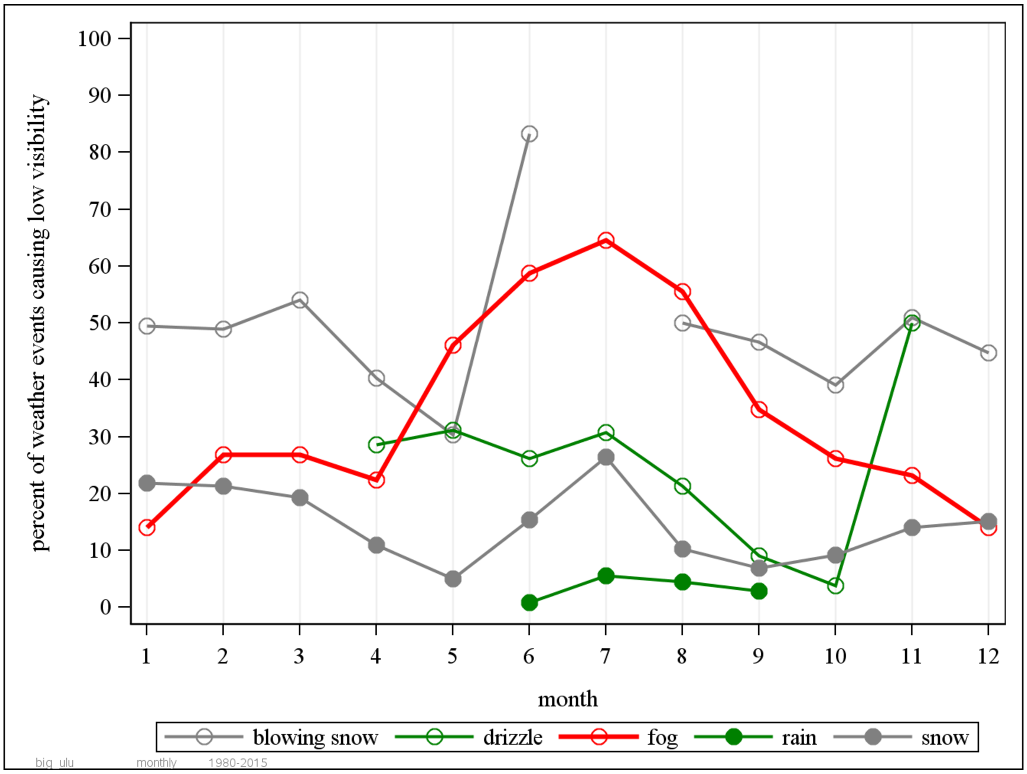

**Figure 5.67:** Percent of occurrences that different weather types were associated with an LV/VLV event for Ulukhaktok, by month.

### 5.5.2.3 Annual by type

At Ulukhaktok the occurrence of blowing snow was most likely to be responsible for LV events from 1987 through 1999 LV/VLV events, but from 2000 to 2011 fog became the most likely weather type to cause LV/VLV events. Drizzle occurrences were less frequently associated with LV/VLV events; large interannual variability is exhibited and there is no particular trend. The occurrence of rain is responsible for very few LV/VLV events (Fig. 5.68). There were no statistically significant trends in the proportion of snow, blowing snow, rain, or drizzle as causes for LV/VLV events (Table 5.2).

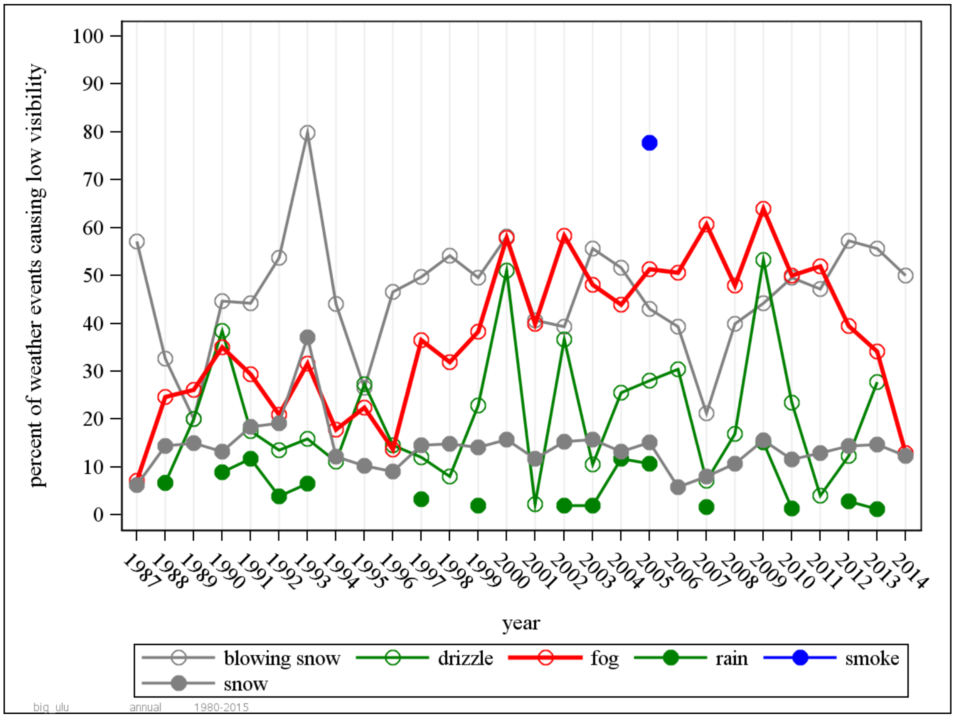

**Figure 5.68:** Percent of occurrences that different weather types were associated with an LV/VLV event for Ulukhaktok, by year.

### 5.5.3 Synoptic analysis

An example of a large-scale advective moisture event occurred at Ulukhaktok on 25 July 2011. A broad low pressure system is located over the northwest coast of North America. This feature has a trough that extends over Great Bear Lake which allows for the advection of air from the vicinity of Great Bear and Great Slave Lakes, over the open water of the eastern Amundsen Gulf region, and into the study region (Fig. 5.69a). The 1000 hPa specific humidity anomaly shows that an unusual amount of moisture was being drawn into the study area in the July 25 2011, as compared to the 30 year mean for this time period (Fig. 5.69b).

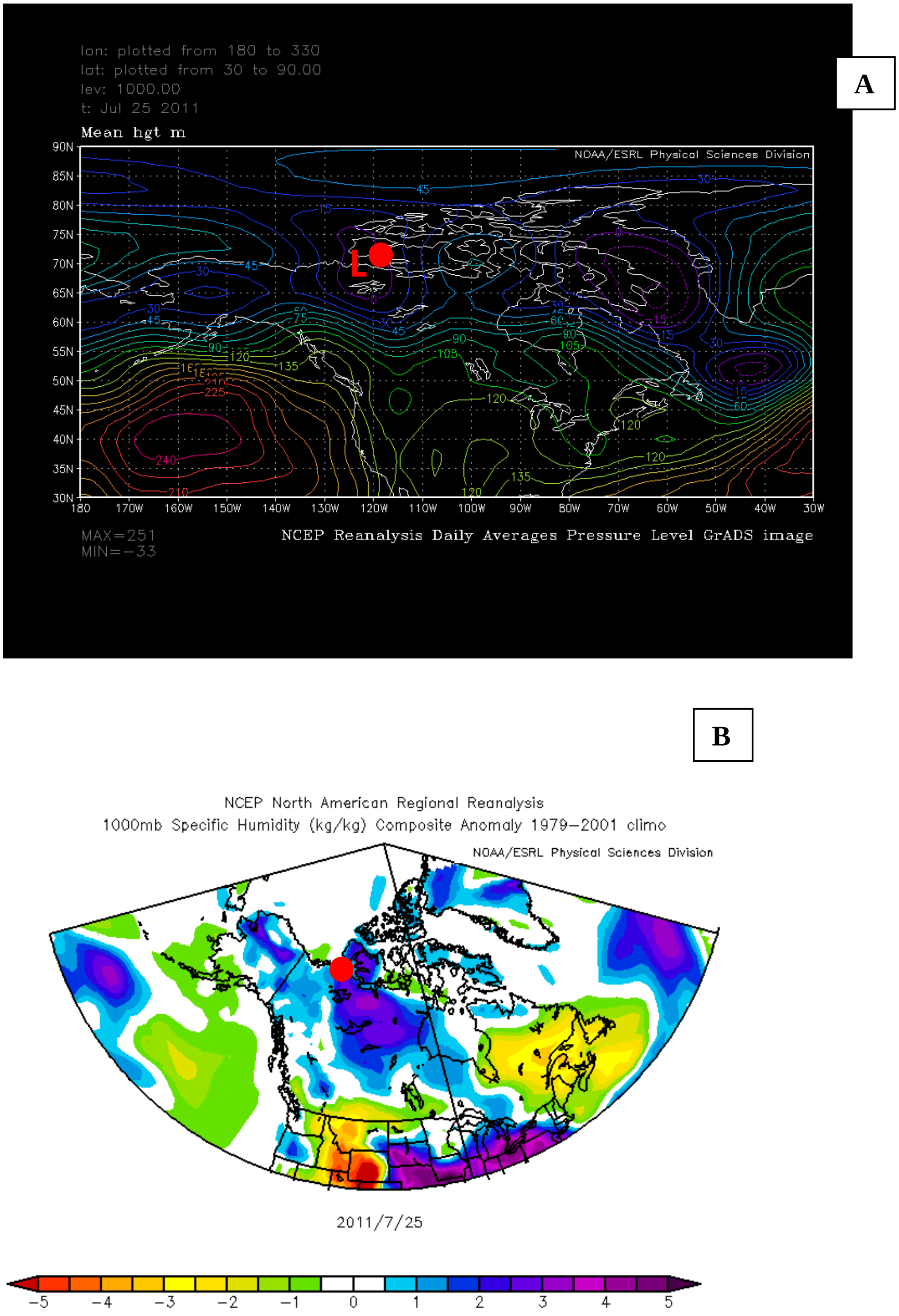

**Figure 5.69:** Selected atmospheric variables for the Ulukhaktok fog event of 25 July 2011. A) height of the 1000hPa pressure surface (m). B) 1000hPa specific humidity anomaly (mean period is 1979-2001).

An example of a fog event driven by local conditions occurred Ulukhaktok 17 March 1993. There is no synoptic-scale advection of moisture (Fig. 5.70a,b); in this case the synoptic charts allow the point to be made that a fog occurrence is a result of local scale processes.

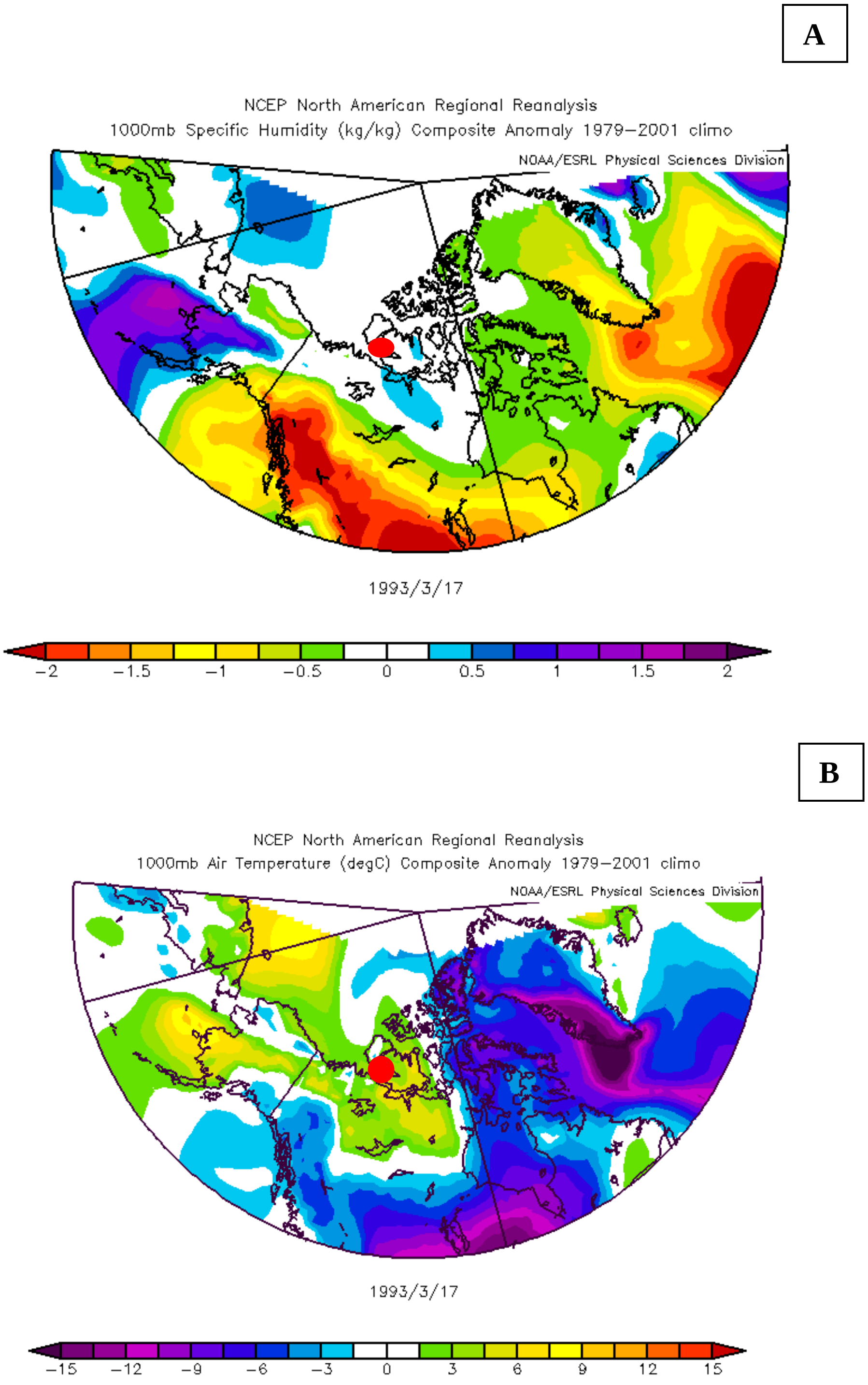

**Figure 5.70:** Selected atmospheric variables for Ulukhaktok the fog event of 17 March 1993. A) 1000hPa specific humidity anomaly (mean period is 1979-2001). B) 1000hPa air temperature anomaly.

## 5.6 Trend analyses

Trend results for change of LV occurrence for any reason over the period of study, as well as trend results for LV and VLV events caused by various weather types, over the period of study are summarized in tabular form (Tables 5.1, 5.2) and were presented in the station results sections above.

**Table 5.1**. Results of trend analysis for LV events caused for any reason. Here "LV event" is any occurrence of visibility below LV threshold; that is, LV and VLV events are included together. Trend and errors are in percent per decade. P-value refers to the probability that a statistically stable trend exists; in particular, it is the probability that the coefficient estimate is actually zero and that no trend actually exists. The analysis was performed on annual proportions which removes the possible influence of greater or fewer numbers of observations from one year to the next.

| Station | Trend | Error | P-value |
|---|---|---|---|
| Aklavik | -0.4 | 0.3 | 0.2560 |
| Inuvik | -0.2 | 0.2 | 0.1699 |
| Sachs Harbour | 0.2 | 0.5 | 0.7324 |
| Tuktoyaktuk | -0.4 | 0.2 | 0.0237 |
| Ulukhaktok | 0.3 | 0.3 | 0.3879 |

**Table 5.2**. Results of trend analysis on the annual values representing the proportion of LV events associated with the five weather types: fog, snow, blowing snow, rain, and drizzle. Trend and error are in percent per decade. “LV events” include all events for which visibility was below LV threshold and includes VLV events, except for when fog was the weather type. For the case when fog was the weather type, the “LV events” category excludes VLV events, which were analyzed separately. P-value refers to the probability that a statistically stable trend exists; in particular, it is the probability that the coefficient estimate is actually zero and that no trend actually exists. Values in black bold have P-values that are less than 0.01, values in black have P-values that are less than 0.1 and greater than 0.01, and values in grey exceed 0.1, and are deemed to likely not represent trends that may be reliably considered for analysis.

| | | **LV events** | | | **VLV events** | | |
|---|---|---|---|---|---|---|---|
| **Stn** | **Weather** | **Trend** | **Error** | **P-value** | **Trend** | **Error** | **P-value** |
| **Aklavik** | Fog | -0.01 | 3.1 | 0.9806 | 1.7 | 8.9 | 0.8 |
| | Snow | -2.2 | 1.2 | 0.0875 | | | |
| | **Blow. snow** | **-17.0** | **4.1** | **0.0004** | | | |
| | Rain | 2.5 | 2 | 0.2307 | | | |
| | **Drizzle** | **-10.2** | **2.9** | **0.0018** | | | |
| **Inuvik** | Fog | -3.4 | 1.9 | 0.0934 | -1.3 | 1.9 | 0.5 |
| | Snow | -0.2 | 0.6 | 0.6568 | | | |
| | Blow. snow | 4.3 | 4 | 0.2899 | | | |
| | Rain | -0.6 | 0.2 | 0.0376 | | | |
| | **Drizzle** | **-4.7** | **1.3** | **0.0012** | | | |
| **Sachs Harbour** | **Fog** | **-10.9** | **2.2** | **0.0001** | -1.5 | 1.9 | 0.45 |
| | Snow | -1.7 | 1.3 | 0.1988 | | | |
| | Blow. snow | -4.8 | 3.4 | 0.1654 | | | |
| | Rain | -0.4 | 1.2 | 0.7158 | | | |
| | Drizzle | -4.9 | 2.6 | 0.0687 | | | |
| **Tuktoyaktuk** | Fog | 0.3 | 1.6 | 0.8376 | -0.8 | 2.7 | 0.78 |
| | **Snow** | **-2.8** | **0.6** | **0.0002** | | | |
| | Blow. snow | -4.1 | 1.6 | 0.0166 | | | |
| | Rain | 0.1 | 0.3 | 0.6237 | | | |
| | Drizzle | -3.1 | 1.5 | 0.0490 | | | |
| **Ulukhaktok** | **Fog** | **-16.2** | **4.4** | **0.001** | -9.3 | 5.2 | 0.09 |
| | Snow | -1.3 | 1.2 | 0.3063 | | | |
| | Blow. snow | 1.1 | 2.8 | 0.6935 | | | |
| | Rain | -1.2 | 1.4 | 0.4081 | | | |
| | Drizzle | 2.1 | 3.5 | 0.5485 | | | |

# 6. Discussion

## 6.1 Climatologies

The occurrence of LV and VLV events for any reason as a proportion of all observations exhibited a certain amount of regional expression over the five sites. The monthly climatologies had surprisingly few broad features in common. All sites fluctuated over the course of the year (Table 6.1). Magnitudes were generally similar: usually no more than 10% of all observations were of LV or VLV visibility type. Sachs Harbour presented a notable departure with a much higher range and values up to 17% of LV/VLV occurrences. An interesting point was the variation in seasonality over what appears to be a fairly similar region, with two sites peaking in October, two in February, and one in August. These seasonality groupings possessed a certain amount of consistency that is explored below.

Inuvik and Aklavik are both inland locations. Their October maximum is likely driven by advection of moist air into the region from the Beaufort Sea during its time of maximum open water; aided by storms that move into the region from the west, an important storm track into the arctic (Maxwell, 1980). This is further suggested by the fact that the most commonly reported weather type at these locations is snow, and only half of LV events were due to fog. Note that at both locations the months of September and November had the two next highest proportions of LV/VLV events. The frequency of snowfall, combined with continued available insolation for daytime melt and increasing magnitude of evening cooling, suggests that radiation fog might be important at this time of year, and in fact almost all VLV events are related to fog. During the winter the proportion of all observations that are either LV or VLV ranges around 4%-5%. The proportion caused by fog is low at this time, suggesting snow plays a larger role, and in fact snow is by far the most frequent weather type. Fog is relatively uncommon in the winter and, when it occurs, the temperatures are below -30 C approximately 25% of the time, suggesting a radiatively driven causal mechanism. A two-sample t-test was performed to see if there is a difference in air temperature during low visibility with and without fog. Although the temperature distribution for temperatures when fog was present was not normally distributed, the t-test indicated a very significant difference between the warmer temperatures of the non-fog low-visibiltiy events.

**Table 6.1:** Comparison of pattern parameters for the five stations for monthly climatologies. Numbers are percent of all observations for which LV or VLV conditions were called. Mean and sd (standard deviation) are presented along with the pattern which indicates when in the year values are high/low.

| Station | Range | Peak month | Mean/sd | Pattern |
|---|---|---|---|---|
| Aklavik | 0.7–9.5 | October | 4.1 / 2.3 | Summer low, fall greatest |
| Ulukhaktok | 2.0-6.5 | February | 4.0 / 1.4 | Winter greatest, spring/fall low, summer elevated |
| Tuktoyaktuk | 2.3-8.6 | February | 5.1 / 2.0 | Winter, spring, fall higher; summer low |
| Inuvik | 0.9-6.4 | October | 3.3 / 1.5 | Winter, spring, fall higher; summer low |
| Sachs Harbour | 8-17 | August | 11.1 / 2.1 | Summer highest; then fall/winter, spring low |

Tuktoyaktuk and Ulukhaktok also grouped together. These sites share coastal locations, although they are hundreds of kilometers apart. Both showed a maximum of LV/VLV frequency in February. This is particularly interesting since it may seem as though Tuktoyaktuk should be more similar to Aklavik and/or Inuvik. The weather type plots for Tuktoyaktuk and Ulukhaktok (Figs. 5.53 and 5.67) indicates the frequent occurrence of blowing snow at this time, and the frequency with which both sites' visibility is low due to fog is also lower than for blowing snow, indicating that the likely cause of the LV/VLV condition is blowing snow. When fog does occur, temperatures and windspeeds tend to be low, suggesting radiation fog at both locations in February.

An interesting divergence between these two sites occurred in the fall. Both locations show a secondary LV/VLV frequency maximum in September/October, but the proportion of these events caused by fog is very different. At Tuktoyaktuk the frequency stays high, above 90%, whereas at Ulukhaktok the value in October drops to ~30%. Weather types at both sites show a similar high frequency of blowing snow – in fact a maximum in October – but it is clear from the LV/VLV proportion plots that visibility at Ulukhaktok is being reduced not due to fog but to blowing snow, whereas blowing snow events at Tuktoyaktuk, even though they are relatively just as frequent as at Ulukhaktok, are not the reason for drop in visibility. At Tuktoyaktuk it is more likely radiation fog, a conclusion supported by examining the hourly climatology of the proportion of LV/VLV events at the two locations for the month of October (plot not shown) – Tuktoyaktuk has a distinct morning peak, indicative of radiation fog, while Ulukhaktok is relatively consistent throughout the day.

Sachs Harbour did not follow any regional pattern. For LV/VLV frequency it showed a strong peak in August of high magnitude (17%), the highest proportion for any month at any site that was studied, by a large margin. This is likely a combination of increasing availability of moisture as a result of the progression of open water season to its September maximum, along with cold temperatures in the main area of the Beaufort Sea, to the northwest of Sachs Harbour, keeping saturation vapour pressure low, which suggests fog. This is supported by the fact that in the July–September timeframe more than 90% of VLV and 70% of LV events were caused by fog.

Time series over the period of study at the five sites showed some statistically significant trends for some parameters. VLV events considered without regard to cause showed no trends at any of the five stations (Table 5.1), and for LV events, only Ulukhaktok showed a weak decline (Table 5.2). Several trends stood out when LV/VLV trends were considered with respect to the weather types causing them. At Aklavik blowing snow and drizzle both showed declines over the period of record. At Inuvik drizzle also showed a decline, but interestingly blowing snow showed a weak increasing trend that was not significant, but which was very different from Aklavik. More work would need to be performed to determine why this might be, but it is likely to have something to do with the frequency of northwest winds blowing in from the Beaufort Sea. It is possible they have decreased in frequency resulting in a decrease of blowing snow events. A seasonal breakdown of these trends would help. Sachs Harbour showed a strong decrease in LV events caused by fog. If sea ice is more often farther away, a decrease in fog-caused LV events could be due to warmer waters around Sachs Harbour. Tuktoyaktuk showed a small but significant decline in snow-caused LV events, and Ulukhaktok shows a large decline in fog events. Similar to Sachs Harbour, this may be a result of less frequently occurring sea ice near to the site. In all of these cases supporting work would include performing trend analyses by season. Another point to note is that the trends are straight-line trends, and some of the more rapid rates of decline in fact appeared to possess a distinct curved aspect, such that the rate of change was rapid initially and has reduced over time. The trend analysis should be repeated with more focus on the type of regression model fit.

Hourlies at the five sites were constrained by the fact that most sites are business hours only. When all months of the year were considered, there was a general pattern of greater frequency of LV/VLV events occurring in the morning, a decrease towards noon and the mid/late afternoon, followed at some locations by an increase again in the late afternoon/early evening. The frequency of LV/VLV events that were associated with fog tended to show this pattern more strongly, with more rapid declines into the afternoon, that were not always followed by a rise again.

Breaking the analysis down into seasons provided more information. In winter (November through March) all stations exhibit a slow increase in total frequency of LV/VLV conditions that peak around 12:00/13:00 hours, followed by a slow decline. In all cases total frequencies range between 4.5 and 7.5%, except for Sachs Harbour, which ranges from 8 up to 12%. Snow is responsible for most LV/VLV occurrences. The slight increase towards noon is likely a reflection of radiation fog conditions – at this time of year the sun has a weak input of energy due to a low solar elevation angle, around solar noon. After the sun has input a bit of energy the radiation fog is broken, which terminates the weak rise in LV/VLV proportions. The small range in LV/VLV proportion values indicates the limited influence radiation fog has, and the small impact the input of solar radiation has on the radiation fog occurrence. All stations in winter exhibit a high proportion of VLV events caused by fog that decline fairly rapidly throughout the day, which then rise again into the late afternoon/early evening, except for Inuvik which remained fairly constant throughout the day, although VLV occurrences were low in the afternoon. LV events caused by fog were a little less regular; only at Tuktoyaktuk did they follow the general pattern of high in the morning, low in the afternoon, and high in the late afternoon.

In summer (June through August) there was a separation between inland stations and coastal stations. The frequency of LV/VLV conditions at the two inland stations was highest in the early morning with fairly low percentages which declined through the afternoon, such that at both locations the occurrence of an LV event is unusual. These stations did not exhibit any VLV events that were caused by fog, and LV events caused by fog start high and then decline rapidly into the day, and their total numbers are very low. Fog is not the most prevalent weather type; rain is. As the day progresses solar heating reduces the frequency of LV events in general, and fog-induced LV events in particular. This is supported by the fact that the frequency of fog also drops rapidly through the day.

The summer situation at other three coastal stations can be discussed individually. At Tuktoyaktuk, the drop in the proportion of LV/VLV occurrences reflects similar physical influences as for Aklavik and Inuvik – strong solar heating – but the proportion of LV events caused by fog remains high, and there are fog-caused VLV events in the morning as well. This will be caused by the coastal proximity of Tuktoyaktuk, which provides access to moisture that the inland stations do not receive. At Ulukhaktok the drop in the proportion of LV/VLV occurrences is not as pronounced as at the other sites and does not exhibit the strong minimum in the afternoon. The proportion of LV and VLV events caused by fog both stay high throughout the day, caused by a ready supply of marine moisture combined with cool sea surface temperatures, and the relative frequency of fog events remains higher throughout the day than at the other stations. The slightly more frequent occurrence of LV and VLV events throughout the day is also likely due to sea surface temperature off of Ulukhaktok being colder than off of Tuktoyaktuk. In late summer 2016, for example, the waters off of Ulukhaktok were 7 C while off of Tuktoyaktuk they were 13 C. Sachs Harbour is again very different from the other stations. Its exposure to moisture and cold air from more directions, combined with the airport elevation and its abrupt rise up from the water's edge, increases the chance of fog and LV/VLV occurrences and ensures they are frequent throughout the day, and that fog is responsible for almost all of them. There is a drop in overall LV/VLV occurrence from the morning throughout the day, likely a function of solar heating.

In the spring and fall time frame the three stations in the Mackenzie area exhibit similar patterns, showing slight differences in total frequency of LV/VLV condition occurrence that is function of access to marine moisture. At Tuktoyaktuk it is the highest; this location has the most ready access to marine moisture. Aklavik is next, which has the previously mentioned route to getting moisture; Inuvik has the lowest frequency of LV/VLV events. The strong diurnal pattern at this time of year is likely a function of readily available solar insolation in the daytime that is incident upon and able to melt snow surfaces, combined with evenings that are still able to cool down. This combination sets the stage for a radiation fog maximum in the early morning that decreases during the day. Ulukhaktok represents a transition between its summer and winter patterns. The snow and blowing snow events that dominate the winter pattern are less frequent and the occurrence of moist air being affected by the cold ocean surface, which dominates the summer, is not very common because the open water is available for only half of the spring/fall timeframe. Sachs Harbour again exhibits the greatest overall frequency of LV/VLV conditions. There is a radiative fog signature in the pattern that decreases from the morning into the afternoon and then rises again late in the day. There is also a partial ice-free moisture signal, appearing as the greatly elevated frequency of VLV events caused by fog.

## 6.2 Synoptic controls of fog events

The synoptic analysis of multi-hour fog events indicated that some events were likely a result of large-scale patterns of pressure and moisture, while other events were more dependent on characteristics of the local environment. In the latter case, the synoptic pattern is still important, because it allowed local characteristics that influence fog formation to become important. An example of the latter is a high pressure system that allows insolation to melt some snow which can increase the moisture content of the lower boundary layer.

A primary mechanism by which large-scale synoptic patterns contributed to local fog events was by advection of moisture from source regions distant from the Amundsen Gulf region. Results suggested five major moisture source regions: Gulf of Alaska, Beaufort Sea, Great Lakes, Bering Sea, and the Interior wetlands of the Northwest Territories, including Great Bear and Great Slave Lakes.

Moisture advection from the Gulf of Alaska (GoA) was not observed to occur directly. The mountains of the Alaska Range and the St. Elias Range form an effective barrier to a direct movement of moisture-laden air from GoA to the Amundsen Gulf region. Instead the typical pattern saw a low over the Gulf of Alaska advecting air over the central Canadian Rockies; this air then wraps around the central Northwest Territories such that it enters the study region from the east.

Moisture advection from the Beaufort Sea occurs during the open water season when a high pressure feature is positioned over the southern Beaufort. In this case, two possible scenarios can occur. First is an advection of moisture around the high to the north and then south over Banks Island into the study area. This provides for the additional moisture into the study area that can trigger fog formation. Second is the formation of fog over the Beaufort Sea, which is then similarly advected around the high into the study area. The high facilitates the formation of fog over the Beaufort Sea through large radiation loss and low temperature. The occurrence of a low over the Beaufort Sea is also conducive to moisture advection. In this case the pathway is very direct with winds into the region from the west/northwest. This was observed during August.

Moisture advection from the Interior wetlands of the Northwest Territories occurs in the presence of a low pressure region situated over the Great Bear/Great Slave Lake region. This is also a fairly direct pathway of moisture-laden air being driven into the study area from the east/southeast. This was observed to occur in July.

Moisture advection from the Bering Sea occurred when low pressure was situated over the northern part of the Bering Sea. The pathway is east across Alaska and then up the Mackenzie Valley from the south into the study area. This was observed to occur during October.

Moisture advection from the Great Lakes/Hudson’s Bay was observed to occur in the presence of a large area of low pressure over southern Nunavut near western

Hudson’s Bay. In this case moist air from Hudson’s Bay and/or from the Great Lakes region is entrained and driven into the study area from the east/southeast. It was also noted that, in some instances, pressure patterns appeared to favour the original moisture source in these cases as being the Gulf of Mexico.

There were several synoptic pattern types that favoured local factors. The presence of a zone of high pressure above the study area allowed rapid surface cooling to occur, which accompanied times of low temperatures in the winter (ice fog). High pressure in the spring and autumn, in the presence of a snow cover, allows large shortwave radiation input during the day. This drives melting which adds moisture to the lowest levels of the boundary layer. At night the loss of radiation causes a drop in temperature which, combined with the moistened near-surface layer, allows dew point to be reached and fog to occur. High pressure is also associated with local fog events in the summer, for the same basic reasons noted above – clear skies in the evening, even when the sun is in the sky all day, allows cooling of the near-surface layers that can reach dew point temperatures. The presence of a low pressure zone over the study area, if the pressure gradient is weak, is more likely to inhibit fog formation by limiting surface cooling.

There are meso-scale circulation influences as well; in particular, a condition of northwest winds that cause moisture from the Beaufort Sea to be channeled into the west side of the Mackenzie Delta. From here it can travel until it reaches Aklavik (NavCanada 2014). This was a persistent pattern that resulted in small but noticeable differences between Aklavik and Inuvik, two stations with otherwise identical situations.

# 7. Conclusion

This analysis has performed a detailed examination of patterns of low visibility, very low visibility, fog and other weather types that typically impede visibility, and the specific impact of fog on LV/VLV. A thorough climatology of occurrences was developed and a synoptic analysis conducted. Overall results include:

1) Several strong trends over the timeframe of the study (1980-2015) were discernible at the five study sites for the parameters considered. These should be explored in greater depth in future work.
2) Although all locations bordered the Amundsen Gulf, there were strong differences amongst the climatologies for the various stations. In particular:
    a. Inuvik and Aklavik in the interior of the Mackenzie Delta were generally similar except for the availability of more moisture at Aklavik, a function of synoptic/meso-scale forcing of moisture into the western area of the Delta.
    b. Tuktoyaktuk was similar to the interior Mackenzie Delta stations, but showed the influences of greater accessibility to marine moisture.
    c. Ulukaktok appeared to show influences of a cold ocean offshore (it is much shallower off of Tuktoyaktuk and gets warmer).
    d. Sachs Harbour exbhibited the most frequent occurrence of events, a function of its great accessibility to moisture and cool air.
3) Seasonal patterns showed the importance of radiative controls and surface types on fog and LV occurrence.

This work can be extended to consider other stations, and it can be shared with Meteorological Service of Canada forecasters who work in this region.

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